

Frontiers in Education 2015

Launching a New Vision in Engineering Education

October 21-24, 2015 | Camino Real Hotel & Conference Center | El Paso, Texas

PROCEEDINGS

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Conference at a Glance

Wednesday, October 21

11:00 AM - 8:00 PM	Registration Open
1:00 PM - 4:00 PM	Workshop Session 1
5:00 PM - 9:00 PM	Workshop Session 2

Thursday, October 22

8:00 AM - 6:00 PM	Registration Open
8:00 AM - 9:00 AM	Focus on New Attendees Breakfast (<i>included in conference registration</i>)
9:00 AM - 10:30 AM	Plenary Session
10:30 AM - 6:00 PM	Exhibit Hall Open
10:30 AM - 11:00 AM	Exhibit Hall Break
11:00 AM - 12:30 PM	Technical Sessions (T1)
12:45 PM - 2:15 PM	HP Terman and Rigas Awards Lunch (<i>included in conference registration</i>)
2:30 PM - 4:00 PM	Technical Sessions (T2)
4:00 PM - 4:30 PM	Exhibit Hall Break
4:30 PM - 6:00 PM	Technical Session (T3)
7:00 PM - 10:00 PM	Reception (<i>included in conference registration</i>)

Friday, October 23

8:00 AM - 6:00 PM	Registration Open
8:00 AM - 9:00 AM	Breakfast (<i>included in conference registration</i>)
9:00 AM - 10:30 AM	Technical Sessions (F1)
10:00 AM - 5:30 PM	Exhibit Hall Open
10:30 AM - 11:00 AM	Exhibit Hall Break
11:00 AM - 12:30 PM	Technical Sessions (F2)
12:45 PM - 2:15 PM	Lunch (<i>included in conference registration</i>)
2:30 PM - 4:00 PM	Technical Sessions (F3)
4:00 PM - 5:00 PM	Focus on Exhibits and New Faculty Fellows
5:00 PM - 6:30 PM	Technical Sessions (F4)
7:30 PM - 10:00 PM	Reception and Awards Banquet (<i>additional ticket required</i>)

Saturday, October 24

8:00 AM - 5:00 PM	Registration Open
8:00 AM - 9:00 AM	Breakfast (<i>included in conference registration</i>)
9:00 AM - 10:30 AM	Technical Sessions (S1)
10:30 AM - 11:00 AM	Break
11:00 AM - 12:30 PM	Technical Sessions (S2)
12:45 PM - 2:15 PM	Lunch (<i>included in conference registration</i>)
2:30 PM - 4:00 PM	Technical Sessions (S3)
4:00 PM - 4:30 PM	Break
4:30 PM - 6:00 PM	Technical Sessions (S4)

Welcome from the General Chair

2015 is the year of the 45th Annual Frontiers in Education (FIE) Conference. It is good to see that we have been doing this conference for 45 years already and I am personally grateful to be a part of it. As always I am privileged to have the help of the sponsoring entities: the IEEE Education Society, the IEEE Computer Society, and the ASEE Educational Research and Methods Division, through the FIE Steering Committee. Beyond that, I am blessed to have the input from my home institution New Mexico State University and our neighbor, the University of Texas at El Paso.

During your visit here, you can enjoy the warm autumn weather of the Southwest United States as well as the newly renovated downtown area of El Paso Texas.

Our theme this year is “Launching a New Vision in Engineering Education”. This fits well with the latest addition to the southern New Mexico businesses, the brand new Spaceport America, as well as other space related facilities such as the National Radio Astronomy Observatory Very Large Array Telescope and the Apache Peak Observatory, home of the Sloan Digital Sky Survey. It would be my honor to schedule tours of any of these facilities and you can contact me directly to do so. However, you need to be ready for long travel times since the closest of these is two hours from the conference center.



Once again this year we have more than 500 speakers and many pre-conference workshops. These continue a long tradition of some of the best educational innovations and research in engineering and computing. We are thankful to these speakers and to the co-chairs of the Program Committee who have selected and organized the papers submitted: Senay Purzer, ASEE Program Co-Chair; Mani Mina, IEEE Education Society Program Co-Chair; Ari Korhonen, IEEE Computer Society Program Co-Chair; Holly Matusovich, Special Session & Workshop Chair; and James Huff, New Faculty Fellows Chair. I also thank the FIE Steering Committee who guided me through the preparation with much needed professional advice and encouragement.

Finally, I cannot be grateful enough for the logistic support of Assistant to the General Chairs, Kevin Curry, and to Conference Catalysts, for their work on the computer applications and the web site.

Special thanks to our sponsors - New Mexico State University and the University of Texas at El Paso; as well as our other sponsors: Hewlett Packard, VentureWell, and the Markkula Center for Applied Ethics.

I hope you enjoy your stay in the home of cowboys, Native Americans, and Mexican culture, and I look forward to meeting each and every one of you.



Conference General Chair

Michael DeAntonio, NMSU, Las Cruces, New Mexico

Welcome from the Program Co-Chairs

Dear Colleagues,

It gives us great pleasure to welcome you to El Paso, Texas, and the 2015 Frontiers in Education Conference.

As conference programme co-chairs we have had the stimulating challenge of managing the reviewing, selection, and scheduling of submissions for what promises to be a truly outstanding conference. This year we received over 700 submissions, from which we have selected approximately 400 for presentation in different formats. The result is a research and innovation packed programme that commences with a day of pre-conference workshops on Wednesday, followed by three full days of presentations, special sessions, panels, and last, but not least, many opportunities over breakfast, lunch and dinner events to meet new friends, renew old acquaintanceships and engage in inspiring debate and discussion.

We have spent a most exciting six months preparing the technical programme. We hope that you enjoy the fruits of our labour, and find the conference as stimulating and interesting to attend, as we have found the process of putting it all together.

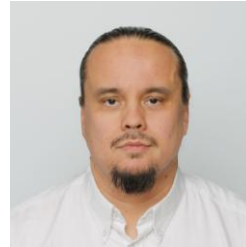
Welcome to FIE 2015 in El Paso!



Senay Purzer
ASEE ERM



Mani Mina
IEEE Education Society



Ari Korhonen
IEEE Computer Society

Message from the FIE Steering Committee Chair

Welcome! And ¡Bienvenidos a El Paso!

The organizers of the 45th annual Frontiers in Education conference are pleased to offer you this opportunity to network and engage in engineering education research that is on the frontier. The FIE Steering Committee welcomes you to El Paso, TX after our successful time in Madrid last year.

If you are like me, you come to FIE to see old friends and find new ideas. I hope you come away from this conference with a renewed sense of commitment to the improvement engineering education and that you have expanded your network of colleagues. For those of you that are “regulars”, I hope you will share your sense of community with those that are new to FIE.

The Steering Committee continues to iterate on ways to improve the conference. This year will be our second time going with a paperless conference. We believe using our resources this way is responsible and keeps us on the frontier. We are also investigating ways to improve the experience of both authors and reviewers in our peer review process within EDAS. Lastly, we are improving the documentation of our processes, so that new FIE volunteers will have a better understanding of their roles. Please continue to provide feedback so we can iterate more effectively.

Below is the list of all current members on the FIE Steering Committee. You can find us at the conference as we will be wearing Steering Committee ribbons on our conference badges. We represent you and your needs for this conference. Please let us know how to improve FIE.

ASCE Educational Research and Methods Division Representatives

- Beth Eschenbach (Chair), Humboldt State University, beth@humboldt.edu
- Archie Holmes, University of Virginia, ah7sj@virginia.edu
- James Morgan, Charles Stuart University, jmorgan@csu.edu.au

IEEE Computer Society Representatives

- Stephen Frezza, Gannon University, FREZZA001@gannon.edu
- Arnold Pears, Uppsala University, Arnold.Pears@it.uu.se
- Deborah Trytten, University of Oklahoma, dtrytten@ou.edu

IEEE Education Society Representatives

- Russ Meier, Milwaukee School of Engineering, meier@msoe.edu
- James Sluss, University of Oklahoma, sluss@ou.edu
- Edmundo Tovar, Universidad Politécnica de Madrid, etovar@fi.upm.es

Next year's conference will be in Erie, Pennsylvania. We will try a new idea where we will have a co-located Saturday conference for K-12 STEM educators. Please invite your K-12 colleagues!

I hope you have a great conference!



Beth Eschenbach, PhD.
Chair of the Frontiers In Education Steering Committee
Department Chair & Professor
Environmental Resources Engineering
Humboldt State University
Arcata, CA USA

FIE 2015 Planning Committee

General Co-Chairs

Mike DeAntonio
New Mexico State University

Virgilio Gonzalez
University of Texas, El Paso

Assistant to the General Chairs

Kevin Curry
University of Kansas
kgcurry@ku.edu

ASEE/ERM Program Co-Chair

Senay Purzer
Purdue University

IEEE/Computer Society Program Co-Chair

Ari Korhonen
Aalto University

IEEE/Education Society Program Co-Chair

Mani Mina
Iowa State University

Special Sessions and Workshop Chair

Holly Matusovich
Virginia Tech

Exhibits Chair

Robert J. Hofinger
Purdue University

International Co-Chair, Australasia

Mark Lee
Charles Sturt University

International Co-Chair, Europe

Edmundo Tovar
Universidad Politecnica de Madrid

International Co-Chair, South America

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Awards Chair

Ed Jones
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n2ecj@iastate.edu

FIE Steering Committee

ASEE Educational Research and Methods Division Representatives

- Beth Eschenbach (Chair)
Humboldt State University
- James Morgan
Charles Stuart University
- Archie Holmes
University of Virginia

IEEE Computer Society

- Stephen Frezza
Gannon University
- Arnold Pears
Uppsala University
- Deborah Trytten
University of Oklahoma

IEEE Education Society

- Russ Meier
Milwaukee School of Engineering
- James Sluss
University of Oklahoma
- Edmundo Tovar
Universidad Politecnica de Madrid

Future FIE Conferences

FIE 2016 Erie, Pennsylvania

FIE 2017 Indianapolis, Indiana

Are you interested in hosting a future FIE conference?
Leave your business card at the registration desk, and an
FIE steering committee member will contact you.

Sponsors

Society Sponsors

The **45th Annual Frontiers in Education Conference** is sponsored by the IEEE Education Society, the IEEE Computer Society, and the ASEE Educational Research and Methods Division.



Academic Host Institutions



A comprehensive land-grant institution of higher learning, **New Mexico State University** is dedicated to teaching, research, and service at the undergraduate and graduate levels. NMSU is a NASA Space Grant College, a Hispanic-serving institution and is home to the very first Honors College in New Mexico. U.S. News and World Report ranks NMSU in the top tier among Best National Universities.



The University of Texas at El Paso (UTEP) was founded in 1914 as the State School of Mines and Metallurgy. Today, UTEP is comprised of seven colleges and offers 71 bachelor's programs, 76 master's programs, 20 doctoral programs and 25 certificate programs. With a student population that exceeds 23,000 and a research portfolio that boasts more than \$83 million in spending, UTEP is on track to become the first national public research university to truly serve the 21st-century student demographic.

Diamond Sponsor



Hewlett-Packard sponsors the ASEE Frederick Emmons Terman Award and the IEEE Harriet B. Rigas Award as well as the luncheon where the awards will be presented.

Sponsors (Continued)

Silver Sponsor



VentureWell sponsors the plenary session the morning of Thursday, October 22, and a complimentary workshop which will focus on stimulating science and technology invention, innovation and entrepreneurship on university and college campuses.

Conference App Sponsor



Markkula Center for Applied Ethics, producer of "**An Introduction to Software Engineering Ethics**" by Shannon Vallor, Associate Professor of Philosophy, Santa Clara University with special contributor Arvind Narayanan, Assistant Professor of Computer Science, Princeton University. This ethics module includes a reading, homework assignments, case studies, and classroom exercises, all designed to spark a conversation about ethical issues that students will face in their lives as software engineers.

FIE 2015 Exhibitors

Exhibit Hall Hours

The exhibits will be open in the Mezzanine Level by the Bathroom from 9:30 AM to 5:00 PM Thursday and from 9:00 AM to 4:30 PM Friday.

EXHIBITOR	WEBSITE
ARM	http://www.arm.com/
Cengage Learning	http://www.cengage.com/
EMA Design Automation	http://www.ema-eda.com/
EPICS	http://www.ema-eda.com/
IonIdea	http://www.ionidea.com/IonEducation.html
JMP Statistical Discovery Software from SAS	http://www.jmp.com/en_us/home.html
MathWorks	http://www.mathworks.com
National Science Foundation	http://nsf.gov
Purdue University Engineering Education	https://engineering.purdue.edu/ENE
Stratasys	http://www.stratasys.com/
Virginia Tech Department of Engineering Education	http://www.enge.vt.edu/
zyBooks	https://zybooks.zyante.com/

Exhibitor Showcase Presentations

Again this year, FIE offers Exhibitor Showcases, which provide our exhibitors a longer block of time for demonstrations or presentations. Additional information about the content of each showcase is in the conference app. Please join us for one of these informative sessions.

Thursday, October 22

11:00 AM - 12:30 PM	Cengage Learning	Juarez B
2:30 PM - 6:00 PM	ARM	Juarez B

Friday, October 23

9:00 AM - 10:30 AM	SAS Institutes, Inc.	Juarez B
11:00 AM - 12:30 PM	IonIdea Inc.	Juarez B
2:30 PM - 4:00 PM	MathWorks	Juarez B
5:00 PM - 6:30 PM	ZyBooks	Juarez B

Special National Science Foundation Presentation

On Thursday, October 22, from 4:30 PM to 6:00 PM in the ballroom, the NSF will hold a special session to discuss funding opportunities to cover ENG/EEC and EHR/DUE programs. Additional information about this presentation is in the conference app.

Meetings at FIE

Wednesday, October 21

5:00 PM -6:30 PM	FIE Steering Committee	Boardroom
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Saturday, October 24

8:00 AM - 10:00 AM	FIE Steering Committee	Boardroom
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1:00 PM - 3:00 PM	FIE 2015 Planning Committee	Boardroom
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Workshops

Workshop 1A

Wednesday, October 21 1:00 PM - 4:00 PM

Integrating Service-Learning into Engineering and Computing Education

Service learning is a rapidly growing pedagogy in higher education and within engineering, technology and computing. Service-learning provides a learning environment that is very well-matched with ABET. Students can learn strong technical skills while developing teamwork, communication and leaderships skills. The community and human context of service-learning provides rich learning experiences for contemporary social, global and ethical issues. Service-learning also provides the kind of curricular efficiency necessary to meet the attributes called for in the National Academy's Engineer of 2020. Evidence suggests that service-learning also has the potential to increase participation among underrepresented populations within engineering, technology and computing. This interactive workshop will provide an introduction to service-learning and allow participants to explore how it could be integrated into their own courses and curricula. Resources, partnerships and potential barriers will be discussed to provide strategies for successful implementation at the participants' own institutions.

Workshop 1B

Wednesday, October 21 1:00 PM - 4:00 PM

Teaching and Assessment Strategies that Value Innovative Thinking

An increasing number of studies point to the issue that engineering students tend to lose their creative edge during their undergraduate education. In our prior studies, we identified three barriers to innovation experienced by students: an overwhelming technical identity that values technical problem solving over creativity, a view of innovativeness as an attribute that is attainable to just few privileged or masterminds, and instructional constraints that demotivate students from taking risks by exploring novel solutions.

This workshop will focus on teaching and assessing in engineering courses so that students see the essential role of innovative thinking for engineers. Examples of student work will be used to illustrate assessment practices that value creativity and innovative problem solving. The participants will develop rubrics to be used in own courses or design projects.

Workshops (Continued)

Workshop 1C

Wednesday, October 21 1:00 PM - 4:00 PM

Process to Draft the Program Educational Objectives for Undergraduate Engineering Degree Programs

This workshop will engage the participants in the process to draft Program Educational Objectives (PEOs) appropriate for undergraduate engineering degree programs at ABET-accredited institutions of higher education. ABET stipulates in its Self-Study Questionnaire under Criterion 2, Category E that there should be a process in place to periodically review and revise PEOs.

PEOs must reflect the Mission Statement of the institution and serve as a yardstick of student achievement three to five years following graduation. The objectives represent the expectations of the department from its graduates and must be crafted such that measurable objective evidence can be obtained through alumni surveys. To be consistent and effective, the entire engineering department must contribute to the discussion, ratification, and eventual adoption of the PEOs. Active participation by the faculty in defining the PEOs yield clear and concise objectives and promotes ownership of the goals of the Department and ABET process. However, not all faculty members are necessarily familiar with the assessment language and the process to evaluate the PEOs. In order to ensure a meaningful contribution from all faculty members involved in defining the PEOs, this workshop presents a framework that facilitates the discussion and the steps taken to define the PEOs that are (1) adhering to the Mission of the University (2) achieving consistent and measurable expectations.

Workshop 1D

Wednesday, October 21 1:00 PM - 4:00 PM

Agile Way of Educating

The goal of this workshop is to help participants explore how Agile development, a management technique borne out of the software industry, can not only change the way that students engage in project-based and team-based course projects, but the Agile mindset can also transform the way that we educate our students. The Agile Way of Working (or Agile) is a collection of principles and practices that supports rapid and flexible response to change. It does this by promoting communication, collaboration, continuous improvement, and reflection within teams of problem solvers. The approach also fosters self-managed teams. Agile accomplishes this by embracing changing requirements, delivering products frequently, using human-centric methods, and engaging the customer in regular collaboration. Agile puts heavy emphasis on articulating goals, facilitating interactions, improving team dynamics, supporting collaboration, and encouraging experimentation and innovation.

There is an increase in interest in how Agile can be applied in higher education settings - both as a topic of study for project management (i.e., Agile Way of Working) and as a pedagogical mindset (i.e., Agile Way of Educating). In this workshop we will: Provide a tutorial overview of Agile; present examples of how Agile has been used for project management for course projects; present examples of how Agile practices has been applied as a pedagogical approach to derive benefit in the areas of encouraging students to take responsibility for their learning (self-managed learning), continuous improvement through reflection, alternative approaches for evaluation, and increased engagement by learners; and engage in activities that demonstrate Agile in practice in order to provide attendees with ideas for applying Agile. Participants will come away with ideas for applying Agile in their courses and resources for a deeper dive into Agile. Participants will also leave the session with resources that will allow them to perform a deeper dive into Agile.

Workshops (Continued)

Workshop 2A

Wednesday, October 21 5:00 PM - 9:00 PM

Encouraging Information Rich Engineering Design

Students frequently spend too little time understanding the problem in their design projects and jump to solutions without considering alternatives. This leads to inefficient use of time and suboptimal results in the final design. Instead of re-inventing the wheel, students need to explore and understand the work of others applied to similar situations, using strong information gathering, application, and evaluation skills. Ultimately, these reinforce core skills needed for students to be lifelong learners, i.e., determining where they have gaps in knowledge and determining how to fill those gaps efficiently and effectively. This workshop will provide a conceptual model and examples of activities that will help instructors keep students problem-focused, allowing them to generate and weigh alternatives, and ultimately settle on a solution that is most promising to meet their stakeholders' needs. Participants will take away techniques they can apply to their own engineering design courses.

Participants will learn how to determine the needs of stakeholders, better understand the context of the design problem, and make sure they meet professional standards and legal requirements for their designs. In addition to their own brainstorming, they investigate the prior art of others to enlarge the solution space they explore. Evaluating and synthesizing information gathered or generated themselves, they determine the most promising of their proposed solutions.

Workshop 2C

Wednesday, October 21 5:00 PM - 9:00 PM

Agile Teaching and Learning

Educators are converting traditional and project-base courses to agile in response, but this is a daunting task with few structured teaching resources methods available to reduce the burden on the educator. This workshop will present a comprehensive approach to teaching Agile methods that is itself agile, employing a highly iterative, continuous feedback-driven process. This workshop will convey instructional resources to participants, and provide the scaffolding to conduct an agile project course. Participants will receive materials including Eclipse-based open source labs, project scripts, and pedagogical scripts to adapt to their classrooms. Pedagogical and assessment strategies will be shared, and the presenter will facilitate a best practices interactive discussion to draw out lessons learned from workshop participants. The workshop agenda will include strategies and instructions for setting up Scrum, and supporting XP developer practices including Continuous Integration and Testing using Jenkins, Source Code Control using Git, unit testing, static analysis, and more. The workshop will also encourage interaction amongst participants to share best practices and lessons learned. Research directions related to the application of agile principles to teaching and learning will be discussed. Post-workshop support will be provided through a website hosted by the presenter.

A custom Eclipse install with requisite tools will be available for installation during the workshop via USB stick and the Web. The presenter will record and coalesce information gathered from collaborative sessions on the agenda and make the record available to participants on his university website. Instructions for server-based installations and trial accounts will be distributed to participants. **Laptop Required. Tablets will be of only limited utility.**

Workshops (Continued)

Workshop 2D

Wednesday, October 21 5:00 PM - 9:00 PM

How to Select an Area of Scholarship and Address the Applicable Review Criteria to Publish a Paper in the IEEE Transactions on Education

Engineering education publications are expected to make substantive contributions to the field, but there is a need to clarify expectations of substantive contributions across the global community of scholars in this field. For the purposes of the review criteria, contributions will be defined as clear statements of how work described in the manuscript is expected to influence future directions of the field. Many different types of contributions are possible. Review criteria need to be specific to broad areas of potential contributions. Review criteria for the IEEE Transactions on Education are organized based on the three categories of scholarship described by Boyer: discovery, application, and integration. Workshop participants should expect to learn more about the three areas of scholarship and be able to select the area most appropriate for their manuscript.

Plenary Session

Thursday, October 22, 9:00 AM - 10:30 AM

Ballroom

Plenary session sponsored by VentureWell

Building a Teaching Academy at Your University — What a Faculty Member or Administrator Can Do

Members of Frontiers in Education know much about university teaching that could—and should—be shared with educators across our home campuses. It is especially important to share outside of STEM fields where research about education is not as robust. But how to share such information on one's own campus? Enter: the teaching academy.

A teaching academy is a member-driven organization designed to enhance teaching. A teaching academy can serve as a center for teaching or coordinate with an already established center. It need not have even one paid staff or even a budget in the beginning. Activities that are common for teaching academies include having members offer workshops, lead learning communities, induct new members, honor teaching award winners, host celebrations of teaching, as well as observe and give feedback on colleagues' online or face-to-face classes.

In this plenary session, Dr. Gray will address how to begin a teaching academy at your university as well as how to build upon an existing one. She will discuss how even one faculty or administrator can create a groundswell of support, demonstrate the impact of the academy, and raise money as necessary.

Tara Gray, Ph.D., serves as associate professor of criminal justice and as founding director of the New Mexico State University Teaching Academy. The Academy was established in 2003. In the five years before the Academy was founded, while working as an associate professor of criminal justice, Dr. Gray directed two popular short courses, raised the money necessary to support them and bring in a half dozen speakers per year, and began building the faculty and administrative support for a Teaching Academy. Today, the Teaching Academy is a full-service center, working to improve student learning by providing professional development to New Mexico State educators.

Dr. Gray was educated at the United States Naval Academy, Southwestern College in Kansas and Oklahoma State, where she earned her Ph.D. in economics by asking, "Do prisons pay?" She taught economics at Denison University before joining the Department of Criminal Justice at NMSU. Dr. Gray has published three books, including *Publish & Flourish: Become a Prolific Scholar*. She has been honored at New Mexico State and nationally with eight awards for teaching or service.

Dr. Gray has presented faculty development workshops to 8,000 participants in more than a hundred colleges and universities, thirty-five states, and Thailand, Guatemala, Mexico, Canada, Saudi Arabia and the United Arab Emirates. Workshop participants report that she is "spirited, entertaining, and informative—she's anything but gray!™"

New Faculty Fellow Program

Each year, FIE invites new engineering and computer science faculty to submit applications for possible selection as New Faculty Fellows. A review panel of engineering and computer science faculty from assistant, associate, and full professorship levels completes a rigorous peer review of each applicant's conference paper, nomination letters and professional résumé. The fellowship provides a \$1,000 grant for conference travel expenses.

The purpose of the program is to promote the involvement of new faculty in the Frontiers in Education Conference so they will be exposed to the "latest and greatest" in engineering educational practices and will have the opportunity to exchange information with leaders in education innovations. This year, FIE 2015 will provide registration and travel grants for the awardee to attend the conference.

Focus on New Faculty Fellows

Each fellow will present a conference paper during FIE 2015. Join them in their session and share your thoughts and ideas about the future of engineering education. Also, during the Focus on Exhibits session Friday at 4 p.m., the Fellows will display posters describing their interests and activities and previewing the full papers that they will present as part of the FIE 2015 technical sessions. Below are this year's recipients and the papers they authored or co-authored.

2015 New Faculty Fellows:

Joyce Main

Purdue University

Session T2D: *Using life course theory to frame women and girls' trajectories toward (or away) from computing: Pre high-school through college years*

Session F2F: *Student evaluations of team members: Is there gender bias?*

Session S2C: *The Institutional Environment for Student Veterans in Engineering*

Session S3B: *Examining How International Experiences Promote Global Competency among Engineering Graduate Students*

Session S4E: *Modeling Student Perceived Costs and Benefits to Cooperative Education Programs (Co-ops) and Pathways to Participation*

Noah Salzman

Boise State University

Session S3C: *Effects of Pre-College Engineering Participation on First-Year Engineering Outcomes*

Nathan Canney

Seattle University

Session F3F: *How engineering students define 'Social Responsibility'*

Conference Amenities

Breakfast • Ballroom

Breakfast is included in your conference registration. On Thursday breakfast will include a plenary presentation.

8:00 AM – 10:30 AM Thursday Includes Plenary Session

8:00 AM – 9:00 AM Friday

8:00 AM – 9:00 AM Saturday

Refreshment Breaks • Mezzanine Level

Morning and afternoon breaks will take place daily on the Mezzanine Level, outside the Ballroom.

Lunches • Ballroom

Lunches are included in your conference registration. On Thursday lunch will include the Hewlett-Packard Awards

Frederick Emmons Terman and Harriett B. Rigas Awards Luncheon Sponsored by the Hewlett-Packard Company

12:45 PM – 2:15 PM Thursday

The Frederick Emmons Terman Award is presented annually to an outstanding young electrical engineering educator by the Electrical and Computer Engineering Division of the American Society for Engineering Education. The Harriett B. Rigas Award is presented annually to an outstanding woman engineering educator in recognition of her contributions to the profession.

Luncheon

12:45 PM – 2:15 PM Friday

Includes Plenary Session

Luncheon

12:45 PM – 2:15 PM Saturday

New Faculty Fellows • Exhibit Area • Mezzanine Level

4:00 PM – 5:00 PM Friday

A special session focusing on the New Faculty Fellows will be held on Friday. This session will provide an opportunity to meet this year's New Faculty Fellows, a group of new CSET educators who were selected based on an application and a full paper being presented at this year's conference. There will also be an opportunity to view their poster presentations at this time.

Focus on Exhibits • Exhibit Area • Mezzanine Level

4:00 PM – 5:00 PM Friday

Visit the FIE exhibits and check out the latest textbooks, computer software, lab equipment, and other innovations while enjoying refreshments.

Awards Banquet • Ballroom

7:30 PM – 10:00 PM Friday

Thanks to our sponsor, the IEEE Education Society, the Frontiers in Education Conference annual gala networking dinner and awards program is only \$30 per person. An opening reception will be followed by a full-service plated meal. This business formal event is sponsored by the IEEE Education Society - a group of more than 3,000 engineers and academics dedicated to advancing the scholarship and practice of engineering education. You do not have to be an IEEE Education Society member to attend. Tickets can be added to your registration on site.

FIE Registration Conference Desk • Mezzanine Level by the Elevators

Registration will be open during these times:

Wednesday	11:00 AM – 8:00 PM
Thursday	8:00 AM – 6:00 PM
Friday	8:00 AM – 6:00 PM
Saturday	8:00 AM – 5:00 PM

Award Selection Committee Chairs

Frontiers in Education Conference

Benjamin J. Dasher Best Paper Award	Diane Rover
Helen Plants Award	Mats Daniels
Ronald J. Schmitz Award	Cynthia Finelli

ASEE Electrical and Computer Engineering Division

Hewlett-Packard Frederick Emmons Terman Award	Changzhi Li
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IEEE Education Society

Awards Policy Committee: Edwin C. Jones, Jr., Chair; Michael Auer; Joanne Bechta Dugan; Lyle Feisel; and Susan Lord.

IEEE William E. Sayle Award for Achievement in Education	Susan Conry
IEEE Transactions on Education Best Paper Award	Jeffrey Froyd and Susan Lord
Chapter Achievement Award	Trond Clausen
Distinguished Chapter Leadership Award	Trond Clausen
Distinguished Member Award	Victor Nelson
Edwin C. Jones, Jr. Meritorious Service Award.....	Susan Lord
Hewlett-Packard/Harriett B. Rigas Award	Joanne Bechta Dugan
Mac Van Valkenburg Early Career Teaching Award.....	Seyed Hosseinn Housavinezhad
Student Leadership Award	Kai Pan Mark



Jeffrey G. Andrews
University of Texas

Past Recipients

'69 Michael Athans
'70 Andrew P. Sage
'71 Joseph W. Goodman
'72 Taylor L. Booth
'73 Sanjit Mitra
'74 Leon Ong Chua
'75 Michael L. Dertouzos
'76 Stephen W. Director
'77 J. Leon Shohet
'78 Ronald A. Rohrer
'79 Martha E. Sloan
'80 V. Thomas Rhyne
'81 Ben Garland
Streetman
'82 Toby Berger
'83 Daniel P. Siewiorek
'84 Mathukumalli
Vidyasagar
'85 Peter S. Maybeck
'86 Lance A. Glasser
'87 Kenneth L. Short
'88 Adel S. Sedra
'89 Frank L. Lewis
'90 Jerry D. Gibson
'91 Barry W. Johnson
'92 H. Vincent Poor
'93 Mark S. Lundstrom
'94 Supriyo Datta
'95 Perinkolam P.
Vaidyanathan
'96 Prithviraj Banerjee
'97 Edward A. Lee
'98 Edwin K. P. Chong
'99 Randy H. Katz
'00 Sergio Verdu
'01 Zoya Popovic
'02 Theodore S.
Rappaport
'03 Wayne Wolf
'04 Keshab K. Parhi

ASEE ECE Division Hewlett-Packard Frederick Emmons Terman Award

*For being the principal author of **Fundamentals of WiMAX**, 449 pages, Prentice-Hall, 2007, a leading textbook in wireless communications, and for research, teaching, and professional service in the discipline of wireless communications.*

Jeffrey G. Andrews (S'98, M'02, SM'06, F'13) received the B.S. in Engineering with High Distinction from Harvey Mudd College, and the M.S. and Ph.D. in Electrical Engineering from Stanford University. He is the Cullen Trust Endowed Professor (#1) of ECE at the University of Texas at Austin and the Editor-in-Chief of the IEEE Transactions on Wireless Communications. He developed Code Division Multiple Access systems at Qualcomm from 1995-97, and has consulted for entities including Apple, Samsung, Verizon, AT&T, the WiMAX Forum, Intel, Microsoft, Clearwire, Sprint, and NASA. He is a member of the Technical Advisory Board of Fastback Networks, and co-author of the books *Fundamentals of WiMAX* (Prentice-Hall, 2007) and *Fundamentals of LTE* (Prentice-Hall, 2010).

Dr. Andrews is an ISI Highly Cited Researcher, received the National Science Foundation CAREER award in 2007 and has been co-author of eleven best paper award recipients including the 2010 IEEE Communications Society Best Tutorial Paper Award, the 2011 IEEE Heinrich Hertz Prize, the 2014 IEEE Stephen O. Rice Prize, and the 2014 IEEE Leonard G. Abraham Prize. He is an IEEE Fellow and an elected member of the Board of Governors of the IEEE Information Theory Society.

About the Terman Award

'05 Ali H. Sayed
'06 Vijay K. Madiseti
'07 Russel Jacob (Jake)
Baker
'08 Keith M. Chugg
'09 David Tse
'10 Bhaskar
Krishnamachari
'11 Tony Givargis
'12 Ali Niknejad
'13 Mung Chiang
'14 Changzhi Li

The Frederick Emmons Terman Award is presented annually to an outstanding young electrical or computer engineering educator by the Electrical and Computer Engineering Division of the American Society for Engineering Education. The Terman Award, established in 1969 by the Hewlett-Packard Company, consists of \$5,000, an engraved gold-plated medal, a bronze replica of the medal mounted on a walnut plaque, and a parchment certificate.



The recipient must be an electrical engineering educator who is no more than 45 years old on June 1 of the year in which the award is presented and must be the principal author of an electrical engineering textbook published before June 1 of the year of his/her 40th birthday. The book must have been judged by his/her peers to be an outstanding original contribution to the field of electrical engineering. The recipient must also have displayed outstanding achievements in teaching, research, guidance of students, and other related activities.

About Frederick Emmons Terman

Frederick Emmons Terman received his A.B. degree in chemistry in 1920, the degree of engineer in electrical engineering in 1922 from Stanford University, and his Sc.D. degree in electrical engineering in 1924 from Massachusetts Institute of Technology. From 1925-1965, he served as instructor, then professor of electrical engineering, executive head of the Electrical Engineering Department, dean of the School of Engineering, provost, vice president, and finally, as acting president of Stanford University.

Among the many honors bestowed upon him were: the IEEE Medal of Honor; the first IEEE Education Medal; the ASEE's Lamme Medal; the 1970 Herbert Hoover Medal for Distinguished Service to Stanford University; an honorary doctor's degree by Harvard; a decoration by the British government; the Presidential Medal for merit as a result of his war work; and the 1976 National Medal of Science from President Ford at a White House ceremony.

Dr. Terman was a professor at Stanford University when William Hewlett and Dave Packard were engineering students there. It was under Dr. Terman's guidance in graduate work on radio engineering that Mr. Hewlett built the first tunable and automatically stabilized Weinbridge oscillator. Partially through Dr. Terman's urging, Hewlett and Packard set up their partnership in an old garage with \$538 and the oscillator as their principal assets.

Dr. Terman died in December 1982. It is in appreciation of his accomplishments and guidance that Hewlett-Packard is proud to sponsor the Frederick Emmons Terman Award.



Sarah Rajala
Iowa State University

Past Recipients

'95 Denise D. Denton
'96 Karan L. Watson
'97 Patricia D. Daniels
'98 Delores M. Etter
'99 Sherra E. Kerns
'00 Leah Jamieson
'01 Valerie Taylor
'02 Nan Marie Jokers
'03 Joanne Bechta Dugan
'04 Jennifer L. Welch
'06 Eve A. Riskin
'07 Bonnie Heck Ferri
'08 Cheryl B. Schrader
'09 Cynthia Furse
'10 Mari Ostendorf
'11 Karen Panetta
'12 Tanja Karp
'13 Nancy Amato
'14 Noel Schulz

IEEE Education Society Hewlett-Packard Harriett B. Rigas Award

For exceptional contributions to electrical and computer engineering education and the global engineering community through student and faculty development, transformational and inclusive institutional and professional leadership, and engineering accreditation service.

Sarah Rajala, who has been a pioneer for women in electrical engineering, graduated with a bachelor's degree in the field.

She is currently serving as dean of the Iowa State University College of Engineering and holds the James & Katherine Melsa Professorship in Engineering. Prior to this, Rajala served as the named dean of Mississippi State University's Bagley College of Engineering and head of the Department of Electrical and Computer Engineering. She earned both master's and doctoral degrees from Rice University, taught at North Carolina State University and Purdue University, and served as an adjunct research faculty member at the Wake Forest University Bowman Gray School of Medicine.

Rajala joined the faculty at NC State in 1979, where she was the first female professor in the Department of Electrical and Computer Engineering. Throughout her career at NC State, she served as a center director, Associate Dean for Academic Affairs, and Associate Dean for Research and Graduate Programs.

She is a Fellow of the American Association for the Advancement of Science and the Institute of Electrical and Electronic Engineers; she served as president and is a Fellow of the American Society for Engineering Education. She served as the chair of the Global Engineering Deans Council and is currently Chair of the Engineering Accreditation Council of ABET. A native of Skandia, Michigan, she was only the third woman to graduate from Michigan Tech with an electrical engineering degree.

At Michigan Tech, Rajala is a member of the Presidential Council of Alumnae and the Electrical Engineering Academy and was the first alumna to receive Tech's Outstanding Young Alumni Award (1986). She was recognized again in 2008 with the Distinguished Alumni Award.

About the Rigas Award

The Harriett B. Rigas Award is presented annually to recognize outstanding faculty women who have made significant contributions to electrical and computer engineering education. The award consists of an honorarium, plaque, certificate, and Frontiers in Education Conference registration.

The recipient must be a tenured or tenure track woman faculty member in an ABET-accredited engineering program in the United States, with teaching and/or research specialization in electrical or computer engineering.

About Harriett B. Rigas

Dr. Harriett B. Rigas (1934-1989), an IEEE Fellow, was an electrical engineer with an international reputation for her hybrid computer and computer simulation research. At Washington State University between 1966 and 1984, she was eventually both full professor and chair of Electrical and Computing Engineering School. Later she chaired larger departments at the Navy's Postgraduate School in Monterey and, at the time of her death, Michigan State University.

Her achievements in engineering research, administration, and service were widely recognized. In 1975-76, Harriett was a Program Director at the National Science Foundation and, over the years, a member of numerous panels and advisory committees at both the NSF and the National Academy of Sciences.

Professor Rigas' success was achieved within a profession and within university administrative structures where there were very few women. Her character and courage were both evident in her strong advocacy of advancement for women. She was involved both locally and nationally in the Society of Women Engineers.



Lecia Barker
University of Texas



Jane Gruning
University of Texas

Frontiers in Education Conference Benjamin J. Dasher Best Paper Award

The Student Prompt: Student Feedback and Change in Teaching Practices in Postsecondary Computer Science by Lecia Barker and Jane Gruning FIE 2014, Proceedings pp, 2873-2880

Lecia Barker is an Associate Professor in the School of Information at the University of Texas at Austin and a Senior Research Scientist for the National Center for Women & Information Technology. Lecia conducts research in attracting, retaining, and advancing groups underrepresented in professional computing and science careers; these studies focus on social climate, identity/belonging, faculty adoption of teaching and curricular practices, and sustainable organizational change. She advises several research and implementation projects intended to advance knowledge about computer science education. She is a co-PI of the NCWIT Extension Services program, which provides customized consulting to support systemic reform of computing and engineering departments. Lecia is currently studying faculty adoption of teaching methods in computer science. Lecia holds a Ph.D. in Communication from the University of Colorado at Boulder, a Master of Business Administration from San Diego State University, and a Bachelor of Arts from the University of Iowa.

Jane Gruning is a doctoral student in the School of Information at the University of Texas at Austin. In addition to her research on retaining underrepresented groups in undergraduate computer science programs, Jane conducts research in the area of human-computer interaction investigating the importance of objects in everyday human life and how this differs between physical and digital objects. Her research has focused on various aspects of this subject, from digital objects in causal gaming, to objects on obsolete media in a workplace, to how people share objects in home settings (study conducted during an internship at Microsoft Research Cambridge). She holds an MSIS from the University of Texas at Austin, an MA in Philosophy from Tulane University, and a BA in English Literature from Loyola University in New Orleans.

Past Recipients

'73 Walter D. Story
'74 Richard Hooper
'75 John J. Alan III and
J.J. Lagowski
'76 John Hipwell and
David Blaume
'77 John W. Renner
'78 Albert J. Morris
'79 Donald R. Woods, Cameron
M. Crowe, Terrence W. Hoffman,
and Joseph D. Wright
'80 Marilla D. Svinicki
'81 Martha Montgomery
'82 A.L. Riemenschneider and
Lyle D. Feisel

'83 Davood Tashayyod, Banu
Onaral, and James M. Trosino
'84 Bill V. Koen
'85 Bill V. Koen
'86 Richard S. Culver
'87 David A. Conner, David G.
Green, Thomas C. Jannett, James
R. Jones, M.G. Rekoff, Jr.,
Dennis G. Smith, and Gregg L.
Vaughn
'88 Richard M. Felder
'89 Richard C. Compton and
Robert York
'90 Cindy A. Greenwood
'91 Robert Whelchel
'92 William LeBold and Dan D.
Budny

'93 Daniel M Hull and Arthur H.
Guenther
'94 Burks Oakley II and Roy E.
Roper
'95 Curtis A. Carver, Jr. and
Richard A. Howard
'96 Val D. Hawks
'97 Edwin Kashy, Michael
Thoennessen, Yihjia Tsai, Nancy
E. Davis, and Sheryl L. Wolfe
'98 A.B. Carlson, W.C. Jennings,
and P.M. Schoch
'99 Wayne Burleson, Aura Ganz,
and Ian Harris
'00 David W. Petr
'02 Zeynep Dilli, Neil Goldsman,
Lee Harper, Steven I. Marcus, and
Janet A. Schmidt

Past Recipients (Continued)

- '03 Glenn W. Ellis, Gail E. Scordilis, and Carla M. Cook
- '04 Matthew W. Ohland, Guili Zhang, Brian Thorndyke, and Timothy J. Anderson
- '05 Gregory A. Moses and Michael Litzkow
- '07 Donna Riley and Gina-Louise Sciarra
- '08 Eric Hamilton and Andrew Hurford
- '09 Steve Krause, Robert Culbertson, Michael Oehrtman, Marilyn Carlson, Bill Leonard, C.V. Hollo, and William Gerace
- '10 Glenda Stump, Jenefer Husman, Wen-Ting Chung and Aaron Done
- '11 Jeffrey L. Newcomer
- '12 Kristi J. Shryock, Arun R. Srinivasa and Jeffrey E. Froyd
- '13 Robin Adams, Alice Pawley and Brent Jesiek
- '14 Hansi Keijonen, Jaakko Kurhila, Arto Vihavainen

About the Dasher Award

The Benjamin Dasher Best Paper Award is given to the best paper presented at the annual Frontiers in Education Conference, as demonstrated by technical originality, technical importance and accuracy, quality of oral presentation, and quality of the written paper appearing in the Conference Proceedings. Papers are nominated for the award by reviewers.

A committee with representation from each of the organizing societies (ERM, IEEE Ed. Soc., IEEE Comp. Soc.) is formed to review nominated papers. During the FIE meeting, the committee attends presentations of the nominated papers. The committee then makes a final recommendation to the FIE Planning Committee for the Ben Dasher Award winner based on the overall quality of both the paper and the presentation.

About Benjamin J. Dasher

Benjamin J. Dasher was born December 27, 1912 in Macon, Ga. He earned his bachelor's and master's degrees in electrical engineering in 1935 and 1945, respectively, and graduated with a doctorate in electrical engineering in 1952 from the Massachusetts Institute of Technology. At MIT, Dr. Dasher worked on the electronics of instrumentation of electromechanical transducers and analog-to-digital converters. He was the author of "Dasher's method" for synthesis of resistance-capacitance two-port networks, which is found in standard textbook treatments.

While at Georgia Tech, Dr. Dasher served as a graduate assistant in 1936, then as an instructor in 1940, and became an assistant professor in 1945. While earning his PhD at MIT, he was an instructor from 1948-51. Before finishing with his PhD, he became an associate professor at Georgia Tech in 1951, was promoted to professor in 1952, and became director of the School of Electrical Engineering in 1954, where he served in that capacity until 1969. In 1968, Dr. Dasher was appointed associate dean in the College of Engineering. At Georgia Tech, Dr. Dasher served as director of network synthesis projects and transistor oscillator projects. His fields of interest included advanced network theory, electronic theory, electronic circuits, electrical engineering education, machine translation, speech analysis, and pattern recognition. He was credited for bringing undergraduate engineering education to the forefront at Georgia Tech and for increasing interactions between undergraduates and industry.

Dr. Dasher was a member of Phi Kappa Phi, ASEE, Sigma Xi, and the American Association of University Professors; he was a Fellow of both the IEEE and the Institute of Radio Engineers. He served as a regional director for IEEE and as the chair for the Atlanta section of IEEE; he was on numerous committees for IRE, AIEE, and IEEE. He served as President of the IEEE Education Group in 1970-71.

Ben Dasher organized the first Frontiers in Education Conference; it was held in Atlanta in 1971, and attracted 100 participants. There were 34 papers in six technical sessions.

Dr. Dasher died of congestive heart failure on December 13, 1971 in Houston, Texas.



Rebecca Bates
Minnesota State
University, Mankato



Lisa Benson
Clemson University



Alan Cheville
Bucknell University

Frontiers in Education Conference Helen Plants Award Best Nontraditional Session at FIE 2014

For their Special Session “Agents for STEM Change –Articulating the Goals of Our Community”, Proceedings, 2014 Frontiers in Education Conference, pp. 1942-1943

The EER Leaders NetWorkshop was formed in 2013 through funding from the National Science Foundation (EEC-1314725 and 1314868; Rebecca Bates and Lisa Benson, co-PI's). Our goal is to provide a mechanism for mentoring and supporting mid-career faculty across distributed locations who are not far enough along in their careers to have administrative or leadership experience, but are frequently stepping into these roles. We seek to develop advocates and future leaders for our emerging discipline of EER by focusing on building community, developing skills to communicate across organizational boundaries and identifying strategies for moving the emerging field forward and supporting rising EER leaders. As a group of about 25 mid-career EER faculty, we have had held face-to-face workshops at and around engineering education conferences. We have also had monthly virtual meetings to learn about ways to influence those outside of our discipline, and ways to navigate important conversations across administrative boundaries within universities. We have learned about sources of influence (such as structural, social and personal), barriers to achieving influence, and change models that are appropriate for engineering education.

Rebecca Bates is a Professor and Chair of the Department of Integrated Engineering at Minnesota State University, Mankato. She directs the Iron Range and Twin Cities Engineering programs, project-based learning programs that provide pathways to four-year engineering degrees for community college graduates. Her research background has focused on speech recognition and understanding as well as engineering and computer science education. Her degrees are in biomedical engineering (B.S., Boston University), electrical engineering (M.S., Boston University, Ph.D., University of Washington) and theological studies (M.T.S., Harvard University).

Lisa Benson is an Associate Professor of Engineering and Science Education at Clemson University, with a joint appointment in Bioengineering. Her research focuses on the interactions between student motivation and their learning experiences. Her projects involve the study of student perceptions, beliefs and attitudes towards becoming engineers and scientists, and their problem solving processes. Other projects in the Benson group include effects of student-centered active learning, self-regulated learning, and incorporating engineering into secondary science and mathematics classrooms. Her education includes a B.S. in Bioengineering from the University of Vermont, and M.S. and Ph.D. in Bioengineering from Clemson University.

Alan Cheville studied optoelectronics and ultrafast optics at Rice University, followed by fourteen years as a faculty member at Oklahoma State University working on terahertz frequencies and engineering education. While at Oklahoma State he developed courses in photonics and engineering design. After serving for two and a half years as a program director in engineering education at the National Science Foundation, he took a chair position in electrical engineering at Bucknell University. He is currently interested in engineering design education, engineering education policy, and the philosophy of engineering education.



Cynthia Finelli
University of Michigan



Jennifer Karlin
South Dakota School of
Mines and Technology



Susan Lord
University of San Diego

Past Recipients

- '80 Helen Plants
- '81 Jim Russell and
John C. Lindenlaub
- '82 Karl A. Smith and
Harold Goldstein
- '83 E. Dendy Sloan and
Charles F. Yokomoto

Frontiers in Education Conference Helen Plants Award Best Nontraditional Session at FIE 2014 (Continued)

Cynthia Finelli is Director of the Center for Research on Learning and Teaching in Engineering and associate professor of electrical engineering at University of Michigan. At U-M, she actively engages in engineering education research, assists other engineering faculty in accomplishing their educational research endeavors, and promotes institutional change through faculty professional development. She currently studies student resistance to active learning, faculty adoption of evidence-based teaching practices, and ethical decision-making in undergraduate engineering students. Dr. Finelli leads an international initiative to create a taxonomy for the field of engineering education research, and she is a Fellow of the American Society for Engineering Education.

Jennifer Karlin is a professor of industrial engineering at the South Dakota School of Mines and Technology. She received her undergraduate degree from Washington University in St. Louis and her Ph.D. in industrial and operations engineering from the University of Michigan, specializing in engineering management. Jennifer studies colleges and universities as organizations and change management to improve learner development and university-based economic development. She has been active in FIE, serving as conference general co-chair for the 2011 conference and an ERM representative on the FIE steering committee. She also served as an ERM Board Member.

Susan M. Lord is Professor and Chair of Electrical Engineering, University of San Diego. She received a B.S. from Cornell University and the M.S. and Ph.D. from Stanford University. Her research focuses on the study and promotion of diversity in engineering including student pathways, diverse populations including Latinos and military veterans, and cross-cultural studies with non U.S. students. Dr. Lord is a Fellow of the IEEE and ASEE and is active in the engineering education community including serving as General Co-Chair of the 2006 Frontiers in Education (FIE) Conference, on the FIE Steering Committee, and as President of the IEEE Education Society for 2009-2010.

Past Recipients (Continued)

- '84 David W. Johnson and
Karl A. Smith
- '85 Billy V. Koen
- '86 Martha A. Nord and
Patricia H. Whiting
- '87 John C. Lindenlaub
- '89 Karl A. Smith
- '91 Troy E. Kostek
- '92 Barbara M. Olds and
Ronald L. Miller
- '93 John C. Lindenlaub and
Alisha A. Waller
- '94 Billy V. Koen
- '95 Burks Oakley II and
Mark Yoder
- '96 Alisha A. Waller,
Edward R. Doering, and
Mark A. Yoder
- '97 Karl A. Smith, James D.
Jones and Elizabeth
Eschenbach
- '98 Alice Agogino
- '99 Melinda Picket-May and
Julie L. Chang
- '03 William C. Oakes
- '04 Susan M. Lord,
Elizabeth A. Eschenbach,
Alisha A. Waller, Eileen M.
Cashman, and Monica J.
Bruning
- '05 Ruth A. Streveler
- '06 Ruth A. Streveler, Karl A.
Smith, and Ronald L. Miller
- '08 Maura Borrego, Lynita
Newswander, and Lisa
McNair
- '09 Lisa C. Benson, Sherrill B.
Biggers, William F. Moss,
Matthew Ohland, Marisa K.
Orr, and Scott D. Schiff
- '10 Russell Korte and Karl A.
Smith
- '11 Mark Somerville, Dave
Goldberg, Sherra E. Kerns,
and Russell Korte
- '12 Şenay Purzer and Jonathan C.
Hilpert
- '13 Lynn Andrea Stein, and
Caitrin Lynch
- '14 Stephanie Cutler, James J.
Pembroke, Matthew
Verleger, Lauren D. Thomas

About the Plants Award

The Helen Plants Award is given for the best special (non-traditional) session at the FIE conference, as demonstrated by originality, session content and presentation including the use of written materials and visual aids, and participation of session attendees.

About Helen Margaret Lester Plants

Helen Margaret Lester was born in Desloge, Missouri, in March 1925, the only child of Rollo Bertell and Margaret Stephens Lester.

She entered the University of Missouri as a journalism major, but soon switched to Civil Engineering. She received her BSCE in 1945. She joined West Virginia University in 1947 as a graduate student and Instructor in Mechanics, and received her MS in Civil Engineering in 1953. She was a Professor of Theoretical and Applied Mechanics and of Curriculum and Instruction in the Division of Education at WVU. She became Professor Emeritus, Mechanical and Aerospace Engineering in 1983. From 1985 to 1990 she served as Chair of Civil Engineering Technology at Indiana University-Purdue University - Fort Wayne.

Her husband Ken Plants had been a "bureaucrat" with the US Bureau of Mines in Morgantown - a chemical engineer with great expertise in cost estimation. Some of their "courting" evenings were spent manually checking the design calculations on the Star City, WV Bridge, designed by the Dean and State Bridge Engineer. While in Morgantown, Helen was active in Trinity Episcopal Church where she served as a Vestryman and Bishop's Man. For many years she was a Girl Scout leader. Helen died in Tulsa, Oklahoma in September 1999.

From the beginning of her academic career, she was a gifted teacher and a role model for the few women students at West Virginia University at that time. Later, she became an advocate of programmed and individualized instruction. She and Wally Venable wrote series of papers on these topics and several texts: *Introduction to Statics, a Programmed Text*, (1975), *A Programmed Introduction to Dynamics* (1967), and *Mechanics of Materials, A Programmed Textbook* (1974). She established the first doctoral program in Engineering Education at West Virginia University.

In 1975, the University of Missouri at Columbia recognized her with the Missouri Honor Award for Distinguished Service in Engineering. She became an ASEE Fellow in 1983 as a member of the first class of Fellows. She also received Distinguished Service Award, Western Electric Fund Award, and was an ASEE Vice-President (1974 – 1976).



Robert J. Hofinger

Past Recipients

'84 Carol Schmitz
'85 Lawrence P. Grayson
'86 John C. Lindenlaub
'87 George Burnett
'88 James R. Rowland
'89 Lyle D. Feisel
'90 Edwin C. Jones, Jr.
'92 Karl A. Smith
'92 Victor K. Schutz
'93 Bruce A. Einstein
'94 David V. Kerns, Jr.
'95 David R. Voltmer
'96 William E. Sayle II
'97 Richard S. Culver
'98 Dan Budny
'99 Robert J. Herrick
'00 Larry J. Shuman
'01 David L. Soldan
'02 Goranka Bjedov
'03 Larry G. Richards
'04 James A. Roberts
'05 Robert J. Hofinger
'06 Jane Chu Prey
'07 Joseph L. A. Hughes
'08 Ted E. Batchman
'09 Russ Meier
'10 Dan Moore
'11 Susan M. Lord
'12 Arnold Pears
'13 Jennifer Karlin
'14 Cynthia Finelli

Frontiers in Education Conference Ronald J. Schmitz Award

For contributions to the Frontiers in Education Conference through developing and maintaining a comprehensive program of informative educational exhibits.

Robert J. Hofinger holds the title of Professor Emeritus from the Electrical and Computer Department in the College of Technology at Purdue University. He received his BSEE and MSEE degrees from the Brooklyn Polytechnic Institute (now the NYU Polytechnic School of Engineering).

Before starting his academic career at Purdue University, he worked as an electrical engineer for over 30 years. His experience included work in the military/aerospace industry with LITCOM electronics, a division of LITTON Industries and RCA Astropace Division where he designed digital circuitry for the decoding and control of hydrogen gas thruster engines on commercial telecommunication satellites; in the gasoline industry with GILBARCO, at the time an EXXON subsidiary, in the design of ultrasound underground metering systems and specialized switching power supplies for gasoline dispensers; in the electric metering industry with LANDIS & GYR, in the design of analog current dividing circuits for accurately measuring the in-phase and quadrature-phase currents for electronic watt-hour metering systems; and the automotive industry with DELCO Electronics (now DELPHI Electronics) in designing Electronic Control Modules (ECMs) for OPEL Motors, a General Motors European subsidiary.

After retirement from full time teaching, he is teaching part time as an Adjunct Professor for the IvyTech Community College of Indiana in the School of Applied Science and Engineering Technology.

He has been active in the American Society for Engineering Education (ASEE) for many years, serving as the program chair for the Instrumentation Division. He was elected to and has held all executive positions in the IL/IN section of the ASEE. He has also held the office of treasurer of the Greensboro, N.C. chapter of the IEEE.

About the Schmitz Award

The Ronald Schmitz Award is given to recognize outstanding and continued service to engineering education through contributions to the Frontiers in Education Conference.

About Ronald J. Schmitz

Ronald J. Schmitz was born near Ionia, Iowa on April 25, 1934. He attended a one-room country school through the eighth grade and then, as was not uncommon at the time, decided to forgo high school and work on his father's farm. At age 18, he joined the United States Navy. He served as an Electricians Mate, spending much of his enlistment at sea and made a round-the-world cruise aboard the USS Saipan.

In the Navy, Ron found an interest in and an aptitude for technology and recognized the need for further education. He completed a GED program in the Navy and, when he was discharged, enrolled in electrical engineering at Iowa State University. He received all his degrees there, finishing his doctorate in 1967.

In the fall of 1967, he accepted appointment as Assistant Professor in the Department of Electrical Engineering at the South Dakota School of Mines and Technology in Rapid City. He was involved in various research activities and directed both masters and doctoral students, but his strongest interest was always in teaching. Ron was a consummate teacher, patient with students who were having difficulty but intolerant of sloth. He received the School of Mines Teaching Award in 1975 and the Western Electric Fund Award for Excellence in Teaching in 1981.

Dr. Schmitz was very active in the IEEE, especially the Education Society, and served as Secretary Treasurer of the Society. He was also active in ERM and attended, and contributed to, many Frontiers in Education Conferences. He served as general chair of FIE 1981 in Rapid City.

Ron was an avid hunter and fisherman, a devoted husband and father and a faithful friend. He served his church as Lector and Lay Minister and was active as a Boy Scout leader.

Ron contracted cancer in 1983 and died on July 19, 1984.



Marco Winzker
Bonn-Rhein-Sieg
University

Past Recipients

- '79 Lawrence P. Grayson
- '80 Demetrius T. Paris
- '81 Lindon E. Saline
- '82 Anthony B. Giordana
- '83 Joseph Bordogna
- '84 John C. Lindenlaub
- '85 John D. Ryder
- '86 James R. Rowland
- '87 Bruce Eisenstein
- '88 Mac Van Valkenburg
- '89 Edward W. Ernst
- '90 Ernst Weber
- '91 J. David Irwin
- '92 Jerrier A. Haddad
- '93 Chalmers F. Sechrist
- '94 Eric A. Walker
- '95 Stephen W. Director
- '96 William H. Hayt, Jr.
- '97 Jerry R. Yeargan
- '98 Ted E. Batchman
- '99 Lyle D. Feisel
- '00 Irene C. Peden
- '01 Donald E. Kirk and
Eli Fromm
- '02 Burks Oakley II
- '03 Frank Barnes and
Delores Etter
- '04 William E. Sayle II
- '05 H. Vincent Poor
- '06 George D. Peterson
- '07 Sarah A. Rajala and
Marwan A. Simaan
- '08 James A. Roberts
- '09 Jose B. Cruz, Jr.
- '10 Rob Reilly
- '11 Susan E. Conry
- '12 Theodore Rappaport
- '13 Karen Panetta
- '14 Raghunath K.
Shevgaonkar

IEEE Education Society William E. Sayle II Award for Achievement in Education

For continuously introducing project-based learning into the engineering curriculum and promoting professional development of the faculty

Marco Winzker (M'10-SM'11) is Professor for digital design and fundamentals of electric circuits at the Bonn-Rhein-Sieg University in St. Augustin, Germany. He joined the faculty in 2004 and was associate dean of the Engineering department from 2007 to 2011. Since 2011 he has been the project manager for Pro-MINT-us, the university project of the German Teaching Quality Pact initiative ("Qualitätspakt Lehre"). Marco studied Electrical Engineering at the University of Hannover, Germany and received his Ph.D. for work on low-power CMOS design. As Design Engineer and Group Leader he developed image processing systems with ASICs and FPGAs. He worked for Philips Semiconductors (now NXP) in Hamburg, Germany and Eindhoven, The Netherlands, for Liesegang electronics in Hannover, and for Silicon Optix (now IDT) in Hannover and Toronto, Canada.

At the Bonn-Rhein-Sieg University he was the Program Director of the first bachelor curriculum in electrical engineering which introduced a new 4-1-4-1-4-1 semester structure. Three weeks of each semester are reserved for project-based learning and self-learning exercises and these project weeks alternate with four weeks of regular lectures, classroom exercises, and hands-on labs. He successfully applied for funding from the Teaching Quality Pact initiative to extend project-based learning to 1st-year students and to strengthen STEM-subjects in the initial study phase. Marco promotes professional development within the faculty by organizing workshops, "education evenings" where professors dine at a restaurant and discuss an education topic and "teaching days" with talks from university staff and external speakers. In the university canteen he enthusiastically reports from education conferences like Educon and invites colleagues to join him at future events.

Marco was selected as participant for the excellence in education program "Lehre-hoch-n". He received an IEEE Educon Best Paper Award and the award for innovation in teaching at the Bonn-Rhein-Sieg University. He wrote an interdisciplinary textbook about electronics for non-engineers ("Elektronik für Entscheider") for a degree course of technical journalism. He was guest editor of the Austrian journal for higher education development ("Zeitschrift für Hochschulentwicklung") and was invited to speak as well as to chair workshops at several national and international education conferences. He regularly participates in summer schools of his university and has accompanied students to Finland, Spain and The Netherlands. He was also guest lecturer at the National Technical University of Argentina in Buenos Aires.

About the Sayle Award and William E. Sayle II

The William E. Sayle II Award is presented to recognize a member of the IEEE Education Society who has made significant contributions over a period of years in a field of interest of the IEEE Education Society. The award consists of a plaque, a certificate, and paid registration to the Frontiers in Education Conference.

Dr. William (Bill) E. Sayle received his BSEE and MSEE degrees from the University of Texas at Austin and his Ph.D. from the University of Washington. He joined the faculty in electrical engineering at Georgia Institute of Technology in 1970, just as Georgia Tech was beginning the transition from an undergraduate institution to a research university. He was the ECE associate chair for undergraduate affairs from 1988-2003 and, following retirement in 2003, served as director of undergraduate programs at Georgia Tech-Lorraine in France until 2007. Bill was a tireless advocate for students, putting in countless late night and weekend hours in addressing student issues, assigning teaching assistants, and meeting with prospective students and parents.

Throughout his career, Bill touched the lives of many people in the worldwide academic community. He was a leader and a pioneer in many areas. In the 1970s, he was a founding member of the IEEE Power Electronics Society, where he served in many leadership roles over the years. He was a champion of diversity and in recruiting underrepresented minorities and women to engineering and science, long before it became a national issue. He visited many high schools on behalf of the Southeastern Consortium for Minorities in Engineering, a role where he made many friends for Georgia Tech among high school administrators and students in the southern part of Georgia.

In his 30-year career at Georgia Tech, Bill received the ECE outstanding teacher award twice, as well as the Georgia Tech outstanding teacher award and outstanding service award. Bill lent his voice and efforts to Georgia Tech faculty governance throughout his career, serving as an elected member of Institute-level committees, the Academic Senate, and the Executive Board.

Bill was a long-time member and active volunteer in the IEEE Education Society and the Electrical and Computer Engineering Division of ASEE. He was a Fellow of both IEEE and ASEE. He was the recipient of the Education Society's 2001 Meritorious Service Award and 2004 Achievement Award and of the ECE Division's 2001 Meritorious Service Award and 2006 ECE Distinguished Educator Award. Bill was the General Chair of the 1995 Frontiers in Education (FIE) Conference, which is still remembered for its all-vegetarian menu, and received the 1996 Ronald J. Schmitz Award for outstanding service to FIE.

Much of Bill's professional career was devoted to engineering accreditation, serving at various times as member and chair of the IEEE Committee on Engineering Accreditation Activities and the IEEE Accreditation Policy Council. He participated in more than 20 visits as a program evaluator, in addition to serving as a team chair and member of the Engineering Accreditation Commission of ABET for more than five years. Bill received the IEEE Educational Activities Board Meritorious Achievement Award in Accreditation Activities in 2004.

Dr. Sayle passed away on February 2, 2008.

IEEE Transactions on Education Best Paper Award

Presented to: Raghu Raman, Krishnashree Achuthan, Prema Nedungadi, Shyam Diwakar, Amrita University, and Ranjan Bose, Indian Institute of Technology New Delhi, for their paper "The VLAB OER Experience: Modeling Potential-Adopter Student Acceptance", IEEE Transactions on Education, 57:4, November 2014, pp. 235-241.

Raghu Raman (M'08, SM '12) received his MBA from Haas School of Business, Berkeley in 2003. He is the Principal Investigator for the National Mission on Education through ICT EdRP Project, Measuring Learning under the HP Catalyst Global Innovation with Carnegie Mellon University and for the Medical Simulation initiative under the Ministry of IT. Currently Raghu is guiding research projects in the areas of learning analytics, serious games and virtual interactive learning environments.

Raghu has over 14 years of product design and architecture experience from NEC Research Labs and IBM and is recipient of the President of India Gold Medal. He is Immediate Past Chair of the IEEE Education Society, India, and recipient of IEEE Outstanding Chapter award for 2013.

Prema Nedungadi (M '12) is the Joint Director of Amrita CREATE (Center of Research in Advanced Technologies for Education) and faculty in School of Engineering. She has coauthored numerous scientific publications. Her research interests are in personalized e-learning solutions using computational intelligence methods, multimodal and virtual reality systems for STEM learning and language learning. She is Principal Investigator for the Online Science Labs and Adaptive Continuous and Comprehensive Evaluation research grants from Govt. of India and Co-Principal Investigator for the Virtual Labs project under National Mission in Education through ICT.

Krishnashree Achuthan holds a Ph.D. in chemical engineering and heads the Center for Virtual and Accessible Laboratories Universalizing Education (VALUE @ Amrita) at Amrita University. VALUE @ Amrita has built over 30 virtual laboratories that are simulation-based, interactive and/or remotely triggerable with over 300 experiments in the areas of Physics, Chemistry, Biotechnology, Computer Science and Mechanical Engineering. She is Principal Institute Coordinator for National Mission on Education through ICT at Amrita University. Her research interests include Science and Engineering under-graduate education amongst others. She has over forty research papers and publications in peer-reviewed conferences and journals. She is also the author of 29 U.S. Patents.

Shyam Diwakar (M '01) received his Ph.D. in computational sciences from the University of Milan, Italy in 2008. Currently, he is an assistant professor at the School of Biotechnology where he is the head of the Computational Neuroscience laboratory. Prior to that he worked as a postdoctoral researcher in the department of General Physiology, University of Pavia, Italy. His research uses principles from electrical engineering and informatics to study the cerebellum and its functioning. Dr. Diwakar is also a member of Indian Academy of Neurosciences, Organization of Computational Neuroscience Societies (OCNS) and the IACSIT.

Ranjan Bose (SM '11) received his B.Tech. degree in electrical engineering from the Indian Institute of Technology (IIT), Kanpur and the M.S. and Ph.D. degrees in electrical engineering from the University of Pennsylvania, Philadelphia. Currently he holds the Microsoft Chair Professorship and heads the Wireless Research Lab in IIT Delhi. His research interests lie in the areas of ultra-wideband (UWB) communications, broadband wireless access and coding theory. He has held guest scientist positions at the Technical University of Darmstadt, Germany, University of Colorado at Boulder, USA and UNIK, Norway. He has published over one hundred research papers in refereed journals and conferences, and holds ten patents.

Past Recipients

'99 J.A. Buck, H. Owen, J.P. Uyemura, C.M. Verber, and D.J. Blumenthal
'00 David J. Russomanno and Ronald D. Bonnell
'01 Christopher W. Trueman
'02 Mohan Krishnan and Mark J. Paulik
'03 Tyson S. Hall, James O. Hamblen, and Kimberly E. Newman
'04 M. Brian Blake
'04 Russell L. Pimmel
'05 Antonio J. Lopez-Martin

'06 Euan Lindsay and Malcolm C. Good
'07 Jason A. Day and James D. Foley
'08 France Bélanger, Tracy L. Lewis, George M. Kasper, Wanda J. Smith and K. Vernard Harrington
'09 Kenneth Ricks, Jeff Jackson, and William A. Stapleton
'10 Keith Holbert and George G. Karady
'11 Julie A. Rursch, Andy Luse, and Doug Jacobson
'12 Susan Lord, Richard Layton, and Matthew Ohland
'13 Benjamin Hazen, Yun Wu and Chetan Sankar
'14 James McLurkin, Joshua B. Rykowski, Meagan John, Quillan Kaseman, and Andrew J Lynch



Rosanna Yuen-Yan Chan
The Chinese University
of Hong Kong

Distinguished Chapter Leadership Award

For her exceptional contribution to the IEEE Education Society and for distinguished leadership in engineering education over a sustained period.

Dr. Rosanna Yuen-Yan Chan is a Senior Member of the IEEE and an Adjunct Assistant Professor at the Department of Information Engineering, The Chinese University of Hong Kong. She has a multidisciplinary background in engineering, education, and learning science. Rosanna is the Founding Chair of the IEEE Education Society Hong Kong Chapter, the Educational Activities Chair of the IEEE Hong Kong Section, and a committee member of the IEEE Educational Activities Board (EAB) Student Educational Resources Committee (SERC) as well as the Chapter Committee of the IEEE Education Society. Rosanna is elected the New Faculty Fellow of the Center for the Advancement of Scholarship on Engineering Education (CASEE), National Academy of Engineering (NAE), USA.



Victor P. Nelson
Auburn University

Past Recipients

'78 Warren B. Boast
'79 Joseph M. Biedenbach
'80 Edwin C. Jones, Jr.
'81 Lyle D. Feisel
'82 Roy H. Mattson
'83 Robert F. Fontana
'84 Gerald R. Peterson
'85 Luke H. Noggle
'86 James A. Mulligan
Sidney S. Shamis
'87 Thomas K. Gaylord
'88 Robert F. Cotellessa
'89 E. Ben Peterson
'90 Darrell L. Vines
'91 Victor K. Schutz
'92 William K. LeBold
'93 Frank S. Barnes
'94 Patricia D. Daniels
'95 Robert W. Ritchie
'96 Marion O. Hagler
Donald E. Kirk
'97 Robert Sullivan
'98 Burks Oakley II
'99 Gerald L. Engel
'00 Ted E. Batchman
'01 William E. Sayle II
'02 James Rowland
'03 David A. Conner
'04 Trond Clausen
'05 J. David Irwin
Rodney J. Soukup
'06 Robert A. Reilly
'07 David V. Kerns, Jr.
'08 James J. Sluss, Jr.
'09 Manuel Castro
'10 Michael E. Auer
'11 Russ Meier
'11 Claudio da Rocha Brito and
Melany M. Ciampi
'12 Susan Lord
'13 Charles Fleddermann
'14 Danilo G. Zutin

IEEE Education Society Edwin C. Jones, Jr. Meritorious Service Award

For service to the Education Society through maintenance, improvement, and implementation of the by-laws and related activities, for overall service to the society, and for service to all of IEEE, ABET, and ASEE.

Victor P. Nelson is a Professor and Assistant Chair of Electrical and Computer Engineering at Auburn University, where he has been on the faculty since 1978. His primary research interests include embedded systems and computer-aided design and testing of digital systems and application-specific integrated circuits (ASICs). He is co-author of the textbook *Digital Logic Circuit Analysis and Design* and IEEE tutorial book *Fault-Tolerant Computing*. He is past chair of the ECE Curriculum Committee and coordinator of the ECE Graduate Program, and served one year as Associate Dean for Assessment in the College of Engineering. He was a co-winner of the 2005 "Wireless Educator of the Year" award from the Global Wireless Education Consortium for his role as one of the developers of the Bachelor of Wireless Engineering program at Auburn University, which is the first of its kind in the U.S., and currently serves as the director of that program. He received the Birdsong Merit Teaching Award in 2000 and the Walker Merit Teaching Award in 2002 from the College of Engineering, and was named outstanding member of the Graduate Faculty in 2004.

He is a member of the IEEE Education Society, in which he has served as a member of the Board of Governors, chair of the Constitution and Bylaws committee, and previously as an associate editor of the *IEEE Transactions on Education*. He was a member of the IEEE Computer Society/ACM Task Force that developed the Computer Engineering 2004 (CE20014) report on model computer engineering curricula, and is a member of the task force updating that report for CE2016. He is active in accreditation activities, having served as an ABET program evaluator and a current member of the ABET Engineering Accreditation Commission, and previously as a member and mentor coordinator of the IEEE Committee on Engineering Accreditation Activities (CEAA). He is also a member of ASEE, and previously served as chair of the ASEE ECE Division.

About the Edwin C. Jones Award

The Edwin C. Jones Meritorious Service Award is presented to recognize a member of the IEEE Education Society who has made pioneering contributions to the administrative efforts of the IEEE Education Society over a period of years. The award consists of a plaque, a certificate, and registration to the Frontiers in Education Conference.

About Edwin C. Jones

Professor Jones served as a Society officer from 1970 through 1976; this service included two years as president. He served as Editor-in-Chief of the IEEE Transactions on Education from 1982-84. Since he first became involved in the Society in the late 1960s, he has held virtually every office in the Education Society. Professor Jones also serves the IEEE as a member of the IEEE Committee on Engineering Accreditation Activities. Dr. Jones is University Professor and Associate Chair, emeritus, Department of Electrical and Computer Engineering, Iowa State University. Prior to joining Iowa State in 1966, he was an Assistant Professor at the University of Illinois from 1962-66. He received his PhD in 1962 from the University of Illinois; the DIC in 1956 from Imperial College of Science and Technology, London; and the BSEE in 1955 from West Virginia University. Dr. Jones' honors and awards include: Fellow, Institute of Electrical and Electronics Engineers; Fellow, American Society for Engineering Education; Fellow, American Association for Advancement of Science; Fellow, Accreditation Board for Engineering and Technology; IEEE Centennial Medal, 1984; ASEE Centennial Medal, 1993; and the Grinter Distinguished Service Award from ABET in 2001. Some of his students founded a scholarship for Electrical and Computer Engineering students at Iowa State University in his honor.



Chengying Xu
Florida State University

Past Recipients

'04 Parham Aarabi
'05 John R. Buck
'06 Lisa G. Huettel
'07 Susan C. Hagness
'08 Kathleen E. Wage
'09 Min Wu
'10 Craig Ziles
'11 Jonathan Makela
'12 Babak Ayazifar
'13 Muhammad Zaman
'14 Jill Nelson

IEEE Education Society Mac Van Valkenburg Early Career Teaching Award

For leadership in engineering education innovation and outstanding classroom teaching, providing students hands-on experience during classes and research, and helping them understand fundamentals using practical examples.

Dr. Chengying “Cheryl” Xu is currently an Associate Professor at the Florida State University, Tallahassee, Florida. She received her Ph.D. in 2006 in mechanical engineering from Purdue University, West Lafayette, Indiana, and her M.S. in 2001 in mechanical manufacturing and automation from Beijing University of Aeronautics and Astronautics, Beijing, China.

Her research interests include manufacturing of advanced materials, manufacturing process optimization and control, high temperature sensor design. Dr. Xu has co-authored a textbook with her doctoral advisor: *Intelligent Systems: Modeling, Optimization and Control* (CRC Press, 2008, 433 pages), and four book chapters. She has authored and coauthored more than 30 journal papers and around 30 refereed conference proceedings.

Dr. Xu is the Journal Guest Editor for *ASME Transactions, Journal of Micro- and Nano- Manufacturing (ASME JNM)*, an Associate Editor of the *International Journal of Nanomanufacturing (IJNM)* from 2008 to 2010, and has been on the Board of Editors for *Journal of Aviation and Aerospace Perspectives (JAAP)* since 2010, and *International Journal of Computational Materials Science and Surface Engineering* since 2007. She served on the Conference Organizing Committee for *ASME Dynamic Systems and Control Conference (DSCC)*, *International Symposium on Flexible Automation (ISFA)*, *SPIE Conference, Smart Structures/NDE, Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems*. She won the Office of Naval Research Young Investigator Award and Society of Manufacturing Engineers’ (SME) Richard L. Kegg Outstanding Young Manufacturing Engineer (OYME) Award in 2011.

She is actively in conducting research in manufacturing field and has attracted an impressively high level of research funding (total > \$4M, where her share > \$2.8M). She has secured significant support from National Science Foundation (NSF), Department of Energy (DoE), Office of Naval Research (ONR), Florida State, international/national companies, and her university to conduct research. She has graduated five Ph.D. and nine M.S. students.



Jeffrey Froyd
Texas A&M University

Past Recipients

'05 Marion O. Hagler and
Burks Oakley II
'06 Ted Batchman and
David A. Conner
'08 David L. Soldan
'10 Manuel Castro
'11 Susan M. Lord
'12 Matthew Ohland
'13 Victor Nelson

IEEE Education Society Distinguished Member Award

For leadership in promoting innovation in STEM education, including service as project director for the Foundation Coalition, service as an ABET program evaluator, and service to the IEEE Education Society as Editor-In-Chief of the IEEE Transactions on Education and past-chair of the Frontiers in Education Conference.

Dr. Jeffrey E. Froyd is a TEES Research Professor in the Office of Engineering Academic and Student Affairs at Texas A&M University, College Station. He received the B.S. degree in mathematics from Rose-Hulman Institute of Technology and the M.S. and Ph.D. degrees in electrical engineering from the University of Minnesota, Minneapolis. He was an Assistant Professor, Associate Professor, and Professor of Electrical and Computer Engineering at Rose-Hulman Institute of Technology. At Rose-Hulman, he co-created the Integrated, First-Year Curriculum in Science, Engineering and Mathematics, which was recognized in 1997 with a Hesburgh Award Certificate of Excellence. He served as Project Director for a National Science Foundation (NSF) Engineering Education Coalition in which six institutions systematically renewed, assessed, and institutionalized innovative, integrated undergraduate engineering curricula.

He has authored over 70 journal articles and conference papers and offered over 30 workshops on faculty development, curricular change processes, curriculum redesign, and assessment. He has served as a program co-chair for three Frontiers in Education Conferences and the general chair for the 2009 conference. He also serves on the IEEE Curricula and Pedagogy Committee, which is part of the University Resources Committee, which is part of the Educational Activities Board. Prof. Froyd is a Fellow of the IEEE, a Fellow of the American Society for Engineering Education (ASEE), an ABET Program Evaluator, the Editor-in-Chief for the *IEEE Transactions on Education*, a Senior Associate Editor for the *Journal of Engineering Education*, and an Associate Editor for the *International Journal of STEM Education*.



German Carro Fernandez

Past Recipients

- '09 Seiji Isotani
- '10 Emmanuel Gonzalez and Kai-Pan Mark
- '11 Dario Schor
- '12 Elio San Cristobal Ruiz and Sergio Martin
- '13 Subhamoy Mandal
- '14 Liang-Bi Chen

IEEE Education Society Student Leadership Award

For Student Branch leadership advocating and facilitating the activities of the UNED Student Branch and collaborations in Spain and Portugal to sustain IEEE Students Branches.

German Carro Fernandez is Doctor, Cum Laude, in Industrial Engineering (UNED, 2014), Master in Research on Electronics, Electricity and Industrial Control (UNED, 2012), Bachelor degree on Computer Systems Engineering Tech. (UNED, 2010), Master on Business Administration and Taxes (UDC and Spanish Public Tax School, Spanish Treasury, 1997) and Bachelor degree on Economics Science and Financial Markets (UDC, 1996). He is on the Board of Directors of Pre-University Activities Sub-Committee of EASC Region 8, was Treasurer of IEEE Spain Section, Chair of Spain Section AG GOLD/YP, Chair of IEEEsb of UNED, Chair of Student Chapter of IEEE Education Society on IEEEsb of UNED, and Member of several IEEE Societies.

He has worked as a freelance economist and engineering consultant for industries and enterprises since 1994. Since 2012 he is working as Professor and Researcher on several projects with main focus on Remote Laboratories, Telematics Control, Robotics and IoT, at UNED, and since 2015 he is Director of the UNED Associate Center on A Coruña (Spain). Since 2006 he has been working as volunteer at IEEE to spread technology on several education areas and promoting the engineering and science on Schools, Universities and Academia receiving several appreciation certificates like "Certificate of Appreciation from IEEE", 2010/2011, and "Certificate of appreciation from IEEE Spain Section", 2012/2013.

IEEE Fellow Award

Susan M. Lord, University of San Diego

For professional leadership and contributions to engineering education



Susan M. Lord is Professor and Chair of Electrical Engineering, University of San Diego (USD). She received a B.S. from Cornell University and the M.S. and Ph.D. from Stanford University. Her research focuses on the study and promotion of diversity in engineering including student pathways, diverse populations including Latinos and military veterans, and cross-cultural studies with non U.S. students. Her research has been sponsored by the National Science Foundation (NSF). Dr. Lord and Dr. Michelle Madsen Camacho are among the first to study Latinos in engineering. In reviewing their 2013 book, *The Borderlands of Education: Latinas in Engineering*, Dr. Riley, Smith College, called it “groundbreaking work...that will challenge your assumptions about women and minorities in engineering”. Dr. Walden, University of Oklahoma said “This book should be high on the must-read list for engineering educators at all levels, from first-year faculty to deans.” Dr. Lord is a Fellow of the IEEE and ASEE and is active in the engineering education community including serving as General Co-Chair of the 2006 Frontiers in Education (FIE) Conference, on the FIE Steering Committee, and as President of the IEEE Education Society for 2009-2010. She is an Associate Editor of the *IEEE Transactions on Education*. She and coauthors received the 2011 Wickenden Award for the best paper in the *Journal of Engineering Education* and the 2011 Best Paper Award for the *IEEE Transactions on Education*. Dr. Lord spent a sabbatical in 2012 at Southeast University in Nanjing, China teaching and doing research. Dr. Lord is currently on the USD team implementing “Developing Changemaking Engineers”, an NSF-sponsored Revolutionizing Engineering Education (RED) project.

IEEE Fellow Award

Mark H. Weichold, Texas A&M University, Qatar

For contributions to international development of engineering education



Dr. Mark H. Weichold is an electrical engineer and has worked for General Dynamics Ft. Worth Division, Motorola in Austin, TX and the U.S. Army Electronic Technology and Devices Laboratory in Ft. Monmouth, NJ. He joined the Electrical Engineering faculty at Texas A&M University in 1982 and now holds the title of Professor. His research interests include electron device fabrication process development, device design and characterization. He has authored more than 80 journal articles, conference papers and scientific reports and holds three US patents. At the University's main campus, he served as the Dean of Undergraduate Programs and Associate Provost for Academic Services. In 2009, he was recognized as a Regents Professor his outstanding work and exemplary contribution to Texas A&M University. In 2013, he was awarded the Abdullah bin Hamad Al Attiyah International Energy Award for 'Lifetime Achievement for the Advancement of Education'.

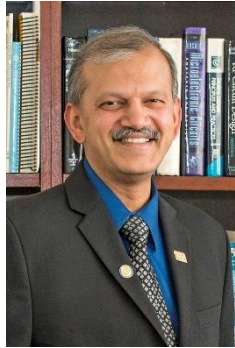
He is a Fellow of the IEEE, a member of the American Physical Society, and a registered professional engineer in the State of Texas.

In January 2007, Weichold became Dean and CEO of Texas A&M University at Qatar. Since its inception, Texas A&M at Qatar has grown to more than 500 currently enrolled students, including 50 graduate students and over 80 faculty members. Of the more than 500 graduates, nearly half are Qatari nationals and 40% are female. Texas A&M at Qatar is also home to a dynamic research program with more than \$160 million in cumulative funding that supports responsive research projects closely aligned with the goals of Qatar National Vision 2030.

IEEE Fellow Award

Sundaram Ramesh, California State University, Northridge

For contributions to entrepreneurship in engineering education



Dr. Sundaram Ramesh has been serving as the Dean of the College of Engineering and Computer Science at California State University, Northridge since 2006. Prior to joining CSUN he was Professor of Electrical and Electronic Engineering at California State University, Sacramento, where he was the Department Chair from 1994 to 2006. His efforts and leadership have created jobs and enhanced the growth of high technology industries through the Center for Entrepreneurship and Innovation and Energy Research Center at CSU Northridge. Examples include a Satellite Clean Tech Incubator, a Master's Degree in Assistive Technology Engineering – whose graduates help design and create products to serve persons with disabilities; and as the PI of the nationally acclaimed five year AIMS² (www.ecs.csun.edu/aims2) program to graduate underrepresented minorities in engineering and computer science with a \$5.5 Million grant from the US Department of Education.

In 2014 Ramesh was invited by the White House Office of Science and Technology Policy (OSTP) to host one of the four national White House STEM workshops at CSU Northridge to broaden participation of minorities in the STEM disciplines, remove barriers, and improve student graduation rates- especially in engineering and computer science. Ramesh serves on several Boards including IEEE EAB, the IEEE-HKN Board of Governors, and ABET Board of Directors. He has served ABET as a program evaluator representing IEEE. He is the IEEE-HKN President-Elect for 2015-16, and chairs the 2015 IEEE EAB Pre-University Coordinating Committee leading signature programs such as TISP (Teacher in Service program) and EPICS (Engineering Projects in Community Service) in IEEE. Dr. Ramesh's professional interests are in Fiber Optic Communications and he received the BE (Honors) degree from the University of Madras, India, in 1981, and the MSEE and PhD degrees from Southern Illinois University, Carbondale, in 1983 and 1986 respectively. For additional information please visit <http://www.csun.edu/engineering-computer-science/ramesh>.

Reviewers

This year, FIE 2015 had over 700 papers and presentations submitted for consideration. The FIE 2015 Program Committee wishes to thank the following individuals for acting as abstract and paper reviewers. The program committee asked these individuals to help control the quality of the presentations at this year's conference by reviewing the submissions for FIE 2015. Their outstanding effort has helped maintain the high standard that has become the reputation of each FIE conference.

Name	Institution
Haqiq Abdelkrim	Hassan University
Otávio Acosta	Federal University of Rio Grande do Sul
Gina Adam	University of California at Santa Barbara
Olusola Adesope	Washington State University
Juan Aguilar-Peña	Universidad de Jaén
Benjamin Ahn	Massachusetts Institute of Technology
Nancy Alajarmeh	New Mexico State University
Carlos Alario Hoyos	Universidad Carlos III de Madrid
Sadot Alexandres	Universidad Pontificia Comillas
Ahmad Al-Jarrah	New Mexico State University
Nuha Alkabour	University of Michigan-Flint
Vicki Allan	Utah State University
Colin Allison	University of St Andrews
Mahmoud Al-Qutayri	Khalifa University
Nesreen Alsbou	Ohio Northern University
Ainhoa Álvarez	University of the Basque Country, UPV/EHU
Rafael Alvarez-Horine	San Jose State University
Luis Alves	Polytechnic Institute of Bragança
Luis Amaral	University of Minho
Toni Amorim	Universidade Estadual do Mato Grosso
Paul Anderson	College of Charleston
Paulo André	Instituto Superior Técnico, Universidade de Lisboa
Boon Chong Ang	EASIC
Nada Anid	New York Institute of Technology
Whitney Anthony	Texas A&M University
Eduardo Aranha	Federal University of Rio Grande do Norte (UFRN)
Eliane Araujo	Federal University of Campina Grande
Maurício Arimoto	University of São Paulo
Sanjeev Arora	Fort Valley State University
Omar Ashour	Penn State Erie
Michael Auer	Carinthia Tech Institute
Asad Azemi	Pennsylvania State University
Patricia Backer	San Jose State University
Abdel-Hameed Badawy	Arkansas Tech University
Nilufar Baghaei	Unitec Institute of Technology
Margaret Bailey	Rochester Institute of Technology

Ellen Barbosa	University of São Paulo
Edurne Barrenechea	Universidad Pública de Navarra
Victor Barros	Science and Education Research Council
Mohammed Basher	King Abdulaziz University
Milton Joel Batres Márquez	Universidad Tecnológica de Chihuahua
Eric Baumgartner	Ohio Northern University
Kemal Bayrakceken	Turkish Air Force Academy
Mark Bedillion	South Dakota School of Mines and Technology
Luiz Begosso	Fundacao Educacional do Municipio de Assis
Avril Behan	Dublin Institute of Technology
Lluís Belanche Muñoz	Universitat Politècnica de Catalunya
Scott Bell	Kansas State University
José Benlloch-Dualde	Universitat Politècnica de València
Bridget Benson	Cal Poly, San Luis Obispo
Lisa Benson	Clemson University
Edward Berger	Purdue University
Luciana Berreta	Federal University of Goiás
Angela Bielefeldt	University of Colorado Boulder
Anna Bilyatdinova	University ITMO
Roberto Bittencourt	State University of Feira de Santana
Sara Blanc	Universitat Politècnica de València
Manuel Blazquez	Universidad Antonio de Nebrija
Brit-Maren Block	Leuphana University of Lüneburg
Klavdiya Bochenina	University ITMO
Diane Bondehagen	Florida Gulf Coast University
Jennifer Bonniwell	Marquette University
Vanessa Borges	University of São Paulo
Silvia Botelho	Federal University of Rio Grande
Jesus Boticario	Universidad Nacional de Educación a Distancia
Ivica Botički	University of Zagreb
Brian Bowe	Dublin Institute of Technology
Marija Božić	Autonomous University of Barcelona
Jacques Brancher	Universidade Estadual de Londrina
Kalinka Branco	USP - University of São Paulo
Anarosa Brandão	Universidade de São Paulo
Leônidas Brandão	University of São Paulo
Henry Braun	Arizona State University
Rex Bringula	University of the East
Claudio Brito	Science and Education Research Council
Natalia Andrea Bueno Pizarro	Universidad EAFIT
Kevin Burger	Arizona State University
John Burkhardt	US Naval Academy
Jake Byrne	Trinity College Dublin
Elizabeth Cady	National Academy of Engineering

Manuel Caeiro	University of Vigo
Carlos Caicedo Bastidas	Syracuse University
María del Carmen Calatrava Moreno	Vienna University of Technology
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Session Chairs

The conference committee would like to thank the people that have agreed to act as session chairs at the 2015 Frontiers in Education Conference. Session chairs play an important role in ensuring the conference runs smoothly and that the technical presentations are a valuable experience for both speakers and attendees. Session chairs also have served a critical role in helping with the Ben Dasher Award process.

The primary responsibilities of session chairs are to:

- Read the session's papers in advance and recommend papers for the Ben Dasher Best Paper committee.
- Contact the authors in the session and become familiar with the authors who are presenting.
- Introduce the session and make any FIE announcements that are needed.
- Briefly introduce each speaker and paper.
- Manage audience questions, and ensure that presentations begin and end within their time slots.

The program committee would like to thank the following individuals and those session chairs not listed for their efforts to help make FIE 2015 both informative and successful:

Code	Title	Start time	Room	Chair
T1A	Special Session: Connecting and Expanding the Emerging Engineering Education Research & Innovation (EER&I) Communities	11:00 AM	Kohlberg	Sohum Sohoni (Arizona State University, USA)
T1B	Special Session: Movin' Along: Investigating Motion and Mechanisms Using Engineering Design Activities	11:00 AM	Pancho Villa	Eric Durant (Milwaukee School of Engineering, USA)
T1C	First and Second Year Topics I	11:00 AM	Angus	Jon Sticklen (Michigan Technological University, USA)
T1D	K-12 Education I	11:00 AM	Brahma	David Reeping (Ohio Northern University, USA)
T1E	Social and Cognitive Aspects of Learning	11:00 AM	Charolais	Monique Ross (Engineering Education, USA)
T1F	Innovation and Entrepreneurship I	11:00 AM	Longhorn	Meagan Vaughan (University of Texas at El Paso, USA)
T1G	Learning in Teams	11:00 AM	Hereford	Katherine Goodman (University of Colorado Boulder, USA)
T1H	Learning Analytics I	11:00 AM	Rio Grande	Molly Hathaway Goldstein (Purdue University, USA)
T1I	Software Engineering Education	11:00 AM	Santa Fe	Rose Gamble (University of Tulsa, USA)
T2A	Special Session: Design Metaphors - Rethinking the Vocabulary of Design Education	2:30 PM	Kohlberg	Colin Smith (Edinburgh Napier University, United Kingdom)
T2B	Special Session: Helping Tomorrow's Engineers Ask Productive Questions	2:30 PM	Pancho Villa	Susan Kowalski (Colorado School of Mines, USA)
T2C	Innovative Curriculum & Course Design I	2:30 PM	Angus	Axel Böttcher (Munich University of Applied Sciences, Germany)
T2D	K-12 Education II	2:30 PM	Brahma	Glenda Young (Virginia Tech, USA)
T2E	Blended Learning Approaches	2:30 PM	Charolais	Asad Azemi (Pennsylvania State University, USA)
T2F	Game Based Learning I	2:30 PM	Longhorn	Todd Fernandez (Purdue University, USA)
T2G	Student Engagement I	2:30 PM	Hereford	Andrea M. Ogilvie (Virginia Tech, USA)

T2H	Learning Analytics II	2:30 PM	Rio Grande	Michael Mogessie Ashenafi (University of Trento, Italy)
T2I	Teaching Cryptography & Computer Security	2:30 PM	Santa Fe	Cem Sahin (Drexel University, USA)
T3A	Special Session: Introduction to Systematic Reviews in Engineering Education Research	4:30 PM	Kohlberg	Liping Liu (Lawrence Technological University, USA)
T3B	Special Session: Exploring the Black Box of Dissemination: The Role of Professional and Organizational Development	4:30 PM	Pancho Villa	Walter C. Lee (Virginia Tech, USA)
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T3D	Curriculum Change	4:30 PM	Brahma	Marja Talikka (Lappeenranta University of Technology, Finland)
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T3F	Game Based Learning II	4:30 PM	Longhorn	Jacques Duílio Brancher (Universidade Estadual de Londrina, Brazil)
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T3H	Motivation	4:30 PM	Rio Grande	Sadan Kulturel-Konak (Penn State Berks, USA)
T3I	Teaching and Learning Math	4:30 PM	Santa Fe	Christine F Reilly (University of Texas - Pan American, USA)
F1A	Special Session: Taking Stock: Using a Landscape Inventory to Drive Curriculum and Program Change	9:00 AM	Kohlberg	Yulei Pang (Southern Connecticut State University, USA)
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F1G	MOOCs and Big Data	9:00 AM	Hereford	Anna Douglas (Purdue University, USA)
F1H	Teaching and Learning Programming I	9:00 AM	Rio Grande	Roberto A Bittencourt (State University of Feira de Santana, Brazil)
F1I	Cyber Security	9:00 AM	Santa Fe	Walter W Schilling, Jr (Milwaukee School of Engineering, USA)
F2A	Special Session: CE2016 Updated Computer Engineering Curriculum Guidelines	11:00 AM	Kohlberg	Xiaosong Li (Unitec Institute of Technology, New Zealand)
F2B	Special Session: What the Heck is That?! Adaptation of Evidence-Based Instructional Practices	11:00 AM	Pancho Villa	Lizabeth Schlemer (Cal Poly, San Luis Obispo, USA)
F2C	Mobile Teaching and Learning	11:00 AM	Angus	Manuel Castro (Spanish University for Distance Education, Spain)
F2D	Game-Based Learning IV	11:00 AM	Brahma	Bhojan Anand (National University of Singapore, Singapore)

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F2G	Faculty Development I	11:00 AM	Hereford	Jacqueline McNeil (University of Louisville, USA)
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F2I	Design Methods	11:00 AM	Santa Fe	Susan Donohue (University of Virginia, USA)
F3A	Special Session: Is the Engineer of 2035 a Maker?	2:30 PM	Kohlberg	Neha Choudhary (Purdue University, USA)
F3B	Special Session: Agents for Change in Engineering & Computer Science Education	2:30 PM	Pancho Villa	Kevin Buffardi (California State University - Chico, USA)
F3C	Using Robots in Teaching and Learning	2:30 PM	Angus	Kevin Gary (Arizona State University, USA)
F3D	Retention	2:30 PM	Brahma	Shaobo Huang (South Dakota School of Mines and Technology, United States)
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F3I	Embedded Systems Education I	2:30 PM	Santa Fe	Victor F. A. Barros (Science and Education Research Council, Portugal)
F4A	Special Session: Qualitative Research on Psychological Experience: A Starting Point for Using Interpretative Phenomenological Analysis	5:00 PM	Kohlberg	James Huff (Harding University, USA)
F4B	Special Session: Aesthetics and Emotional Engagement: Why it Matters to Our Students, Why it Matters to Our Professions	5:00 PM	Pancho Villa	Nathan Canney (Seattle University, USA)
F4C	Student-Centered Education I	5:00 PM	Angus	Brian Rague (Weber State University, USA)
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F4I	Embedded Systems Education II	5:00 PM	Santa Fe	Firas Hassan (Ohio Northern University, USA)
S1A	Panel: International iCampus Forum (IC15) on "Smart Education in Smart Cities"	9:00 AM	Kohlberg	Jason Ng (British Telecom, United Kingdom)
S1B	New Approaches-Student-Center	9:00 AM	Pancho Villa	Rangith Baby Kuriakose (University of Technology, South Africa)

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S1F	Online Assessment	9:00 AM	Longhorn	Dazhi Yang (Boise State, USA)
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S2E	Innovative Curriculum & Course Design IV	11:00 AM	Charolais	Brian Faulkner (University of Illinois, USA)
S2F	K-12 Education III	11:00 AM	Longhorn	Noah Salzman (Boise State University, USA)
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S3C	Outreach & University, Community Collaborations	2:30 PM	Angus	Natascha Trellinger (Purdue University, USA)
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S3G	K-12 Education IV	2:30 PM	Hereford	DeLean Tolbert (Purdue University, USA)
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S4C	Non-Traditional Students	4:30 PM	Angus	Maura Borrego (University of Texas at Austin, USA)
S4D	Technological Tools II	4:30 PM	Brahma	Jaspal Subhlok (University of Houston, USA)
S4E	Co-Ops and Early Career Training	4:30 PM	Charolais	Samantha Brunhaver (Arizona State University, USA)

S4F	Communication and Storytelling	4:30 PM	Longhorn	Imelda Smit (North West University, South Africa)
S4G	Computing Education	4:30 PM	Hereford	David R Monismith, Jr. (Northwest Missouri State University, USA)
S4I	Innovative Curriculum & Course Design VIII	4:30 PM	Santa Fe	Chiu Choi (University of North Florida, USA)

Session Grid – Wednesday, October 21st

Time	Brahma Room	Angus Room	Santa Fe Room	Pancho Villa Room	Kohlberg Room
1:00 PM - 4:00 PM	1A: Pre-Conference Workshop: Integrating Service-Learning into Engineering and Computing Education	1B: Pre-Conference Workshop: Teaching and Assessment Strategies that Value Innovative Thinking	1C: Pre-Conference Workshop: Process to Draft the Program Educational Objectives for Undergraduate Engineering Degree Programs	1D: Pre-Conference Workshop: Agile Way of Educating	1E: Pre-Conference Workshop: Ideas at Play: Bring games to your classroom to increase student engagement and deep learning
5:00 PM - 8:00 PM	2A: Pre-Conference Workshop: Encouraging Information Rich Engineering Design		2C: Pre-Conference Workshop: Agile Teaching and Learning	2D: Pre-Conference Workshop: How to Select an Area of Scholarship and Address the Applicable Review Criteria to Publish a Paper in the IEEE Transactions on Education	

Session Grid – Thursday, October 22nd

Time	Kohlberg Room	Pancho Villa Room	Angus Room	Brahma Room	Charolais Room	Longhorn Room	Hereford Room	Rio Grande Room	Santa Fe Room
11:00 AM - 12:30 PM	T1A: SS: Connecting and Expanding the Emerging Engineering Education Research & Innovation (EER&I) Communities	T1B: SS: Movin' Along: Investigating Motion and Mechanisms Using Engineering Design Activities	T1C: First and Second Year Topics I	T1D: K-12 Education I	T1E: Social and Cognitive Aspects of Learning	T1F: Innovation and Entrepreneurship I	T1G: Learning in Teams	T1H: Learning Analytics I	T1I: Software Engineering Education
2:30 PM - 4:00 PM	T2A: SS: Design Metaphors - Rethinking the vocabulary of design education	T2B: SS: Helping Tomorrow's Engineers Ask Productive Questions	T2C: Innovative Curriculum & Course Design I	T2D: K-12 Education II	T2E: Blended Learning Approaches	T2F: Game based learning I	T2G: Student engagement I	T2H: Learning Analytics II	T2I: Teaching Cryptography & Computer Security
4:30 PM - 6:00 PM	T3A: SS: Introduction to Systematic Reviews in Engineering Education Research	T3B: SS: Exploring the Black Box of Dissemination- The Role of Professional and Organizational Development	T3C: Engineering Identity	T3D: Curriculum change	T3E: Assessment in Computer Science	T3F: Game based learning II	T3G: Gender in Engineering and Computing I	T3H: Motivation	T3I: Teaching and Learning Math

Session Grid – Friday, October 23rd

Time	Kohlberg Room	Pancho Villa Room	Angus Room	Brahma Room	Charolais Room	Longhorn Room	Hereford Room	Rio Grande Room	Santa Fe Room
9:00 AM - 10:30 AM	F1A: SS: Taking Stock: Using a Landscape Inventory to Drive Curriculum and Program Change	F1B: SS: Helping your students learn "Engineering-ese": Using the results of conceptual change research to inform your instruction	F1C: Innovative Mobile Tools and Applications	F1D: Game-Based Learning III	F1E: Flipped Classroom	F1F: Industry Oriented Teaching and Learning	F1G: MOOCs and Big Data	F1H: Teaching and Learning Programming I	F1I: Cyber Security
11:00 AM - 12:30 PM	F2A: SS: CE2016 Updated Computer Engineering Curriculum Guidelines	F2B: Special Session: What the Heck is That?! Adaptation of Evidence-Based Instructional Practices	F2C: Mobile Teaching and Learning	F2D: Game-Based Learning IV	F2E: Student Engagement II	F2F: Gender in Engineering and Computing II	F2G: Faculty Development I	F2H: Teaching and Learning Programming II	F2I: Design Methods
2:30 PM - 4:00 PM	F3A: SS: Is the Engineer of 2035 a Maker?	F3B: Special Session: Agents for Change in Engineering & Computer Science Education	F3C: Using Robots in Teaching and Learning	F3D: Retention	F3E: Design Education II	F3F: Social Responsibility and Ethics	F3G: Faculty Development II	F3H: Interdisciplinary Education in Programming	F3I: Embedded Systems Education I
5:00 PM - 6:30 PM	F4A: SS: Qualitative Research on Psychological Experience: A Starting Point for Using Interpretative Phenomenological Analysis	F4B: Special Session: Aesthetics and Emotional Engagement: Why it Matters to Our Students, Why it Matters to Our Professions	F4C: Student-Centered Education I	F4D: K-12 Teacher Education and Computational Thinking	F4E: K-12 Education III	F4F: Design Education III	F4G: Philosophy of Engineering	F4H: Professional Skills	F4I: Embedded Systems Education II

Session Grid – Saturday, October 24th

Time	Kohlberg Room	Pancho Villa Room	Angus Room	Brahma Room	Charolais Room	Longhorn Room	Hereford Room	Rio Grande Room	Santa Fe Room
9:00 AM - 10:30 AM	S1A: Panel: International iCampus Forum (IC15) on "Smart Education in Smart Cities"	S1B: New Approaches- Student- Center	S1C: Student Center Education	S1D: Assessment I	S1E: First and Second Year Topics II	S1F: Online Assessment	S1G: Innovative Curriculum & Course Design I	S1H: Innovative Curriculum & Course Design II	S1I: Faculty Development III
11:00 AM - 12:30 PM	S2A: Technological Tools I	S2B: Computer Based Learning	S2C: Innovative Curriculum & Course Design III	S2D: Curriculum Design III	S2E: Innovative Curriculum & Course Design IV	S2F: K-12 Education III	S2G: Online- distance Learning	S2H: Assessment	S2I: Innovative Curriculum & Course Design V
2:30 PM - 4:00 PM	S3A: Innovative Curriculum & Course Design VI	S3B: Global Programs	S3C: Outreach & University, Community Collaborations	S3D: First and Second Year Topics III	S3E: Student Interest	S3F: Student- Centered Education IV	S3G: K-12 Education IV	S3H: Innovative Curriculum & Course Design VII	S3I: Project- Based Learning
4:30 PM - 6:00 PM		S4B: Innovative Tools and Approaches	S4C: Non- Traditional Students	S4D: Technological Tools II	S4E: Co-Ops and Early Career Training	S4F: Communication and Storytelling	S4G: Computing Education		S4I: Innovative Curriculum & Course Design VIII

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Carla B. Zoltowski (Purdue University, USA)

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2:30 PM - 4:00 PM

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Chair: Michael Mogessie Ashenafi (University of Trento, Italy)	
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Chair: Liping Liu (Lawrence Technological University, United States)
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Room: Kohlberg Room

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Chair: Walter C. Lee (Virginia Tech, USA)
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Room: Pancho Villa Room

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Chair: Thomas Staubit (Hasso Plattner Institute for Software Systems Engineering, Germany)	
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Chair: Virginia Grande (Uppsala University, Sweden)
4:30 PM - 6:00 PM
Room: Hereford Room

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Debatri Chatterjee (Tata Consultancy Services Ltd., India)

Rajat Das (Tata Consultancy Services Ltd., India)

Arijit Sinharay (Tata Consultancy Services Ltd., India)

T3I: Teaching and Learning Math**Chair:** Christine F Reilly (University of Texas - Pan American, USA)**4:30 PM - 6:00 PM****Room:** Santa Fe Room

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Rebecca Torrey (Brandeis University, USA)

Timothy Hickey (Brandeis University, USA)

Friday, October 23

F1A: Special Session: Taking Stock: Using a Landscape Inventory to Drive Curriculum and Program Change

Chair: Yulei Pang (Southern Connecticut State University, USA)

9:00 AM - 10:30 AM

Room: Kohlberg Room

TAKING STOCK: USING A LANDSCAPE INVENTORY TO DRIVE CURRICULUM AND PROGRAM CHANGE..... 654

Elizabeth Nilsen (VentureWell, USA)

Victoria Matthew (VentureWell, USA)

Mary Besterfield-Sacre (University of Pittsburgh, USA)

Thema Monroe-White (SageFox Consulting Group, USA)

F1B: Special Session: Helping your students learn "Engineering-ese": Using the results of conceptual change research to inform your instruction

Chair: Ruth Streveler (Purdue University, USA)

9:00 AM - 10:30 AM

Room: Pancho Villa Room

HELPING YOUR STUDENTS LEARN "ENGINEERING-ESE": USING THE RESULTS OF CONCEPTUAL CHANGE RESEARCH TO INFORM YOUR INSTRUCTION 658

Ruth Streveler (Purdue University, USA)

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F1C: Innovative Mobile Tools and Applications

Chair: Amalia Rusu (Fairfield University, United States)

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Chair: Bunmi Bababajide (Purdue University, United States)

9:00 AM - 10:30 AM

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Chair: Roberto A Bittencourt (State University of Feira de Santana, Brazil)	
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F2B: Special Session: What the Heck is That?! Adaptation of Evidence-Based Instructional Practices**Chair:** Lizabeth Schlemer (Cal Poly, San Luis Obispo, USA)**11:00 AM - 12:30 PM****Room:** Pancho Villa Room

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F2C: Mobile Teaching and Learning**Chair:** Manuel Castro (Spanish University for Distance Education - UNED, Spain)**11:00 AM - 12:30 PM****Room:** Angus Room

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F2D: Game-Based Learning IV**Chair:** Bhojan Anand (National University of Singapore, Singapore)**11:00 AM - 12:30 PM****Room:** Brahma Room

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Chair: Ricardo José Rocha Amorim (State University of Bahia (UNEB), Brazil)	
11:00 AM - 12:30 PM	
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Chair: Amir Zeid (American University of Kuwait, Kuwait)

11:00 AM - 12:30 PM

Room: Longhorn Room

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F2G: Faculty Development I

Chair: Jacqueline McNeil (University of Louisville, United States)

11:00 AM - 12:30 PM

Room: Hereford Room

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Chair: Ivan Mauricio Cabezas (Universidad de San Buenaventura, Colombia)	
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Room: Rio Grande Room	
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F2I: Design methods

Chair: Susan Donohue (University of Virginia, United States)

11:00 AM - 12:30 PM

Room: Santa Fe Room

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F3A: Special Session: Is the Engineer of 2035 a Maker?

Chair: Neha Choudhary (Purdue University, USA)

2:30 PM - 4:00 PM

Room: Kohlberg Room

IS THE ENGINEER OF 2035 A MAKER? 1053

Shawn Jordan (Arizona State University at the Polytechnic Campus, USA)
Micah Lande (Arizona State University at the Polytechnic Campus, USA)

F3B: Special Session: Agents for Change in Engineering & Computer Science Education

Chair: Kevin Buffardi (California State University - Chico, United States)

2:30 PM - 4:00 PM

Room: Pancho Villa Room

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Alan Cheville (Bucknell University, USA)

Cynthia Finelli (University of Michigan, USA)

Jennifer Karlin (SD School of Mines and Technology, USA)

Susan M. Lord (University of San Diego, USA)

F3C: Using Robots in Teaching and Learning

Chair: Kevin Gary (Arizona State University, USA)

2:30 PM - 4:00 PM

Room: Angus Room

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Yasuhiro Hayakawa (National Institute of Technology, Nara College, Japan)

Mitsuyoshi Shimaoka (National Institute of Technology, Nara College, Japan)

Yoshihiro Oshida (National Institute of Technology, Nara College, Japan)

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Kevin Rivera (University of Puerto Rico-Mayagüez, Puerto Rico)
Kelvin del Valle (University of Puerto Rico-Mayagüez, Puerto Rico)
Angel Rodriguez (University of Puerto Rico-Mayagüez, Puerto Rico)
Eduardo Ortiz-Rivera (University of Puerto Rico-Mayagüez, Puerto Rico)

F3D: Retention

Chair: Shaobo Huang (South Dakota School of Mines and Technology, United States)

2:30 PM - 4:00 PM

Room: Brahma Room

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Axel Böttcher (Munich University of Applied Sciences, Germany)
Anne Brüggemann-Klein (Technisch Universität München, Germany)
Veronika Thurner (Munich University of Applied Sciences, Germany)
Kathrin Schlierkamp (Munich University of Applied Sciences, Germany)

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Robert Culbertson (Arizona State University, USA)

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F3E: Design Education II

Chair: Jay R Porter (Texas A&M University, United States)

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Joseph Morgan (Texas A&M University, USA)
Richard Lester (Texas A&M University, USA)
Adam Steele (Texas A&M University, USA)
Jorge Vanegas (Texas A&M University, USA)
Rodney Hill (Texas A&M University, USA)

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Chair: Wilkistar Otieno (University of Wisconsin-Milwaukee, United States)	
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Room: Longhorn Room	
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Kari Jordan (Embry-Riddle Aeronautical University, USA)

Heidi Steinhauer (Embry-Riddle Aeronautical University, USA)

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Irene Mena (University of Illinois at Urbana-Champaign, USA)

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Ann Gates (University of Texas, El Paso, USA)

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F3H: Interdisciplinary Education in Programming**Chair:** Laura R. Hanlan (Worcester Polytechnic Institute, USA)**2:30 PM - 4:00 PM****Room:** Rio Grande Room

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Washington Batista (State University of Feira de Santana, Brazil)

Henderson Chalegre (State University of Feira de Santana, Brazil)

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Tiago Gonçalves Botelho (Federal Institute of Science and Technology - Campus Muzambinho, Brazil)

Ricardo José Martins (Federal Institute of Science and Technology - Campus Muzambinho, Brazil)

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F3I: Embedded Systems Education I

Chair: Victor F. A. Barros (Science and Education Research Council, Portugal)

2:30 PM - 4:00 PM

Room: Santa Fe Room

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José-V. Benlloch-Dualde (Universitat Politècnica de València, Spain)

F4A: Special Session: Qualitative Research on Psychological Experience: A Starting Point for Using Interpretative Phenomenological Analysis

Chair: James Huff (Harding University, USA)

5:00 PM - 6:30 PM

Room: Kohlberg Room

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Chair: Nathan Canney (Seattle University, USA)
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Room: Pancho Villa Room

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Antonio Manuel González Marrero (Universidad de La Laguna, Spain)
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5:00 PM - 6:30 PM
Room: Brahma Room

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E. Pontelli (New Mexico State University, USA)	
V. Szczepanski (New Mexico State University, USA)	
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Chair: Mary M Capraro (Texas A&M University, United States)	
5:00 PM - 6:30 PM	
Room: Charolais Room	
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Madaline Polmear (University of Colorado, Boulder, USA)
Ben Graves (Delta School District 50, USA)

F4F: Design Education III

Chair: Deeksha Seth (Drexel University, USA)

5:00 PM - 6:30 PM

Room: Longhorn Room

**MEASURING UNDERGRADUATE STUDENTS' SELF-EFFICACY IN ENGINEERING
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Deeksha Seth (Drexel University, USA)
James Tangorra (Drexel University, USA)
Ahmed Ibrahim (University of California, Riverside, USA)

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Farshid Marbouti (Purdue University, USA)
Heidi Diefes-Dux (Purdue University, USA)
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Todd Fernandez (Purdue University, USA)
Şenay Purzer (Purdue University, USA)
Michael Fosmire (Purdue University, USA)
Amy Van Epps (Purdue University, USA)

F4G: Philosophy Of Engineering

Chair: Geoffrey Herman (University of Illinois at Urbana-Champaign, United States)

5:00 PM - 6:30 PM

Room: Hereford Room

IMPLICATIONS OF ANONYMOUS ASSESSMENT 1404

Arnold Pears (Uppsala University, Sweden)
Aletta Nylén (Uppsala University, Sweden)

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Mani Mina (Iowa State University, USA)	
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John Heywood (Trinity College Dublin, Ireland)	
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Värri Hanna (Lappeenranta University of Technology, Finland)	
Eskelinen Harri (Lappeenranta University of Technology, Finland)	
Rimppi Heli (Lappeenranta University of Technology, Finland)	
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John Heywood (Trinity College, Dublin, Ireland)	
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Åsa Cajander (Uppsala University, Sweden)	
Anna Eckerdal (Uppsala University, Sweden)	
Mats Lind (Uppsala University, Sweden)	
Aletta Nylén (Uppsala University, Sweden)	
Tony Clear (Auckland University of Technology, New Zealand)	
Roger McDermott (Robert Gordon University, United Kingdom)	
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<i>F4H: Professional Skills</i>	
<i>Chair:</i> Abe Zeid (Northeastern University, United States)	
<i>5:00 PM - 6:30 PM</i>	
<i>Room:</i> Rio Grande Room	
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<i>ADDRESSING THE PROBLEM OF MAL-EMPLOYMENT OF LIBERAL ARTS GRADUATES</i>	<i>1430</i>
Abe Zeid (Northeastern University, USA)	
Chitra Javdekar (MassBay Community College, USA)	
Marina Bograd (MassBay Community College, USA)	
Susanne Steiger-Escobar (MassBay Community College, USA)	
Shamsi Moussavi (MassBay Community College, USA)	
Claire Duggan (Northeastern University, USA)	
Daniel Sullivan (Northeastern University, USA)	
Sagar Kamarthi (Northeastern University, USA)	
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Peter Reimann (The University of Sydney, Australia)	
Lina Markauskaite (The University of Sydney, Australia)	
<i>CAMPUS TO CAREER, UNDERSTANDING HOW ENGINEERING STUDENT SKILL PERCEPTIONS LINK TO FUTURE CAREER PATHWAYS</i>	<i>1438</i>
Glenda Young (Virginia Tech, USA)	
David Knight (Virginia Tech, USA)	

F4I: Embedded Systems Education II

Chair: Firas Hassan (Ohio Northern University, USA)

5:00 PM - 6:30 PM

Room: Santa Fe Room

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BOARDS AND ENGINEERING EDUCATION NEEDS THEM 1442

Peter Jamieson (Miami University, USA)

Jeff Herdtner (Miami University, USA)

***DESIGN AND IMPLEMENTATION OF A MICROCONTROLLER BASED WORKSTATION WITH
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Juan Felipe Patarroyo (University of Puerto Rico at Mayaguez, Puerto Rico)

Gerson Beauchamp (University of Puerto Rico at Mayaguez, Puerto Rico)

Aidsa Santiago (University of Puerto Rico at Mayaguez, Puerto Rico)

***AUTONOMOUS ROBOT: AN INTELLECTUAL WAY OF INFUSING MICROCONTROLLER
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Chirag Parikh (Grand Valley State University, USA)

***DEVELOPMENT OF A NOVEL MODULAR INTEGRATED STACKABLE LAYER - ANALOG SYSTEM
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Joseph Morgan (Texas A&M University, USA)

Jay Porter (Texas A&M University, USA)

Hester Yim (Texas A&M University, USA)

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Brent Carmer (Oregon State University, USA)

Mike Rosulek (Oregon State University, USA)

Saturday, October 24

SIA: Panel: International iCampus Forum (IC15) on "Smart Education in Smart Cities"

Chair: Jason Ng (British Telecom, United Kingdom)

9:00 AM - 10:30 AM

Room: Kohlberg Room

INTERNATIONAL ICAMPUS FORUM (IC15) ON "SMART EDUCATION IN SMART CITIES"..... 1473

Jason Ng (United Arab Emirates, UAE)

***AN EXPLORATION INTO THE ATTITUDES OF YOUNG GIRLS TOWARD THE
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JJ LaBouliere (SDSU, USA)

Amanda Pelloth (SDSU, USA)

Chiao-Ling Lu (SDSU, USA)

Jason Ng (Etisalat British Telecom Innovation Center, UAE)

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Ling Cen (Khalifa University of Science, Technology and Research, UAE)

Dymitr Ruta (Khalifa University of Science, Technology and Research, UAE)

Leigh Powell (Khalifa University of Science, Technology and Research, UAE)

Jason Ng (Khalifa University of Science, Technology and Research, UAE)

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S.S. Ling (Khalifa University of Science, Technology and Research, UAE)

F. Saffre (BT Research and Innovation, United Kingdom)

D.L. Gater (Khalifa University of Science, Technology and Research, UAE)

L. Bt. Halim (National University of Malaysia, Malaysia)

A. F. Isakovic (Khalifa Semiconductor Research Center, UAE)

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David M. Liu (Etisalat BT Innovation Center, UAE)

George Wesley Hitt (Khalifa University of Science, Technology and Research, UAE)

A. F. Isakovic (Khalifa University of Science, Technology and Research, UAE)

Di Wang (Etisalat BT Innovation Center, UAE)

Benjamin Hirsch (Etisalat BT Innovation Center, UAE)

Jason W.P. Ng (Etisalat BT Innovation Center, United Kingdom)

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Di Wang (Khalifa University, UAE)

Ahmed Al-Rubaie (Khalifa University, UAE)

Ahmed Al Dhanhane (Khalifa University, UAE)

Jason Ng (Khalifa University, United Kingdom)

SIB: New Approaches-Student-Center**Chair:** Rangith Baby Kuriakose (University of Technology, South Africa)**9:00 AM - 10:30 AM****Room:** Pancho Villa Room

A B-LEARNING NEW APPROACH APPLIED TO A PRACTICAL POWER***ELECTRONICS CONVERTERS COURSE 1504***

Alfonso Lago Ferreiro (University of Vigo, Spain)

Andrés A. Nogueiras Meléndez (University of Vigo, Spain)

Ana María Cao-Paz (University of Vigo, Spain)

Jorge Marcos Acevedo (University of Vigo, Spain)

Manuel Castro (Spanish University for Distance Education (UNED), Spain)

INITIAL INVESTIGATION INTO ENGINEERING STUDENTS PROBLEM SOLVING***WITHIN CONTROLS 1512***

Jessica Swenson (Tufts University, USA)

Ethan Danahy (Tufts University, USA)

William Messner (Tufts University, USA)

OPTIMAL CONTROL DESIGN AND IMPLEMENTATION FOR THE DOUBLE***INVERTED PENDULUM SYSTEM IN A GRADUATE CONTROL COURSE..... 1516***

Felix Muñoz-Rodríguez (University of Puerto Rico at Mayagüez, Puerto Rico)

Gerson Beauchamp-Báez (University of Puerto Rico at Mayagüez, Puerto Rico)

Gerardo Cruz-Díaz (University of Puerto Rico at Mayagüez, Puerto Rico)

Juan Carlos Santos-Ferrer (University of Puerto Rico at Mayagüez, Puerto Rico)

A LOW-COST SYSTEM FOR EXPERIMENTS WITH DIGITAL CIRCUITS 1525

Flávio H Toribio Destro (Federal University of Mato Grosso do Sul, Brazil)

Rafael A. Costa (Federal University of Mato Grosso do Sul, Brazil)

Fábio Iaione (Federal University of Mato Grosso do Sul, Brazil)

THE EXPLORATION FOR COMPUTER SYSTEM CAPACITY TRAINING***IN EXPERIMENTAL TEACHING 1531***

Li Shan-shan (Tsinghua University, P.R. China)

Quan Cheng-bin (Tsinghua University, P.R. China)

Chen Yong-qiang (Tsinghua University, P.R. China)

SIC: Student Center Education**Chair:** Brian Skromme (Arizona State University, United States)**9:00 AM - 10:30 AM****Room:** Angus Room

HELPING UNDERGRADUATE ENGINEERING STUDENTS DISCOVER THEIR INTERESTS***(AND REDUCE THEIR FEAR OF RESEARCH) 1537***

Mary Anderson-Rowland (Arizona State University, USA)

Armando Rodriguez (Arizona State University, USA)

Anita Grierson (Arizona State University, USA)

DEVELOPING AN ECOSYSTEM FOR STUDENT SUCCESS IN ENGINEERING***IN RIO SOUTH TEXAS 1545***

Javier A. Kypuros (The University of Texas-Pan American, USA)

Stephen W. Crown (The University of Texas-Pan American, USA)

Arturo A. Fuentes (University of Texas-Pan American, USA)

Horacio Vasquez (The University of Texas-Pan American, USA)

Virgil Pierce (The University of Texas-Pan American, USA)

Jessica Lavariega Monforti (The University of Texas-Pan American, USA)

<i>LEARNING TO LEARN: CREATING ENGINEERING CLASSROOMS FOR DEEP UNDERSTANDING</i>	<i>1549</i>
Sarah Hug (University of Colorado Boulder, USA)	
Elsa Q. Villa (The University of Texas at El Paso, USA)	
Peter Golding (University of Texas at El Paso, USA)	
Gabby Gandara (University of Texas at El Paso, USA)	
<i>AGILE LEARNING THROUGH CONTINUOUS ASSESSMENT</i>	<i>1554</i>
Kevin A. Gary (Arizona State University, USA)	
Suhas Xavier (Arizona State University, USA)	
<i>AMNESIA: A LEARNING OBJECT FOR MEMORY HIERARCHY TEACHING</i>	<i>1558</i>
Fernando Tiosso (University of São Paulo, Brazil)	
Sarita Mazzini Bruschi (University of São Paulo, Brazil)	
Paulo S. Souza (University of São Paulo, Brazil)	
Ellen Barbosa (University of São Paulo, Brazil)	
Carlos Emilio de Andrade Cacho (University of São Paulo, Brazil)	
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<i>SID: Assessment I</i>	
Chair: Vladik Kreinovich (University of Texas at El Paso, United States)	
9:00 AM - 10:30 AM	
Room: Brahma Room	
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<i>HOW SHOULD WE ESTIMATE A MISSING EXAM SCORE?</i>	<i>1565</i>
Michael C. Loui (Purdue University, USA)	
Athena Lin (University of Illinois at Urbana-Champaign, USA)	
<i>HOW TO TAKE INTO ACCOUNT A STUDENT'S DEGREE OF CERTAINTY WHEN EVALUATING THE TEST RESULTS</i>	<i>1568</i>
Joe Lorkowski (University of Texas at El Paso, USA)	
Olga Kosheleva (University of Texas at El Paso, USA)	
Vladik Kreinovich (University of Texas at El Paso, USA)	
<i>THE ACADEMIC PERFORMANCE INDEX: CREATING A MORE ROBUST AND LESS BIASED MEASURE OF STUDENT ACADEMIC PERFORMANCE.....</i>	<i>1573</i>
Allison Godwin (Purdue University, USA)	
Tyler D. Scott (Northwestern College, USA)	
Geoff Potvin (Florida International University, USA)	
Gerhard Sonnert (Harvard University, USA)	
Phillip M. Sadler (Harvard University, USA)	
<i>EVALUATING METRICS FOR AUTOMATIC MIND MAP ASSESSMENT IN VARIOUS CLASSES</i>	<i>1581</i>
Amber Franklin (Miami University, USA)	
Peter Jamieson (Miami University, USA)	
Walter Vanderbush (Miami University, USA)	
Tuo Li (Miami University, USA)	
Julie Semlak (Miami University, USA)	

SIE: First and Second Year Topics II**Chair:** Frank Vahid (University of California, Riverside, USA)**9:00 AM - 10:30 AM****Room:** Charolais Room

STUDENT LED CURRICULUM DEVELOPMENT AND INSTRUCTION OF INTRODUCTION TO ENGINEERING LEADERSHIP COURSE 1589

America Fernandez (The University of Texas at El Paso, USA)

Erwin Delgado (The University of Texas at El Paso, USA)

Yazmin Montoya (The University of Texas at El Paso, USA)

Roger Gonzalez (The University of Texas at El Paso, USA)

Meagan Vaughan (The University of Texas at El Paso, USA)

ENHANCING THE EXPERIENCE OF FIRST-YEAR ENGINEERING STUDENTS WITH AN ENTRY-LEVEL STS COURSE: SCIENCE-TECHNOLOGY-SOCIETY 1597

Jan DeWaters (Clarkson University, USA)

Jessica Halfacre (Clarkson University, USA)

John Moosbrugger (Clarkson University, USA)

Elisabeth Chapman (Clarkson University, USA)

Elisabeth Wultsch (Clarkson University, USA)

ASSESSING STUDENT VIEWS OF TRADITIONAL, FREE, AND INTERACTIVE MODIFICATIONS FOR AN INTRODUCTORY NETWORKING COURSE 1605

Patrick Seeling (Central Michigan University, USA)

A PEDAGOGICAL MODEL FOR INTRODUCING 3D PRINTING TECHNOLOGY IN A FRESHMAN LEVEL COURSE BASED ON A CLASSIC INSTRUCTIONAL DESIGN THEORY..... 1609

Pit Ho Patrio Chiu (City University of Hong Kong, Hong Kong)

King Wai Chiu Lai (City University of Hong Kong, Hong Kong)

Tsz Ki Frankie Fan (City University of Hong Kong, Hong Kong)

Suk Han Cheng (City University of Hong Kong, Hong Kong)

OUTCOMES OF ACCEPTING OR DECLINING ADVANCED PLACEMENT CALCULUS CREDIT 1615

Karen De Urquidi (Purdue University, USA)

Dina Verdin (Purdue University, USA)

Stephen Hoffmann (Purdue University, USA)

Matthew W. Ohland (Purdue University, USA)

SIF: Online Assessment**Chair:** Dazhi Yang (Boise State, United States)**9:00 AM - 10:30 AM****Room:** Longhorn Room

TECEVAL: AN ON-LINE DYNAMIC EVALUATION SYSTEM FOR ENGINEERING COURSES AVAILABLE FOR WEB BROWSERS AND TABLETS 1621

Jesus Jaquez (Tecnologico de Monterrey, Mexico)

Julieta Noguez (Tecnologico de Monterrey, Mexico)

Gerardo Aguilar-Sanchez (Tecnologico de Monterrey, Mexico)

Luis Neri (Tecnologico de Monterrey, Mexico)

Andres Gonzalez-Nucamendi (Tecnologico de Monterrey, Mexico)

SEED-PA. A PRACTICAL INSTRUMENT FOR ASSESSING INDIVIDUAL ETHICS INITIATIVES..... 1629

Trevor S. Harding (California Polytechnic State University, USA)

Donald D. Carpenter (Lawrence Technological University, USA)

Janel A. Sutkus (Carnegie Mellon University, USA)

Cynthia J. Finelli (University of Michigan, USA)

<i>AUTOMATIC FILL-THE-BLANK QUESTION GENERATOR FOR STUDENT SELF-ASSESSMENT</i>	<i>1633</i>
Girish Kumar (Agency for Science, Technology and Research, Singapore)	
Rafael E. Banchs (Institute for Infocomm Research, Singapore)	
Luis Fernando D'Haro (Institute for Infocomm Research, Singapore)	
<i>PLUGGABLE REPUTATION SYSTEMS FOR PEER REVIEW: A WEB-SERVICE APPROACH.....</i>	<i>1636</i>
Yang Song (North Carolina State University, USA)	
Zhewei Hu (North Carolina State University, USA)	
Edward Gehringer (North Carolina State University, USA)	
<i>ARCHITECTURAL SUPPORT FOR NON-EXPERT DEPLOYMENT OF REMOTE LABORATORIES.....</i>	<i>1641</i>
Khanh Nguyen (University of Sydney, Australia)	
David Lowe (University of Sydney, Australia)	
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<i>SIG: Innovative Curriculum & Course Design I</i>	
Chair: Venky Shankararaman (Singapore Management University, Singapore)	
9:00 AM - 10:30 AM	
Room: Hereford Room	
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<i>STUDENT-CONSTRUCTED CONCEPT MAPS FOR ACTIVE LEARNING IN A FOUNDATIONAL UNDERGRADUATE ENGINEERING COURSE.....</i>	<i>1649</i>
Ning Fang (Utah State University, USA)	
<i>O-CHARTS: TOWARDS AN EFFECTIVE TOOLKIT FOR TEACHING TIME COMPLEXITY.....</i>	<i>1654</i>
Scott Barlowe (Western Carolina University, USA)	
Andrew Scott (Western Carolina University, USA)	
<i>ANALYZING EDUCATIONAL COMMENTS FOR TOPICS AND SENTIMENTS: A TEXT ANALYTICS APPROACH.....</i>	<i>1658</i>
Gokarn Ila Nitin (Singapore Management University, Singapore)	
Gottipati Swapna (Singapore Management University, Singapore)	
Venky Shankararaman (Singapore Management University, Singapore)	
<i>PREPARING ECE STUDENTS FOR RESEARCH CAREER IN NANOTECHNOLOGY VIA TRACK PROGRAM</i>	<i>1667</i>
Maher E. Rizkalla (Indiana University-Purdue University Indianapolis, USA)	
Mangilal Agarwal (Indiana University-Purdue University Indianapolis, USA)	
<hr/>	
<i>SIH: Innovative Curriculum & Course Design II</i>	
Chair: Wei-Fan Chen (Penn State University, United States)	
9:00 AM - 10:30 AM	
Room: Rio Grande Room	
<hr/>	
<i>CURRICULUM DRIVEN CLASSROOM DESIGN</i>	<i>1672</i>
Kerry Milligan (Drexel University, USA)	
Adam K. Fontecchio (Drexel University, USA)	
<i>RUBRICS FOR ASSESSMENT ITEM DIFFICULTY IN ENGINEERING COURSES</i>	<i>1676</i>
Shilpi Banerjee (International Institute of Information Technology, India)	
N.J. Rao (International Institute of Information Technology, India)	
Chandrashekar Ramanathan (International Institute of Information Technology, India)	

***INSPIRING UNDERGRADUATE STUDENTS IN ENGINEERING LEARNING,
COMPREHENDING AND PRACTICING BY THE USE OF ANALOG DISCOVERY KITS..... 1684***
 Lei Zhang (University of Maryland Eastern Shore, USA)
 Ibibia Dabipi (University of Maryland Eastern Shore, USA)
 Yuanwei Jin (University of Maryland Eastern Shore, USA)
 Payam Matin (University of Maryland Eastern Shore, USA)

TEACHING PROJECT MANAGEMENT USING A REAL-WORLD GROUP PROJECT..... 1688
 Lawrence Collingbourne (Victoria University of Wellington, New Zealand)
 Winston K.G. Seah (Victoria University of Wellington, New Zealand)

***USING 3-D OPEN SOURCE SOFTWARE TO FACILITATE STUDENTS' SPATIAL
VISUALIZATION SKILLS..... 1696***
 Wei-Fan Chen (The Pennsylvania State University, USA)
 Pao-Nan Chou (National University of Tainan, Taiwan)
 Robert Carey (The Pennsylvania State University, USA)

SII: Faculty Development III
Chair: Megan Tomko (Georgia Institute of Technology, USA)
9:00 AM - 10:30 AM
Room: Santa Fe Room

***LEARNING ABOUT ENGINEERING EDUCATION RESEARCH: WHAT CONCEPTUAL
DIFFICULTIES STILL EXIST FOR A NEW GENERATION OF SCHOLARS? 1699***
 Ruth A. Streveler (Purdue University, USA)
 Nicole P. Pitterson (Purdue University, USA)
 Avneet Hira (Purdue University, USA)
 Héctor Rodríguez-Simmonds (Purdue University, USA)
 Juan Ortega Alvarez (Purdue University, USA)

***APPRENTICESHIP OF OBSERVATION: IMPLICATIONS FOR THE ADOPTION OF
EVIDENCE-BASED INSTRUCTIONAL PRACTICES 1705***
 Kari L. Jordan (Embry-Riddle Aeronautical University, USA)
 James J. Pembridge (Embry-Riddle Aeronautical University, USA)
 Heidi M. Steinhauer (Embry-Riddle Aeronautical University, USA)
 Timothy Wilson (Embry-Riddle Aeronautical University, USA)
 Douglas Holton (Embry-Riddle Aeronautical University, USA)

AMBIGUITY DURING ENGINEERING PROBLEM SOLVING 1712
 Elliot P. Douglas (University of Florida, USA)
 Sevcen Agdas (University of Florida, USA)
 Christine Lee (California State University East Bay, USA)
 Mirka Koro-Ljungberg (Arizona State University, USA)
 David J. Therriault (University of Florida, USA)

***BACKGROUND AND DEMOGRAPHIC FACTORS THAT INFLUENCE GRADUATION:
A COMPARISON OF SIX DIFFERENT TYPES OF MAJORS..... 1716***
 Sara Hahler (Louisiana Tech University, USA)
 Marisa K. Orr (Louisiana Tech University, USA)

S2A: Technological Tools I**Chair:** Jean Hertzberg (University of Colorado Boulder, USA)**11:00 AM - 12:30 PM****Room:** Kohlberg Room

UNDERGRADUATE EXPERIMENTS WITH APERIODIC GRATINGS BASED ON THE FIBONACCI SEQUENCE 1723

J.A. Monsoriu (Universitat Politècnica de València, Spain)

M.H. Giménez (Universitat Politècnica de Valencia, Spain)

E. Ballester (Universitat Politècnica de València, Spain)

L.M. Sanchez-Ruiz (Universitat Politècnica de València, Spain)

AN INTERACTIVE LEARNING ENVIRONMENT FOR ASSISTING STUDENTS IN SOLVING PROBLEMS ON DESIGNING OF LOGIC DIGITAL CIRCUITS BY USING MULTIPLE REPRESENTATIONS..... 1726

Evandro de Barros Costa (University of Alagoas, Brazil)

Hemilis Joyse Barbosa Rocha (Federal Institute of Alagoas, Brazil)

ADAPTIVE VISION STUDIO - EDUCATIONAL TOOL FOR IMAGE PROCESSING LEARNING..... 1732

Krystian Radlak (Silesian University of Technology, Poland)

Mariusz Frackiewicz (Silesian University of Technology, Poland)

Marek Szczepanski (Silesian University of Technology, Poland)

Michał Kawulok (Silesian University of Technology, Poland)

Michał Czardybon (Future Processing, Poland)

ANALYSIS OF OPPORTUNITIES AND CHALLENGES OF THE ELECTRONIC DUAL-BOARD IN INSTRUCTION..... 1740

Li-ping Cai (Central China Normal University, P.R. China)

Rui-hua Shi (Central China Normal University, P.R. China)

Wen-yan Niu (Central China Normal University, P.R. China)

Ming-Wen Tong (Central China Normal University, P.R. China)

AESTHETICS AND EXPANDING PERCEPTION IN FLUID PHYSICS 1747

Katherine Goodman (University of Colorado, USA)

Jean Hertzberg (University of Colorado, USA)

Noah Finkelstein (University of Colorado, USA)

S2B: Computer Based Learning**Chair:** Rogério Garcia (São Paulo State University, Brazil)**11:00 AM - 12:30 PM****Room:** Pancho Villa Room

STEP-BASED TUTORING SYSTEM FOR INTRODUCTORY LINEAR CIRCUIT ANALYSIS..... 1752

B. J. Skromme (Arizona State University, USA)

P. J. Rayes (Arizona State University, USA)

B. E. McNamara (Arizona State University, USA)

V. Seetharam (Arizona State University, USA)

X. Gao (Arizona State University, USA)

T. Thompson (Arizona State University, USA)

X. Wang (Arizona State University, USA)

B. Cheng (Arizona State University, USA)

Y.-F. Huang (University of Notre Dame, USA)

D.H. Robinson (Colorado State University, USA)

IMPLEMENTATION OF AN INTELLIGENT TUTORING SYSTEM USING MOODLE	1761
Vyshnavi Malathi Ramesh (International Institute of Information Technology, India)	
N. J. Rao (International Institute of Information Technology, India)	
Chandrashekar Ramanathan (International Institute of Information Technology, India)	
 A USER PROFILE DEFINITION IN CONTEXT OF RECOMMENDATION OF OPEN EDUCATIONAL RESOURCES. AN APPROACH BASED ON LINKED OPEN VOCABULARIES.....	1770
Janneth Chicaiza (Universidad Técnica Particular de Loja, Ecuador)	
Nelson Piedra (Universidad Técnica Particular de Loja, Ecuador)	
Jorge Lopez-Vargas (Universidad Técnica Particular de Loja, Ecuador)	
Edmundo Tovar-Caro (Universidad Politécnica de Madrid, Spain)	
 SUPPORTIVE ENVIRONMENT FOR TEACHING AND LEARNING DIGITAL IMAGE PROCESSING.....	1777
Lenon Fachiano Silva (Universidade Estadual Paulista "Júlio de Mesquita Filho", Brazil)	
Celso Olivete Júnior (Universidade Estadual Paulista "Júlio de Mesquita Filho", Brazil)	
Pedro Henrique Reis (Universidade Estadual Paulista "Júlio de Mesquita Filho", Brazil)	
Rafael Silva Santos (Universidade Estadual Paulista "Júlio de Mesquita Filho", Brazil)	
Ronaldo Celso Messias Correia (Universidade Estadual Paulista "Júlio de Mesquita Filho", Brazil)	
Rogério Eduardo Garcia (Universidade Estadual Paulista "Júlio de Mesquita Filho", Brazil)	
 ADAPTATION RESOURCES IN VIRTUAL LEARNING ENVIRONMENTS UNDER CONSTRUCTIVIST APPROACH: A SYSTEMATIC REVIEW	1784
Vitor Bremgartner (Federal University of Amazonas, Brazil)	
José Magalhães, Netto (Federal University of Amazonas, Brazil)	
Crediné Silva de Menezes (University of Rio Grande do Sul (UFRGS), Brazil)	

S2C: Innovative Curriculum & Course Design III
Chair: Rebecca Reck (University of Illinois at Urbana-Champaign, United States)
11:00 AM - 12:30 PM
Room: Angus Room

BRIDGING THE DIVIDE: STRATEGIES FOR COLLEGE TO CAREER READINESS IN COMPUTER SCIENCE.....	1792
Wendy A Lawrence-Fowler (The University of Texas-Pan American, USA)	
Laura M. Grabowski (University of Texas-Pan American, USA)	
Christine F. Reilly (University of Texas-Pan American, USA)	
 THE INSTITUTIONAL ENVIRONMENT FOR STUDENT VETERANS IN ENGINEERING	1800
Catherine E. Brawner (Research Triangle Educational Consultants, USA)	
Catherine Mobley (Clemson University, USA)	
Joyce Main (Purdue University, USA)	
Susan M. Lord (University of San Diego, USA)	
Michelle M. Camacho (University of San Diego, USA)	
 ASSESSING AN AFFORDABLE AND PORTABLE LABORATORY KIT IN AN UNDERGRADUATE CONTROL SYSTEMS COURSE	1805
Rebecca M. Reck (University of Illinois at Urbana-Champaign, USA)	
Ramavarapu S. Sreenivas (University of Illinois at Urbana-Champaign, USA)	
Michael C. Loui (Purdue University, USA)	
 HANDS ON PROJECT EXPERIENCE IN A CORE CLASS FOCUSED ON SUSTAINABILITY.....	1809
Anoop Desai (Georgia Southern University, USA)	

S2D: Curriculum Design III**Chair:** Rebecca Reck (University of Illinois at Urbana-Champaign, USA)**11:00 AM - 12:30 PM****Room:** Brahma Room

BIOINFORMATICS CURRICULUM DEVELOPMENT**AND SKILL SETS FOR BIOINFORMATICIANS 1813**

Huanmei Wu (School of Informatics and Computing, USA)

Amritha Palani (School of Informatics and Computing, USA)

STUDENTS LEARN MORE WITH LESS TEXT THAT COVERS THE SAME CORE TOPICS 1820

Alex Edgcomb (University of California, Riverside, USA)

Frank Vahid (University of California, Riverside, USA)

Roman Lysecky (University of Arizona, USA)

VIRTUAL LABORATORY PLATFORM FOR COMPUTER SCIENCE CURRICULA..... 1825

Yuanyuan Li (Central South University, P.R. China)

Lei Xiao (Central South University, P.R. China)

Yu Sheng (Central South University, P.R. China)

CLOUD-BASED TEACHING IN AN ENGINEERING-PHYSICS COURSE..... 1832

John M. Long (Deakin University, Australia)

AN AUTOMATION OF THE COURSE DESIGN BASED ON MATHEMATICAL**MODELING AND GENETIC ALGORITHMS 1840**

Alexey Dukhanov (ITMO University, Russia)

Maria Karpova (ITMO University, Russia)

Vadim Shmelev (ITMO University, Russia)

S2E: Innovative Curriculum & Course Design IV**Chair:** Brian Faulkner (University of Illinois, USA)**11:00 AM - 12:30 PM****Room:** Charolais Room

STUDENTS OF ENGINEERING ON BEHALF OF PEOPLE WITH DISABILITIES:**EVALUATING THE IMPACT OF AN INSTITUTION'S FLAGSHIP PROJECT..... 1844**

Orna Muller (ORT Braude College of Engineering, Israel)

Noga Shalit (ORT Braude College of Engineering, Israel)

Orit Braun Benyamin (ORT Braude College of Engineering, Israel)

ENHANCING THE EDUCATIONAL EXPERIENCE FOR DEAF AND HARD OF HEARING**STUDENTS IN SOFTWARE ENGINEERING 1849**

Daniel E. Krutz (Rochester Institute of Technology, USA)

Samuel A Malachowsky (Rochester Institute of Technology, USA)

Scott D. Jones (Rochester Institute of Technology, USA)

Jayme A. Kaplan (St. Mary's School for the Deaf, USA)

GETTING THE ATTENTION OF UNDERREPRESENTED MINORITY COMMUNITY**COLLEGE STUDENTS TO CONSIDER ENGINEERING AS A CAREER..... 1858**

Mary R. Anderson-Rowland (Arizona State University, USA)

Armando A. Rodriguez (Arizona State University, USA)

Anita E. Grierson (Arizona State University, USA)

EFFECT OF ASSERTION HEADINGS AND EXPANDABLE EXAMPLES IN AN ONLINE**ENGINEERING TEXTBOOK..... 1866**

Brian Faulkner (University of Illinois at Urbana-Champaign, USA)

Geoffrey Herman (University of Illinois at Urbana-Champaign, USA)

S2F: K-12 Education III**Chair:** Noah Salzman (Boise State University, United States)**11:00 AM - 12:30 PM****Room:** Longhorn Room

STEM SUMMER CAMP FOLLOW UP STUDY: EFFECTS ON STUDENTS' SAT SCORES AND POSTSECONDARY MATRICULATION..... 1875

Peter Boedeker (Texas A&M University, USA)

Ali Bicer (Texas A&M University, USA)

Robert M. Capraro (Texas A&M University, USA)

Mary Margaret Capraro (Texas A&M University, USA)

Jim Morgan (Texas A&M University, USA)

Luciana Barroso (Texas A&M University, USA)

NANOTECHNOLOGY STEM PROGRAM VIA RESEARCH EXPERIENCE FOR HIGH SCHOOL TEACHERS 1883

Mangilal Agarwal (Indiana University-Purdue University Indianapolis, USA)

Qurat-ul-Ann Mirza (Indiana University-Purdue University Indianapolis, USA)

Joseph Bondi (Indiana University-Purdue University Indianapolis, USA)

Brandon Sorge (Indiana University-Purdue University Indianapolis, USA)

Maher Rizkalla (Indiana University-Purdue University Indianapolis, USA)

Richard Ward (Indiana University-Purdue University Indianapolis, USA)

Corbin Feldhaus (Charlestown High School, USA)

Amy Hinshaw (McKenzie Center for Innovation & Technology, Indianapolis, USA)

Kody Varahramyan (Indiana University-Purdue University Indianapolis, USA)

L.E.A.P.: LOCALIZED ENERGY AWARENESS PROGRAM THROUGH COLLABORATIVE K-UNIVERSITY STEM PROJECTS 1888

Jamie Kennedy (Drexel University, USA)

Brandon Morton (Drexel University, USA)

Adam Fontecchio (Drexel University, USA)

USING COMMON ELEMENTS TO EXPLAIN ELECTROMAGNETISM TO CHILDREN: REMOTE LABORATORY OF ELECTROMAGNETIC CRANE..... 1892

German Carro Fernandez (Spanish University for Distance Education - UNED, Spain)

Ramon Carrasco Borrego (Spanish University for Distance Education - UNED, Spain)

Elio Sancristobal Ruiz (Spanish University for Distance Education - UNED, Spain)

Manuel Castro Gil (Spanish University for Distance Education - UNED, Spain)

Francisco Mur Perez (Spanish University for Distance Education - UNED, Spain)

S2G: Online-distance Learning**Chair:** Larry Richards (University of Virginia, USA)**11:00 AM - 12:30 PM****Room:** Hereford Room

AN AGILE LEARNING DESIGN METHOD FOR OPEN EDUCATIONAL RESOURCES..... 1897

Maurício Massaru Arimoto (University of São Paulo, Brazil)

Ellen Francine Barbosa (University of São Paulo, Brazil)

Leonor Barroca (The Open University, United Kingdom)

STUDENT-PERCEIVED EFFECTIVENESS OF ONLINE CONTENT DELIVERY MODES..... 1906

Julie S. Mullen (Worcester Polytechnic Institute, USA)

John M. Sullivan, Jr (Worcester Polytechnic Institute, USA)

TOPIC BASED SEGMENTATION OF CLASSROOM VIDEOS 1910

Tayfun Tuna (University of Houston, USA)
Mahima Joshi (University of Houston, USA)
Varun Varghese (University of Houston, USA)
Rucha Deshpande (University of Houston, USA)
Jaspal Subhlok (University of Houston, USA)
Rakesh Verma (University of Houston, USA)

**MOTIVATING STUDENTS WITH NEW MECHANISMS OF ON-LINE ASSIGNMENTS
AND EXAMINATION TO MEET THE MOOC CHALLENGES FOR PROGRAMMING..... 1919**

Xiaohong Su (Harbin Institute of Technology, P.R. China)
Tiantian Wang (Harbin Institute of Technology, P.R. China)
Jing Qiu (Harbin Institute of Technology, P.R. China)
Lingling Zhao (Harbin Institute of Technology, P.R. China)

SUPPORTING REAL OPEN EDUCATIONAL RESOURCES IN EDU-AREA 1925

Manuel Caeiro-Rodríguez (Universidade de Vigo, Spain)
Martín Llamas-Nistal (Universidade de Vigo, Spain)
Manuel Fernández-Iglesias (Universidade de Vigo, Spain)
Fernando Mikic-Fonte (Universidade de Vigo, Spain)
Manuel Lama-Peñín (Universidade de Santiago de Compostela, Spain)

S2H: Assessment

Chair: Senay Purzer (Purdue University, USA)

11:00 AM - 12:30 PM

Room: Rio Grande Room

**ON THE EFFECTIVENESS OF USING MIDTERM EXAMINATIONS
STRICTLY FOR FORMATIVE FEEDBACK..... 1933**

Robert M. O'Connell (University of Missouri, USA)

AN ASSESSMENT ARCHITECTURE FOR COMPETENCY-BASED LEARNING: VERSION 1.0 1936

Jeffrey J. Evans (Purdue University, USA)
Esteban Garcia (Purdue University, USA)
Michael Smith (Purdue University, USA)
Amy Van Epps (Purdue University, USA)
Michael Fosmire (Purdue University, USA)
Sorin Matei (Purdue University, USA)

SYSTEMS THINKING SKILLS OF UNDERGRADUATE ENGINEERING STUDENTS..... 1943

Shaobo Huang (South Dakota School of Mines and Technology, USA)
Karim Heinz Muci-Kuchler (South Dakota School of Mines and Technology, USA)
Mark D. Bedillion (South Dakota School of Mines and Technology, USA)
Marius D. Ellingsen (South Dakota School of Mines and Technology, USA)
Cassandra M. Degen (South Dakota School of Mines and Technology, USA)

**AN ANALYSIS OF THE PROVISION OF CONTEXT WITHIN EXISTING
REMOTE LABORATORIES 1948**

Tania Machet (The University of Sydney, Australia)
David Lowe (The University of Sydney, Australia)

EVALUATION AND CONTINUOUS IMPROVEMENT IN A MULTIDISCIPLINARY S-STEM PROGRAM FOCUSING ON PROFESSIONAL SKILLS, GOALS & MENTORING 1957

Robert H. Kinzel (Minnesota State University, Mankato, USA)
Jennifer Veltsos (Minnesota State University, Mankato, USA)
Rebecca A. Bates (Minnesota State University, Mankato, USA)
Rachel E. Cohen (Minnesota State University, Mankato, USA)
Winston Sealy (Minnesota State University, Mankato, USA)
Deborah K. Nykanen (Minnesota State University, Mankato, USA)

S2I: Innovative Curriculum & Course Design V

Chair: Dan Tappan (Eastern Washington University, USA)

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A COMPARATIVE ANALYSIS OF TWO GLOBALLY DISTRIBUTED GROUP PROJECTS: A PERSPECTIVE FROM CSCW/CSCL RESEARCH..... 1964

Roger McDermott (Robert Gordon University, United Kingdom)
Mats Daniels (Uppsala University, Sweden)
Åsa Cajander (Uppsala University, Sweden)
Julian Bass (Robert Gordon University, United Kingdom)
JayPrakash Lalchandani (International Institute for Information Technology, India)

A QUASI-NETWORK-BASED FLY-BY-WIRE SIMULATION ARCHITECTURE FOR TEACHING SOFTWARE ENGINEERING 1973

Dan Tappan (Eastern Washington University, USA)

PEER INSTRUCTION METHODOLOGY FOR LINEAR ALGEBRA SUBJECT: A CASE STUDY IN AN ENGINEERING COURSE..... 1981

Katiuscia C. B.Teixeira (Federal University of Ceará, Brazil)
Thomaz E. V. Silva (Federal University of Ceará, Brazil)
Joao C. M. Mota (Federal University of Ceará, Brazil)
Natália C. Barroso (Federal University of Ceará, Brazil)
Eduardo V. O. Teixeira (Federal University of Ceará, Brazil)

AN INTEGRATED CURRICULUM FOR INTERNET OF THINGS: EXPERIENCE AND EVALUATION..... 1988

Simon G. M. Koo (Jesuit Liberal Arts College, Hong Kong)

USING AN INTERACTIVE ANIMATED TOOL TO IMPROVE THE EFFECTIVENESS OF LEARNING CPU SCHEDULING ALGORITHMS..... 1992

Sukanya Suranauwarat (National Institute of Development Administration (NIDA), Thailand)

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Chair: Paul B. Crilly (United States Coast Guard Academy, USA)

2:30 PM - 4:00 PM

Room: Kohlberg Room

ANOTHER PERSPECTIVE FOR LINEAR EQUATIONS, MATRICES AND THE TECHNOLOGICAL TOOLS IN LEARNING 1999

Rogelio Palomera-Garcia (U. of Puerto Rico at Mayaguez, Puerto Rico)

HOW MANY POINTS SHOULD BE AWARDED FOR INTERACTIVE TEXTBOOK READING ASSIGNMENTS?..... 2004

Alex Edgcomb (University of California, Riverside, USA, USA)
Frank Vahid (University of California, Riverside, USA, USA)

COMBINING MATLAB® SIMULATION WITH TELECOMMUNICATIONS INSTRUCTIONAL MODELING (TIMS™) IN A SENIOR LEVEL COMMUNICATIONS COURSE..... 2008
Richard J. Hartnett (U.S. Coast Guard Academy, USA)
Paul B. Crilly (U.S. Coast Guard Academy, USA)

MORE THAN JUST RIGHT OR WRONG: USING CONCEPT QUESTIONS TO DISCERN STUDENTS' THINKING IN MECHANICS..... 2012
Jeffrey L. Newcomer (Western Washington University, USA)

S3B: Global Programs

Chair: Joyce B. Main (Purdue University, United States)

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Room: Pancho Villa Room

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Ricardo Llamasa-Villalba (Industrial University of Santander, Colombia)
Dario J. Delgado Q. (Industrial University of Santander, Colombia)
Luz Torres Carreño (Industrial University of Santander, Colombia)
Andres Bueno Barajas (Industrial University of Santander, Colombia)
Ana M. Paéz Q. (Industrial University of Santander, Colombia)
Edgar Garcia Sneyder (Industrial University of Santander, Colombia)

EVIDENCE-BASED APPROACHES FOR ENGINEERING GLOBAL PREPAREDNESS PROGRAMMING: RESEARCH TO INFORM PRACTICE..... 2028
Scott C. Streiner (University of Pittsburgh, USA)
Mary Besterfield-Sacre (University of Pittsburgh, USA)

EXAMINING HOW INTERNATIONAL EXPERIENCES PROMOTE GLOBAL COMPETENCY AMONG ENGINEERING GRADUATE STUDENTS..... 2033
Lauren B. Denney (Purdue University, USA)
Matilde Sánchez-Peña (Purdue University, USA)
Joyce B. Main (Purdue University, USA)

A SEMESTER-LONG STUDY ABROAD MODEL FOR ENGINEERING STUDENTS - THE UNIFIED PROJECT APPROACH..... 2041
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Theresa M. Marks (The University of Oklahoma, USA)
Chris Ramseyer (The University of Oklahoma, USA)
James J. Sluss (The University of Oklahoma, USA)
P. Simin Pulat (The University of Oklahoma, USA)
Kirk Duclaux (The University of Oklahoma, USA)

S3C: Outreach & University, Community Collaborations

Chair: Natascha Trellinger (Purdue University, United States)

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Michael C. Loui (Purdue University, USA)

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G. Donald Allen(Texas A&M University, USA)	
Michael Pilant (Texas A&M University, USA)	
Robert M. Capraro (Texas A&M University, USA)	
Mary M. Capraro (Texas A&M University, USA)	
Jim Morgan (Charles Sturt University, USA)	
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Allison Godwin (Purdue University, USA)	
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Matthew Ohland (Purdue University, USA)	
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Arturo A. Fuentes (University of Texas-Pan American, USA)	
Javier A. Kypuros (The University of Texas-Pan American, USA)	
Mohammad Azarbayejani (The University of Texas-Pan American, USA)	
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Alison Stevenson (IUPUI, USA)	
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Melanie Villatoro (NYC College of Technology, CUNY, USA)	
Michael C. Loui (Purdue University, USA)	
James E. Becvar (University of Texas El Paso, USA)	
Geoffrey B. Saupe (University of Texas El Paso, USA)	
Wayne Johnson (Mass Insight Global Partnerships, USA)	
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Louis S. Nadelson (Utah State University, USA)	
Kimberly Hardy (Boise State University, USA)	

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Anne Marie McCarrick (Dublin Institute of Technology, Ireland)	
Fionnuala Farrell (Dublin Institute of Technology, Ireland)	
Una Beagon (Dublin Institute of Technology, Ireland)	
Lance C. Pérez (University of Nebraska-Lincoln, USA)	
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Eduardo I. Ortiz-Rivera (University of Puerto Rico Mayagüez Campus, Puerto Rico)	
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Savita Bhat (Tata Consultancy Services Limited, India)	
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J.-A. Morano (Universitat Politècnica de València, Spain)	
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L.M. Sánchez Ruiz (Universitat Politècnica de València, Spain)	
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Ann Q. Gates (University of Texas at El Paso, USA)	
Monika Akbar (University of Texas at El Paso, USA)	

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Rebecca J. Christianson (Olin College of Engineering, USA)

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Federico Baeza (Fundación Cotec para la Innovación Tecnológica, Spain)

Manuel Castro (Spanish University for Distance Education - UNED, Spain)

Elio Sancristobal (Spanish University for Distance Education - UNED, Spain)

Pablo Losada (Spanish University for Distance Education - UNED, Spain)

German Carro (Spanish University for Distance Education - UNED, Spain)

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Javier Garcia-Zubia (University of Deusto, Spain)

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Dongni Li (Beijing Institute of Technology, P.R. China)

Jun Zheng (Beijing Institute of Technology, P.R. China)

Sanyuan Zhao (Beijing Institute of Technology, P.R. China)

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Paul Curtis (Arizona State University, USA)

Photini Spanias (Arizona State University, USA)

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Room: Santa Fe Room

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Paul Littleton (University of Illinois Urbana-Champaign, USA)
Arthur Schmidt (University of Illinois Urbana-Champaign, USA)
Lance Schideman (University of Illinois Urbana-Champaign, USA)
Morgan Johnston (University of Illinois Urbana-Champaign, USA)
Jose Mestre (University of Illinois Urbana-Champaign, USA)
Geoffrey Herman (University of Illinois Urbana-Champaign, USA)
Irene Mena (University of Illinois Urbana-Champaign, USA)
Emily Gates (University of Illinois Urbana-Champaign, USA)
Jason Morphew (University of Illinois Urbana-Champaign, USA)
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Chair: Efraín O'Neill-Carrillo (University of Puerto Rico-Mayaguez, Puerto Rico)

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M. Castro (Universidad Nacional de Educación a Distancia, Spain)	
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B. Hammad (The Hashemite University, Jordan)	
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Cristina Pomales-García (University of Puerto Rico-Mayagüez, Puerto Rico)	
Emilio Contreras (University of APEC, Dominican Republic)	
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Chair: Maura Borrego (University of Texas at Austin, USA)	
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Neuman de Souza (Federal University of Ceará, Brazil)

Thomaz E. V. da Silva (Federal University of Ceará, Brazil)

Zarathon L. Viana (Federal University of Ceará, Brazil)

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Chair: Samantha Brunhaver (Arizona State University, United States)

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Celso Olivete Junior (Universidade Estadual Paulista "Júlio de Mesquita Filho", Brazil)	
Analice C. Brandi (Universidade Estadual Paulista "Júlio de Mesquita Filho", Brazil)	
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Omar Portillo (Universidad de Pamplona, Colombia)	
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Chair: Chiu Choi (University of North Florida, United States)	
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Sheng Bi (Dalian Maritime University, P.R. China)	
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Integrating Service-Learning into Engineering and Computing Education

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Abstract – Community Engagement or Service-learning is a rapidly growing pedagogy in higher education and has come under increased visibility within engineering and computing education. It has been cited as a potential tool for increasing student engagement as well as diversity among our engineering, technology and computing student bodies. It also has opportunities to prepare the next generation of professionals, addressing issues including retention, diversity, learning and professional preparation. This workshop will introduce interested faculty, students, administrators and professionals to service-learning models including EPICS and provide resources for participants to implement such programs at their respective institutions.

Index Terms – Community Engagement, Service-learning, Design Education

GOAL AND OVERVIEW

The goals of the workshop are to

- 1) introduce participants to the pedagogy of community engagement and service-learning and
- 2) explore they it could be integrated into the curriculum at their home institution.

Community engagement or service learning is a growing pedagogy within engineering, and computing globally. It has been widely documented in engineering, computing and many other disciplines [1-26]. It is well-matched with calls for strong technical skills along with a broad set of professional and cultural skills that are beings demanded by industry and accreditation bodies. It provides the kind of curricular efficiency to meet these broad set of attributes without adding times to graduation. Community engagement has been used in many countries to provide service to their communities and enhance learning. The pedagogy is consistent with research in learning sciences and student success [27-32]. There is a growing number of faculty who are using community engagement and service-learning to equip students with the skills needed for leadership in the 21st century's global economy. This workshop will guide

participants through an introduction to the pedagogy and engage them in active discussions about how engagement is perceived and exists within different countries' cultures. Connections to engineering and computing will include models for design education [33-37]. Participants will be guided through the process to integrate the pedagogy into their own classes. Resources, partnerships and potential barriers will be discussed to provide strategies for successful implementation. Participants will be provided additional resources for further support beyond the workshop [38-42]. The workshop will engage participants in discussion about community engagement, student learning, cultural issues and change within the academy. Successful models will be presented and discussed, including the EPICS model [43-61] which was created at Purdue University and is a Signature Program of the IEEE Foundation. The facilitators have conducted more than 70 workshops on six continents and are experienced in working with a diverse community of current and future educators and administrators.

AGENDA TOPICS

- Introduction to the workshop, agenda and format – 10 minutes
- Overview of Service-Learning –20 minutes
 - What are the key characteristics of Service-Learning, Opportunities and Successful models
- Institutional needs assessment – 10 minutes
 - What are the educational needs at one's own institution and how can S-L meet the needs
- Getting started, what are the first steps – 15 minutes
- Course and curriculum issues – 15 minutes
 - How is it managed, What are the course structures, How does it fit EPICS Model and examples
- Break – 10 minutes
- Maximizing Learning with Analysis and Reflection – 15 minutes
- Assessing student learning – 20 minutes
 - EPICS examples
- Developing partnerships - community and corporate – 15 minutes
- Building institutional support – 10 minutes

- Tools and resources – 10 Minutes
- Developing Individual Models and Plans – 20 Minutes
- Questions and discussions – 15 minutes
- Workshop evaluation – 5 minutes

AUDIENCE

Current and future engineering, technology and computing educators or administrators interested in multidisciplinary teams, diversity, retention, innovation or entrepreneurship, design education and service learning or engagement will find this workshop valuable.

AUTHOR INFORMATION

William Oakes, Ph.D., P.E. is the Director of the EPICS Program at Purdue University, one of the founding faculty members of the School of Engineering Education and a professional engineer. He was the first engineer to win the U.S. Campus Compact Thomas Ehrlich Faculty Award for Service-Learning and was a co-recipient of the U.S. National Academy of Engineering's Bernard Gordon Prize for Innovation in Engineering and Technology Education.

Carla Zoltowski, Ph.D., is the Co-Director of EPICS at Purdue University. She has been recognized at Purdue for her leadership in EPICS and community engagement and nationally within the U.S. as the vice-Chair of the Community Engagement in Engineering Education Division of the American Society for Engineering Education (ASEE). She has published extensively on research in design education, ethics in engineering and computing and student experiences in community engagement.

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Teaching and Assessment Strategies that Value Innovative Thinking

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Abstract— Through undergraduate engineering education, we hope to create graduates who have the ability to think creatively and be innovative. Yet, prior studies suggest that students might be losing their creative edge during their undergraduate education. In this workshop, we will review key literature on engineering students' views of innovation and results from a series of studies conducted by the presenters through an NSF CAREER grant. We will then cover strategies to effectively promote and value student innovation. We will focus on planning design activities or projects that are more likely to elicit innovative behavior in students as well as adjustments to assessment practices and grading rubrics that encourage or allow for more innovative work by students.

Keywords—Assessment, creativity, innovation

I. INTRODUCTION AND BACKGROUND

An increasing number of studies indicate that many engineering students are losing their creative edge during their education [1]–[3]. These phenomena are especially troubling in light of the continued push by employers asking for engineers who are more innovative problem solvers [4]. Closing the gap between this employer need and student reality is of fundamental importance to economic competitiveness.

In prior studies, three barriers to innovation experienced by students have been identified: (1) An overwhelming technical identity that values technical problem solving over creativity, (2) a view of innovativeness as an attribute that is attainable by just a few privileged individuals or masterminds, and (3) instructional constraints that demotivate students from taking risks by exploring novel solutions [5].

In addition to understanding the underlying student behaviors, many different approaches have been taken to understand how to measure design creativity and innovativeness [6]. These include evaluations of student sketches [7] to explore the breadth of the design space that students populate in the ideation phase of design.

A mixed bag of assessment methodology is apparent in the entrepreneurship field as well. A literature synthesis by Purzer and colleagues [8] identified a range of instruments used for student assessment in entrepreneurship. However, the literature studied shows little indication of assessment schemes designed to robustly elicit measurable characteristics in a rigorous way.

What is seen in the broad range of assessment in both of these fields is that a large number of instruments and methods exist. However, they often exist without a solid alignment of the assessment methods with course design and pedagogical implementations that collectively form the course.

This workshop is intended to help practitioners bridge the phenomena that constrict innovativeness in student approaches to engineering design. The workshop will focus on strategies for course design and assessment that will value and help elicit more innovativeness during student design projects and build students' long-term ability to think more innovatively.

II. WORKSHOP DESCRIPTION AND TAKEAWAYS:

This workshop will focus on how instructors can teach and assess students in engineering courses that illuminates and values critical, and critically important, innovative thinking for students. Examples of student work from the facilitators' prior teaching and research on the subject will be used to illustrate assessment practices that value creativity and innovative problem solving. The participants will develop rubrics to be used in their own courses or design projects and discuss the merits of these rubrics with other participants.

The workshop is intended to facilitate both theoretical and practical takeaways for participants. The theoretical takeaways are focused on understanding what research literature can tell practitioners about students' conceptions and cognitive implementations of the concepts of innovation and creativity, especially in engineering design. These include expansion upon the phenomena explained in the background section and ways in which assessment strategies can be used to influence manifestation of innovation in students.

The practical takeaways focus on how instructors may orient classroom content, assessment, and pedagogy to elicit innovative behavior through design projects. These will include the development of project scopes and grading rubrics that participants will have the opportunity to take home.

III. WORKSHOP GOALS:

This workshop has two goals: (1) to unpack the implications of key literature on engineering students' views of innovation and the results from a series of studies conducted by the presenters through an NSF CAREER grant, and (2) to develop teaching and assessment strategies that value and promote innovative thinking. These strategies include the development

of grading rubrics that effectively elicit and reward innovative ideas while balancing key learning objects.

IV. WORKSHOP AGENDA

This three-hour workshop includes interactive group learning activities, demonstrations, discussions, and presentations. The first half will focus on prior research and participants' prior experiences. The second half will include interactive group activities that allow workshop attendees to work to put the literature on into practice for their specific needs and courses.

- Introductions and Overview of the Workshop (5min)
- Preview of participants' approaches to teaching and assessing innovation (20min)
- Review of prior research (15min)
- Interactive group activity on rubric development (20 min)
- Break (10 min)
- Presentations of group work by participants (30 min)
- Interactive group activity on design project (20 min)
- Presentations of group work by participants (30 min)
- Connect back to research (15 min)
- Concluding remarks (10 min)
- Feedback/workshop assessment (5 min)

V. QUALIFICATIONS OF THE PRESENTERS:

The first presenter is an engineering education faculty member and researcher who studies innovativeness among engineering students (first-year students to seniors) and teaches a first-year engineering design course. She is the PI of the NSF Career grant whose research grounds the workshop and has authored multiple publications in the research area on which this workshop focuses.

The second presenter is also an engineering education researcher with extensive experience working with high tech start-ups. He has instructed and mentored undergraduate capstone design teams and led the creation of an innovative first year engineering design project using a 'design client' model. Prior to entering the engineering education research field, he worked professionally in the semiconductor industry, as a design and manufacturing consultant with hardware startups, and the director of engineering for a biotechnology startup.

VI. MATERIALS PROVIDED

Workshop materials will be made available to all participants during and after the event. With approval from participants, the group presentations will shared after the workshop's completion. This is intended to help participants collaborate beyond the workshop to continue building shared knowledge.

VII. ACKNOWLEDGMENT:

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this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Process to Draft the Program Educational Objectives for Undergraduate Engineering Degree Programs

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Abstract - This pre-conference workshop will engage the participants in the process to draft Program Educational Objectives (PEOs) appropriate for undergraduate engineering degree programs at ABET-accredited institutions of higher education. The PEOs must reflect the Mission Statement of the institution and serve as a yardstick of student achievement three to five years following graduation. The PEOs must be crafted such that measurable objective evidence can be obtained through appropriate alumni surveys. To be consistent and effective, the entire engineering department must contribute to the discussion, ratification, and eventual adoption of the PEOs. In order to ensure a meaningful contribution from all faculty members involved in defining the PEOs, this workshop presents a framework that facilitates the discussion and the steps which can be taken to define the PEOs that (1) adhere to the Mission of the University (2) achieve consistent and measurable expectations. In addition, the workshop discusses internal and external review procedures to periodically review and revise the language, assessment, and evaluation of the PEOs. The attendees should expect to gain the following from this workshop.

- Understand the step-by-step process to draft and assess PEOs
- Draft PEOs which establish the link between the Undergraduate Engineering Degree program and the Mission of the University
- Work as individuals and on teams to develop the Department-wide consensus on the formulation and assessment language for each PEO
- Learn to clearly distinguish the PEOs from student outcomes

Index Terms – Program Educational Objectives, Accreditation, Assessment, Bloom taxonomy

INTRODUCTION

Program Educational Objectives (PEOs) for undergraduate engineering degree programs constitute the vision of the program for its graduates three to five years after graduation. ABET stipulates in its Self-Study Questionnaire [1] under Criterion 2, Category E that there should be a

process in place to periodically review and revise PEOs. These objectives represent the expectations of the department from its graduates and must be crafted such that measurable objective evidence can be obtained through alumni surveys. In addition, there must be in place internal and external review procedures to periodically review and revise the language, assessment, and evaluation of the PEOs.

The focus of this workshop is to understand and implement the step-by-step process to draft and assess the PEOs. The framework that is proposed is first to provide an assessment language that is similar to the cognitive learning pattern of *Bloom's Taxonomy for Knowledge, Comprehension, Application, Analysis, Evaluation and Synthesis* during the different stages completed by our graduates in their career path.

Faculty members should recognize that the students in the undergraduate degree program are viewed as *learners* who must acquire the intended skills over the duration of the baccalaureate program. These students are then expected to *demonstrate* the application of these skills three years following graduation. They are expected to assume more responsibilities in management or to *lead* in their profession and/or society six years after graduation. Ten or more years after graduation, these students should become *contributors* with significant influence on policy and decision making in their chosen profession and/or society.

The assessment language at these different stages of our graduates' career path is different. Hence, it is important to use the proper set of assessment language intended for the PEOs that focuses only on the immediate or first three years to measure the direct impact of our program on young careers, not the six-year or the ten-year longer term objectives which would measure learning experiences and contributions beyond the direct impact of the engineering degree program. Second, the framework requires faculty to extract key words from the Mission Statement of the institution which emphasize the broad and specific intent of undergraduate education along with a set of key words that the faculty see as attributes to gauge graduates in becoming the individuals the PEOs intended. Third, capture the distinction between educational objectives and student

outcomes, and formulate each objective recognizing the need for measurability.

The undergraduate engineering degree programs at institutions across the country adopt different approaches to create and review PEOs. For instance, the ECE program at one pre-eminent institution [2] develops the PEOs according to three expected outcomes from graduates five years after graduation – *professional expertise, innovativeness, and leadership*. At another institution [3], continuous education program assessment is addressed by bringing together a working team of departments and education specialists using a Web-based assessment process to gather and evaluate the data. There are also institutions that stipulate the PEOs of the program without empowering the faculty to develop, own, and adopt a consistent set of measurable PEOs.

The faculty of the Electrical and Computer Engineering (ECE) department at our institution met on different occasions for discussion and a final work session for almost six hours to complete the steps of the process in order to revise the existing set of PEOs. The PEOs of our fully accredited undergraduate ECE program (accreditation period from 2012 to 2017) were deemed to have language that was very similar to that used in the ABET student outcomes. Therefore, it was imperative to distinguish the PEOs from the ABET student outcomes since the PEOs must quantify the expected attainments of graduates a few years after graduation.

Section 2 describes the framework to formulate the PEOs and outlines the agenda and timetable of the workshop. Section 3 provides a broad overview of the PEO assessment cycle at our institution with internal and external review processes, and the assessment and evaluation process which includes the mapping of these PEOs to the ABET student outcomes. The conclusions appear in Section 4.

SECTION 2: FRAMEWORK TO FORMULATE PEOs

The first step is to recognize that faculty members as *individuals* have independent PEO ideas, which leverage their multi-cultural and multi-discipline resources. Then, the faculty members, objectively as a *team*, have long workout sessions to revise and commit to these new PEOs, thus promoting PEO ownership as individuals and as the entire Department. At the beginning of the workout session, the faculty members identify and agree to the following keywords from the Mission Statement of the institution (e.g. as shown in the following paragraph) such as *holistic development, value-centered, professional, leadership roles, cultural diversity, and lifelong learning*.

This Institution is a Catholic, Diocesan, student-centered University which provides for the holistic development of undergraduate and graduate students in the

Judeo-Christian tradition. As such, it offers each student outstanding teaching and a value-centered education in both liberal arts and professional specializations in order to prepare students for leadership roles in their careers, society, and church. The University faculty and staff are committed to excellence and continuous improvement in teaching, learning, scholarship, research, and service. The University's environment is to be one of inclusiveness and cultural diversity.

In addition, the faculty identified the categories in which objective evidence shall be obtained to measure each key word keeping in mind the proper set of assessment language. Faculty members then formed break-out groups of two to draft the PEO suitable for each key word. Finally, the faculty reconvened as one group to review and revise each objective as well as to arrange the objectives in the order of chronological impact and accomplishment before reaching agreement for adoption.

The framework for the review and revision of the PEOs at the departmental level involving all the faculty members comprises the following broad stages.

1. Provide the assessment language.
2. Use the key words and phrases extracted from the Mission Statement of the institution to identify attributes to gauge graduates.
3. Capture the distinction between the educational objective and the student outcomes.
4. Formulate each objective to be measurable.

The assessment language is based on the *Cognitive domain* of Bloom's taxonomy [4]. Bloom's taxonomy was developed in 1956 as the classification of learning objectives within education to improve communication between educators on the design of curricula and examinations. There are three domains - Cognitive, Affective, and Psychomotor. The Cognitive domain (or *What should I know?*) corresponds to the recall or recognition of specific facts, procedural patterns, and concepts that serve in the development of intellectual abilities and skills.

The six major categories in the Cognitive Domain - *Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation* – which range from simple to complex, are covered within every course at all levels (first year to senior year) but the focus of the pattern of learning at each level of course is as shown in Table I.

TABLE I
FOCUS OF LEARNING

Level of Course	Focus of learning
First year	<i>Knowledge</i>
Second year	<i>Comprehension</i>
Third year	<i>Application & Analysis</i>
Fourth year	<i>Evaluation & Synthesis</i>

Table II lists the sequence of activities and the expected duration of each activity planned for this pre-conference workshop. The expected total duration of the workshop is 2 hours (120 minutes).

TABLE II
WORKSHOP SCHEDULE

Activity #	Activity	Duration	Remarks
1	Introduction and Overview	15 minutes	Framework of discussion
2	Review topic: Bloom Taxonomy (BT)	10 minutes	Explain the domains of BT
3	Break-out activity #1(individual)	10 minutes	Keyword extraction
4	Review topic: ABET student outcomes	10 minutes	Discuss link to BT
5	Break-out activity #2 (teams of two to three)	15 minutes	Use BT and ABET student outcomes to formulate PEOs
6	Review topic: Program Educational Objectives (PEOs)	10 minutes	Discuss the language and emphasis of PEOs
7	Break-out activity #3 (teams of two to three)	15 minutes	Revise the sample PEOs; draft the new PEOs
8	Review topic: Assessment of PEOs	10 minutes	Discuss internal and external assessment methods
9	Break-out activity #4 (complete group – all attendees)	20 minutes	Map the new PEOs to the ABET student outcomes
10	Summary and Conclusions	5 minutes	Review the process of PEO; attendees assess the workshop

SECTION 3: PEO ASSESSMENT CYCLE

The program constituents for the PEO assessment process comprise the faculty, staff, students, and the local industry represented by its members on the Engineering Advisory Council (EAC). The PEO assessment cycle is conducted over the 3 to 5 year period and is shown in Figure 1.

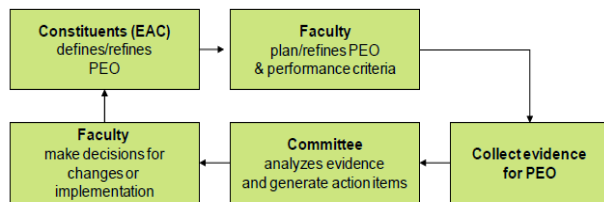


FIGURE 1
PEO ASSESSMENT CYCLE

The two primary approaches to PEO assessment are (1) internal review, and (2) external review. The internal review consists of assessing the attainment of student outcomes, through senior exit surveys and embedded course assessment processes, to determine if the skill sets necessary for attainment of PEOs are being provided within each course and across the curriculum.

The external review comprises the assessment of data gathered through the alumni survey to determine how well our graduates are performing in the workforce three to five years following their graduation. This measures the level of attainment of each PEO.

The PEO evaluation process determines the relevancy of each PEO to address and successfully meet the needs of the program constituents. The program constituents are faculty, students, alumni, and industry. The evaluation of the PEOs by both the EAC and the faculty members helps address the needs of program constituents. Action items generated at faculty and EAC review meetings are expected to lead to changes in the PEOs and have significant impact on the shaping of our educational practices.

The mapping of the student outcomes to the PEOs is intended to help us determine if our educational practices within each course and across the curriculum prepare our graduates to meet the intended PEOs. Table III illustrates the mapping of PEOs to ABET student outcomes.

TABLE III
MAPPING OF PEOs TO ABET STUDENT OUTCOMES

ABET Student Learning Outcomes	PEO 1	PEO 2	PEO 3	PEO 4	PEO 5
Ability to apply knowledge of mathematics, science, and engineering	X				X
Ability to design and conduct experiments, as well as to analyze and interpret data					X
Ability to design a system, component, or process to meet desired needs	X				X
Ability to function on multi-disciplinary teams			X	X	
Ability to identify, formulate, and solve engineering problems	X				X
Understanding of professional and ethical responsibility		X	X		
Ability to communicate effectively				X	
Broad education necessary to understand the impact of engineering solutions in a global and societal context	X	X	X	X	
Recognition of the need for, and an ability to engage in life-long learning	X		X		
Knowledge of contemporary issues	X		X	X	
Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	X				X

The toolsets used in the PEO assessment process are as follows:

- Alumni survey (*external*)
- EAC review (*external*)
- Executive summary report for student outcomes (*internal*)

The alumni survey provides the data for assessment of the PEOs as part of the external review. The survey is administered through secure access on the Web [5] and addresses the following primary question:

How well are our graduates really doing in the workforce?
The survey has quantitative and qualitative sections in the following categories.

- *General information*
- *Employment History*
- *Preparedness of Gannon Education*
- *Soft Skills and Broad Education*
- *Liberal Studies*
- *Intern Experience and Professional Societies*
- *Rate education based on the PEOs*

For instance, Table IV lists the questions asked in the quantitative section of the alumni survey for the category titled *Soft Skills and Broad Education*.

TABLE IV
QUANTITATIVE SECTION

Soft Skills and Broad Education	
Questions	
1	Do you feel your Gannon education helped you to understand the ethical responsibilities of your profession?
2	How well did your Gannon education prepare you to give oral presentations?
3	How well did your Gannon education prepare you to write technical reports and other written communications?
4	Do you feel you have the ability to use the most modern engineering tools and techniques effectively?
5	Do you feel your education at Gannon was broad enough to give you a perspective on how a particular engineering solution might impact society?

SECTION 4: CONCLUSIONS

The following are the primary goals or expected learning outcomes of this workshop.

- Understand the step-by-step process to draft the PEOs
- Use carefully crafted PEOs to establish the link between the Undergraduate Engineering Degree program and the Mission of the University
- Work as individuals and on teams to develop the Department-wide consensus on the formulation and assessment language for each PEO
- Learn to clearly distinguish the PEOs from student outcomes

These goals are aligned with those of FIE because they look to offer attendees ways to nurture their skills, knowledge, and/or materials that they can use in their own teaching practice or scholarship of learning and teaching. The key requirements to guarantee success of this process are as follows:

- Engagement and commitment of the entire engineering department to the discussion, ratification, and eventual adoption of the PEOs
- Active participation by the faculty in defining the PEOs to promote ownership of the goals of the Department and ABET process
- Adherence to the Mission of the University
- Distinguish PEOs from student outcomes
- Draft PEOs with measurable outcomes

Anticipated Audience & Desired Maximum Count

Faculty members, chairpersons and/or those actively engaged in the drafting of program educational objectives in ABET-accredited engineering programs. The desired maximum count would be 30 attendees (10 teams of 2 to 3 per team for the break-out sessions would be manageable).

Author Preparation

The author/facilitator has conducted workshops on the topics related to this proposal [6], [7] and is conversant with the detailed step-by-step process required to train the attendees, having participated in this process as part of the ABET accreditation of an undergraduate engineering degree program.

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Agile Way of Educating

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Abstract— We have investigated whether Agile practices can be applied as a pedagogical approach to derive benefit in the areas of encouraging students to take responsibility for their learning (self managed learning), continuous improvement through reflection, alternative approaches for grading, increased engagement by learners, and more effective data collection and assessment of outcomes. Agile is an umbrella term for values, principles and practices applied to the process of software development. The Agile movement has aimed to develop a new and better culture within the software development community and has seen an increased rate of adoption within corporate settings. The goal of this workshop is to help participants explore how Agile development, a management technique borne out of the software industry, can not only change the way that students engage in project-based and team-based course projects, but also transform the way that we educate our students.

Keywords—Agile; Innovative Pedagogy; Project-based Learning

I. INTRODUCTION

The New Media Consortium NMC creates a yearly publication called the Horizon Report for Higher Education [1]. In the most recent issue, the NMC has identified Agile practices as a trend to be observed for potential long-term adoption for higher education. Agile is an umbrella term for values, principles and practices applied to the process of software development. The Agile movement has aimed to develop a new and better culture within the software development community and has seen an increased rate of adoption within corporate settings [2,3,4,5].

Agile development has transformed the way that many software development and production organizations create knowledge products. Environments where the end product is being discovered and constantly refined are a perfect fit for Agile. Education is by definition based on learning and discovery. As such, as learning becomes more personalized and requires adjustment to changing conditions and requirements while fulfilling stringent accreditation standards, new pedagogical methods are required that can reduce the cost of change.

We have investigated whether Agile practices can be applied as a pedagogical approach to derive benefit in the areas of encouraging students to take responsibility for their learning (self managed learning), continuous improvement through reflection, alternative approaches for grading, increased engagement by learners, and more effective data collection and

assessment of outcomes. The goal of this workshop is to help participants explore how Agile development, a management technique borne out of the software industry, can not only change the way that students engage in project-based and team-based course projects, but also transform the way that we educate our students.

The *Agile Way of Working* (or Agile) is a collection of principles and practices that supports rapid and flexible response to change. It does this by promoting communication, collaboration, continuous improvement, and reflection within teams of problem solvers. The approach also fosters self-managed teams. Agile accomplishes this by embracing changing requirements, delivering products frequently, using human-centric methods, and engaging the customer in regular collaboration. Agile puts heavy emphasis on articulating goals, facilitating interactions, improving team dynamics, supporting collaboration, and encouraging experimentation and innovation. Agile originated and is widely adopted in the software development industry. In a worldwide survey of individuals in the software community, 88% of respondents said their organizations were practicing agile [6]. Other surveys have shown similar usage rates.

II. WHAT IS AGILE?

In 2001, a group of thought leaders in software development created the Agile Manifesto, a set of values to guide how software products are developed (see <http://www.agilemanifesto.org/>). The manifesto stresses a number of specific values including:

- Individuals and interactions over processes and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

Based on these values the following set of principles were defined to characterize the Agile approach:

- Customer satisfaction by rapid delivery of useful software
- Welcome changing requirements, even late in development
- Working software is delivered frequently
- Working software is the principal measure of progress
- Sustainable development, able to maintain a constant pace

- Close cooperation between business people and developers
- Face-to-face is the best form of communication
- Projects built around motivated (and trusted) individuals
- Continuous attention to technical excellence
- Simplicity is essential
- Self-organizing teams
- Regular adaptation to changing circumstances

These values and principles are translated into action through work practices and tools. The practices are used by teams to realize the benefits of the Agile way of working. Commonly used agile practices include (partial list):

- Whole team: all are accountable for quality of the product
- Time-boxing: fixed time allocation to each planned activity
- Open workspace: face-to-face communication is valued
- Frequent releases: deploying the product in short cycles to create checkpoints
- Sustainable Pace: a constant pace to plan, work, and reflect
- **Story Card Writing**: a short statement about user observable system capability or function
- **Story Wall**: a way to display the status of each story card
- **Retrospectives**: meetings after each iteration designed to help the team improve their process
- **Workshops**: time-boxed meetings with stakeholders to define stories
- Showcases: demonstration of the product to the customer

III. WORKSHOP AGENDA

The workshop length is 3 hours. In addition to overviews and experience reports, a number of Agile exercises and techniques will be demonstrated through active collaboration.

1. Tutorial Overview of Agile (1 hour) - The purpose of the tutorial overview is to provide participants with basic knowledge to understand what Agile is, the techniques used, and resources necessary for a deeper dive into the mindset and practices.
2. Presentations and practical examples on experience using Agile for project and team-based courses (1/2 hour) - These presentations will show how Agile has been applied in the context of the lowest lying fruit - as a way of having students (self) manage their team.
3. Presentations and practical examples on experience using Agile as an educational mindset (1/2 hour) - These presentations will show how Agile principles such as *collaboration*, *transparency*, and *continuous improvement* as well as practices such as *retrospectives* and *Kanban/story walls* can be applied to the educate students.

4. Guided activities to aid participants in generating ideas on using Agile in their courses (1 hour) - In this segment of the session, participants will engage in brainstorming and collaborative activities to identify potential areas within their courses where Agile can be applied. These activities will be used to help build a community for longer-term interaction.

IV. WORKSHOP DETAILS

A. Audience

The topic of this workshop is applicable to any FIE conference attendee. Educators that use project-based or otherwise use team projects in courses will be interested in the workshop for the practical management methods. Others will be interested in the applicability of the Agile Way of Educating as pedagogical methodology.

B. Outcomes

The outcomes for this workshop are the following:

- Basic knowledge of Agile – participants will be exposed to:
 - The history and mindset of Agile
 - Agile practices that facilitate effective communication and Agile values
 - Agile practices that facilitate effective communication in order to control risks and adapt to challenges of working in teams
 - Agile practices that help student teams to prioritize work and consistently deliver high quality content that meets course learning objectives
 - Agile practices that help student team's to plan, monitor, and improve their way of working (especially their way of educating)
- Experience in applying Agile engagement methods for facilitating brainstorming and discussion participants will see a number of methods used within Agile that illustrate benefits for both project work and pedagogical mindset
- Ideas for applying Agile as either a way of working or a way of educating (or both!) - participants will come away with ideas for applying Agile in their courses
- Resources for a deeper dive into Agile - participants will leave the session with resources that will allow them to expand their knowledge and skills with Agile.

C. Logistics

The workshop will use a standard presentation setup including video projector, power strips, and flip charts. We will also need at least one post-it note pad per participant (standard square 3"x3") and Sharpie Fine Point Markers for each participant.

D. Fees

We expect to have a full packet of materials printed and bound for presentations, as well as the aforementioned brainstorming tools (post-it notes, Sharpies, etc.). Fees appropriate to these expenditures are expected.

WORKSHOP ORGANIZERS

Gerald C. Gannod is a Professor of Computer Science and Software Engineering at Miami University and is an ICAgile Certified Professional and Agile Coach. Dr. Gannod is the co-facilitator for the Agile University Faculty Learning Community at Miami. While on sabbatical in AY 13-14, Dr. Gannod was a solution architect on the BT Digital Team with the Suncorp Group in Sydney, Australia, where he gained extensive experience in using Agile.

Jerome Eric Luczaj is an Associate Professor in the Department of Computer & Information Technology. Before entering academia he worked in industry for a decade and a half as a system designer, project leader, and system architect, performing Quality Assurance and Architectural Reviews internationally and domestically.

Diane T. Rover is a Professor in the Department of Electrical and Computer Engineering at Iowa State University. Since beginning her academic career at Michigan State University, she has developed, adapted, and guided effective strategies for student teaming, collaborative learning, and faculty development. Dr. Rover is a Fellow of the ASEE and a

member of the ABET Engineering Accreditation Commission Executive Committee.

Douglas A. Troy is Director of Graduate Programs in Miami University's College of Engineering and Computing, Director of the Agile Launchpad project, an Affiliate of the Myaamia Center focusing on Information Technology strategy, and is Professor emeritus. Dr. Troy joined Miami in 1983 after working in the software development industry at Bell Labs and CompuServe Network.

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Workshop: Encouraging Information-Rich Engineering Design

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Abstract— Students frequently spend too little time understanding the problem in their design projects and jump to solutions without considering alternatives. This leads to inefficient use of time and suboptimal results in the final design. Instead of re-inventing the wheel, students need to explore and understand the work of others applied to similar situations, using strong information gathering, application, and evaluation skills. Ultimately, these reinforce core skills needed for students to be lifelong learners, i.e., determining where they have gaps in knowledge and determining how to fill those gaps efficiently and effectively. This workshop will provide a conceptual model and examples of activities that will help instructors keep students problem-focused, allowing them to generate and weigh alternatives, and ultimately settle on a solution that is most promising to meet their stakeholders' needs. Participants will take away techniques they can apply to their own engineering design courses. This workshop aligns with FIE's focus on turning Research into Practice.

Keywords— engineering design; information literacy; evidence-based decision making;

I. DESCRIPTION

The Information Rich Engineering Design model [1] provides the foundational underpinning for this workshop. The model identifies information activities corresponding to each stage of the engineering design process. In the course of the workshop, attendees will play the role of designers, responding to scenarios and identifying where internal and external information can be obtained to better understand a problem, generate and evaluate solutions, and embody the design. In particular, participants will learn how to determine the needs of stakeholders, better understand the context of the design problem, and make sure they meet professional standards and legal requirements for their designs. In addition to their own brainstorming, they investigate the prior art of others to enlarge the solution space they explore. Evaluating and synthesizing information gathered or generated themselves, they determine the most promising of their proposed solutions.

The format of the workshop is to take each stage sequentially in 30 minute chunks, spending approximately 5 minutes introducing the stage of the engineering design

process and its information components, followed by 15 minutes of hands-on small-group activity illustrating the information gathering and application component, with 10 minutes of reports out to the full group. The workshop will culminate with participants debriefing their experiences, reflecting on which activities seemed to resonate, and how they might adapt some of the activities in their own practice. We anticipate this activity will be synergistic between the facilitators and participants, as a collaborative inquiry approach will uncover experiences and insights that lead to greater understanding of what an informed approach to engineering design means, and the challenges students face incorporating that approach in their own practice.



Fig. 1. Information Rich Engineering Design (IRED) model [1]

II. AGENDA

The workshop will be divided to cover four main topics, corresponding to important, information-rich stages of the engineering design process. After an introduction and orientation to the IRED model (see Figure 1), participants will engage in hands-on activities that illustrate the importance of information gathering, evaluation, and utilization in generating optimal design solutions. The activities provide examples that can be integrated into engineering design courses at any level.

Workshop Time:

0:00-0:10 Introduction and Orientation

0:20-0:40 Overview of the IRED design model

0:40-1:10 Creating a Knowledge Management Strategy

5 minutes: overview of concepts

15 minutes: small-group exercise

10 minutes: debrief

1:10-1:40 Determining Stakeholder Needs

5 minutes: overview of concepts

15 minutes: small-group exercise

10 minutes: debrief

1:40-1:50 Break

1:50-2:20 Evaluating Potential Design Solutions

5 minutes: overview of concepts

15 minutes: small-group exercise

10 minutes: debrief

2:20-2:50 Capturing Lessons Learned, i.e., Reflective Practice

5 minutes: overview of concepts

15 minutes: small-group exercise

10 minutes: debrief

2:50-3:00 Wrap-up

III. TAKE AWAY SKILLS AND AUDIENCE

This workshop is appropriate for engineering design educators in any discipline who are looking for techniques to improve the quality of and innovation in design solutions of their students.

Participants in the workshop will be able to

- Develop strategies for improving student management and communication of information
- Identify the role of information in different stages of the engineering design process
- Create activities to promote the effective use of information in student design projects
- Encourage reflective practice in students to promote lifelong learning skills

IV. FACILITATORS

Professors Fosmire and Van Epps have each taught information literacy in engineering design for over fifteen years. They have published extensively on information literacy instruction, information habits of engineers, and assessment of information literacy skills in an engineering context.

Laura Hanlan is Research and Instruction Librarian at Worcester Polytechnic Institute, where project-based learning is an integral part of the educational process. Hanlan provides instructional support for capstone design projects in mechanical and electrical engineering, using the IRED approach. She has published and presented at ASEE and FIE conferences on the integration of information into engineering design.

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Pre-Conference Workshop: Agile Teaching and Learning

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Abstract— Agile methods are the fastest rising software lifecycle process methods in software engineering. Educators are converting traditional and project-base courses to agile in response, but this is a daunting task with few structured teaching resources methods available to reduce the burden on the educator. In professional practice, agile methods have been particularly effective in empowering experienced software engineers through its focus on empirical process control and constant feedback loop. These process traits are difficult to simulate in an academic setting, as student developers are inexperienced, synchronous meeting times are few and far between, and obtaining meaningful constant feedback a laborious undertaking. This workshop will present a comprehensive approach to teaching Agile methods that is itself agile, employing a highly iterative, continuous feedback-driven process. Pedagogical and assessment strategies will be shared, and the presenter will facilitate a best practices interactive discussion to draw out lessons learned from workshop participants. Specific agile practices with supporting labs from the popular Scrum and eXtreme Programming (XP) process models will be presented. The workshop will also encourage interaction amongst participants to share best practices and lessons learned. Research directions related to the application of agile principles to teaching and learning will be discussed.

Keywords—*agile; software engineering; software process; assessment; integration*

I. INTRODUCTION

Agile methods are the fastest rising software lifecycle process methods in software engineering, yet they present unique challenges to educators. Many educators are familiar with agile methods but have not practiced them in an industrialized setting. Further, most textbooks have introduced agile only in later additions with little supporting material, and curricular resources are either scarcely available or geared toward the industry practitioner. This workshop will convey instructional resources to higher ed instructors, and provide the scaffolding to conduct an agile project course. Participants will receive materials including Eclipse-based open source labs, project scripts, and pedagogical scripts to adapt to their classrooms. Additionally, the workshop will include strategies and instructions for setting up Scrum, and supporting XP developer practices including Continuous Integration and Testing using Jenkins, Source Code Control using Git, unit

testing, static analysis, and more. Post-workshop support will be provided through a website hosted by the presenter.

The goals of the workshop are to:

1. Provide participants with ready-to-implement materials and practices for teaching agile methods in the classroom.
2. Identify a community of interest in applying agile methods to project-based learning.
3. Discuss research potential in applying these software engineering principles to teaching and learning.

II. INTENDED AUDIENCE

Post-secondary Computer Science educators who are interested in Agile methods applied to teaching and learning, particularly in a hands-on, project-centered course. Teachers from other disciplines can also benefit through the presentation of Agile principles and considerations for adoption in other disciplines. Engineering education researchers may find the potential research directions of agile and teaching and learning of interest.

III. PRESENTER BIOGRAPHIES

Kevin Gary is an Associate Professor in the School of Computing, Informatics, and Decision Systems Engineering (CIDSE) within the Ira A. Fulton Schools of Engineering at Arizona State University. Kevin is a founding program faculty member for the new B.S. and M.S. degrees in Software Engineering at ASU. He created the Software Enterprise, a highly iterative, agile pedagogy in 2004, which has served as the project spine of 8 courses in the Software Engineering degrees. Contact him at kgary@asu.edu

Sohum Sohoni is an Assistant Professor in the School of Computing, Informatics, and Decision Systems Engineering (CIDSE) within the Ira A. Fulton Schools of Engineering at Arizona State University. Prior to ASU, he was an Assistant Professor at Oklahoma State University. He has published over 25 peer-reviewed papers in journals and conferences including papers in ACM SIGMETRICS, IEEE Transactions on Computers, the International Journal of Engineering Education, and Advances in Engineering Education. His research interests are broadly in the areas of computer architecture and performance analysis, and in engineering and computer science

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education. He has received many teaching awards including the Regents Distinguished Teaching Award in 2010 at OSU. He has received a best paper award for his work in computer engineering from the IETE Technical Review journal, and two best paper awards for his work in engineering education from the ASEE Midwest Section. He received the B.E. degree in Electrical Engineering from Pune University, India, in 1998 and a PhD in Computer Engineering from the University of Cincinnati, Cincinnati, Ohio, in 2004.

Suhas Xavier is a graduate student in the Master of Science in Software Engineering program at Arizona State University. Suhas' interests are in big data, learning analytics, and software engineering. Prior to enrolling at ASU, Suhas worked in industry as a software engineering for Tech Mahindra Private Limited in India. Suhas holds a Bachelor of Engineering in Information Science (First Class with Distinction) from the Visvesvaraya Technological University

IV. MATERIALS PROVIDED

Each participant will receive printed handouts of slides presented at the workshop. Additionally, a custom Eclipse install with requisite tools will be available for installation during the workshop via USB stick and the Web. The presenter will record and coalesce information gathered from collaborative sessions on the agenda and make the record available to participants on his university website. Instructions for server-based installations and trial accounts will be distributed to participants.

V. AGENDA

1. Topic one: Introduction to Agile Methods, (20 minutes).
 - a. Quick recap of Agile, including Scrum and eXtreme Programming (XP), for those somewhat unfamiliar with these methods.
2. Topic two: Integrating Agile Projects into a semester course (50 minutes)
 - a. Interactive exploration: Challenges teaching agile (table discussions)
 - b. Scheduling Scrum activities during the semester

- c. Setting student expectations
3. Topic three: Establishing an Agile Rhythm (45 minutes)
 - a. What does rhythm mean and why is it important?
 - b. Encouraging continuous project participation using Scrumboards.
 - c. Continuous project assessment
 - d. The role of tools and scaffolding
4. Utilizing Agile development best practices in an Agile project context (45 minutes)
 - a. Agile best practices labs including source code control with Git, continuous integration and testing using Jenkins.
 - b. Immediate synthesis of best practices into agile course project
5. Wrap-up (20 minutes)
 - a. Interactive: Eliciting best practices and lessons learned
 - b. Agile recap

VI. REQUIREMENTS

A. Audio/Visual and Computer Requirements:

It is strongly recommended participants bring a laptop to the workshop, though it is not strictly required. Laptop users will be able to browse/experiment with lab materials and remote server tools. However non-laptop users will still be able to follow along the pedagogical and curricular discussions and participate in the interactive sessions. Wireless Internet is recommended to access remote server tools, though the presenters will also demo these up front. Software will be provided that will be distributed on a website or by USB stick for those without Internet access.

B. Laptop Required:

Laptops are highly recommended. Tablets will be of only limited utility.

C. Space and Enrollment Restrictions:

None. No fee required for materials or expenses.

How to Select an Area of Scholarship and Address the Applicable Review Criteria to Publish a Paper in the IEEE Transactions on Education

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Abstract—The Editorial Board for the IEEE Transactions of Education developed and published a new set of review criteria. The review criteria have been built on the foundation of the areas of scholarship offered by Ernest Boyer. The purpose of this workshop is to help authors address the review criteria.

Keywords—Boyer's areas of scholarship; scholarship of discovery; scholarship of application; scholarship of integration; review criteria

I. WORKSHOP GOALS

In an effort to clarify expectations for manuscripts to be published in the IEEE Transactions on Education, the Editorial Board (Editor-in-Chief and Associate Editors) developed and published review criteria for three areas of scholarship proposed by Ernest Boyer. The review criteria were published in July 2013. Since both the FIE Planning Committee and FIE participants are committed to raising the quality of scholarship published in engineering education practice and research, examination of these review criteria could provide valuable input to the engineering education community about expectations for scholarly publication. Workshop participants will be able to:

1. Explain criteria for progress in development of the interdisciplinary field of engineering education
2. Select the appropriate area of scholarship for proposed initiatives in engineering education
3. Explain review criteria for each area of scholarship
4. Evaluate how well sample manuscripts address each of the review criteria.

II. DESCRIPTION

Engineering education publications are expected to make substantive contributions to the field, but there is a need to clarify expectations of substantive contributions across the global community of scholars in this field. For the purposes of the review criteria, contributions will be defined as clear statements of how work described in the manuscript is expected to influence future directions of the field. Many different types of contributions are possible. Review criteria need to be specific to broad areas of potential contributions. Review criteria for the IEEE Transactions on Education are organized based on the three categories of scholarship described by Boyer: discovery, application, and integration.

Workshop participants should expect to learn more about the three areas of scholarship and be able to select the area most appropriate for their manuscript.

A. Maintaining the Integrity of the Specifications

The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

III. SCHOLARSHIP OF DISCOVERY

Contributions within this area of scholarship will be primarily in the form of new knowledge. New knowledge in the field of engineering education could take many forms. For example, it might be include a tool or process for assessing student learning in a specific subject area. It might be an explanation of difficulties that students encounter when learning one or more concepts. But these are only examples, and there exist are many more forms that new knowledge might take. Assertions that new knowledge is being contributed require significant understanding of prior contributions. Review criteria will be described in the following areas: relevance, focus, contribution, context, methodology, findings, and conclusions.

IV. SCHOLARSHIP OF APPLICATION

Contributions within this area of scholarship will often be models of how prior research on learning and teaching, in general, or in a specific knowledge domain, e.g., engineering, has been applied to design and evaluate instructional strategies. Strategies may be developed for, but are not limited to, courses, course segments, curricula, laboratory experiments, course projects, capstone courses, and outreach activities. Faculty members across the world design these activities for their students, but published papers should provide models of how prior research on learning and teaching has been applied to one or more areas. Review criteria will be described in the following areas: relevance, intended outcomes, context, application design, findings, and conclusions.

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V. SCHOLARSHIP OF INTEGRATION

Contributions within this area of scholarship will often be multidisciplinary, integrative, and/or interpretive syntheses across vast prior research to identify patterns, themes, trends, needs, and opportunities upon which other scholars can build. Review criteria will be described in the following areas: relevance, focus, context, contribution, methodology, findings, and conclusions.

VI. WORKSHOP AGENDA

The agenda for the workshop is shown in Table 1.

TABLE I. WORKSHOP AGENDA

Time	Total Time	Participant Activity
10 minutes	10 minutes	Participant Introductions
10 minutes	20 minutes	Overview
5 minutes	25 minutes	Introduction to Scholarship of Discovery
15 minutes	40 minutes	Small-group Exploration of the Scholarship of Discovery
5 minutes	45 minutes	Introduction to Scholarship of Integration
15 minutes	60 minutes	Small-group Exploration of the Scholarship of Integration
5 minutes	65 minutes	Introduction to Scholarship of Application
15 minutes	80 minutes	Small-group Exploration of the Scholarship of Application
15 minutes	85 minutes	Review Criteria: Scholarship of Application
15 minutes	100 minutes	Small-group Exploration – Review Criteria: Scholarship of Application
15 minutes	115 minutes	Review Criteria: Scholarship of Integration
15 minutes	130 minutes	Small-group Exploration – Review

		Criteria: Scholarship of Integration
15 minutes	145 minutes	Review Criteria: Scholarship of Discovery
15 minutes	160 minutes	Small-group Exploration – Review Criteria: Scholarship of Discovery
20 minutes	180 minutes	Summary, Wrap-up, Next Steps

VII. WORKSHOP FACILITATOR

Jeffrey E. Froyd has served as the Editor-in-Chief of the *IEEE Transactions on Education* since September 2012. Dr. Jeffrey E. Froyd received the B.S. degree in mathematics from Rose-Hulman Institute of Technology and the M.S. and Ph.D. degrees in electrical engineering from the University of Minnesota, Minneapolis. He is a TEES Research Professor in the Office of Engineering Academic and Student Affairs at Texas A&M University, College Station. He has authored over 70 papers and offered over 30 workshops on faculty development, curricular change, curriculum redesign, and assessment. He has served as a program co-chair for three Frontiers in Education Conferences and the general chair for the 2009 conference. Prof. Froyd is a Fellow of the IEEE, a Fellow of the American Society for Engineering Education (ASEE), an ABET Program Evaluator, the Editor-in-Chief for the *IEEE Transactions on Education*, a Senior Associate Editor for the *Journal of Engineering Education*, and an Associate Editor for the *International Journal of STEM Education*.

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Connecting and Expanding the Emerging Engineering Education Research & Innovation (EER&I) Communities

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Abstract— Currently there is a lot of emphasis on engineering education research (EER) and engineering education innovation (EEI). In the EER domain, several universities have established or are considering establishing engineering education research centers and PhD programs. In the EEI domain, the National Academy of Engineering launched the Frontiers of Engineering Education (FOEE) symposium and NSF recast CCLI as TUES, and more recently IUSE (Improving Undergraduate STEM Education). In 2014 NSF funded a pilot implementation of the NSF Innovation Corps for Learning (I-Corps™ L) and additional cohorts have been conducted and are planned. The growth of interest in the scholarship of teaching and learning (SoTL) has great potential to contribute to EER and EEI as indicated by the response to the ASEE *Virtual Communities of Practice* (VCP) project. Faculty and graduate students interested in engineering education research and innovation (EER&I) are widely distributed and often isolated in their department and institution. Many are eager to meet and interact with colleagues who have similar interests. This session provides the opportunity to for people who have been involved in engineering education research and innovation to reconnect, and to welcome new folks into this emerging community.

Keywords—Engineering Education Research, Capacity Building

I. INTRODUCTION

There are many recent developments in EER&I such as the emergence of new Departments of Engineering Education (e.g., at the University of Texas – El Paso), the NSF *Innovation Corps for Learning* (I-Corps™ L) project [1, 2] that is now in its second year, and the ASEE *Virtual Communities of Practice* project [3, 4] that is focused on the implementation of evidence-based instructional practices. Also, the publication of the National Research Council's Discipline-Based Education Research practitioner guide, *Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering* [5].

A little over ten years ago, the National Science Foundation (NSF) sponsored three projects to build capacity in engineering education research: Rigorous Research in Engineering Education: Creating a Community of Practice (RREE) [DUE-

0341127], Strengthening HBCU Engineering Education Research Capacity, [HRD-0411994], and the Institute for Scholarship in Engineering Education (ISEE), an element of the Center for the Advancement of Engineering Education [ESI-0227558]. These programs attracted tremendous interest, with participant applications outweighing available slots by a ratio of approximately 3 to 1. The engineering education research communities that RREE and ISEE helped to foster have expanded and now have global reach. Capacity building has also been aided by the creation of PhD-granting departments of Engineering Education at several US and international institutions [e.g., 6, 7].

NSF subsequently funded a new project to continue and expand the work done by RREE and ISEE. Expanding and sustaining research capacity in engineering and technology education. Building on successful programs for faculty and graduate students (which we will call the REEE2) (DUE-0817461) broadens the Community of Practice (COP) model successfully used to develop the RREE and ISEE programs [e.g., 8]. The National Academy of Engineering (NAE) has sponsored the Frontiers of Engineering Education symposium since 2009 and the focus is on engineering education innovation (EEI).

Funded by NSF, the ASEE *Virtual Communities of Practice* (VCP) is a project that enables faculty members to implement evidence-based educational practices in engineering courses [3, 4]. Starting in the fall of 2012, the VCP project provided the infrastructure for faculty members to engage virtually over a sustained period (two academic terms), collaborate, and support each other as they learned and implemented new educational approaches in their classrooms. Spanning two cohorts, the ASEE VCP project involved over 175 faculty members from more than 125 institutions; the project produced a knowledgeable and skilled faculty community of leaders and implementers with a deeper understanding of and experience with evidence-based instructional approaches.

In 2014 NSF funded a pilot implementation of the Innovation Corps for Learning (I-Corps™ L). The eight-week I-Corps™ L program uses a lean approach to scaling teaching and learning innovations into broad practice by using

established strategies for start-ups. Participating teams go through a hypothesis-testing, scientific method of discovery to gather important insights and identify issues associated with their projects [1, 2]. The principal goal of I-Corps™ L is to foster an entrepreneurial mindset within the STEM education community and to impact the way innovations are designed and implemented. A second cohort of 24 teams was conducted on January-February 2015, and two additional cohorts are planned to start in July 2015 and January 2016, respectively.

The Research in Engineering Education Network ([REEN](#)) is an independent, international and inclusive forum in which quality research on engineering education is conducted, discussed and disseminated. REEN has organized symposia about every two years since 2007. The next one will be in Dublin, Ireland, July 2015

These foundation-building efforts have helped build capabilities for engineering education research and innovation; however, continual emphasis is essential to maintain the momentum.

Faculty and graduate students interested in engineering education research and innovation are widely distributed and often isolated in their department and institution. Many are eager to meet and interact with colleagues who have similar interests. This session provides the opportunity for people who have been involved in engineering education research and innovation to reconnect, and to welcome new folks into this emerging community.

II. SESSION DESCRIPTION

A. *Intended Audience*

This session is intended for educators who are interested in strengthening their involvement or exploring becoming more involved with the emerging engineering education research and/or innovation communities. Noting the success of past special sessions and workshops where participants actively engaged in exploring engineering education research, participants interested in engaging in a lively networking and brainstorming session may also enjoy and benefit from attending.

B. *Goals*

The session is designed to provide an informal opportunity for participants to meet and interact with like-minded colleagues, bringing hallway conversations into the meeting room, and to foster the building of community. Participants will meet many people and begin to identify common interests. It is our belief that this combination of interaction, update and reflection will help participants identify the levels of their involvement in engineering education research and innovation. Further, through the shared experience of meeting and interacting with colleagues in a special session, participants will identify a group of peers from whom they can continue interacting in the future.

This session will provide participants with an update on the status, and an opportunity to meet and interact with people

interested in engineering education research and innovation (EER&I) and contribute to future plans by:

- Increasing familiarity with activities and people involved in engineering education research and innovation
- Actively participating in EER&I community building and especially the interaction of the two communities
- Participating in the planning for next steps

C. *Expected Outcomes*

At the completion of this special session, it is anticipated that participants will be able to:

- Articulate the current status of the emerging engineering education research and innovation communities
- Describe key aspects of current efforts at face-to-face and virtual community building
- Identify interested colleagues with whom they will continue the conversation
- Clearly articulate their interest in engineering education research and innovation.

III. SESSION AGENDA

The session is structured as follows:

- **Introduction of session and facilitators** (10 minutes)
- **Brief report on status of EER&I** (25 minutes)
 - Update on Departments, PhD Programs and Centers
 - Update on EER initiatives – NRC DBER, ASEE VCP
 - Update on EEI initiatives – NSF I-Corps™ L, NAE – FOEE
- **Participant Networking** (25 minutes)
 - Rapid introductions around guided questions – Four to five conversations in groups of 3 – as a way to meet many people
 - Identification of “intellectual neighborhoods” around research and innovation questions and opportunities – individual reflection and writing
- **Brainstorming on strategies to connect, expand, and sustain the emerging EER&I communities** (20 minutes)
 - Summary of ideas for (1) local, (2) national and international conferences, etc. and (3) virtual communities
- **Individuals share reflections with the large group, facilitators sum up the session and participants complete feedback forms** (10 minutes)

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FIE 2015 Special Session – *Movin' Along*: Investigating Motion and Mechanisms Using Engineering Design Activities

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Abstract – This special session will introduce participants to engineering design activities that use mechanisms, devices that transform one type of motion to another, to support student learning about motion, a topic that recurs throughout K-12 science studies. The activities come from new and revised K-12 Engineering Teaching Kits (ETKs). ETKs are self-contained standards-based and project-based instructional units. Their format and contents reflect an integrated approach to STEAM/d (STEM + Art + design) education. Participants will learn key concepts guiding ETK development and implementation; discuss methods for integrating ETKs and therefore engineering design concepts, practices, and models seamlessly and transparently into their curriculum; discover how engineering design and inductive learning principles help students learn and own key concepts in STEM; and work through selected engineering design activities. This special session is for those interested in exploring a philosophy of engineering education that stresses an integrative, project-based approach to instruction and practice grounded in design, the fundamental process of engineering.

Index Terms – Engineering design process, Engineering Teaching Kits, inductive learning, P-16 engineering education, STEM.

INTRODUCTION

While the intersection of engineering and humanities has long enhanced and reinforced learning in the individual disciplines, the active integration of art, music, and composition activities in STEM studies has been gaining traction in many pre-college (P-12) environments during the past few years. The growing STEAM (STEM + Art) approach emphasizes a hands-on, project-based, interdisciplinary approach to the study of science, technology, engineering, and math (STEM). To emphasize the importance of using engineering design principles to *integrate* learning in science and math and gain technological literacy, this educational movement may also be called STEAM/d. The addition of “d”esign and the integral sign to the STEAM acronym recognizes the kinship between art and engineering as complimentary design-based disciplines and that design is an integrative process. The STEAM/d philosophy is at the heart of Engineering

Teaching Kits (ETKs), our means for delivering integrative, holistic learning. ETKs provide the framework for this session’s activities.

ETKs are self-contained standards-based instructional units grounded in the constructivist philosophy of education [1], [2] and the principles of guided inquiry and active learning [3], [4]. Our primary goal in developing the ETKs is to engage students in a series of age-appropriate engineering design challenges to reinforce targeted concepts in math, science, and technological literacy.

By the end of the session, participants will be introduced to key components of the engineering design process and the STEAM/d movement and be able to identify methods for using engineering design activities to integrate STEAM/d studies seamlessly and transparently in the curriculum as well as strengthening key “21st century skills” like systems thinking, critical thinking, and problem-solving.

MOTIVATION

Years of K-12 outreach activities provide abundant examples of students becoming totally engaged by engineering design activities and project-based learning [5]. However, the majority of outreach initiatives tend to be short-term and episodic, with many leaders conducting activities chosen with little to moderate regards to participant knowledge, culture, experiences, or values. A main goal for our professional learning communities, therefore, is to determine how to ensure consistent exposure to engineering and computer science in ways that truly connect student and learning in context throughout the P-16 – pre-college and undergraduate – experience. Thanks to a growing body of research results, a data-driven design is possible. Realizing that a many-pronged approach is more likely to engage and encourage K-12 students to commit to postsecondary STEM studies – one thing we should have learned by now is that “one size (activity) doesn’t fit all” – we offer our philosophy and curriculum in this session for consideration.

We also recognize that the earlier interventions happen the greater the opportunities to recruit P-12 students into the STEM academic pipeline and, just as importantly, retain them.

While all P-12 students have the ability to benefit from early experience in an integrated STEAM/d educational environment, students from underrepresented populations in

STEM may especially benefit. Many decisions about inclusion in enrichment programs such as gifted and talented courses are made in early elementary grades, and an English Language Learner / English as a Second Language student may be at a disadvantage with respect to entry into these programs if his/her English language skills cannot correctly convey his/her abilities and intelligence [6]. An integrative STEAM educational environment with a design-driven project-based curriculum, with opportunities to connect with all learning styles [7], is one means for engaging students from diverse backgrounds.

OUR CORNERSTONE: ETKs

Since 2002, teams of students and faculty at the University of Virginia have developed, tested, and distributed ETKs for use in science and math classes - initially in middle schools but now throughout K-12 [8], [9]. An ETK is a set of five 50 minute standards-based lesson plans designed to teach targeted math and science concepts in the context of the engineering design process. Lessons are structured to develop understanding of key concepts at both abstract and concrete levels.

The primary goal of ETKs is to promote awareness of and excitement about the nature of engineering. Each ETK emphasizes the engineering design approach to problem solving through a series of design challenges, and includes real-world constraints such as budget, cost, time, risk, reliability, safety, and customer needs and demands. Students develop an appreciation for the tradeoffs involved in the practice of engineering, and how engineering decisions have an impact on society, culture, and the environment. The design/build/test cycle provides opportunities for creativity and exploration. No two designs are ever the same!

Over 50 ETKs are in various stages of development; a dozen are in frequent use in schools in the United States and several other countries in both classroom and professional development workshop settings. The most popular ETKs are *RaPower* (solar cars), *Save the Penguins* (heat transfer), *HoverHoos* (hovercrafts), *Under Pressure* (submersible vehicles), *Brainiacs* (biomedical engineering involvement in the fight against cancer), *Catapults in Action* (projectile motion), *Bridges to Engineering* (bridge design and construction), and *Trash Sliders* (sustainability, vehicle design).

ETKs are also designed to integrate other subjects in the curriculum with the exploration of STEM concepts. For example, an interdisciplinary team of eighth-grade teachers at a Central Virginia middle school uses the *Catapults in Action* ETK as the basis for a week-long series of integrated classes on medieval history, thus folding history, art, and language arts activities into the study of catapults and projectile motion. The potential for similar multidisciplinary activities can be found in all ETKs and thus make them appropriate for use in STEAM programs.

Further, ETKs are designed to be adaptable and flexible. As previously stated, ETKs were initially developed for

students in grades 6 – 8, but have been proven scalable for use by students at all grade levels by varying the amount of scaffolding and support given.

ETK 2.0

We are actively expanding the scope of concepts, material, and activities covered in ETKs. Four of our current initiatives are described in this section.

I. Addressing Misconceptions

A major addition to our initial ETK content is a set of activities and instruments to assess and remediate misconceptions in mathematics and science. We are using adapted and authored concept inventories to assess misconceptions and discrepant events to provide an opportunity for reformulating misconceptions.

Ia. Defining Misconceptions

It is important to understand the process of cognition when developing definitions of concepts and misconceptions. The most basic definition of cognition is the “process of knowing...and the content of those processes.” It is a **fundamental** concept in the science of learning, since learning is dependent on prior knowledge and the nature of changes students can make in both processes and content. (see, for example, [10]; emphasis added) The primary components affecting a person’s level of cognition are declarative knowledge and procedural knowledge. Declarative knowledge can also be defined as “semantic information...(knowledge about ideas)” and procedural knowledge as the “complement” of declarative knowledge; together, they “represent categories for describing knowledge in general” [11, p. 28]. The interplay between the acquisition and application of sets of related declarative and procedural knowledge helps students identify and internalize underlying concepts. However, students may internalize concepts incorrectly for a variety of reasons, and the resulting misconceptions can be a factor in student disengagement and other negative (re)actions.

A concept, therefore, is a mental construct or model that helps a person organize knowledge. It is inductively built from interactions and experiences [2]. Misconceptions, also known as alternative frameworks or invented theory, arise from a flawed development process in which the cognitive process of trying to connect new information to existing knowledge reshapes the new information to fit with the structure of the existing knowledge [12]. They can be remarkably resistant to change [2], [13], [14]. A misconception is distinct from *misunderstanding*, a situation in which a learner does not have sufficient correct information for comprehensive comprehension. The former is a cognitive issue; the latter, a factual issue.

The physics education community has long been involved in the assessment and remediation of misconceptions, especially with respect to Newtonian forces. The concept inventories in this area were pioneered by physicist David Hestenes and his colleagues at Arizona State

University beginning in the 1980s; see, for example, [15], which is one of many articles on the Force Concept Inventory. Other validated methods for evaluating conceptual knowledge are peer instruction [16], direct interview [17], and strategy writing [18].

Ib. Addressing Misconceptions in Movin' Along

Common misconceptions with respect to motion and the concept with which it's typically paired, force, include the following [19], [20]:

- Action-reaction forces act on the same body.
- Friction can't act in the direction of motion.
- The normal force on an object is equal to the weight of the object by the 3rd law.
- The normal force on an object always equals the weight of the object.
- Equilibrium means that all the forces on an object are equal.
- Only animate things (people, animals) exert forces; passive ones (tables, floors) do not exert forces.
- Once an object is moving, heavier objects push more than lighter ones.
- You need force to keep a car moving.
- Friction is an inherent part of an object.
- Going at a steady velocity in a circle around the Earth means there are no accelerations.
- Your weight tells you how much stuff you have.
- Equilibrium is the absence of forces.
- "Energy" and "force" are interchangeable terms.

These misconceptions about force and motion are challenged, in part, by the following "classic" discrepant events that nonetheless should have further distribution:

- The coin, card, and glass exercise, which addresses misconceptions regarding friction and inertia [20]
- The Coke / Diet Coke exercise, which addresses misconceptions regarding buoyancy and density [21]
- The hollow egg and book exercise, which addresses misconceptions about material strength, shapes, and forces [22]
- The glass full of water and card exercise, which addresses misconceptions about gravity [23]

These discrepant events were researched and adapted for inclusion in the *HoverHoos/Save the Glades*, *Under Pressure/Save the Whales*, *Bridges to Engineering*, and *Imagineer Your Ride* ETKs. We are developing a set of new discrepant events for *Movin' Along*.

II. Grounding the ETKs in Society's Problems

ETKs are also being updated to address the need to connect STEM to student context and experience by grounding an ETK's theme in real world issues. In *Save the Penguins*, for example, student learning about materials science and heat transfer and supporting design activities occur within the context of an environmental issue that affects them - climate change - using an appealing subject population: penguins [24]. Similarly, *HoverHoos* was restructured as *Save the Glades* and *Under Pressure* was restructured as *Save the*

Whales in order to have students connect the practice of engineering to the solution of large scale societal problems. This restructuring is prompted by the noted phenomenon of attracting students from underrepresented populations in STEM by offering socially relevant projects and the chance to solve society's needs via engineering design projects (see, most recently, [25]).

III. Parent-Teacher Guides

Another addition to the ETK library are detailed guides for parents and teachers, in part to promote the family engineering movement [26] so that student learning is supported in both formal and informal learning environments, and in part to provide additional support to activity leaders who may not necessarily have a background in the topic(s) covered by a given ETK. These guides provide background on the engineering design, science, and math concepts addressed in the targeted ETK as well as information to use in guiding students and other participants through the design challenges. This support is especially important for the growing number of parents searching for engineering education opportunities for summer enrichment or to supplement a homeschool curriculum.

IV. Scaling ETKs to Fit Time Constraints

We have also successfully tailored ETKs to fit time and interest constraints. For example, we have successfully adapted *RaPower* and *Save the Penguins* to 3 hour versions for summer camp activities [27] and to 90 minute versions for professional development sessions [28]. Similarly, we have created a 90 minute version of *Wind-E* for outreach and enrichment programs [29], [30] and professional development [28]. Ninety minute versions of *HoverHoos* (*Save the Glades*) and *Under Pressure* (*Save the Whales*) were piloted at the Village School's Take Your Daughter to Work Day [31].

THE BASICS OF MOVIN' ALONG

The main subjects covered in the *Movin' Along* ETK are from the discipline of kinematics, or the study of motion. We focus on types of motion and the mechanisms used to transform and redirect motion. There are four types of motion in mechanical systems: linear, or motion in a straight line; oscillating, or repetitive motion about a central point or between different states; reciprocating, or motion (sometimes called "strokes") back and forth or up and down in a straight line; and rotational or rotary motion, motion that is circular. In constructing mechanisms to redirect motion or transform one type of motion to another, gears and/or linkages are used. The resulting mechanisms include the cam, slide, and follower, which transforms rotary and reciprocating motion; the chain and sprocket, which translates rotary and linear motion; the crank, link, and slider, which transforms oscillating and rotary motion; the peg and slot, which transforms oscillating to rotary motion; the rack and pinion, which transforms rotary motion to linear or reciprocating; and the rope and pulley and wheel and axle,

which transform rotary motion to linear [32], [33].

Mechanical systems abound in our world, but students may not be aware about how many are involved in their lives. For the opening exercise, students are asked to brainstorm about the systems they encounter on a regular basis and why we would need to transform one type of motion to another. Vehicles provide good examples due to the high probability of student familiarity with commonly available/used ones. To make the discussion concrete, students work through how bicycles transform rotary motion to linear motion.

The larger societal context includes discussions about the need for alternatives to the internal combustion engine and other methods of mechanical propulsion, which lead to the major issues of depletion of non-renewable sources of energy and climate change. For example, marine propulsion methods are, at best, 70% efficient. Increasing this efficiency by 10% would result in annual saving of millions of gallons of fuel and the related monetary and environmental costs. As it happens, many marine species achieve up to 87% efficiency; a number of researchers are involved in designing propulsion systems inspired by sea turtles, manta rays, dolphins, penguins, and whales [34], [35]. This problem formulation adds the opportunities to discuss how engineers can help preserve endangered species and bio-inspired design practices.

Design challenge activities include the assembly of automata, a mechanical system (typically, a toy like a Jack in the Box) that's constructed to look as though it's moving on its own; designing and building kinetic sculptures and Rube Goldberg systems (an overdesigned mechanical system built to accomplish a very simple goal) out of various types of mechanisms; and spirographs, in which students choose the type of gears and linkages they want to use in tandem to make drawings. The last one can involve the designing of gears, for example, in a CAD program for construction on a 3D printer, thus including other activities that may be in the curriculum and giving students to construct linkages among seemingly disparate learning activities.

SESSION AGENDA

The session is structured as follows:

- **Welcome, Introductions, and Agenda Review** (10 minutes)
- **Initial Exercises** (20 minutes)
Participants will construct a set of physical models that illustrate different types of motion – linear, rotary, reciprocating, and oscillating – and mechanisms for translating one type of motion to another. They will be encouraged to explore how their models could be joined with others to form a functioning mechanism or system of systems. The final product may be an automaton, a kinetic sculpture, or a Rube Goldberg system; participant interest will drive this decision.
- **Regroup, Reflect on Lessons Learned, and Review of Important Concepts** (15 minutes)

- **Follow-on Activities** (40 minutes)
Participants will work in groups with the facilitators to elaborate on their designs. We will also discuss scaling the activities to various grade levels. This discussion will include a review of expectations as to cognitive development and skill levels for students in those grades, necessary to the proper scaling and scaffolding of the activities.
- **Concluding Activities and Discussions** (5 minutes)

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Alumni as a Resource to Increase Student Retention in Early Computer Science Courses

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Abstract—Student persistence in computing majors is one of the keys to providing the talent needed to fill the projected job openings in the computing professions. A range of factors can affect a student's decision to remain in a computing major or change to another major. In this paper we describe an assignment that we use in a course for first semester computing majors. The assignment is based on students interacting with alumni on an individual basis. The nature of the assignment addresses a number of the factors that have been shown to influence students' persistence and may result in an individual student getting the specific intervention that he or she needs.

Keywords—computer science education; student persistence; first year courses

I. INTRODUCTION

Retention of students in computer science programs is key to increasing the number of students graduating with computing degrees and ultimately being available to fill the numerous projected job openings in the computing occupations. Some of the reasons that students choose not to persist in a computer science major include uncertainty that the jobs available after graduation will be of interest to them long-term, limited or misinformation about career opportunities, and a lack of confidence in their ability to succeed in more advanced computing courses. A range of tactics have been recommended to encourage students to persist in the early computing courses. These include breadth-first courses, separate courses for students with no programming experience from those for students with programming experience, appropriate problem selection, and pair programming.

We have been utilizing an assignment that pairs first year students with alumni as a means of introducing the students to some of the many careers available to them after graduation for approximately fifteen years. Feedback from students indicates that the assignment gives them a much broader perspective on computing careers than they had prior to the assignment. Because of the one-on-one nature of the assignment, the alumni often provide information and encouragement about other issues that first-year students may be encountering. As an example, students sometimes confide in emails to their alumni

that they are finding college coursework much more difficult than they had anticipated. Hearing back from an individual, who is now successfully employed in the field and who may also have had similar problems early in college, can give a student the needed reassurance that perhaps what is needed is a bit of hard work, better study habits, or better time management. In this paper we describe our implementation of the assignment, along with a description of how and why the assignment has evolved over the years. Our goal is to provide sufficient detail to allow others to use a similar assignment in their courses. Since multiple retention related interventions occur in our course, it is difficult to independently assess the effectiveness of this specific assignment. Hence, we rely on more anecdotal evidence that we do have that demonstrates the value of this specific assignment as it relates to factors identified to impact student persistence in a computing major.

II. BACKGROUND

A. The Need

The need for computing graduates is well-documented as the job projections through 2022 continue to show strong growth in computing occupations [1]. Although enrollments in undergraduate computing degree programs are increasing [2], student persistence in the major can still be an issue. Various studies have examined factors that influence a student's decision to persist in computer science.

One significant issue appears to be the limited knowledge that students have regarding the actual breadth of the computing field. During a study that examined how students choose courses, Hewner interviewed an academic advisor who estimated that about a third of incoming students had "a very off-base view of what CS is about" [3].

Another significant issue is students' lack of awareness of potential careers available to them if they graduate with a computing degree. Hewner and Guzdial reported that students were not aware of career options "beyond working at Google" and had a difficult time envisioning possible career options that did not involve programming [4]. These results are not dissimilar to what Carter found when studying why high school

students chose not to major in computer science [5]. Carter found that many students believed that a computer scientist sits in front of a computer and programs all day. Others simply had no idea what a computer scientist might do.

A study by Uzoka et al. demonstrated that students lack a solid understanding of the differences among computing fields [6]. In their study, students were asked to indicate how well certain tasks fit in with different computing disciplines. Students did best identifying the tasks that are most closely associated with computer engineering, i.e., tasks that involve hardware or integrate hardware and software. Students were least able to identify the tasks typically associated with software engineering. Some of the tasks that students had the greatest difficulty with are less directly focused on technology, e.g., “Manages large scale technological projects” and “Evaluates and improves the usability (user experience) of computing systems.” In addition, the amount of uncertainty indicated by students showed that the students had significant gaps in their understanding of the various computing disciplines.

An interesting study by Biggers, Brauer, and Yilmaz examined differences between students at Georgia Tech who graduated with a degree in computer science and those who left the major [7]. Those who remained in a computer science degree and graduated tended to describe computer science using an active voice with expressions such as “creating the applications, processes, and tools that allow computers to solve real world problems”. Students who had changed majors used more passive expressions, e.g., “learning how to manipulate code”. In addition many of the students who had left the major focused on perceived negative aspects of the job environment such as “Sitting at the computer with minimal human interaction.” Perhaps most telling that computing students are aware of widespread misperceptions of their chosen field is the observation that many of the computer science graduates replied in a negative fashion when describing what computer science is. That is, they tended to state, for example, that CS is not about fixing hardware or being a code monkey. According to Biggers et al., these specific terms were exactly the terms used by students who had changed majors from computer science. They conclude with an indication of several areas in which changes can be made to improve the retention of students in computing majors. These include students’ belief that CS is coding and the students’ lack of awareness of the bigger picture, the students’ perception that what they are learning is not relevant to the real-world and that computing is asocial. Finally, Biggers et al. suggest their findings show that students who leave the major “lack vision and understanding of opportunities a career in computing affords them and they leave within a limited time” and thus their recommendations include a need to “create vision and excitement around the major and network them with positive role models so they can have an early vision of a broader dream, and can ‘keep their eyes on the prize’ as they go through the major.”

Another group of studies examine aspects related to a student’s sense of self or identity and how that relates to persistence in a computer science major. A study by Veilleux et al. [8] indicated that a student’s sense of belonging is closely related to a student’s perception of his or her ability to do

computer science and that a student may discount his or her actual performance when determining self-efficacy. Lewis et al. [9] identified five factors that impacted students’ decisions to major in CS. These were: ability in CS, enjoyment of CS, their fit in CS (“the extent to which their own values and identity align with the values and cultural expectations they associate with CS”), utility of CS, and the opportunity cost. Students measured their CS-related ability based on their previous experiences, their speed in completing CS-related tasks, and grades. Student interpretations of these factors were influenced by whether they believed ability was fixed or malleable. Kinnunen and Simon [10] also studied students’ sense of self-efficacy and their success in programming. They found that computer science majors tended to develop their sense of self-efficacy based on a comparison of themselves with their classmates. These findings are consistent with some focused more broadly on STEM education [11, 12].

A recent study by Dempsey et al. looked at gender differences in student perceptions and their intent to study computer science [13]. Based on a survey they measured student perceptions of CS, attitudes about science and CS, self-efficacy in science and CS, self-concept and intention to continue in CS. The subjects of their study were students in an introductory computer science class that is taken predominately by CS, mathematics, and engineering majors. Examining their results by gender they found no statistically significant differences in the scores of men and women for perceptions of CS, attitudes of science, attitudes of CS, or science self-efficacy. They did find statistically significant differences in the scores for CS self-efficacy, CS identity, and CS intention. In all three cases the women’s scores were lower than the men’s scores. This seems to indicate that the women are less likely to see themselves as succeeding in CS and less likely to see themselves as computer scientists. Their concluding recommendation is that focusing on changing women’s perception of themselves in a computer field may increase the effectiveness of efforts to encourage more women to go into computing.

In summary, we see multiple factors that may potentially lead computing students to change their major early in their college career. These include the misperception that computer science is just programming and consistent with that misperception a lack of awareness of the breadth of the computing field, the belief that the computing field is asocial, a sense that their coursework is not relevant to the real world, a limited awareness of career opportunities, a belief that intelligence is fixed rather than malleable, and particularly for women a lack of self-efficacy and the inability to see oneself as a computer scientist.

It is our experience that the alumni assignment that we use in the orientation course for our majors helps to ameliorate these issues at least for some of the students. The nature of the assignment allows the students to some extent to tailor it to address their individual questions and perceptions. The next section will provide the context in which we give the assignment, followed by a section that discusses the assignment in detail.

III. THE CONTEXT

A. Our Environment

Michigan Technological University enrolls approximately 7,000 students primarily in STEM-related degree programs, with about two-thirds of the undergraduate students enrolled in programs in the College of Engineering. The Department of Computer Science is the largest department in terms of undergraduate enrollments in the College of Sciences and Arts and offers undergraduate degree programs in computer science and software engineering, as well as MS and PhD programs in computer science. We have approximately 375 undergraduate majors total in the undergraduate degree programs with a typical first year class of around 100 students

The Department currently offers three introductory programming courses. CS1121, Introduction to Programming I, is the expected starting point for students majoring in our Department. This is a typical CS1 course with no previous programming experience required. Majors make up less than half of the students enrolled in CS1121. CS1131, Accelerated Introduction to Programming, is aimed at students with previous programming experience. This course covers in one semester the material normally covered in typical CS1 and CS2 courses. Students can begin in this course instead of CS 1121 if they have had sufficient programming experience, regardless of the programming language they know. Typically, computer engineering and computer science majors enroll in CS1131. CS1111, Introduction to Programming in C/C++, is for students in electrical engineering and certain technology degree programs. It does not serve as a pre-requisite for advanced courses in the Department.

B. Explorations in Computing Course

The Department first introduced a majors-only one-credit course around 1990 to augment the introductory programming course during a student's first semester. The original course focused on an introduction to the department, e.g., the faculty and various departmental procedures; advising matters, e.g., degree requirements and co-op opportunities; and computing skills, e.g., e-mail, word processing, and useful Unix commands. It evolved over the years as the students' backgrounds and the degree programs changed. From 2004 to 2011 the course was also taken by computer engineering majors who were uncertain whether their interests were in computer engineering or computer science. During those years the emphasis was placed on covering a breadth of material across the two disciplines to help students better understand the differences between the degree programs. Early lectures in the course focused on topics closer to the hardware such as computer logic, followed by core CS topics such as operating systems and ultimately covered areas such as artificial intelligence and graphics.

With the focus of the course once again solely on majors within our Department since Fall 2012, it was possible to reevaluate the goals for the course. A major issue within our Department, like many computer science departments, has been retention of our majors. For example, of the students who started in Fall 2008, only 42% had either graduated from or were still working toward completing a degree in our

Department four years later. In fact after just one semester, the Fall 2008 class was down to 80% of the original members. By Spring 2010 the class was down to 49%. Clearly the majority of the retention problem is within the first semesters.

In a recent paper [14] we discussed retention issues in our computing degree programs and how changes in CS1000 appear to be having a positive impact. In this paper we focus on an assignment regularly given in CS1000 that we believe is contributing to student success and retention in the major.

C. An overview of CS1000

In Fall 2014 the course consisted of 14 class sessions.

- The first class session highlighted computing history.
- Half of the class sessions were lectures by computer science faculty members introducing their research area. Topics covered included data mining, virtual reality, computer vision, machine learning, human computer interaction, and software engineering. The goal of these lectures is to give the students a sense of the breadth of the field including a taste of some of the opportunities available to them later in their academic careers.
- During the second class session, an industry representative explained how to write a professional resume. Students were required to prepare a resume after this session and prior to our Fall Career Fair.
- In two sessions representatives from various industries discussed the range of opportunities for computing professionals in their companies.
- Other sessions included presentations on Study Abroad opportunities, student organizations, and computing in the news.
- Students were given opportunities to earn extra credit by attending specified events on campus. Examples of such events included the career fair, industry informational sessions, and an informal session with a visiting computer science alumna.

Class attendance is required. Some weeks the students have a small homework assignment, usually related to the lecture topic of the week. The major assignment involves corresponding with an assigned alumnus/a. This assignment is described in detail in the next section.

IV. THE ALUMNI ASSIGNMENT

The alumni assignment is built around an email correspondence between each student and that student's assigned alumnus/a. The initial intent of the assignment was to give the students a better sense of possible careers and career paths for graduates with computing degrees. Over the years we have come to see that the assignment plays a broader role, at least for some of the students. This section will describe the assignment in detail. The following section will discuss comments and feedback from students and alumni that demonstrate the different impacts the assignment has on individual students.

A. Description of the assignment

The assignment consists of three parts:

1. Email correspondence with an alumnus/a.
2. A one page report describing what the student learned from the email correspondence.
3. A second one page report discussing three other alumni of their choice based on the other students' reports.

The following subsections provide greater detail on each aspect of the assignment.

1) *Introducing the assignment.* Students are told that the primary goal of the assignment is for them to learn about career opportunities, but that most of the alumni are comfortable giving advice about school-related concerns as well as talking about a broad range of topics from their experiences as a student to "life after college". A bit of time is devoted to talking about the appropriate level of professionalism to be demonstrated in the email correspondence. The intent is not to make the assignment into a formal business correspondence but to expose the students to the reality that the professional world can be "small" at times. In addition to letting the students know that some of the alumni attend the career fairs and recruit for their companies, I rely on several anecdotes to convey the message. One of the stories involves a CS1000 student who was offered a part-time job by his alumnus which upon the student's graduation became the student's full-time position. A second anecdote perhaps shows more clearly how small the professional world can be. After taking an initial job upon graduation, a former CS1000 student decided to pursue other options on the West coast. It turned out that one of the people he interviewed with was his CS1000 match. Students are also introduced to LinkedIn and we suggest that they look up their alumni match on LinkedIn.

2) *Email correspondence logistics.* Initially each student is emailed the name and email address of the assigned alumnus/a. The student alumni matches are random with the exception that female students are matched with alumnae. (Some male students are also assigned to alumnae in hopes of helping to dispel the possible misperception that the field is only populated by males.) The alumnus/a is also emailed the name and email address of the student. Students are told to use their Michigan Tech email address and to use a specified subject (e.g., Michigan Tech CS 1000) to facilitate the alumni recognizing the email from an unfamiliar person. Students are typically given three to four weeks to correspond with their alumni. This is usually ample time for several exchanges between the student and alumnus/a even if one or the other is really busy or will be away from email for a few days. Students are given a set time by which they must send an initial email to their alumni, usually about 5 days after the assignment is given. Since many of our students are

introverts, we quickly learned that many students needed the deadline to get over their hesitation/fear/procastination and send that first email. We require they copy the initial email to a grader email account. This allows us to verify that they emailed by the stated deadline. Additionally, it provides a way to examine an email that was sent and identify possible problems if the email didn't reach the alumnus/a. Subsequent emails may be private between the student and the alumnus/a.

3) *Thank you email.* At the end of their correspondence with the alumni, we require students to send a brief thank you email expressing their appreciation for their alumni's time and insights. Again this email is to be copied to the special email account. Besides encouraging good manners, this also serves as a mechanism for the alumni to know when the obligatory correspondence has ended. In some cases the alumni and students continue their correspondence on their "own time".

4) *Initial report.* Students are expected to write a one-page, single-spaced report summarizing what they learned from their alumni and any reactions they had to the correspondence. In addition, each student submits a short (approximately five words) description of his or her alumnus/a. The reports are then posted in our course management system using the short description as the label of a link to the given report.

5) *Final report.* After the reports are posted, students then read the posted reports and choose three alumni not including their original match on which to write a second report. They are told they can pick these alumni for any reason, but they should indicate why they chose the alumni. Examples of reasons include interesting career paths, similar interests either in terms of work or hobbies, or geographic location of interest.

B. Rationale for the current structure of the assignment

The assignment had originally only consisted of the correspondence with an alumnus/a and the initial report. The obvious weakness was that each student was only exposed to one career path. Depending on the career path of that particular alumnus/a, this may not have broadened the student's perspective much. Thus, we wanted a second component to the assignment that would expose the students to other alumni reports. Requiring students to read all the other reports isn't realistic considering there are typically 100 students in the class. Since most of the alumni have had fairly different career paths by requiring that students look at a minimum of at least three reports, they tend to get at least some sense that there are a variety of career options available to them.

Posting the reports in a table and using the student-generated descriptive phrases as links to the reports is a relatively recent addition. Initially we had posted the reports by some non-descriptive identifier. With no information to help them choose which reports to read, most students read the first three reports. We have found that students are reporting

on a more diverse set of reports now that they have some way of identifying reports that may be of interest to them. And an additional benefit of the descriptive phrases is that as they scan the list, they are exposed to bits of information about the alumni. In some cases, it's a bit of a job description or a company that they work at or even a hobby. Here is a sampling of the student descriptions of their alumni matches from last fall include:

- Cellular software developer, master architect, and other management
- Director of product management
- Working at his own start-up
- Entrepreneur, innovator and developer
- Writing drive system software for giant mining trucks
- Medical programming and system testing
- Eased my mind about classes and grades
- Working on systems for aircraft
- Successful, experienced, flexible, skilled, happy
- Advantages of a large company

As can be seen from this sample, just skimming the list can broadened one's awareness of career opportunities and career paths. It might even subtly attack one's biases about types of individuals who succeed in the field. And it may even ease a student's concern that he or she is struggling a bit with coursework. By not prescribing precisely how the students should describe their match, the students are free to pick what they see as most important.

C. Grading

The alumni assignment is worth 35% of a student's grade. I give 10% of the points for the initial email and another 10% for the thank you email. The remaining 80% of the grade is divided between the two reports. The reports are primarily graded on effort – did the student produce a report that meets the length requirement and has relevant material.

D. Soliciting Alumni

Over the years we have built a list of alumni who are willing, and even eager, to correspond with the first year students. The initial list came from a broad solicitation to alumni in a departmental newsletter article that explained the assignment. Many of those original alumni have been consistent volunteers year after year. Occasionally an alumnus/a will indicate a need to take a year off due to a timing conflict, such as an extended business trip or a new baby. But most alumni indicate that they look forward to interacting with a new student each fall. Most of our alumni live out of the area, so this is one way for them to stay in touch with what is happening on campus. To make up for the inadvertent lost contact due to a changed email address, I typically add a few students from the recent graduating class to the list. This also ensures that the list includes new, as well as well-established

professionals. A few times when the incoming class was particularly large, I have needed to put out another broad call.

I am frequently reminded that many of the alumni truly enjoy the experience. One small example occurred this spring. I received an email from an alumnus who had realized that he hadn't gotten his regular fall request from me. His division was sold to another company and the transition occurred in fall. Since his email had changed, he hadn't gotten my request and the work transition had distracted him. He had contacted me as soon as he remembered to be sure I had his new email for the round next fall.

E. The alumni

Since a goal of the project is to expose students to the range of career possibilities with a computing degree, we have gathered a diverse set of alumni volunteers. A wide range of industries are represented including automotive, medical, chemical, computer, gaming, aerospace, transportation, entertainment, and finance. Alumni are in a wide range of positions such as web and mobile applications developer, software engineer, test engineer, research scientist, project manager, consultant, various types of executives, and entrepreneurs. Companies range from the major well-known corporations to small start-ups. The most recent graduates are from 2014 with the other extreme being 1976. A few of the alumni are retired.

V. THE IMPACT

A. Career Awareness

The stated purpose of the assignment is to provide students with some insight into the range of possibilities for careers in the computing field. Based on the student writings, it is clear that at least for some of the students the assignment did increase the students' knowledge of computing careers. Here are some quotes from student reports to support this statement:

...it has helped me gain some insight into the professional field of computer science.

Perhaps the biggest thing I took away from my correspondence with [alumnus] was the fact that with a computer science degree, you can literally do whatever you would like, the possibilities are endless.

I told her what I was interested in doing with my education and she suggested some really cool, high demand, jobs.

I definitely feel like I have a better idea of what jobs are available to me in my future.

A few comments in the survey given at the end of the course also indicate that students learned substantial information about computing careers. For instance,

... from the Alum assignment I got to hear a lot of different possible careers, including some that are really specific so aren't the kind you would see on a list

of "Possible Computer Science Careers" so I found the diversity really interesting

... this course showed me many different things software engineers can do and lots of different employment opportunities I have once I graduate.

I think this is worth noting, as it shows that for computer science majors [who] have an understanding of computer science but don't necessarily want to do actual programming when it comes to a long-term job that there is certainly a place for computer science people in managerial positions.

Before seeing her response I hadn't thought much of the idea of traveling as a consulting firm to assist people with their software development, and just find it to be an interesting idea for a potential job for CS/SE majors in the future.

A few students were particularly enthusiastic about having learned about careers. For example,

Getting to see all the opportunities available to a CS major is awesome.

B. Dispelling negative stereotypes

A few of the student comments show that the assignment went beyond simply given students information about possible careers, but also helped to dispel the negative stereotypes associated with computing jobs. For example,

This correspondence has shown me that the Computer Science field has a wide variety of applications. When I used to picture a job involving Computer Science, I used to think of someone working in cubicles, or an office, and I imagined that the programs that they were working on had to do with computers, software, or video games. My alum has worked on many diverse things.

And from the final survey,

... it has opened my eyes to so many opportunities in my major. Knowing that I can do other things in this specific major alone instead of just sticking to computers all day I can branch off and do so many other things.

A large part of [alumna]'s day-to-day work also involves communicating with others about her progress, mostly through email. Although it may not appear to be so on the surface, human interaction does play a significant role in the computing field.

As discussed earlier, Biggers et al. found that students who left a computing major held stereotypical, negative beliefs about computing careers [7]. Helping to dispel those

stereotypes early may support the student persisting in the major.

Some of the descriptive phrases that the students used to describe their match may also help to dispel the image that everyone in the computing field is an asocial, nerdy, male computer geek. Here are a few examples:

A cheerfully, intelligent, programming mother.

Google, funny, nice, interesting.

[Alumnus] can be surprisingly cool.

She is an awesome person who works for a government agency ...

C. Breadth of Computer Science

Student reactions to the assignment also demonstrate that they learned more about the breadth of the field.

After corresponding with my assigned alum, I feel my knowledge of the work involved with Computer Science has increased. I used to think the field of computer science was much more narrow [sic] before I talked to my alum.

D. Relevance of course work

Multiple student reports included comments related to the relevance of course work. Some, for example, related to general education courses.

The fact that he said "It is interesting that some of the classes like chemistry that I thought I would never use once I finished my prerequisites have proven very useful when working in several of my different roles" makes me much happier that a lot of the general education courses will actually come in handy and not just something I will forget about and never use again gave me some much needed confidence that yes these classes do matter.

... he said that taking a wide diversity of classes gave him a wide perspective in life and in his career and is a good idea for students.

Of course, computer science students were curious about programming languages and whether they were learning the "right" ones and enough different languages. Here are some examples of what they learned from their alumni:

One should always learn the fundamentals of computer science, instead of just focusing on one small aspect or language. What this means is that you should learn how the languages themselves work at the core, the theory behind the languages, and the practice behind what they allow to be expressed. Doing this will give you the most flexible future, as you will know a much broader range of information and have a much better time when learning something new.

I also asked him how many programming languages I should learn to feel comfortable in a workplace. I don't want to get a job and not know what I'm doing there or feel inferior to my peers. He said that "I think of programming languages like driving a car. Once you know how to drive one car really well, you can almost drive any other car in the world with little effort."

Besides programming languages, first year students are often concerned that they should be acquiring certifications since many of them were exposed to certifications in high school. Here's one example of a student report describing what he learned from his alumnus:

I asked my alumni, [alumnus], if getting a Cisco Certification would be helpful for finding jobs in my career path. I asked because at a tech center I went to in high school, we were pushed to start the Cisco curriculum. Since I already had the majority of it finished, I was curious if it would be worth my time to finish it. [Alumnus] said that they were not very useful for finding a job for companies other than Cisco. I also asked about getting a Microsoft Certification. [Alumnus] works for Microsoft ... [Alumnus] did not get Microsoft Certified until after joining Microsoft. He said, "I think if you just focus on school work, you'll be fine."

E. Self-efficacy

One of the short descriptive phrases used to describe alumni presented in the previous section (*Eased my mind about classes and grades*) demonstrates that for at least one student getting reassurance about his class performance was important enough that it was how he described his match. Other students also commented about getting support and encouragement by hearing advice and or similar stories from their alumni match. Some examples are:

I also brought some of the issues I was having in CS1131 and he told me that programming can be extremely stressful, and you'll even want to quit, but the challenges are the fun part. Doing something you already know how to do over and over can just become extremely tedious.

[Alumnus] had a rough time adjusting at first, and that makes me feel better because I'm having the same problem.

... a bit of advice: Even if you have never taken any Java classes and have no experience, if you like it, keep working at it because in the end all of the hard work that you put into it will pay off.

It's nice to know that [alumnus] struggled and survived Tech. At my high school I was considered one of the "smart people", then I came here and I'm just like everybody else. The word smart is taken to a whole new level, the kids I grew up thinking were smart are

only average by Michigan Tech standards. In a way, this is a really good thing because it pushes people like me to work harder than ever.

F. Fixed versus malleable mind-set

Although alumni did not use terminology related to fixed or malleable mindsets, students often reported that their alumni stressed the need to work hard.

If you're looking for words of wisdom, I would say that you can come back up from anything if you're willing to put the work in piece by piece. Everyone does bad on a homework or a class, or a work thing every now and then, but being able to recognize mistakes and slowly recover from them is what it's all about. I remember doing badly in one of my first computer science classes at MTU. My problem was not starting assignments in time and expecting to be able to finish them. I recovered enough to get a B in that class, and do the same or better in subsequent more challenging classes.

I have taken from this that if I work hard I can have a life where I travel the world, experience a bevy of impactful careers, and make lifelong friends and companions. [Alumnus] himself said he was not the greatest student but he still was able to make an incredibly successful career, meet his wife on campus, and still have time to spend on hobbies. That sounds like a life after Tech that I would like to make as well.

G. Identity

Identifying with a computing professional can be one way of helping an individual to see him or herself as a computing professional in the future. Here are some examples of how students identified with their alumni and or the field after their alumni correspondence.

I'm excited to be in a major that is in such high demand. It makes working hard to get my degree that much more meaningful.

I hope that one day I have as many opportunities as she did with her CS degree from Tech.

... starting a business is something that is very appealing to me. As I reach a point in my life where my path will no longer be set in stone and I'm free to do whatever I want, that is the path that seems most appealing to me. Hearing that to this day, your friend is still managing to get by perusing [sic] his business ventures is inspiring.

In reference to her alumna's discussion of her family,

I would also like to have a family when I'm older. It's really important to me. I don't want a career that will overtake my life.

The following statement from an upper level student when asked about her CS1000 experience with the alumni assignment also expressed a stronger sense of confidence in pursuing computer science after being able to identify with someone in the field who had managed a family and a career.

Talking to my CS alum made me more confident that I could have a career and be married and have kids, and I really appreciated that.

H. Words of Wisdom

Several students shared words of wisdom from their alumni. It's likely that the students could have gotten similar wise tidbits from numerous people on campus, but perhaps it has greater impact coming from an alumnus/a rather than a faculty member. Here are some examples:

[Alumnus] had some words of wisdom for me, he said that if you take anything away from this story, it should be you never know who you will run into during your college career, and how much of an impact it will have on your life.

I had the opportunity to learn from [alumna], whose daughter I know and is also attending Michigan Tech, demonstrating how small our world truly is.

... he provided a large amount of incredibly useful information that is applicable to nearly everyone. The first thing he mentioned was that getting to know the faculty (such as professors) is an important step. The next thing [alumnus] mentioned was the natural beauty of Houghton. Another piece of advice was the importance of getting involved in groups on campus. [Alumnus] made the point that going to the career fair is an amazing opportunity.

First, she recommends to make time for internships and co-ops even if you take more than four years to graduate in the process. ... She also believes studying abroad to be a great opportunity that one should pursue.

Her end message was to peruse whatever you find interesting in your college career, because that will deliver you to the job you'll like the most.

VI. DISCUSSION AND CONCLUSION

As discussed in the background section, a variety of factors have been shown to relate to student decisions to persist in computer science or to switch majors. These include the misperception that computer science is just programming and consistent with that misperception a lack of awareness of the breadth of the computing field, the belief that the computing field is asocial, a sense that their coursework is not relevant to the real world, a limited awareness of career opportunities, a belief that intelligence is fixed rather than malleable, and,

particularly for women, a lack of self-efficacy and the inability to see oneself as a computer scientist.

The extent that any given factor influences a given student is likely a function of that particular student's experiences and abilities. Thus, a student who did not have to study much in high school might feel uncertain about his or her choice of major when encountering academic challenges for the first time in a university-level computer science course. Meanwhile a student who learned that success in high school depended on hard work and good study habits would be less likely to have such doubts when faced with a challenging assignment. Similarly, a student with parents in computing professions likely has a greater awareness of computing careers than one with no role models. The nature of this assignment allows the individual student to focus on the factors that may be most relevant to him or her and thus get an appropriate intervention through the assignment. We have not verified systematically how frequently this is what is occurring, but based on the student reactions to the assignment it occurs fairly frequently.

It was quite interesting when reviewing the student papers and surveys that the factors discussed in the literature as being related to persistence accounted for much of what was discussed between students and their matches. This may be considered additional support that indeed these issues are on the minds of first semester students and are likely influencing their next steps.

In summary, we find that this alumni assignment provides the students with an opportunity to network with a role model, broaden their vision of the field of computing and careers in computing, demythify the asocial nature of computing, and learn about the relevance of the field to the real world. The nature of the assignment is such that it could be used in a number of different types of courses taken by first year computing majors. Assuming enrollments in computing programs continue to increase, more departments may find it increasingly challenging to address individual student needs as the students struggle with deciding whether to continue in a computing major. Relying on alumni to provide individual communication through a structured assignment such as this one, may mean that more first year computing students are actually retained in the major and ultimately help meet the demand for computing talent in the workforce.

To conclude, here are some student expressions of the value of the assignment to them.

I plan on staying in contact with him because knowing somebody who has real world experience and is willing to help guide me along could possibly be a life savor [sic] in the future

I may have just got lucky, but I definitely feel like emailing alumni makes your first year a lot better.

This assignment was actually a very neat thing to do, and I wish that more majors would have something like this in place so the majority of students could begin networking their freshman year.

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Comparing Common and Discipline-Specific First-Year Engineering Programs: Examining the Need and Explaining the Study

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Abstract—Work in Progress: Although there exists a variety of first-year engineering (FYE) course structures and content areas, there is little understanding supported by research of which structures or content may be more or less appropriate for novice engineering students compared to others. This Work in Progress addresses the clear need for comparing different FYE programs through a research study. We begin our comparison through the lens of community of practice because community and identity have been linked to current and important engineering issues such as retention. We employ a semi-longitudinal exploratory mixed methods design to investigate two popular FYE program structures. One of the data collection sites utilizes a common first-year and the other site utilizes discipline specific courses for each of separate engineering disciplines. Our research will result in tools that can be used to gather information about engineering community and identity development in different FYE landscapes. This research is relevant to anyone who works with FYE students and those interested in improving FYE through research.

Keywords—*first-year engineering, introduction to engineering, identity, community*

I. MOTIVATION FOR COMPARING FYE PROGRAMS

Despite numerous and repeated calls for change in engineering education (e.g., [1-3]), new practices have not been widely adopted [4, 5]. One commonly noted exception lies with first-year engineering (FYE) courses. Nationally, nearly three-fifths of engineering programs have established a FYE course [6]. Based on discussions at the First-Year Engineering Education (FYEE) conference, engineering programs without a first-year course are looking to adopt one and other programs may modify existing first-year courses to ensure continual improvement. FYE education, while arguably established, is changing within a field that is also changing. This flux is exciting as there are opportunities for impactful change; however, change as a singularity does not automatically produce positive or desired results.

In her Journal of Engineering Education guest editorial, Watson [7] states the importance of research for changing and improving engineering education commenting that change

must be consciously designed based on what is known from research. While in many cases, the structure and content of FYE education programs is heavily dependent on the history, design, and political structure of the host institution, that fact does not negate the need for using research to inform the creation and alteration of first-year courses for improvement. A common question of many engineering faculty that has not been addressed by engineering education researchers is: Is common-year or discipline specific better in the first-year? While it is likely that the answer is that neither is better or worse, there are differences, and it is important to tease out the differences so faculty and administrators can make informed decisions regarding FYE change and improvement. Equally, these differences may not result in major changes to a first-year program, but instead the awareness of differences in student development may result in different approaches of educating engineers in subsequent years. To contextualize Watson's [7] concerns, changes in first-year programs, uninformed by research, will lead to mistakes, wasted resources, and inadequate foundations for future efforts. It is our goal that changes be rigorously designed and informed by research so that programs have intended and desired positive impacts.

Institutional history, design, and political structure have combined to produce multiple different approaches to the first-year (e.g., discipline specific, common first-year). Recently, research projects have been conducted to better understand the differences between these structures considering admission into major processes [6, 8] and course content [9, 10]. While these research projects provide useful information that help us better understand the FYE landscape, they tell us little about the student experience, which is critical for understanding how students develop within these structures and for making informed changes. Our work-in-progress aims to fill this gap through an exploratory case study of two different FYE structures at two different yet similar institutions. The overarching research question guiding this proposed investigation is:

How do different first-year engineering structures and their corresponding content impact engineering student development?

In this work, examine student experiences through the lens of a community of practice. Specifically, we are interested in understanding the similarities and differences between student experiences in these structures and what effect, if any, they and their content have on engineering community and identity development. We recognize that other structures, programs, and people may affect a student's community and identity (e.g., living learning communities, women and minority in engineering programs, specific courses); however, through our semi-longitudinal exploratory mixed methods research design, we will be able to determine if FYE structure has an impact or if other mechanisms are more impactful. This research study, in conjunction with future research studies addressing our overarching research question, will provide concrete evidence for engineering colleges looking to make FYE change.

II. THEORETICAL FRAMEWORK: COMMUNITY OF PRACTICE

Through our research, we focus on engineering community and identity development. Wenger defines a social theory of learning as including practice, community, meaning, and identity [11]. This theory or approach to understanding learning begins with the concept of a community of practice that includes and affects the elements identified above. Our research uses this perspective as our framework where practice, community, meaning, and identity will be explored in relation to FYE and its effects beyond the first-year. Specifically in a community of practice, legitimate peripheral participants learn new skills and take on responsibilities over time to become central members of their group [11]. For our work, this process includes becoming an engineer and belonging to an engineering community, which could be the field in general or a specific discipline. Other researchers in engineering education have embraced communities of practice as a theoretical lens, but they have not employed it to study FYE (e.g., [12-14]). Our research builds on past community of practice research by applying the framework to FYE and specifically focusing on the impacts regarding identity.

Community and identity are appropriate constructs to investigate since both have been previously tied to recruitment and retention in engineering (e.g., [15-19]), topics which has the potential to have a real impact on engineering. While previous studies provide information related to the identity development of engineering students, they do not consider the impact that different FYE structures or content have on student experiences. Our work adds a direct investigation into the impact FYE structures and content may have on community and identity development.

III. METHODS

Our research design is a case study of two different FYE programs with different structures and content. Our design employs a semi-longitudinal exploratory mixed methods approach to ensure we generate both a depth and breadth of understanding related to student experiences. Our design is consistent with Creswell and Plano Clark's design recommendations [20]. Our study is separated into three phases, each designed to answer one of the following research questions:

- RQ1 How do students experience engineering communities in different FYE structures with varying content areas?*
- RQ2 To what extent do various factors impact students' engineering identity and community?*
- RQ3 Based on the results of Phase 2, how can student accounts of their experiences further our understanding of the quantitative findings?*

A. Research Sites

Our data collection sites include two separate engineering colleges strategically selected for their similarities (i.e., both are large research focused land grant institutions) but different approaches to FYE education. One site has a FYE enrollment of 2300 students and utilizes a common first-year. The second site has a FYE enrollment of 850 students utilizes discipline specific courses for each of its disciplines. According to Chen et al. [6], these two sites represent the most common engineering matriculation taxonomy classifications: pre-major matriculation with a FYE structure (FYE), and direct matriculation with introduction courses required by all majors (DMa). Interestingly, within the overall FYE taxonomy for each data collection site, there exist a variety of courses based on content areas based on Reid et al.'s FYE course classification scheme [9] (e.g., one engineering skill focused, one professional skills focused, etc.), which provides multiple subcases that will be examined in this research. Table 1 outlines the differences and subcases for our two research sites. Reid and his coauthors provide a description of course content for each classification listed in Table 1.

TABLE I. SUMMARY OF RESEARCH SITES AND SUBCASES

Site	Matriculation Taxonomy Classification [6, 8]	Number of FYE Students	Number of Engineering Disciplines	Primary Course Content Classification [9-10]
1	Pre-major with FYE structure (FYE)	2300	14	DESN/ESTT
				ACAD
2	Direct matriculation with departmental introduction courses (DMa)	850	11	DESN/ESTT
				ENPR/ACAD
				ENPR/DESN
				ENPR/ESTT

B. Phase 1 Methods and Analysis

In Phase 1, we will interview both men and women at the sophomore and senior levels at our two research sites to gather semi-longitudinal data to understand community development over time. We plan to conduct at least 28 interviews to cover the various courses at the two institutions. These interviews will be semi-structured in nature where we will have a list of pre-determined questions, but we will follow up on interesting and important portions of each interview as needed. By interviewing sophomore students, we will be able to examine community and identity immediately after the conclusion of

FYE courses. By interviewing senior engineering students, we will be able to examine lasting effects and changes after FYE courses. The questions used in the interviews will be developed based on the theoretical framework and past studies designed to measure similar constructs in FYE.

All of the interviews will be recorded and transcribed verbatim for analysis. Additionally, summaries of the interviews will be provided to participants as a form of member checking to ensure trustworthiness in the findings. Analysis will include open coding, axial coding, and theme generation. The notion of a community of practice will serve as a lens to view the data, but the analysis will not be confined to the framework. Due to the exploratory nature of this project, we want to ensure we allow themes to develop directly from the data. Once the themes have been generated, they will be used to guide the development of a survey based on community in FYE and identity.

TABLE II. SUMMARY OF PHASE 1

<i>RQ1: How do students experience engineering communities in different FYE structures with varying content areas?</i>		
Measurement Tool	Analysis Method	Outcomes
Interviews with sophomores and seniors	Open coding and thematic analysis of interviews	Understanding of the FYE experience and carryover effects
		A set of best practices for establishing community

C. Phase 2 Methods and Analysis

In Phase 2, our effort is focused on using the qualitative findings from the participants in Phase 1 to inform survey instrument design and then test the instrument with a broader population. The Phase 2 survey will measure student perceptions of community and identity with Likert-type scales and will include demographic questions so we can investigate differences between groups (e.g., men and women). We will create contingency tables highlighting the influence of FYE structure and content areas on identity and community. We will also perform Analysis of Variance (ANOVA) tests (or Kruskal-Wallis tests, the non-parametric ANOVA equivalent) to examine differences between the mean (median) for various groups. Phase 2 participants include all undergraduate engineering students at the two research sites (site 1 ~ 3200 students, site 2 ~ 4500 students).

TABLE III. SUMMARY OF PHASE 2

<i>RQ2: To what extent do various factors impact students' engineering identity and community?</i>		
Measurement Tool	Analysis Method	Outcomes
Survey of freshman, sophomores, junior, and seniors	ANOVAs between student groups and between different FYE structures, courses, content areas, majors, gender, etc.	Tool to measure students' engineering identity and community
		A comparison of identity and community between key factors

D. Phase 3 Methods and Analysis

In Phase 3, the mixing phase, we plan to use focus groups to follow-up with student participants from each research site. We will also hold focus groups with TAs and faculty to provide a more complete picture of the FYE courses. Since Phase 3 directly depends on the results of Phase 2, it is difficult to fully define what the focus groups will entail; however, we do have a preliminary idea how these groups will function. For example, if we do find gender differences related to community and identity, we will hold focus groups separated by gender. We will hold at least 2 focus groups for each identified area so we can ensure we are finding trends in our analysis opposed to anecdotes.

As with the interviews in Phase 1, the focus groups will be semi-structured in nature and will be recorded and transcribed verbatim for analysis. The analysis of the focus groups will take an *a priori* approach where the items observed in the survey will serve as the initial coding scheme for the focus groups. After the *a priori* coding, open coding will be conducted to reveal any new findings related the impact of the first-year on community and identity.

TABLE IV. SUMMARY OF PHASE 3

<i>RQ3: Based on the results of Phase 2, how can student accounts of their experiences further our understanding of the quantitative findings?</i>		
Measurement Tool	Analysis Method	Outcomes
Focus groups with students, TAs, and faculty	Targeted <i>a priori</i> analysis to better understand survey results	Further understanding of the FYE experience through triangulated data points

IV. CLOSING

The three phases of this work are each distinct, but they will build a better understanding of the impacts of FYE structure and content through the research study described herein. The three study phases will provide avenues for future investigations into other types of FYE approaches and additional comparisons of FYE approaches using alternate theoretical frameworks and lenses.

This research will produce tools that can be used to gather information about community and identity development in different FYE landscapes. The results from this study and from our future work will allow for informed decision making when creating new or redesigning FYE programs, particularly at large land grant institutions such as the two case study sites. This Work In Progress paper outlines our research study through an overview of our theoretical framework and methods. Results of this research including applications and implementations for practice will be presented in future articles and publications.

This research is relevant to anyone who works with FYE students and those interested in improving FYE through research. These individuals will include faculty assigned to teach FYE courses and administrators that are in charge of determining the structure and content of FYE. Since

differences in student development identified through this investigation will provide explanatory power to other studies, our results will also be relevant to engineering education researchers conducting research in FYE programs. Additionally, our findings, while situated in engineering, will be of interest to other STEM disciplines as there are similarities across the domains. For example, in physics in the United States from 2008 to 2010 females accounted for 21% of bachelor degrees awarded [21]. Similarly in engineering, females accounted for 18.9% of bachelor degrees awarded in 2012 [22]. These similarities in retention and diversity make transferability possible.

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An “Objects First, Tests Second” Approach for Software Engineering Education

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Abstract—Since unit testing is a skill required of professional software developers, lecturers have to develop this skill in their software engineering students. Therefore, we introduce the approach of “objects first, tests second”, which incorporates unit testing into introductory programming classes. We discuss requirements that teaching materials must meet to effectively support this approach, and present a concept for assessing the quality of student written tests. An analysis of students’ results illustrates the effectiveness of this teaching approach.

Keywords — *Computer science education; Software engineering; Design for testability*

I. BACKGROUND AND MOTIVATION

Introducing objects early on in courses on object-oriented software development is a widely used and well accepted teaching approach, known as “objects first” [4], [12]. It ensures that objects and classes are established in the students’ minds as the crucial concepts, on which object-oriented software systems are based nowadays.

Another indispensable technique in modern professional software development is unit testing [14]. As a consequence, students holding a degree in software related study programs ought to be well educated in this area. However, a detailed analysis of both textbooks on software development and current curricula has shown that unit testing often is addressed only in later stages of the education process, if at all.

In this paper, we investigate into how unit testing can be taught effectively right from the beginning of first term programming classes, in order to equip students with an amount of expertise and experience that meets the requirements of their later jobs in this area. As well, we analyse how the success of this teaching approach can be measured, by assessing the testing skills that students acquired. We call our approach “*objects firsts, tests second*”, reflecting the fact that we introduce unit testing right after the concept of objects in our two-term course on software development in Java [2].

II. GOALS

To appropriately prepare our students for their later professional lives, we attempt to equip them with at least solid foundations in relevant software engineering practices and techniques at an early stage of their studies. Among others, this includes proper unit testing.

In this work, we tackle the question of how to effectively teach unit testing to students. More precisely, our teaching goals are that, firstly, students write unit tests as a matter of

course in any given programming task. Secondly, these unit tests should reach a high code coverage. Thirdly, students’ unit tests are required to be of high quality, i.e. they should be likely to detect defects within the program’s logic.

As our goal is to teach these issues *effectively*, we need to define criteria which measure to what extent we achieved these goals. Our first issue of students writing unit tests as a matter of course can be measured by simple observation – either they do or they don’t. To assess our second issue of test coverage, we employ the tool emma [5] to formally measure code coverage. Finally, to evaluate whether our students write high quality tests, we develop a tool that measures the quality of our students’ tests by running them iteratively against our sample solution, into which specific errors were patched in each iteration. Thus, we can formally assess to which extent students’ tests detect defects within the programming logic.

III. RELATED WORK

To investigate the state of the art of teaching unit testing to students, we analysed curricula of several software engineering courses (e.g. from within Germany, UK and USA) as well as existing literature. Although nowadays, unit testing is considered to be a fundamental, essential skill for any developer in the software work force, most of the analysed curricula cover it explicitly only at a rather late stage, if at all. Nonetheless, literature provides several proposals for approaches to adopt testing early in fundamental programming courses, e.g. [4], [6], [7], [10], [15], [16].

Very fundamental and useful work has been performed by Edwards [3], [4]. He reflects on the concept of objects-first, and states that students must provide test cases to demonstrate the correctness of their own code right from the beginning. In addition, he offers advice on how to implement this concept.

Patterson et al. [16] describe how JUnit can be integrated into BlueJ [12], a Java development environment especially designed for programming novices. Janzen and Saiedian [10] report positive effects early testing has on the students’ performance, but mention also that students are reluctant to adopt a test-first approach. Furthermore, they describe tools that were developed in order to support beginners in their writing of tests, as well as tools that facilitate automated grading.

Also, several approaches have been undertaken to evaluate the quality of students’ tests. An overview of work in this area was recently provided by Edwards [5]. Despite all these efforts, introductory textbooks that focus testing right from the

beginning are thin on the ground. Of the 40 English and 20 German text books we consulted, only two (see [8] and [13]) introduced testing at an early stage.

IV. OVERALL COURSE DESIGN

Note that as our class addresses freshmen students, there are no pre-requisites regarding computer science knowledge.

Our approach of teaching unit testing to freshmen students requires some changes to the traditional teaching of object-oriented programming. One major difference concerns the order in which the different topics are introduced. We start out with object-orientation. As soon as students have this down their belt, we follow up with unit testing. Thus, we call our approach “objects first, tests second”. As a consequence, students learn about unit testing almost immediately at the beginning of their first term of studying computer science.

In fact, students have their very first contact with unit testing even before we officially introduce them in class as a technical concept, as they have to implement their very first assignment on object-orientation against some unit tests that we lecturers provide via the automatic grading system that we employ.

As a next step, we present some theoretical background information on unit testing in our lecture, rounded off with introductory sample code. Based on that, students work on a lab session assignment focussing unit testing. Here, they actively implement their first unit tests, which have to be handed in to be graded.

From then on, all assignments comprise both productive code and the corresponding unit tests. More precisely, we establish the general rule that every assignment automatically includes the development of appropriate tests, even if tests are not explicitly mentioned. Thus students have to actively implement tests right from the beginning of the course.

In addition, for each assignment we provide tests in our automatic grading system, to evaluate the students’ productive code. However, these tests usually are not visible to the students before they hand in their assignments.

V. REQUIREMENTS ON TEACHING MATERIALS

To effectively incorporate testing right from the start, teaching materials must meet certain requirements, which in our case required some major adjustments of existing material.

A. Samples and sample code must be testable

First of all and quite obviously, to set an appropriate example all our sample code must be testable. This implies two major consequences: For one thing, we must refrain from writing code into the `main()`-method. For another thing, all methods must return a proper result value, rather than writing information to the console via `System.out.println()` (as is frequently done in many textbooks, to visualize changes in the program’s state).

1) *The trouble with `main()`*: Execution of any code must have an entry point. Using public static void `main(String... args)` introduces a lot of voodoo and – even worse – is not an object-oriented concept. Furthermore, entry points seen by programmers in today’s software projects are tests or callback methods in component-based or in web frameworks (“Don’t call us – we call you”) – and not a `main()`-method. Thus, entering crucial parts of the productive code into the `main()`-method opposes best practices of modern software development. So obviously, we should not teach this to our students.

2) *The trouble with `System.out.println()`*: To make students aware of what they have really implemented, it is important to visualise the effects of their running software. The traditional way to give insight into the state of objects is the creation of some output on the console, using `System.out.println()`. “Hello World” is probably the most commonly used introductory example for programming.

However, there are some drawbacks to this approach. *Hello World* is normally not presented in an object-oriented way – and if so, it can become quite complicated and thus is not suitable for beginners, as carried to its extreme by Kerievsky [11].

Furthermore, output to the console is hard to test: replacing the JVM’s standard output stream with a `PrintStream` printing to a `ByteArrayOutputStream` whose bytes can then be compared to the expected output, is definitely a concept that is far too abstract to be suitable for beginners. Finally, printing to the console is not useful for the majority of today’s software. For the creation of output, logging is introduced into today’s software projects [17]. Here again, logging is not a concept that is suitable for beginners.

Note that avoiding `System.out.println()` in our examples implies that we cannot rely on console output to inspect the program state. Therefore, an alternative way to visualize the program state is needed, which helps students to haptically explore their software, in addition to running tests.

B. Provide GUIs to allow inspection of program state

As unit tests are a quite abstract means to get feedback on their code, our students requested a more tangible way to follow the change of their programs’ state. Since we banned printing to the console, we decided to use graphical user interfaces (GUIs) instead. Thus, as a second major amendment to our teaching materials, we develop GUIs for the examples we use, which we provide with our assignments. These GUIs use the classes implemented by our students, and give visual feedback on the program state.

As an example, consider an exercise to implement classes representing points and rectangles in the plane. The class `Rectangle` is required to provide a method that returns `true` if and only if a rectangle intersects another one, which is passed as parameter. The GUI allows dragging rectangles around and color codes them, depending on whether that method returns `true` or `false` (see Fig. 1).

This GUI provides a very immediate, easy to understand feedback to the students. Therefore, it can be used right from

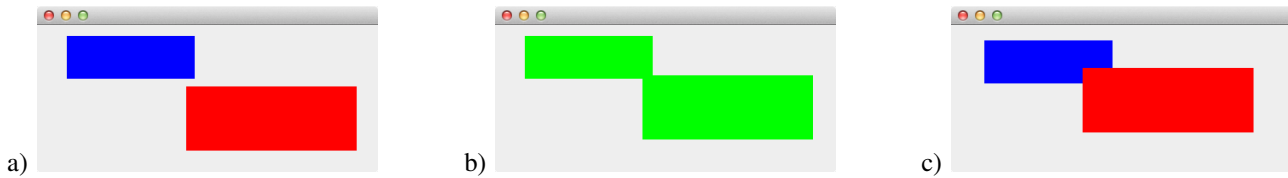


Fig. 1. Simple GUI that lets students drag and drop rectangles. Colors are changed when the student-written `intersects()`-method returns `false` or `true`, respectively (cases a) and b)). In case c), we observe a bug in the student's implementation: as they visually intersect, rectangles should be depicted in the same colour. However, the student's implementation of `intersects()` returns `false`.

the beginning of the course.

Overall, our approach is based on similar pedagogical ideas as presented by Kölling et al. for their BlueJ approach [12].

VI. PROVIDING FEEDBACK TO STUDENTS

For keeping students' motivation up throughout the whole semester, it is helpful to provide them with feedback on their learning achievements on a regular basis. As well, we as lecturers need information on our students' learning progress, to get a notion of whether our teaching reaches our students successfully or not. Therefore, to support our goal of teaching unit testing, we need an effective means for assessing the testing skills of our students.

There are several strategies for giving feedback to the students based on their code. An overview is given by [5]. Among others, for our own approach we were inspired by the idea of *mutation analysis* [1], but adapted the concept of mutations to meet our specific needs for assessing test quality.

To equip our students with a high level of practical expertise in the area of software development and unit testing, classes are backed up with lab sessions, during which students actively apply the newly acquired knowledge. In addition to individual feedback provided by the lecturer during lab sessions, we employ three tool based approaches for offering feedback to our students.

1) *Run tests against students' code*: Students hand in the results of their lab session assignments via an automated grading platform. For each assignment, this is backed up with a set of given test classes provided by the lecturer, which are run against the students' solutions. Thus, we generate feedback on the quality of the students' *productive* code.

2) *Measure the achieved code coverage*: A rather straight forward quality criterion for unit tests is the achieved code coverage. To measure this, we employ the tool *emma* [5], integrated into our automatic coding platform.

3) *Test the students' test quality*: Last but not least, we attempt to provide feedback on the *quality* of the tests our students write. To assess this automatically, we designed and developed a new infrastructure. This not only enables us to run the students' productive code against the tests provided by the lecturer. Rather, it allows us to apply individual sets of "patches" (which introduce selected sets of errors on purpose) into a reference sample solution. Then, it automatically checks whether the students' tests detect these errors, thus measuring the quality of the tests that our students developed. On this

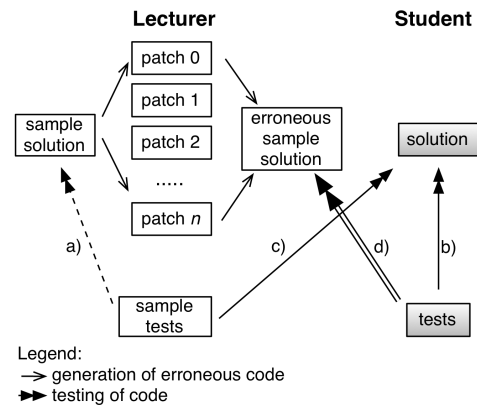


Fig. 2. Evaluation of productive code and corresponding tests: a) Lecturer's sample tests against sample solution. b) Student's tests against their own solution. c) Lecturer's tests against students' solution. d) Student's tests against intentionally buggy sample solutions.

basis, we are able to provide detailed feedback on the quality both of the students' tests and of their productive code.

Fig. 2 visualizes all four combinations of code and tests that can be considered in this tool setting:

- The lecturer provides both a sample solution and a comprehensive set of sample tests. Run against this sample solution, all tests are required to pass.
- Students hand in the productive code of their own solution, accompanied by corresponding self-written tests. When run against their own solution, the student's tests are required to pass, indicating consistency of the implemented logic and the requirements documented as test cases.
- Running the lecturer's sample tests against the productive code of the students' solution is part of many automatic assessment systems [9]. In this case, passing tests indicate the quality of the students' productive code.
- Finally, as an innovative feature in our solution, we run the students' test cases successively against a set of modified erroneous sample solutions. Here, tests are supposed to fail in every iteration, indicating that students identified and implemented sufficient and well chosen test cases, so that they reliably detect errors in the productive code.

VII. RESULTS AND FINDINGS

We applied our approach to bachelor students of computer science related study programs of the Faculty of Computer Science and Mathematics, Munich University of Applied

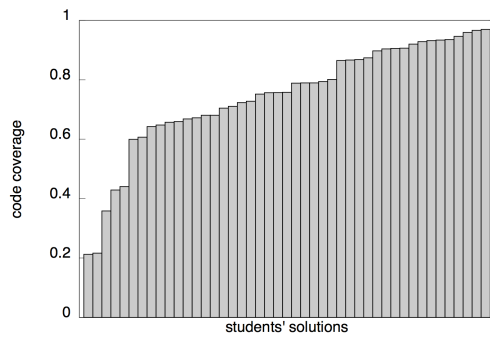


Fig. 3. Measured code coverage using emma [5] for 45 students' solutions (teams of max. 2) before concept of code coverage was introduced in class.

Sciences. The following data reflects the experience gathered with freshmen students from Scientific Computing and from Geotelematics. Both include a compulsory software engineering learning path, starting with software development in Java.

In our approach, from an early point of the class, students had to write unit tests on their own to ensure the quality of their productive code. After introducing the theoretical background on unit testing in a lecture, the corresponding assignment that explicitly focused on unit testing provided a rather detailed description of what to test. After that, we established the general rule that appropriate unit tests must be turned in as part of every assignment, even if they are not requested explicitly. *All* of our students adhered to this rule and provided unit tests. Thus, we achieved that students internalized *always* to implement test classes along with their productive code.

In the second semester (and thus rather late), we explicitly required our students to use the tool emma [5] to evaluate their code coverage themselves. Even before that, and right from the start of first term, we lecturers employed emma to assess the students' code coverage, as one quality indicator we used in the grading process.

Fig. 3 shows the coverage measured for the turned-in solutions of an exercise, just before code coverage was introduced explicitly in class. It indicates that students reached a good coverage even without having heard about this concept before. This supports our observation that students accepted the habit of thorough unit testing as a matter of course.

Finally, we evaluated the students' test quality, using our patch-and-test tool to introduce selected errors on purpose into the sample solution, and then running the students' tests against this erroneous solution. Fig. 4 visualizes the quality of the unit tests written by 64 students, against a total of eight errors that were introduced into the sample solution on purpose. The corresponding assignment was set in the middle of the first semester, where students only had very limited experience in unit testing yet.

Of these 64 student written tests, 9 indicated errors when run against the *correct* sample solution. Nevertheless, 35 students (more than 50%) detected *all* the errors that were patched into the solution. Another 16 students (25%) detected 7 errors out

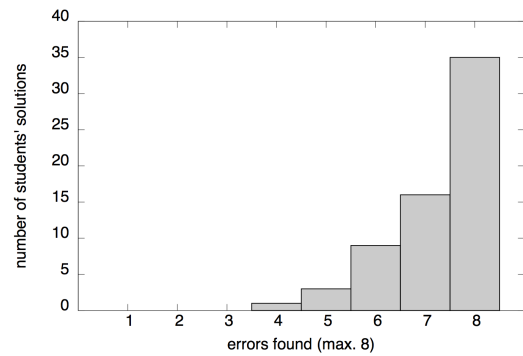


Fig. 4. Quality of students' unit tests (from 64 students), trying to detect a total of eight errors introduced on purpose.

of 8, and 9 students (14%) still detected 6 errors out of 8. None of the students detected only 3 or less errors.

This confirms that our teaching approach helped students to learn writing high quality unit tests as a matter of course.

VIII. CONCLUSIONS AND FUTURE WORK

Nowadays, appropriate unit testing is a skill that is required from any professional software developer. Therefore, we as lecturers need to foster this skill in our students as software-developers-to-be.

To achieve this, we introduced our approach of "objects first, tests second" and described our overall course design. Then, we discussed the specific requirements that the teaching materials must meet to effectively support our approach. Based on this, we presented our concept for assessing the quality of student written tests, which directly reflects on the success of our teaching.

In our teaching experience, this approach has proven to be successful. Students internalized the development of tests along with their productive code and achieved high test coverage. In addition, the vast majority of students learned to write meaningful tests that help detect critical errors within the program's logic.

However, introducing testing in the first semester rises some fundamental questions, some of which still remain to be clarified.

The first set of questions addresses didactic aspects. Generally, as time is limited, there is only a certain amount of knowledge and skill that can be developed during a single term. As a consequence, when introducing testing as an additional topic in a beginners' course on software development, previous content necessarily will be curtailed to a certain extent. This leads to two related questions, namely: Where do we cut previous content?, and: When, and to what extent, do we cover the theory of software testing in our teaching?

Another, more content related question is: How do I know that I've written the right tests, and enough of them? Answering this question appropriately involves both a significant amount of test theory and practical experience. How this can be taught effectively is subject of further research.

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The Impacts of Project Based Learning on Self-Directed Learning and Professional Skill Attainment

A Comparison of Project Based Learning to Traditional Engineering Education

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Abstract— Based upon a successful implementation of an upper-division project based learning (PBL) curriculum, an integrated first/second year PBL experience was designed and implemented. The integrated courses were physics 1, statics, design, and professionalism. The curriculum has been delivered from 2012 to 2015. This work in progress paper describes the design process, the trajectory of the program as it continuously improved, data collection methods, and initial results. Two of the members of this research team were members of the team that adapted the Aalborg (Denmark) model of PBL to an upper division 100% PBL curriculum. The model evolved into an ABET accredited program that is based on the solution of complex industry problems for the last four semesters of a bachelors degree. The results were used as the basis for the design of this lower division PBL program. The lower division program evolved from 2012 to 2015. Upon conclusion of the lower division experience, survey instruments were administered to students. Tools specific to self-directed learning and professional development were employed. The instruments are the Motivated Strategies for Learning Questionnaire (MSLQ) and professional development and professional expectations instruments designed by the authors of this paper.

Keywords— *Self-Directed Learning, Evaluation, Project Based Learning, Professional Skills and Abilities*

I. INTRODUCTION

In recent years Project Based Learning (PBL) has continued to emerge as a pedagogical model in engineering education [1]. PBL implementations exist on a continuum from one course in a traditional engineering program to fully integrated PBL curricula [2]. One of the motivations to implement PBL is an increased development of professional outcomes by student participants [3].

For over a decade, there have been numerous calls for a transformation in engineering education [4,5,6,7,8]. In response to these calls, a Midwestern community college and a Midwestern university collaborated to develop a two-year, upper-division, completely integrated PBL model of engineering education [9]. The program has 75 graduates to date and has earned ABET-EAC accreditation. The

community college developers of this upper-division program adapted the curricular model used in the 3rd/4th year PBL curriculum into a portion of the 1st/2nd year engineering education at the community college. This paper analyzes the adaptation/implementation and provides initial results of the impact this PBL engineering program has had on the student attainment of professional outcomes in comparison to students in traditional engineering programs.

II. BACKGROUND

In 2009, a new upper-division only undergraduate project based learning (PBL) engineering program was developed and implemented as an adaptation of the Aalborg model [10]. The developers of this PBL model sought to address the alignment gap between the outcomes desired for engineering graduates and those attained by graduates of traditional engineering programs [9]. It was designed to address the three interrelated domains of professional, technical, and design competence [11]. Design projects became the central theme upon which design learning, technical learning, and professional learning took place [12].

Each semester, these upper-division students select engineering projects from industry clients. Working on teams, with a faculty mentor as a guide, students complete the design process from an initial scoping to final deliverable. They acquire skills in engineering design, practice ideation, manage resources, and produce products. Integral to the design is the acquisition of technical knowledge required to complete the design. Faculty members scaffold the self-directed learning skills students will need upon graduation to independently acquire the technical competence they will need as practicing engineers [11]. The third domain of professionalism is highly integrated into the design work. Specifically targeted are written communication, verbal communication, project management, entrepreneurialism, lifelong learning, professional responsibility, personal marketing, and inclusivity [12]. Students, working with faculty, characterize

their initial competence level in each area on a scale from deficient to exemplary [12].

In 1967, Carl Rogers, a highly regarded psychologist, wrote “The only man who is educated is the man who has learned how to learn” [13]. Acquiring this skill is an outcome of an engineering education, arguably one of the most important. The recruiter for the PBL bachelors program previously described often engages potential students with this commentary:

“I’d like you to visualize your first day of work after graduation. Let me tell you two things that are not going to happen on that day... two things your new boss isn’t going to say. First, he won’t say *“Greetings John, welcome to ABC Engineering, we are glad you are here. I would like to introduce you to Dr. Jill, we have hired her to be your professor. When you need to learn something new, Dr. Jill will be here to teach it to you.”* The second thing he is not going to say is *“Here are some text books. Each week, your job is to do the problems at the end of each chapter. If you get them correct, we will issue you a paycheck. At the end of each month we will give you some written exams. Your performance on the written exams will determine the amount of your bonus.”*”

This story resonates with the students. To this point in their engineering education, nearly all of their learning has been one-directional from an instructor and nearly all of their performance has been through the completion of closed-ended chapter problems and written exams. They know this is what they neither expect nor want as the duties in their profession and they struggle with this misalignment of activities during college with expectations after college.

Lifelong learning, self-directed learning, continuous professional learning, self-regulated learning, and being metacognitive are all terms used, often interchangeably, to address the outcome expected of new graduates. A summary is that new engineering graduates are expected to be able to acquire new knowledge efficiently and effectively and be able to use it to solve complex, ill-defined, problems quite different than those at the end of a chapter in a textbook.

Originally developed in the 1990’s by a team led by Pintrich [14] the Motivated Strategies for Learning Questionnaire (MSLQ) is an 81 item survey that addresses both motivation (intrinsic & extrinsic goal orientation, task value, control of learning beliefs, self-efficacy for learning & performance, and test anxiety) and learning strategies (rehearsal, elaboration, organization, critical thinking, metacognitive self-regulation, time/study environmental management, effort regulation, peer learning, and help seeking). Pintrich’s group completed reliability and validation testing at the time of the MSLQ’s development. The MSLQ was originally developed for addressing course specific motivations and learning strategies [14]. It was modified by removing course specific questions and reducing it down to 44 questions. Rotgans and Schmidt showed the modified MSLQ to be reliable and validated for general curricular use [15]. The MSLQ has four relevant subscales. They are self-efficacy, intrinsic motivation, cognitive strategy use, and self-regulation.

A pair of 2005 studies by Shuman [16] and Loui [17] focused on the ineffectiveness of the traditional lecture format for teaching the ABET professional skills and argued that a modern engineering education should focus on active and cooperative learning approaches. The Loui study identified that students primarily learn about professionalism from relatives and co-workers who are engineers and rarely from their technical courses and proposed that engineering education should have a focus of “socializing students to become professional engineers”.

A promising approach for developing the professional competencies is a curricular focus on professional identity formation. Ibarra and Barbulescu [18] identified professional identity as an important factor in the student adaption to the workplace. Sheppard, et. al. [5] describes professional identity in terms of standards of the professional community, “to serve the public with specialized knowledge and skills through commitment to the field’s public purposes and ethical standards”. Eliot and Turns [19] define it as the “personal identification with the duties, responsibilities, and knowledge associated with a professional role”; developed through a social process where students are connecting expectations with their own needs, wants, and attitude.

Thorton and Nardi [20] proposed that professional role identification is a four-stage developmental process where individuals go from having idealized perceptions of the professional role to a more personalized role aligned with their own values and goals: 1) Anticipatory Stage: Individuals start with a highly idealized understanding of the role of the professional, which is often incomplete; 2) Formal Stage: Individuals undergo a formal learning experience with the purpose of learning the duties, responsibilities, and knowledge for a professional role; 3) Informal Stage: Individual encounters the unofficial or informal expectations associated with the professional role which that may align or contradict the formal expectations; and 4) Personal Stage: Individual begins internalizing the professional role expectation and attempts to align or adapt it with their values and goals.

The development of the PBL model in this study focused on creating for students their professional identify as engineers with the purpose for their acquiring professional competencies. In the development process, three core curricular foci emerged: 1) the recognition of the social nature of engineering education and the importance of students developing their professional identity as an engineer; 2) the importance for the learning to be embedded in professional practice [21]; 3) the potential a PBL curriculum has to support the first two foci [1]. This model is reflected in Figure 1.

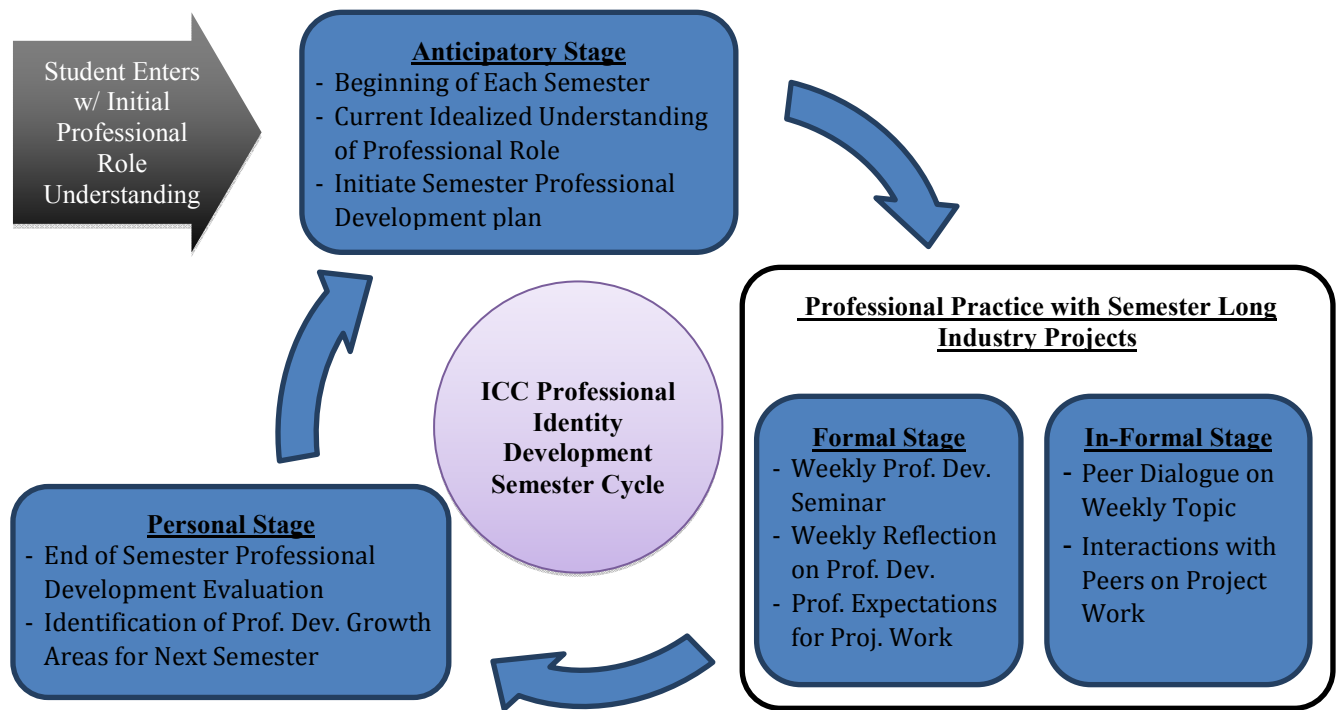


Figure 1. PBL Professional Identity Development Semester Cycle

Currently there are limited well-established resources for assessing student attainment of professional skills [16]. As part of the quantitative study, two instruments were developed to evaluate the professional growth of students in the PBL model as compared to students studying in a more traditional model.

The first, **Individual Professional Development Instrument**, focuses on the professional abilities of the individual. It is 1-5 Likert-scale survey tool, based on the ABET student outcomes [22], that evaluates a set of 19 professional expectations. Students self-identify the importance they place on a professional development topic and their current level of performance.

The second, **Team Professional Development Instrument**, identifies students' beliefs on the importance of professional development and their current performance level within the context of functioning as a member of a team. It is a 1-5 Likert-scale survey tool based upon the TIDEE professional development work of Denny Davis and Steve Beyerlien [23]. Results for both instruments are discussed in section V.

III. DEVELOPMENT OF THE PROJECT BASED LEARNING (PBL) ENGINEERING EDUCATION MODEL

As the successes of the upper division PBL program began to emerge, so did the belief that many of the successes could also be achieved in lower division. The first adaptation came from the perspective that engineering education flows through the integration of the three domains of design learning, technical learning, and professional learning. For nearly ten years, the community college program had focused on these three domains. It was done through the separate instruction of

technical knowledge in traditional courses and in a combined engineering professionalism and design course for each of the 4 semesters of lower division. This separation however, did not promote the use of technical knowledge in design, nor the integration of all three as being the *act of engineering*. Further, there was a sense across all instructors that students lacked the ability to transfer technical knowledge from any one learning experience into another.

PBL as a pedagogy provided the opportunity to gain this integration and transfer, while the successes in the upper-division program were indicating these outcomes were possible.

The model implementation built off of the existing 4-semester design sequence [21]. Students start the fall in a cohort with a six-credit design focused introduction to engineering and engineering graphics course pairing. In the first year of implementation, spring 2012, a group of ~30 students selected in the spring of their freshman year to participate in a nine-credit PBL pairing of engineering physics 1, static mechanics, and a second engineering and professional development course. This "PBL Cohort" met daily to develop the course outcomes for students in engineering physics 1 and static mechanics. This learning took place in the context of students developing these outcomes to support their projects. Professional development was an integral component of the experience. Each week a professional development topic was introduced with the expectation for students to reflect and internalize the skill associated with the topic. The experience followed the model displayed in figure 1. At the core of this experience was the creation of the professional identity of each student. These students moved on in their sophomore year to have an engineering and professional development

course each semester. The difference being that students took engineering courses related to their intended engineering discipline and there was not the intentional integrating of the student technical learning with their design and professional learning.

In the second year of development, the spring sophomore semester PBL model was expanded to include all students who met the math prerequisites to be in engineering physics 1. In the second year, there was an increased emphasis of the weekly cycle of professional development dialogue described in figure 1. Since then, the program has adopted this model for all students in the spring of their sophomore year and continues to further develop each semester.

IV. METHODS

This in-progress study looks specifically at how students in the lower division project based learning environment develop compared to students in a more traditional program. There are two student groups in this comparative study:

1. **PBL Completers:** Community college students just having completed their second year of engineering including one semester of the PBL program described in this paper as part of the four-semester course sequence. All students who completed the PBL program were asked to complete the instruments. There are three subgroups in the PBL completers, those who participated in the semester PBL program in the springs of 2012, 2013, and 2014. The 2015 group will be evaluated at the end of their sophomore year in the spring of 2016.
2. **Traditional University Student:** University students just having completed their second year of engineering without any PBL experience. A group of students at a Midwestern university were contacted through their professors and asked to complete the instruments.

MSLQ data and the professional development instruments results were analyzed using a two-tailed t-test with $p < 0.05$.

V. RESULTS

The greater research question for the implementation of this PBL curriculum is "How do PBL students experience the development of these professional and learning skills?" By comparing PBL students to traditional students, the differences of the experiences can be highlighted. Further qualitative studies can then be designed and implemented to characterize the PBL development experience.

The MSLQ areas studied in this research are self-efficacy, intrinsic value, cognitive strategies, and self-regulation. Students answer on Likert 7-point scale from 1-not at all true of me to 7-very true of me. Table 1 details the results of this comparison study.

TABLE I. MSLQ RESULTS

	PBL (n=73)	Comparison (n=80)	t-test ($p < 0.05$)
Self-Efficacy	5.63	4.93	4.53
Intrinsic Value	6.05	5.75	2.34
Cognitive Strategy Use	4.97	4.81	1.26
Self-Regulation	4.79	4.69	0.84

The self-efficacy score relates to both the students' perceptions that they can master a task and their confidence in doing so [14]. The higher the score, the higher the self-efficacy. Intrinsic value relates to the level to which the student is participating in the learning for personal mastery, challenge, and curiosity. Cognitive strategy use scores the levels students use rehearsal, elaboration, and organization. Self-regulation refers to the levels to which students continually monitor and refine their learning strategies [14].

The results would indicate that the PBL experience significantly increases the self-efficacy of engineering students, as well as the intrinsic goal orientation of their learning. While cognitive strategy use and self-regulation are less impacted. Further qualitative study will be designed to determine which aspects of the student experiences led to the marked differences in self-efficacy and intrinsic value and to further investigate impacts on cognitive strategy and self-regulation.

Given these results, it would be expected to see a higher reported professional importance and performance of professional skills for the students who experienced the PBL experience versus the control group. However, there are no areas in the 31 items of the two instruments where the PBL students combined from all subgroups self-reported higher than the control group. An evaluation of each sub group itself compared to the control group shows similar results with no items of higher reporting for the 2012 and 2014 groups.

An evaluation of the 2013 subgroup shows six items of higher self-reporting than the control group. Five items of higher importance for the individual professional development are:

1. Speak professionally, free of vulgarities and with appropriate grammar
2. Meet the needs of your team by completing work on time and of high-quality
3. Give proactive feedback to others
4. Continually seek to improve yourself
5. Act safely while completing all tasks

One item of higher performance for the team professional development:

Developing shared vision & plans; empowering to achieve individual & mutual goals

Further qualitative study will be designed to determine why the 2013 group only has the items of higher self-reported results.

VI. ACKNOWLEDGMENTS

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An Evaluation of How Changes to the Introductory Computer Science Course Sequence Impact Student Success

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Abstract—Our university, as with many others throughout the world, has a relatively low pass rate in the introductory computer science courses. Over the course of more than fifteen years, various changes have been made to the introductory course sequence with the hope of improving student success. We describe these changes and perform an initial analysis of student course performance that finds little change in pass rates. We propose new changes to the course sequence and to individual courses within this sequence. These new changes are focused on increasing student engagement and developing the problem solving skills that are necessary for being a successful computer science major. We propose pilot projects that implement these changes and outline evaluation strategies for these pilot projects.

I. INTRODUCTION

Over the span of more than fifteen years, our Computer Science department has made a number of changes to the sequence and content of the introductory courses. Many of these changes have been motivated by the faculty's desire to improve student success and learning outcomes, while other changes have been motivated by institutional factors. Our department is fairly typical in the fact that our courses change over time and with the motivating factors for these changes [1]–[5]. Various studies have found that computer science faculty tend to use intuition and anecdotal evidence as the motivation for their course changes. We acknowledge that many of our changes have been based on these non-scientific motivations, but now aim to evaluate the changes that have been made and to use research to drive future changes.

We begin this paper by describing the evolution of the introductory course sequence in our department over the past fifteen years. Next, we evaluate the effects of these changes on student success. We then discuss how other factors may impact the success of our students. Finally, we present changes that are in progress and outline our plans for evaluating the effects of these changes.

II. OVERVIEW OF OUR COMPUTING PROGRAMS

Our university is a primarily undergraduate, state-supported institution with an enrollment of more than 20,000 students. We are a Hispanic Serving Institution with over 90% of these students being Hispanic. The majority of our students are first generation college students. The university primarily

serves the local region, and the demographics of the university are similar to those of the region.

The Computer Science Department at our university offers an ABET accredited bachelor's degree in Computer Science, and master's degrees in Computer Science and Information Technology. The department also offers an ABET accredited bachelor's degree in Computer Engineering, in cooperation with the Electrical Engineering Department. In Fall 2014, we had 343 undergraduate Computer Science majors, 282 Computer Engineering majors, and 124 master's students.

As is typical at many universities throughout the world [6], our sequence of introductory computer science courses have a high fail rate. Over a four and a half year period, we found that on average both our CS1 and CS2 courses had a 60% pass rate [7]. The instructors who teach these courses are frequently examining methods for improving the pass rates. In addition to making changes to the individual courses, we also consider these courses as a sequence. In this paper, we focus on the pipeline of introductory computer science courses as a sequence and examine how changes in this sequence impacts student performance. We begin this discussion with a presentation of the recent history of our introductory computer science course sequence.

A. History of Computer Science Introductory Courses

When the department was formed in the mid-1990's we initially offered a three-hour CS1 course that focused on introducing programming concepts and a three-hour CS2 course that provided an introduction to data structures. The core objectives of our CS1 and CS2 course remain largely the same today as they were almost 20 years ago. One change is that now CS1 is a four credit-hour course (three hours of lecture, and one credit-hour for a 3 hour seat time lab). The major changes during the past 20 years have been to the course sequence, as described in detail below. These changes included the introduction of a course in-between CS1 and CS2, then the removal of this course along with the introduction of a CS0 course.

In 1998, a three-hour course called "Foundations of Computer Science" (course number CSCI 1381 at our university) was introduced and was placed in between CS1 and CS2 in

the course sequence. One of the goals of this course was to include the breadth of computer science early in the sequence of courses for Computer Science majors, while another goal was to help students better transition to the level of abstraction required for CS2. The impacts of CSCI 1381 on student learning outcomes and success in CS2 were analyzed after CSCI 1381 had been offered for three years. It was found that students reported that they achieved the learning outcomes, but there was not a clear improvement in performance in CS2 [8]. Some of the lack of improvement in CS2 performance was attributed to students not taking the courses in the proper sequence. Additionally, the impacts of CSCI 1381 likely changed over time because the number of programming assignments in CSCI 1381 were increased following the first few semesters that the course was offered.

In the late 2000's, the Computer Engineering program began offering a Bachelor's degree in Computer Engineering. This program is jointly administered by the Computer Science and Electrical Engineering departments. Most of the Computer Engineering courses are cross-listed with either Computer Science or Electrical Engineering courses. The Computer Engineering majors take the same CS1 and CS2 courses as Computer Science majors. However, CSCI 1381 was not included in the Computer Engineering degree program. Therefore, upon reaching CS2, the Computer Science and Computer Engineering majors had different levels of programming experience.

In Spring 2011, a one-hour "Introduction to Computer Engineering" (course number CMPE 1101) was introduced as a requirement for the Computer Engineering major and was set as a pre-requisite for CS1. The goals and content of CMPE 1101 are discussed below. One of the reasons for introducing CMPE 1101 was to more closely align the Computer Engineering major to the other engineering majors within our college that already had a one-hour introductory course.

The final change to the introductory course sequence came in Fall 2011 when CSCI 1381 was phased out and a one-hour "Introduction to Computer Science" (course number CSCI 1101) was introduced. This change was made to more closely align the beginning of the Computer Science major courses with the Computer Engineering major courses.

We also note that some of our Computer Science and Computer Engineering students have transferred into our university from the local community college. The community college offers a three-hour version of CS1 and continues to offer an equivalent course to CSCI 1381. However, the community college does not offer a course that is equivalent to CSCI 1101 or CMPE 1101. For this study, we focus on the students who began the introductory computer science course sequence at our university, but we acknowledge that some of the students in our CS2 course took CS1 and CSCI 1381 at the local community college.

B. Description of Our CS0 Courses

Currently, the first class in the sequence of introductory computer science courses for students who major in Computer Science is "Introduction to Computer Science" (CSCI 1101). The first class in the sequence of introductory computer science courses for students who major in Computer Engineering is

TABLE I. TOPICS COVERED IN CSCI AND CMPE 1101

Number representation
<ul style="list-style-type: none"> • Unsigned binary numbers • Hexadecimal representation • Signed binary numbers • Binary floating point representation
Using bits to represent text, images, and sound
Digital logic
<ul style="list-style-type: none"> • Boolean algebra • Circuits
Computer architecture, machine language, and program representation
Algorithms and problem solving
<ul style="list-style-type: none"> • Programming using LEGO Mindstorms • Overview of searching and sorting algorithms
Miscellaneous topics
<ul style="list-style-type: none"> • Operating systems • The Internet and the World Wide Web

"Introduction to Computer Engineering" (CMPE 1101). CMPE 1101 was first offered in Spring 2011, and CSCI 1101 was first offered in Fall 2011. Initially, the courses were very similar and they remain mostly similar to this day.

The prerequisite for CS1 is either CSCI 1101 or CMPE 1101, along with a co-requisite of college algebra. Both CSCI 1101 and CMPE 1101 are one credit-hour laboratory courses that have two and one half hours of seat time per week. They are typically offered on a two-day per week schedule for one hour and fifteen minutes per day.

CSCI 1101 and CMPE 1101 were started following a similar pilot course [9]. Much of the computer science breadth material from CSCI 1381 was carried over to CSCI 1101 and CMPE 1101. These courses also include programming assignments using the LEGO Mindstorms robots. The LEGO Mindstorms programming environment has an intuitive drag and drop block programming interface. This environment allows students to gain experience with basic programming concepts and control structures without the frustration of syntax errors. The goal of the programming component of CSCI 1101 and CMPE 1101 is to provide an introduction to programming concepts so that students already have some familiarity with these concepts when they reach CS1.

Table I shows an outline of the topics that are covered in both CSCI 1101 and CMPE 1101. The Computer Science course tends to spend a bit more time on algorithms and programming, while the Computer Engineering course tends to spend a bit more time on number representation.

The class time for both CSCI 1101 and CMPE 1101 is approximately evenly split between traditional lecture and time that students spend working on the lab assignments. Because these are scheduled as laboratory classes, the goal is for students to be able to complete the bulk of the coursework during class time.

A typical section of CSCI 1101 or CMPE 1101 has between twenty and forty students. Because the class is held in a computer lab, enrollment is absolutely capped at a maximum of 45 students. In addition to the full-time faculty instructor,

TABLE II. PASS RATE IN CS1 BASED ON WHEN 1101 IS TAKEN

When Took CMPE or CSCI 1101	Number of Students	Percent Passing CS1
Never took 1101	397	60%
Prior to CS1	155	54%
Concurrently with CS1	163	63%
After CS1	87	55%

CMPE 1101 typically has one or two graduate student teaching assistants assigned to each section in order to assist during the lab. Typically, CSCI 1101 has a full-time faculty instructor plus an undergraduate student assistant.

III. IMPACT OF CHANGES TO COURSE SEQUENCE

We have performed an initial data analysis in order to evaluate whether or not taking CSCI 1101 or CMPE 1101 helps students perform better in CS1. This analysis is summarized in Table II. The data set includes all students who took CS1 at our university between Fall 2009 and Fall 2014, a total of 802 students.

The column titled “When Took CMPE or CSCI 1101” indicates when the student took the 1101 course in relation to when they took CS1. The first row, “Never took 1101” is likely to mostly contain students who took CS1 prior to the introduction of 1101. Students in the row labeled “Prior to CS1” are those who took 1101 in some semester prior to the semester when they took CS1. The students labeled “Concurrently with CS1” are those who took 1101 and CS1 in the same semester. The last row, labeled “After CS1” are students who took 1101 in a later semester than they took CS1.

The results shown in Table II are somewhat counterintuitive and we hypothesize that the results are indicating the impact of factors other than the 1101 course on student performance in CS1. These initial results show that students who take the 1101 course during the same semester as they take CS1 have a higher pass rate in CS1 than the students who take 1101 prior to taking CS1. The Computer Science department and Computer Engineering program are typically willing to give permission for students to take 1101 and CS1 concurrently for those students who have prior programming experience or have other indicators that they are well prepared for CS1. Therefore, the students who are taking 1101 and CS1 concurrently are likely to be higher performing students in general.

Another observation of the data presented in Table II is that the pass rate in CS1 for students who never took 1101 is not remarkably different from the pass rate of students who did take 1101. One of the goals of having a CS0-type course is to better prepare students for CS1. It does not appear that our 1101 course is currently meeting that goal.

At this point, we could dive deeper into the data that we have on grades in these courses. We could also analyze whether removing CSCI 1381 (the course that was once taken between CS1 and CS2) has had any impact on student performance in CS2. However, our intuition is that there are other factors that are having a greater impact on the success of students in the pipeline of introductory computer science courses than a simple analysis of performance from one course to the next can reveal. Also, we think it is unlikely that we could reintroduce a course in-between CS1 and CS2. Therefore, we have decided

to focus the remainder of this paper on taking a closer look at some of the other factors that may influence the success of students in our courses, as well as considering how we could better leverage our current courses to better meet the educational needs of our students.

IV. IMPACT OF OTHER STUDENT SUCCESS FACTORS

As was presented in Section II, the majority of students at our university are first generation college students who attended high school in the Rio Grande Valley region of South Texas. This region has one of the highest poverty rates in the United States, and is also one of the most rapidly growing regions of the country. Students enter our university with a wide range of levels of college readiness.

The faculty in our department have informally noted that many of the students who do not pass our courses are not fully engaged in the course. These students typically have poor class attendance and do not complete all of the required work for the course. Of course, if a student does not turn in the required course work, they will not earn the points necessary for passing the course.

In this section, we present a snapshot of the amount of coursework that is completed by students who fail CMPE 1101 and CS1. We also reflect on various issues that affect student engagement. In Section V we will discuss ideas for changes that may increase student engagement.

We compiled data on the percent of assigned coursework that was completed by the students who failed CMPE 1101 and CS1 over a number of semesters. In CMPE 1101, this assigned coursework is the lab assignments that are worth 50% of the course grade. Figure 1 shows the fraction of the students who failed CMPE 1101 (on the y-axis) that completed various amounts of the required work (on the x-axis). CS1 has two types of assignments. The lab assignments, which are intended to be completed during the weekly lab period, are worth 30% of the course grade. There are also larger programming assignments that are completed throughout the course of the semester and are worth 20% of the course grade. Figure 2 shows the fraction of the students who failed CS1 (on the y-axis) that completed various amounts of the labs and programming assignments (on the x-axis). We see in Figures 1 and 2 that a few of the students who fail do complete all or almost all of the required work. However, the majority of students who fail these courses are completing a small amount of the required coursework.

We understand that there are many factors that may impact an individual student’s decision of whether or not to complete required coursework. Because most of the students in these courses are lower-division students, they may have not yet developed good time management skills. From conversations with our students, we have learned that some of them are balancing other demands on their time in addition to school. Some students work more than 20 hours per week, or have family responsibilities that require a good amount of their time. The combination of work and family commitments with poor time management skills can make it difficult for a student to complete the coursework. Another factor that may affect many of our students is that first-generation college students are sometimes hesitant to ask for help, may not recognize when

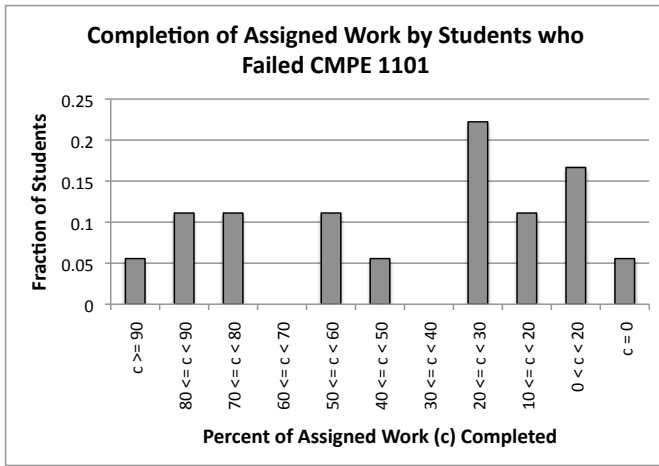


Fig. 1. Completion of Assigned Work by Students who Failed CMPE 1101

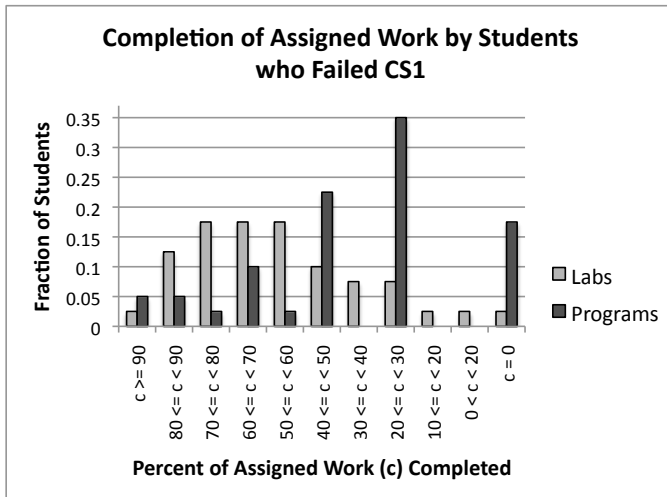


Fig. 2. Completion of Assigned Work by Students who Failed CS1

they need to ask for help, or may not be aware of the various sources of help that are available.

Therefore, we propose that the most effective approach for improving performance in our introductory computer science courses is to focus on developing and encouraging a collaborative atmosphere that provides many opportunities for students to become engaged in the learning process. We also propose the need to focus on the overall concepts and skills that are required for computer science and computer engineering, as opposed to focusing on small details.

V. IDEAS FOR MOVING FORWARD

Over the past several years, the Computer Science faculty have often discussed how we could redesign the courses in the introductory sequence to improve student success. Suggested changes involve revisions to the course sequence as a whole and to individual courses. The various ideas for changes demonstrate how the Computer Science faculty continue to struggle with identifying the core issues that affect student success in Computer Science and Computer Engineering courses.

During many informal discussions, our Computer Science faculty have identified common issues among students that appear to lead to diminished student success in computer science, both at the introductory level and downstream. These issues include a general lack of problem solving skills, low engagement and motivation, lack of participation in class and in completing assignments out of class, and difficulty with varying levels of abstraction. These issues are certainly not unique to our department, university, or program. Many university faculty members express concerns about student engagement [1], and the growing emphasis on active learning reinforces the importance of drawing students into an active learning process.

In this section, we first describe ideas for changes to the sequence of introductory computer science courses. Then we discuss specific changes to the CS0 and CS1 courses that are currently being piloted or will be piloted in an upcoming semester.

A. Changes to the Pipeline

Several of our faculty members advocate reviewing the entire introductory course sequence (CSCI or CMPE 1101, CS1, CS2) by first identifying what the *sequence* should accomplish, as opposed to thinking about the courses in isolation. This type of revision is far more sweeping than the incremental changes that have been made over time by individual faculty members. Consequently, such alterations to the introductory sequence have not yet been implemented.

One suggested approach to these far-reaching revisions to our introductory sequence focuses on improving engagement and problem solving skills. With this approach, CS0 (*i.e.*, CSCI and CMPE 1101) will focus on problem solving and broad ideas, providing a better foundation for programming in CS1 and CS2. Some details of proposed changes to the content of CS0 are provided below. In this redesign, the CS1 course will concentrate on enhancing problem solving skills and introducing core programming concepts. Even though the existing CS1 course content includes all the core programming concepts, some faculty members feel that the students struggle with the details of syntax in C++. It is also challenging for faculty to devise interesting and engaging assignments for CS1 using C++. In light of these two notions, we are considering changing the language used in CS1 to Python, with a switch to C++ in CS2. This approach has been tested successfully at other institutions, with no significant difference in performance between students who switched languages after CS1 and those who used C++ in both CS1 and CS2 [10]. Our reasons for considering using Python for CS1 include the relative ease of use and reduced syntactic complexity of Python as compared to C++, and the fact that the many libraries available in Python enable students to execute more interesting and engaging programming projects much sooner than students writing in C++. In this revised course sequence, CS2 will begin with a brief review of the CS1 content to introduce C++ to the students, and then continue with much of the current CS2 content (*e.g.*, dynamic memory allocation, data structures), retaining a focus on modular programming, with nearly all considerations of object-oriented programming and design addressed in an additional course. We have not yet fully addressed how to deal with the impact of the proposed redesign

on downstream computer science courses, but a number of possible solutions to these issues have been suggested and we are confident that this is not a major stumbling block to pursuing the revision of the introductory sequence.

B. Changes to CS0

Although the Computer Science department faculty have not yet determined how extensively the introductory course sequence should be modified, two faculty members who teach CS0 are working on revisions to that course that can set the stage for the larger revisions discussed above. The two faculty members will collaborate on developing a new course structure and course materials for CS0 in Summer 2015, and will use the revised course in two pilot sections in Fall 2015. We hope to leverage existing collaborations with colleagues in social sciences and education to design tools to measure the impact of the revised course on student problem solving skills and student engagement.

The modified course will revolve around three “big” ideas: algorithms, the stored program concept, and social impacts of computing. These three ideas provide a conceptual framework for organizing the course content, and allow exploring ideas that students will revisit time and time again in their future course of study. The updated course will use a strong active learning approach that encourages and rewards student involvement. While these approaches and activities are not novel, introducing more active learning in our CS0 course will set the stage for increased use of such approaches throughout courses in the Computer Science department.

Algorithms is, without a doubt, a core concept in computer science and engineering. Beginning the CS0 course with algorithms allows us to address topics such as problem solving processes and paradigms, algorithm design and description, and the notion of “one algorithm, many implementations, many languages.” These ideas will be supported with hands-on class activities. Problem solving approaches will be investigated through games and puzzles. Creating and communicating an algorithm clearly can be explored in engaging activities such as building with Legos. The concept that one algorithm can be executed many ways and with many programs will be addressed by exercises such as implementing the same simple algorithm using different tools (*e.g.*, Scratch and Lego Mindstorm robots). Placing algorithms at the start of the course introduces important concepts, but also may promote student interest and increase engagement in the course. With this topic, we have the opportunity to have students do many game-like activities early on and have them working with robots right away in the course.

The stored program concept is critical to both programming and the design of computing machinery. This core idea allows us to address issues such as data representation, the instruction cycle, and computer hardware components. Although this topic appears much “drier” than the previous topic at first glance, there are many activities available that deal with the information in appealing ways.

CS0 provides an ideal context for introducing the idea of social impacts of computing. Although our students will all take professional ethics courses as part of their degree requirements, addressing the societal and cultural dimensions

of computing in the very first major course introduces a discipline-centered perspective on those questions and underscores the importance of considering these issues. This topic will allow us to address issues related to privacy, security, and professional ethics in computer science and engineering. We will also be able to explore sustainability as it relates to computing. This topic is a particularly good opportunity to provide content that is tailored for computer science or computer engineering students. For example, the computer engineering students may look at considerations in chip design that impact power consumption, while computer science students may explore a variety of software applications that support community sustainability and green technology.

C. Changes to CS1

In academic year 2014 – 2015, we began a pilot study in some sections of our CS1 course with the goal of identifying more effective interventions for student success. These interventions are part of a large-scale collaboration between the College of Engineering and Computer Science and the College of Science and Math at our university. The first initiative is the development of a pre-test for CS1 that could identify students who are at risk of failing. The second initiative is the use of the pre-test data to inform intentional intervention with peer mentors. An overview of these initiatives is provided below. We plan to publish a separate paper that details the results of these interventions following the conclusion of the current study.

While the pre-test data is only preliminary, we have already found interesting results that are driving the continued development of the pre-test. Through two semesters, pre-test questions on basic algebra and logic puzzles have had virtually no correlation (correlation coefficient < 0.1) with exam scores or final course scores. Samples of these questions are shown in Table III. This was quite surprising, as the connection between these questions and CS1 material seems intuitively obvious. One question that does have a correlation with exam scores or final course grades is a multi-equation word problem, which had a correlation coefficient of 0.28 in the first semester ($n = 31$) and 0.173 in the second semester ($n = 41$). This problem is shown in Table IV.

In the second semester, we tried pre-test questions on simple automation, showing a robot on a grid with pseudo-code to move it up, down, left, or right with conditional checks for blocked squares. We also included a question requiring students to post a simple note on the course blog later that day, in order to examine organizational skills. Those questions showed more promise, with an overall correlation coefficient of 0.30 ($n = 41$).

The second intervention we are piloting in some CS1 sections is peer mentoring. An often overlooked element of engaged learning is having effective life skills, including a good social support network. A student can be interested and have every intention of learning, but fail to manage the process and fall short in their learning goals. This is particularly true for lower-division students who are adjusting to college life. For this reason, the mentoring initiative in this course is focused on relationships, goals, plans, and progress rather than traditional tutoring. Students met, in groups, with a peer

TABLE III. CS1 PRE-TEST QUESTIONS THAT DO NOT CORRELATE WITH COURSE PERFORMANCE

1)	Given the equation: $x = 8 \times (y + 3)$ Let $y = 2$, then the value of x is ____
2)	Given the equation: $y = 8 \times 2(x - 1)$ Let $y = 6$, then the value of x is ____
3)	<p>Five cities got more rain than usual this year. The five cities are: Last Stand, Mile City, New Town, Olliopolis, and Polberg. The cities are located in five different areas of the country: the mountains, the forest, the coast, the desert, and in a valley. The rainfall amounts were 12 inches, 27 inches, 32 inches, 44 inches, and 65 inches.</p> <ul style="list-style-type: none"> • The city in the desert got the least rain; the city in the forest got the most rain. • New Town is in the mountains. • Last Stand got more rain than Olliopolis. • Mile City got more rain than Polberg, but less rain than New Town. • Olliopolis got 44 inches of rain. • The city in the mountains got 32 inches of rain; the city on the coast got 27 inches of rain. <p>Which city got the least amount of rain? Where is Mile City located?</p>

TABLE IV. CS1 PRE-TEST QUESTIONS THAT DO CORRELATE WITH COURSE PERFORMANCE

<p>John is three times as old as Greg, and Greg is half the age of Bob. Steve is two times the age of John and Bob combined. If Steve's age is 60, how old is Greg's older cousin Jane, who is 2 years older than Greg?</p> <p>Jane's age: ____</p>

mentor to discuss their expectations, methods of preparation, and results from the first 2-week exam in the course. Each student was required to create a plan of study to go over with the group indicating their expectations and actual experiences with time spent in different course activities. While this is initiative is in its early stages, we have some evidence that students connected with each other for support networks and followed up with the mentor for tutoring at a higher rate. Going forward with this activity, we are developing an online web-based tool for students to do simple weekly progress check-ins, so that they can see how their expectations and effort correlate to performance in class activities. The peer mentors in academic year 2015 – 2016 will be working to roll out that system with the students and evaluate its effectiveness in keeping them engaged and actively planning for success.

VI. CONCLUSIONS

This paper marks a shift in the focus we are taking when making changes to our introductory computer science courses.

Instead of focusing on small performance metrics, we are now looking at the bigger picture of student success. The changes that we are piloting in select sections of our CS0 and CS1 courses aim to increase student engagement and confidence.

We expect that our introductory computer science courses and course sequence will continue to evolve over time. Our goal is to make changes that are motivated by well-known best practices in engineering education and to scientifically evaluate the changes that we make. We are currently working to achieve this goal by using pilot sections to test changes and using initial results from these pilot projects to guide future changes.

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Empowering Teachers to Teach CS – Exploring A Social Constructivist Approach for CS CPD, using the Bridge21 Model

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Abstract— This paper describes current research exploring the adaption of the Bridge21 pedagogical model for the provision of a Computer Science (CS) Continuing Professional Development (CPD) Programme for post-primary/high school teachers in the Republic of Ireland. This paper outlines the design of the programme and explores the delivery of two, week long CS CPD interventions delivered in the authors' home institution over the summer of 2014. The interventions were designed to help teachers develop expertise in areas such as computational thinking, programming and game design, text based programming and hardware configuration. The Bridge21 Learning and Activity Models were used throughout each workshop delivery and teachers were invited to use the same models in their own delivery of CS classroom activities. An Exploratory Case Study approach, using Evaluation Theory, informed data collection, coding and analysis procedures. Teacher reactions towards the Bridge21 CS CPD programme were investigated. Analysis indicate that teacher reaction towards the programme was positive and that teachers intended to use elements of the Bridge21 Learning and Activity model for CS delivery in the classroom.

Keywords—*Computing and Programming; 21st Century Teaching and Learning; Social Constructivist Pedagogy; CPD.*

I. INTRODUCTION

There is an international trend, within a number of education systems, exploring the inclusion of CS at both primary and post-primary/high school levels. In the Republic of Ireland, a number of “short courses” in Digital Media [1] and Coding [2] are available for the first time in post-primary/high schools across the first three years of the Junior Cycle (ages 12 – 15 approx.) curricula. These courses are being introduced as part of an overall reform of the Junior Cycle the aim of which is to move away from more traditional teacher-centred delivery approaches to flexible approaches that foster creativity, problem solving and help students develop a wide range of 21st Century key skills [3].

Teaching computing using flexible delivery methods results in courses that broadly encourage project work using a wide range of digital media, including coding. Their aim is to help learners develop expertise in the design, construction and implementation of computer generated artefacts. Despite the

introduction of these flexible learning models, there is limited CPD available to teachers that targets the creation of digital content and fewer still that combine it with a 21st Century approach to learning that is also promoted in these “short courses”.

II. LITERATURE

Policy makers and industry both agree that the economic and social trends in the 21st Century are shifting work practices, particularly in the Computer Science domain, from one of simply creating goods and offering services to one of knowledge, information and innovation [4-6]. This shift requires education systems to update pedagogical approaches in order to help students develop skills needed to work in this knowledge intensive world. Recent pedagogical approaches suggest developing the whole learner through the development of problem-solving, meta-cognitive skills [7]. With these approaches, students are not viewed as simply passive “Knowers” who reproduce received information, but “Learners” who develop transferable learning dispositions [4].

Social constructivist learning models emphasis learning through doing and encourage knowledge acquisition through problem solving and self-directed learning [8]. A self-directed approach to teaching and learning, with an emphasis on helping the learner construct new meanings from prior knowledge [9], offer teachers one possible route towards helping their students play a more active role in their own learning. The need to help students become more active, and autonomous learners, comes from educational reform concerned with helping students push deeper into curricula content knowledge. There is also a need to guide student development in a range of social and technical skills designed to help them engage with content in ways which shape understandings, while also providing students with the confidence to express and share their learning with their peers [10].

Refocusing post-primary (high school) curricula to nurture the development of these skills also coincides with renewed emphasis on Computer Science delivery as a 21st Century (21C) subject option for post-primary students [11].

Computing and programming are increasingly perceived as essential skills for 21st century learners [12].

Supporting this transition to new 21st Century work practices in Computer Science and ICT across both social and economic sectors, requires students' who are both capable of learning to use a wide range of technical tools whilst also developing a wide range of transferable 21st Century skills needed to effectively work as part of a team. The challenge here is to create a safe environment within which students, with the guidance of their teachers, can develop and hone both these technical and transferable 21st Century skills.

A. Computing is not easy

Teaching computing, and programming in particular, is inherently difficult due to what is perceived as the abstract concepts and technical nature of constructing programs [13]. Lathinen et. al [14] suggest that novice programmers should have experiences that are problem-solving in nature rather than explicitly focusing on abstract concepts. This emphasis on problem-solving resonates with the 21C approach to learning, as described above.

B. Approaches to Continual Professional Development

Given that computing is perceived as a difficult subject for students to learn, and for educators themselves to learn and subsequently teach [15-18], this raises questions as to how best to support teachers with appropriate professional development [19]. Social constructivist learning models, may offer one solution to this problem. Peer collaboration, a core tenant of CPD [20] enables teachers to share existing knowledge and experience, while also providing a forum that teachers can use to explore ideas and engage in practical work in a collegial environment. CS CPD programmes, using 21st century learning models in their delivery, are positioned to help CS teachers both experience and practice techniques designed to encourage students to become more active learners. These programmes also provide teachers with first-hand computing and programming experiences in an attempt to scaffold expertise and build confidence with delivering CS in schools.

III. PROGRAMME DESIGN

A. The Bridge21 Learning Model

Bridge21 is a practical model of 21st century teaching and learning which is being used by teachers across a number of Irish secondary schools, in subjects ranging from history [21] to mathematics [22]. The core elements of the Bridge21 learning model are: (1) structured team-based pedagogy, (2) project based activities, (3) technology-mediated learning, (4) recognition of the social context of learning and (5) facilitation, guiding and mentoring [23, 24].

B. Bridge21 Activity Model

Although the Bridge21 pedagogical model describes the structural and contextual elements necessary to orchestrate and deliver an effective 21C learning experience; it does not provide a detailed guide around which activities can be

designed. The Bridge21 Activity Model (Figure 1) consists of seven steps around which a learning activity can be designed. The activity model builds on ideas from design thinking [25] where teams move through phases of inspiration, ideation, and implementation. As with design thinking the activity model allows for a non-linear approach where the teams can go back and revise previous phases if required.

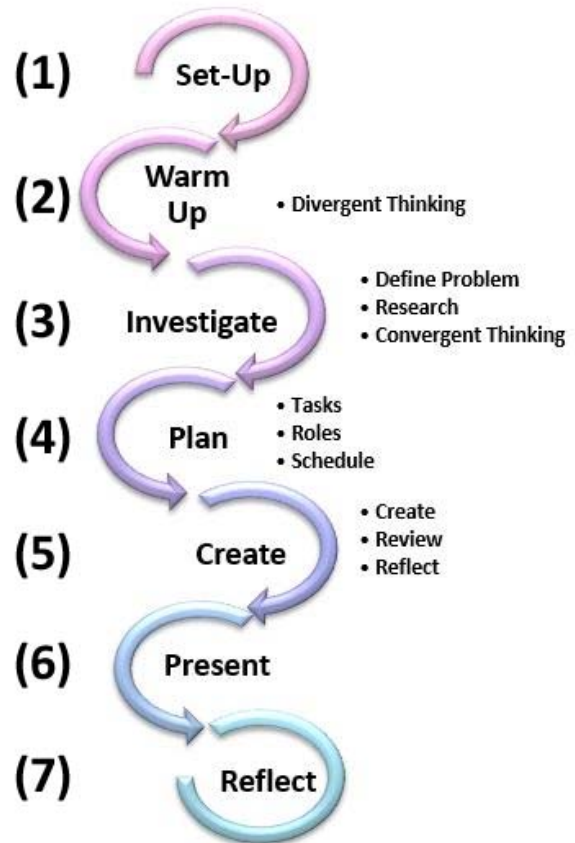


Fig. 1. Bridge21 Activity Model

1) Set-Up

A typical activity will start with an optional (1) “set-up” activity that is usually employed when the group is new to team work or does not know each other. It also provides an opportunity for team formation. There is usually some sort of “ice-breaker” activity to help the members of the group get to know each other and establish intra-group communication. Team formation follows the ice-breaker, is facilitator orchestrated and is an essential element of the Bridge21 model. It is important for the facilitator to make sure that there is a spread of ability in each team so that they can support each other as they progress through the activity.

2) Warm Up

The (2) “warm up” activity is designed to promote divergent thinking and get the teams working together and thinking in a creative manner. Initial brainstorming can either

be topic specific or be deliberately unrelated. It is desirable to get the teams practicing and modelling creative practices before tackling the central topic of the main activity.

3) Investigate

The (3) “investigate” phase involves convergent thinking and sets the context of the workshop. Teams investigate, ideate, research and define the problem context, which is set or scoped by the facilitators. It is here that the activity model can explore the design thinking elements of “inspiration” and “ideation”. Here, teams are encouraged to use lateral thinking to explore ideas, and formulate areas of interest to investigate further. The context is refined and focused when the facilitators give the teams a task where they have to create some digital artefact that addresses a number of requirements or targets. Teams are encouraged to identify and then explain problems that need to be addressed in order to fulfil the defined task targets. This can require further research into the problem context in preparation for planning and the creation of some digital artefact. This phase can also be used by the facilitator to deliver some technical content knowledge that may be needed in order to tackle the task, this may be delivered in a traditional didactic approach but it is recommended that these periods are kept short and interspersed with practical “hands-on” experience to help contextualise the materials being presented.

4) Plan

In the (4) “planning phase” team members negotiate the assignment of tasks, roles and agree a schedule for the delivery of work to be completed. A comprehensive task list should be developed based on the refined problem context that arose from the investigate phase. The facilitator may provide a template that helps scaffold the activity and implementation (e.g. using a story boarding and crew roles templates for video production). The goal here is to get the teams taking responsibility for completing the activity and thinking practically about how they are going to achieve their goals.

5) Create

The creation phase is a cyclical process in which the teams (5) “create/implement” their plan. This phase is where the teams’ task list/outlines are put into action. In line with design thinking there is opportunity to revise the plan in the short cycles of execute-review-reflect. This is time/context dependant and the facilitator can liaise with team leaders as to gauge how they are progressing and provide an opportunity for the teams to review and reflect on their progress. Utilising team leaders in such a fashion can help to reduce disruption to the whole group by limiting the number of individuals whom need to stop working on the main activity, while also promoting intra-team communication when the team leader reports back to their team.

6) Present

Once the deadline has been reached and the teams have completed the task they are invited to (6) “present” their digital artefacts to their peers and share what they have learned.

7) Reflection

A final (7) “reflection” phase is used to consolidate the learning. Here both teams and individuals reflect on their experiences using the provided templates. This provides an opportunity for the team members to reflect on how they worked together and what they personally learnt during the activity. Emphasis should be put on using the outputs from this step to improve future learning scenarios.

The activity model is used to design Bridge21 workshops, the “set up” phase (1) is optional if the teams are already formed or the group is familiar with each other. Additionally the “reflection” phase (7) is generic/not content specific and follows each workshop. Content specific material is therefore generally present in phases 2-6. Workshop design will generally follow this formula unless noted otherwise.

C. CS CPD Workshop Design

In order to help teachers to up-skill in Computer Science and gain expertise in 21C teaching and learning strategies, a series of 6 workshops were designed and then delivered on campus during weekends and school holidays. The programme consists of 1 “Digital Media and 21C Teaching and Learning” workshop followed by 5 computer science and programming related workshops. Each was delivered using the Bridge21 learning and activity models.

1) Digital Media Literacy and 2C Teaching and Learning

The Digital Media Literacy workshop is a primer that introduces the Bridge21 Learning and Activity Models without too much technical content. This allows teachers to focus on the pedagogical model rather than worrying about keeping up with any highly-technical content. This workshop provides an opportunity to use the Bridge21 Model to produce a number of artefacts relating to Digital Media issues using digital media editing software and skills.

The workshop starts with a (1) “set up phase” in which there is an introduction to the Bridge21 Model followed by a “Low Tech Social Network” ice-breaker. This activity requires teachers to complete a one page profile, which then then exchange with others in order to obtain the most number of ‘matches’ or shared items. This offline activity was designed to replicate the concept of “following”, used on social media applications. This ice-breaker has everyone individually fill out a paper profile, then they have to find those that have the same “favourite” things on their profile. The person with “the most friends” is the first to get all items matched with others in the room. The rules are then changed so that they have to find another person with a matching item and then swap profiles and repeat. The profile should move away from the original creator and the first with 8 swaps is the one that has gone “viral”. Once the ice-breaker is complete teams are formed and introductions are made.

This is followed by a (2) “warm up” activity which is designed to encourage divergent thinking and get the teams working together and thinking creatively. A typical activity is to ask teams to brainstorm “*different ways of communicating.*”

Next the (3) “investigate” phase promotes convergent thinking and sets the context of the workshop and makes up the majority of the time. Here the group works to define what is within the scope of “Digital Media Literacy” and brainstorm what they consider are the key issues which need to be addressed with students, e.g. On-line Safety, Piracy, Privacy, Cyber Warfare, etc.. The teams then select one of these issues and use the internet to research the topic, using guiding questions. Teams are then set a task to create a 1 minute information video and 30 second radio advert as part of an awareness campaign on the Digital Media issue they choose.

The teams then (4) “plan” what sub-tasks need to be completed, how much time do they have them and to whom tasks should be delegated.

Teams then (5) “create” their digital artefacts. Once the deadline is reached the teams are encouraged to (6) “present” their work to their peers as well as what they learned and what they might like to try in the classroom. A final (7) “reflection” phase is used to consolidate the learning and gain feedback to inform the workshop design.

2) Problem Solving for the 21st Century

This workshop differs from a general Bridge21 activity in that the majority of the workshop resides in the “investigate” phase as it is largely composed of lots of small problem solving activities which are inspired by CS Unplugged [26] in which algorithmic thinking is exercised without the use of a computer.

For example, in the initial (1) “set-up”, the ice-breaker gets the group to pair up and guess each other’s name, or middle name, using a set of predefined questions. After working out the other’s name, they have to describe their approach and add two more questions that they think will make for a more efficient strategy.

The “warm up” (2) phase asks teams to brainstorm “*what computers are good at.*”

The (3) “investigate” phase is comprised of lots of short problem solving activities including those from CS Unplugged. The only time a computer is used is when the teams have to write short programs using the Blockly tool [27]. After a number of these activities the teams are provided with a sheet developed by the CSTA and ISTE [28] that explore “*computational capabilities*” across the curriculum. The teams are then set the task to design learning experience that includes a number of these capabilities.

Teams then (5) “create” a brief presentation of their learning experience. Once the deadline is reached the teams are encouraged to (6) “present” their work. The final (7) “reflection” phase is used to consolidate the learning and gain feedback.

3) Introduction to Programming Through Animation

This workshop uses the Scratch programming environment to introduce basic programming concepts, such as operators.

As with all workshops, this starts with a (1) “set up” and (2) “warm up” phases, consisting of an ice-breaker, team formation and divergent thinking activity.

Next the (3) “investigate” phase introduces the scratch programming environment using two short Youtube videos. This is followed by a brief team free play with Scratch to familiarise the teams with the interface. The group is brought back together and a discussion follows about what algorithms are. Each team is given an image and asked to write a set of verbal instructions that would enable another team to duplicate the image without seeing it. This emphasises the importance of using common and clear language in designing the steps in an algorithm. Once completed the teams are then asked to interpret what a given Scratch¹ program does but without actually executing it. Once completed the teams are set the task to create a 2 scene animation that must include an audio component.

The teams (4) “plan” by deciding what sub-tasks, such as story-boards, need to be completed.

Teams then (5) “create” the animations using Scratch. Once completed the teams (6) “present” their work to their peers as well as what they learned. Finally the (7) “reflection” phase helps consolidate the learning and gain feedback to inform the workshop design.

4) Intermediate Programming Through Game Design

This workshop again utilizes Scratch to explore advanced concepts, such as variables, events and concurrency.

Again the workshop starts with a (1) “set up” and (2) “warm up” phases, consisting of an ice-breaker, team formation and divergent thinking activity. Here they brainstorm “*Types of computer games*”.

Next the (3) “investigate” phase introduces a number of advanced scratch features such as operators, events, broadcasts and variables. A brief group discussion explores what makes a good game, highlighting that they need to be challenging, fun and look good. The teams are set the task of creating a 2 level game.

The teams (4) “plan” deciding what sub-tasks such as controls, mechanics and game aesthetics that need to be delivered

Teams then (5) “create” their games using Scratch. Once completed the teams (6) “present” their work to their peers as well as what they learned. Finally the (7) “reflection” phase is used to explore their learning in more depth and provide feedback to inform the workshop design.

5) Exploring Computer Systems

This workshop is centred around the Raspberry Pi computer and the Python programming language and introduces embedded systems and inputs and outputs.

Again in the (1) “set up” phase groups are formed and introductions are made. This is followed by a (2) “warm up” where the teams are asked to brainstorm examples of

¹ <http://scratch.mit.edu/>

computers in everyday life, with an emphasis on inputs and outputs. Examples usually include applications such as house alarms, ATMs and smartphones.

Next the (3) “investigate” stage has teams investigate how the Raspberry Pi is setup and explore how to alter a pre-existing code base to interface with a gaming controller using the General Purpose Input Output (GPIO) pins. This is followed by a Python exercise that interfaces with an LED and switch, again using the GPIO pins.



Fig. 2. Team Working at Raspberry Pi workshop

The teams are scaffolded in the set-up of the hardware and installation of the default ‘Raspbian Operating System’ as recommended by the Raspberry Pi foundation². Once the Pi is powered up they launch the OS, open the Scratch programming interface and create a very simple program that moves the character around using the arrow keys on the keyboard (Figure 2). A Makey-Makey, a hardware controller device that enables users to create control inputs by attaching any household object that can conduct electricity, can be used to briefly show an alternative control mechanism for controlling the on screen character or sprite. After completing the set-up tasks, a tutorial available from Adafruit Industries³ is followed in order to setup a retro gaming controller to control the character in Scratch using the on-board General Purpose Input Output pins. Teams are also asked to tweak the accompanying code to alter the output actions. On completion of this task the Python GPIO library is introduced and they are tasked with wiring up an LED and switch and using a Python program to turn on the LED when the switch is pressed.

The (4) “planning phase” involves teams exploring what projects they might do with their students in school, and exploring various options online. Participants are then invited to (5) “create” a presentation. Teams are encouraged to (6) “present” to their peers, - what they learned and what they might like to try in the classroom. Finally (7) “reflection”

phase is used to consolidate the learning and gain feedback to inform the workshop design.

6) Advanced programming

The Advanced Programming workshop introduces Python, a first text-based programming language, and uses it to solve a number of mathematical tasks.

As with each workshop it starts with a (1) “set up phase” in which groups are formed and introductions are made. This is followed by the (2) “warm up” where the teams are asked to brainstorm examples of “things that are programmed”. In this conversation, there is an emphasis on how Python can be used for many of these applications in order to highlight the relevancy of the language.

In the (3) “investigate” phase teams are set a “Python from Scratch” task. The teams are handed out a sheet with a list of Python commands on it and they are tasked with coming up with the Scratch code equivalents. These commands vary from printing text, entering variables to conditional statements and loops.

Once the teams have completed the first task they can progress onto a number of progressively harder tasks in which they must create Python programs. The tasks are stated as problems, beginning with “create a program that prints out ‘hello world’”. The teams can use their sheet from the “Python from Scratch” task as a cheat sheet to figure out what to write. These activities progress to problems which calculate speed, distance and time based on user input (conditionals) or iterated over a certain distance (loops). For more advanced students the task is to download an existing piece of code that uses Python on the Raspberry Pi to return a distance using an ultrasonic rangefinder and the GPIO pins. This code is a practical example of the mathematics used for calculating distance, speed and time as the returned distance is calculated using these equations. The final task is to turn the existing code into an ultrasonic speedometer that alerts the user is an object is travelling over a certain speed.

As this workshop deals with technical content, a large proportion of the workshop is spent in the “investigate” phase. After completion of the above tasks the teams are asked to put together a very quick presentation. The (4) “planning” phase involves teams exploring what they learnt during the workshop, what might do with their students in school and one thing they wished the workshop had covered. Participants are then invited to (5) “create” a presentation. Teams are encouraged to (6) “present” to their peers including what they learnt and what they might like to try in the classroom. Finally (7) “reflection” phase is used to consolidate the learning and gain feedback to inform the workshop design.

IV. DELIVERY

The contents of each week session were delivered in the order described above, with the exception of the Problem Solving workshop. Elements of the Problem solving workshop were used as warm up activities at the start of each day rather than delivered as a workshop in itself. The first of the two week sessions ran from Monday 9th June until Friday 13th

² <https://www.raspberrypi.org/downloads/>

³ <https://learn.adafruit.com/retro-gaming-with-raspberry-pi/>

June, with N = 91 attendances. The second week ran from Monday 9th July until Friday 11th July 2014, with N = 73 attendances, resulting in a combined total of N = 164 attendances. Each week ran concurrently for 5 days and each day commenced at 10 am and concluded at 3.30 pm. Participants attended the Bridge21 CS CPD workshop interventions of their own accord, and thus samples were self-selecting. Some participants had prior CS delivery experience, with others new to the domain of CS.

V. RESEARCH QUESTIONS AND METHODS

This paper explores teacher reactions towards the use of the Bridge21 model for CS CPD delivery, during the two weeklong pilot workshops.

A. Methods

The authors used an exploratory case study design to define the research context, the case and units of analysis [29]. The context relates to teaching Computer Science (CS); the case refers to use of the Bridge21 model for post primary/high school teacher CS CPD delivery and each CS workshop is defined as an individual unit of analysis. The authors then combined evaluation theory [30] with an exploratory case study approach to examine teacher reactions to the CPD programme.

1) Evaluation Framework

The evaluation framework used to organise data collection was that of Kirkpatrick [31]. This evaluation framework operates over four levels. Level 1 explores participant reactions to the training and Level 2 explores participant learning in the context of the training environment. Level 3 examines perceived changes in behaviour as a result of the training, while Level 4 examines results, in terms of changes to wider organisational workplace practices as a result of the training. This paper presents results gained from the administration of a Kirkpatrick Level 1 – Reaction instrument which explores participant reactions towards CS CPD programme delivery. The authors are also engaged in designing Level 2, 3 and 4 instruments, to explore learning as a result of the CPD, and use of the CPD on return to teaching.

The authors’ adapted an existing Kirkpatrick mixed methods reaction instrument [32]. The instrument contained 12 closed numeric (Likert) questions and 4 open text questions to capture reactions across each of the six programme topics.

B. Reaction Instrument Question Design

The 12 Likert questions were organised into four question categories, each of which explored participant reactions towards the CPD. Category 1 contained 4 questions which focused upon Workshop Design. Category 2 contained 4 questions, which explored the use of Facilitation as a delivery method. Category 3 contained 3 questions which examined usefulness of learning Activities and Case Studies. Finally, Category 4, contained 1 question prompting for an overall workshop satisfaction rating. All questions were scaled left to right, with 1 = Strongly Agree, allocated a 100% rating, to 7 = Strongly Disagree, allocated 0%.

The instrument also contained four open, text questions. Question 1 asked participants to identify workshop topics they would like to spend more or less time on. Question 2 asked participants to list key learnings. Question 3 asked participants to comment on perceived changes to their delivery as a result of the CS CPD, where they intended to teach CS and Question 4 asked participants to comment on the perceived usefulness of the CPD.

C. Data Collection Procedures

Data collection occurred as follows. The authors distributed a hard copy ethics and consent form to all participants on the first day of each week. Participants whom opted into the research process provided a signature (a total of N = 33 unique signatures were obtained from a total of N = 36 individuals over the two week period); while others opted out by leaving forms blank. As each workshop ended, participants were invited to complete the Kirkpatrick Level 1 Reaction form. A total of N = 157 forms were collected over the two week period. Instrument completion was optional and this paper includes data from participants with a corresponding ethics signature.

VI. ANALYSIS

The section describes coding processes used to analyse quantitative and qualitative data sets.

TABLE I. PERCENTAGE RESPONSE PER QUESTION CATEGORY

Question Category	Percentage Response
Design	82%
Facilitator	93%
Other Aspects	92%
Overall Rating	93%

TABLE II. TEXT RESPONSE CODE REDUCTION

Coding Stage	Codes
Inductive Coding Cycle 1	215
Deductive Coding Cycle 1	123
Deductive Coding Cycle 2	28
Sub-Themes	2
Theme	1

A. Quantatative Data

Likert responses were processed using SPSS statistical software. SPSS summed the total number of responses per workshop question category, and then generated an average of means. The average or mean score was then converted into a percentage, as detailed in Table I.

Text responses were manually and then electronically transcribed, open coded and stored in a searchable database.

Three iterations of manual re-coding were performed against the transcribed text responses. This process resulted in the generation of 215 text codes from a total number of 383 database records. Comparative coding was used to reduce the qualitative data set [33] to a total of 28 codes. These codes (Table II) were further reduced into 2 sub-themes, which were then linked to the central theme of teacher 'empowerment.'

B. Sub Themes and Themes

The theme 'empowerment' emerged from qualitative data analysis. The sub themes of 'delivery model' and 'self-directed learning' emerged as sub themes related to empowerment.

VII. FINDINGS AND DISCUSSION

This section is structured as follows. Section A explores teacher reactions towards the use of the Bridge21 model for CS CPD delivery using a combination of statistical results and participant text responses. Section B then explores empowerment and related sub themes with text examples.

A. Reactions to the Workshops

As detailed in Table I, teacher reactions across all quantitative question categories were positive, indicating a high level of satisfaction with the delivery of the workshops. The following discussion explores these reactions in detail.

1) Design

Participants reacted positively to the week long programme giving an overall satisfaction rating total of 82%. The qualitative data revealed that the programme helped participants think about how they might teach CS. One participant stated that workshops had demonstrated *the importance of introducing new topics slowly.* This approach prompted another participant think about giving *'more time in classes to harder topics not just rush,*' and had helped another *'with my timing and planning of difficult concepts.'*

2) Facilitation

Participants also reacted positively to the use of facilitation for CPD delivery, registering a satisfaction rating of 93%.

The qualitative data revealed that the experience had encouraged one participant to want to *'act more as facilitator in class,*' while another now wanted to *'re-think completely how group work is facilitated and organized,*' having experienced group based CPD. Group work exposure encouraged participants to think about adjusting their own delivery. One participant reflected *'because I have been forced to work in groups and problem-solve myself I have enjoyed it. I will feel more comfortable about using this model in the classroom.* Another reflected that they had also gained a better *'understanding of student difficulties with basics so as to assist them in a full understanding of the use of technology.'*

3) Other Aspects

The 'other aspects' workshop question category asked participants to comment on the use of case study materials and activities used during the workshops. Participants gave an overall satisfaction rating of 92%. One participant enjoyed

using practical approach to CPD *'as opposed to following book or showing end product.'* Other participants also enjoyed the practical exercises and could visualizing using them - *'basic (programming) worksheet exercises are good class fillers,*' also the activities provided *'good material and structure for class,*' with *'good templates / demo of how things can be done.'* The range of practical exercises provided *'a good alternative for differentiated delivery,*' and had exposed participants to a *'new model to play with,*' and a structure with which to introduce *'new ideas for class.'*

4) Overall Rating

Participants again, registered a positive overall satisfaction rating of 93% towards the week long Bridge21 CS CPD sessions. At the end of the first week, one participant reflected, *'I learned a bucket load so thanks very much. I admit that I did struggle at times but a higher competence in math's would have helped so it is my ability rather than the course itself. That said, I will certainly peruse these skills in the future as I believe they have a place in Secondary Schools.'* At the end of the second week, another participant commented that that they would *'certainly be able to advise students on computers / programming and getting involved in computer clubs. (The workshop topics are) also relevant to our chemistry club. Also languages - encouraging girls (in computing) as many girls good at languages but see computers as something completely different.'*

B. Teacher Reactions to the Bridge21 CS CPD Programme

This section sets out to explore the theme of empowerment, and sub themes of delivery model and self-directed learning.

1) Empowerment

Empowerment is defined as developing processes or programmes which seek to 'help people, help themselves' [34]. Following this definition, the theme of empowerment is discussed with the aim of exploring the extent to which the CS CPD programme helped participants again in confidence to adjust delivery methods to enhance teaching and learning according to a 21st century approach, and gain in confidence to teach CS in their schools.

The activity and hands on approach to CS CPD delivery offered by Bridge21 was not expected by one participant whom was surprised that the programme was *'was not a math's course - I came today with a calculator and lots of tables!'* Instead, participants gained a *'working with variables and lists in Scratch,*' and were encouraged to *'spend time experimenting with Scratch'* and other digital tools. One participant commented that they had learned how to *'work around for issues; don't over complicate the code on scratch.'* Visual programming had also helped another participant *'think more about approaches to scratch with the class and for coding short course.'* The completion of group based coding projects had also helped contribute to a positive learning experience, where learning *'scratch can be fun - the harder you make it the better fun it can be!'* Participants felt energized and confident to apply their learning in the classroom - *'I feel confident that I could use scratch in class,'*

while another participant shared that they *'felt I could introduce this to students through I think they could pass me out technically very quickly! And teach me!'* In relation to the delivery of the more advanced computing workshops (Raspberry Pi and Python), participants liked bridging activities *'I liked matching Scratch codes -> Python Codes'* and other hands on activities which helped to demonstrate the *'importance of correct codes and one mistake can affect everything.'* One participant reflected that they had learned *'how important language is to coding,'* while another commented they now understood how to combine codes, and the *'the impact one code has on another.'* The group based approach to coding and programming also generated conversation on the role team and group projects played on learning computing concepts - *'group work is great for complex project.'* Introducing and using team based, facilitated activities for exploring computing systems had helped to *'motivate, stimulate and brighten up student learning'* in ways which had enabled participants to think about how they might *'integrate more coding and computational exercises in classes.'*

a) Delivery Model

The CS CPD programme had introduced participants to an delivery model which encouraged them to reflect on their own teaching style, and think about how they might adjust their own delivery in light of experiencing a 21st century approach to teaching, and learning. One participant reflected that *'you primarily teach the way you were taught,'* indicating that it is difficult to change or switch between delivery methods. Another participant reflected that they intended to change their delivery methods so that *'students and myself should discover how to do something as opposed to being led.'* The CPD experience had also helped one participant *'realize how others think and learn differently,'* and the practical approach had provided another participant with a range of techniques and activities with which to *'complement the things I already do in my teaching.'* For those new to computing, the facilitated nature of the delivery, *enabled* one participant to explore *'coding and its processes,'* and the delivery process was perceived by another participant as potentially *'great for students understanding of the process that goes into making a game and logical thinking.'* The delivery process also helped one participant become *'more familiar and confident using this (the Bridge21 model) in class and the process is important - not having perfected the task!'* One participant continued that *'this process will help me raising awareness on responsibility re: digital media,'* while another participant expressed the view that the Bridge21 CS CPD approach to delivery was a *'good tight format, practical workshop, good pace, I will seek to emulate.'* The workshop design helped participants explore computing concepts, but within a structure, they could see themselves using in the classroom with their students. As summarised by one participant, *'I think its brilliant, it really energizes and interests me, I'm really looking forward to using it in after school activities'.*

2) Delivering a Self-Directed Approach to Learning

The theme of self-directed learning indicated intent towards adopting a self-directed learning approach when they

returned to the classroom. One participant commented that they intended to use *'less teacher directed learning and more self-directed learning.'*

The workshops had also prompted consideration of a number of other delivery changes. One participant intended using more *'problem-based learning in the classroom,'* while another participant aimed to use *'problem solving in my classes'* as the activities undertaken in the workshops had helped expose participants to a *'logical structure to problem solving,'* which some aimed to use with the computing students. The Bridge21 approach to CS delivery had helped participants explore the *'importance of learning from other members of your team,'* and develop some *'techniques for software and team dynamics,'* resulting in the use of *'use more group work in the classroom.'* Using team work in a classroom setting was prosed as a key delivery change on return to teaching. One participant commented that *'team work (creates a learning experience where) all can learn from each other.'* Team work also helps students with their time management where groups are working towards *'deadline pressures'.* The Bridge21 experience had encouraged one participant to *'use more experiential learning in classroom'* but had also provided others with a mechanism by which to help their *'students can help each other,'* as *'student lead learning is the way forward!'* One key learning participant had taken from the Bridge21 CS CPD experience was the knowledge and practice to implement a self-director approach to teaching and learning in the classroom, either for use in helping students explore some of the complexity surrounding learning to use computing tools and write computing programmes, or as a mechanism for changing general subject delivery to help engage students.

VIII. CONCLUSIONS

This paper set out to investigate teacher reactions towards the Bridge21 CS CPD programme. The previous analysis and subsequent discussion indicate that teachers' reactions towards the programme were positive (see Table I). Teachers also expressed how they intended to use aspects of the Bridge21 Activity Model for CS delivery and move their teaching practice, and student learning towards a more self-directed, 21C approach.

Not only has our approach introduced teachers to CS topics but has opened some teachers' minds *'to new content and methodologies'.* This suggests that there is a move towards *'more learning by discovery / more peer learning'.* A combination of the Activity Model and using problem solving and visual programming languages such as Scratch as a starting point has helped address a number of the difficulties associated with teaching novice programming.

This CPD programme, using the Bridge21 Models helped CS teachers both experience and practice using techniques designed to combine self-directed learning, computing and programming activities and gain the experience, expertise and confidence needed to empower teacher in their own delivery of CS in their schools.

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Engage K-12 Students in Engineering: Model for Engineering Project Activities to Inspire K-12 Students to Pursue Careers in Engineering

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Abstract - This paper discusses the model to create and implement the exploratory “Engage K-12 students in engineering” program to inspire K-12 students to pursue careers in engineering disciplines. Through this program, the K-12 students will participate in engineering project activities with science, technology, engineering, and mathematics (STEM) components. Engage K-12 students in engineering will (a) raise the level of awareness among K-12 students of the promising careers in the engineering disciplines upon graduation with baccalaureate and/or advanced degrees (b) establish and sustain the dialog between the K-12 schools and the University to encourage the K-12 school students to pursue and excel in subjects with STEM components (c) promote the interaction between the engineering faculty at the University and the K-12 school students through activities which deliver critical STEM components. “Engage K-12 students in engineering” will be identified at all levels of K-12 STEM education and will be delivered to a widespread audience of K-12 students through (a) direct outreach activities such as on-campus visits, (b) extended outreach activities through cyber-learning networks, and (c) University partnership with the K-12 schools.

Keywords – STEM-based engineering projects, Outreach

INTRODUCTION

The factors that contribute to the high drop-out rates of students from the STEM school systems and the low enrollment of school graduates in the STEM colleges and universities across the U.S. include (a) lack of awareness of the promising careers after the successful completion of STEM-based school and college education (b) STEM curricula in K-12 schools which fail to inspire the students to develop a life-long passion for STEM learning (c) inadequate preparation and the lack of technological resources available to the K-12 STEM teachers to effectively deliver STEM teaching. The partnership between the engineering departments at Universities which offer the ABET-accredited baccalaureate degrees and K-12 schools with STEM curricula is viewed as a means to exploit the synergy between the two environments and can address the critical issues facing STEM learning and teaching in the following areas.

(1) *Introduce revisions to K-12 STEM courses and curriculum*

The K-12 curriculum must include new and revised STEM courses which introduce the engineering design process and teach students how to use engineering technology to solve engineering problems with design and cost constraints. These courses will incorporate project-based and goal-oriented STEM learning experiences to supplement the traditional STEM curriculum.

(2) *Raise student motivation and desire to learn STEM concepts*

The proliferation of the internet technologies with multimedia make it possible to deliver the hands-on STEM-based project activities as a virtual educational experience to a geographically widespread audience of K-12 students and teachers. The easy access to STEM education materials will (a) encourage the students to advance their understanding of basic and advanced STEM concepts (b) equip the K-12 STEM teachers with the knowledge and skills required to sustain the STEM learning experience for their students.

(3) *Improve the retention of STEM concepts by the students*

The students participating in the outreach and cyber-learning environment will reinforce the learning of STEM components through activities and interaction that is structured, consistent, and constantly motivating. The students will improve their retention of STEM concepts learned in the classroom through hands-on project activities.

This paper documents the work-in-progress to create and implement the “Engage K-12 students in engineering” program. The program will consist of hands-on STEM learning activities delivered through forms of outreach [1]-[5] and collaborative partnerships between the University and K-12 schools. The outreach from the University to the K-12 schools is broadly classified as direct and indirect.

The direct outreach will include the following.

- (1) K through pre-middle school students participate in day-long introductory STEM-related activities
- (2) middle school students participate in day-long STEM-based engineering project activities
- (3) high school students participate in day-long STEM-based engineering project activities.

The extended outreach will take place through cyber-learning networks. The cyber-learning networks will create the internet-based environment for presentation of and access to STEM learning materials. The networks would create the environment to enable widespread and remote K-12 schools and school districts to participate in the activities and thus have a *virtual* STEM education experience. In addition, the K-12 teachers can adopt new and/or revised instructional practices to raise the STEM learning standards of the students.

Section 2 provides details of past and on-going direct STEM outreach initiatives launched by the University in general as well as by the Electrical and Computer Engineering (ECE) department in particular. Section 3 identifies one of the cyber-learning infrastructures to deliver the proposed extended STEM outreach initiative. Section 4 addresses the evaluation and dissemination of the proposed outreach project. Section 5 summarizes the conclusions and work planned for the future of the “Engage K-12 students in engineering” program.

SECTION 2: DIRECT OUTREACH

The ABET-accredited undergraduate engineering programs at our University can establish and sustain “Engage K-12 students in engineering.” The engineering laboratories are equipped with state-of-the-art equipment to deliver STEM-related project activities to enhance the STEM learning by K-12 students. The direct outreach programs are identified in the following categories.

- (1) Discipline-specific
- (2) Broad engineering
- (3) Engineering summer camp
- (4) Engineering explorer program

(1) Discipline-specific

The ECE department at our University hosts *ECE day* [5] during its spring session (typically, the month of April). ECE day features project activities for high school students in electronic circuits, wireless communication, wind-based electricity generation, and embedded system design through hands-on laboratory activities related to project design, test and validation. The students work on the project under the guidance and supervision of the ECE faculty member and undergraduate students assigned to coordinate the project activity. The project activity lasts for about one hour and is intended to stimulate the student interest in practical, real-world STEM-based applications of engineering principles. The ECE projects are summarized as follows:

Project title: *Renewable energy mini project -- wind power*
Project summary:

The students worked with a small-scale windmill, 5” generator, wire, and LED to convert the wind power into electricity and power the LED.

Project title: *Traffic signal control circuit*

Project summary:

The students operated the three-light traffic signal set up on the printed circuit board (PCB) with timer and counter chips.

Project title: *ZigBee for Wireless Communication*

Project summary:

The students configure communication devices to create a wireless network and demonstrate “*instant messaging*” over the network.

Project title: *Logic circuit and FPGA design*

Project summary:

The students perform logic circuit design through the capture of schematics and execute their design on the FPGA board.

Figure 1 illustrates the flow of project components in one of the ECE laboratories during the ECE day event. The students engage in a similar sequence of activities in each of the four ECE labs over an interval of four hours.

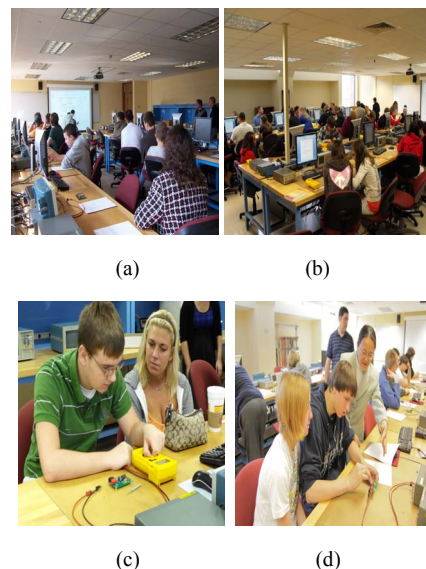


Figure 1. Project (a) overview (b) activity (c) test and (d) validation.

(2) Broad engineering

The engineering departments at our University have hosted Engineering Day (E-day) events for high school students to participate in pre-engineering STEM-related project activities in the following engineering programs - electrical and computer engineering, environmental engineering, and mechanical engineering.

Electrical and Computer Engineering (ECE):

Project title: *Traffic signal control*

Project summary:

The students assembled the circuit to control the operation of red, yellow, and green lights of a three-light traffic signal. Environmental Engineering (ENV):

Project title: *Water Filtration Hydraulics*

Project summary:

The students operated lab-scale versions of sand filters to purify drinking water based on the counter flow model. The “head loss” is measured and the results are compared to the head loss predicted by theoretical equations.

Mechanical Engineering (ME):

Project title: *Watercraft*

Project summary:

In this activity, the students build a platform to float on water for a specified duration while supporting a weight. The students are scored based on efficiency of material used and the design objectives met.

(3) Engineering summer camp

The Engineering summer camp is designed for students who are entering their junior or senior year of high school with the interest and aptitude to pursue careers in engineering. This week-long camp introduces the students to principles of engineering, the engineering design process, methods for scientific computation and issues related to the environment. Students gain hands-on experience with design projects in mechanical engineering, electrical and computer engineering, and environmental engineering. The students work in teams of two to three members and compete in contests to determine the design with the best features.

(4) Engineering explorer program

This program introduced local area high school students to the undergraduate electrical and mechanical engineering degree programs at our University. The students participating in this program would visit the campus for two hours, one day each week during the first seven weeks of the spring semester (January through May). The activities would take place after the students concluded their school activities for the day. During each meeting, there would be (a) laboratory demonstrations by engineering faculty and undergraduate engineering students and, (b) Engineering design projects which can be completed in at most a couple of hours.

The proposed initiative comprises (a) identification of STEM-based engineering project activities for K-12 students (b) set up of the schedule for direct outreach (c) creation and delivery of the STEM educational materials through cyber-learning networks.

Figure 2 illustrates the direct outreach activities and schedule for all grades of the K-12 students. The students in each grade category will participate in STEM-based engineering project activities tailored to their level of understanding of STEM concepts. These project activities will range from introductory to advanced across the K-12 grade structure and offer the students the opportunity to relate engineering concepts to engineering design and practice.

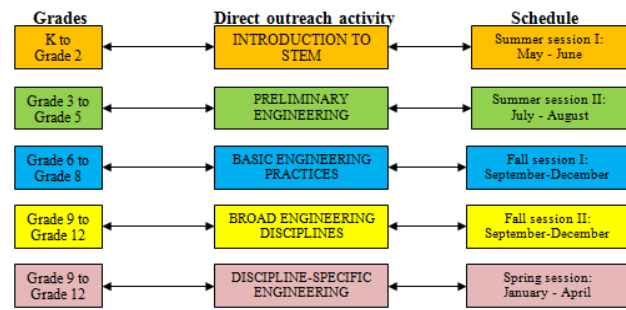


Figure 2. Direct outreach across STEM K-12.

Summer session - I: *E-Day for K to grade 2*

Occurrence: Two per month (May – June)

Theme: *Introduction to STEM*

The direct outreach activity for students from K to grade 2 consists of simple and introductory STEM projects to motivate the students toward STEM learning. The emphasis is on the demonstration of the use of engineering to solve problems in daily life.

Summer session - II: *E-Day for grades 3 to 5*

Occurrence: Two per month (July – August)

Theme: *Preliminary engineering in STEM*

The direct outreach activity for grade 3 to grade 5 identifies STEM projects to explore creative approaches to solving engineering problems using mathematics, science, and technology.

Fall session - I: *E-Day for grades 6 to 8*

Occurrence: One per month (September – December)

Theme: *Broad engineering*

The middle school students from K-12 programs with STEM components participate in engineering project activities which engage the students in problem solving with constraints on design and cost at their level of STEM education.

Fall session - II: *E-Day for grades 9 to 12*

Occurrence: One per month (September – December)

Theme: *Broad engineering*

The high school students from K-12 programs with STEM components participate in engineering project activities which challenge the STEM learning of the student in the process of engineering design, test, and validation.

Spring sessions: *ECE, ENV, ME Day*

Occurrence: Each discipline assigned to one day in the specified month (January – April)

Theme: *Discipline specific*

The high school students engage in laboratory-based sessions in each discipline. For instance, the ECE project activities take place in four different ECE laboratories. The

duration of each activity is 55 minutes during which the students are assigned the engineering design problem, given the required background material and step-wise instructions. The students must then build and test their engineering solutions.

Table I illustrates the schedule for the set up of E-day activities in the fall session in three categories of items to be addressed i.e. pre-activity, activity, and post activity.

TABLE 1
SET UP SCHEDULE OF E-DAY

Pre-activity items	Activity	Post-activity items
Admissions contacts schools; schedules date for E- Day	Mail invitations	Create the roster of participants and their contact information
Engineering departments prepare for E-Day	E-Day	Departments follow through with the participants (coordinate with admissions)
Admissions contacts schools; determines the students with interest; offers incentives to enroll in one of the engineering programs at the University	Invite these students to the discipline-specific Spring sessions	Continue the dialog with these students; set-up the mentoring process for students who confirm enrollment
Assessment setup for identifying "intend" to major in engineering or another subject	Matrix tracking of student's development to apply to other schools in engineering fields	Track students enrollment in engineering at other universities/colleges

The schedule for set up of the discipline-specific outreach day would be similar to Table 1 but the E-day would be discipline specific for instance, ECE day or ENV day.

SECTION 3: EXTENDED OUTREACH

The proposed initiative will lead to the creation of new instructional material, laboratory experiments, and design projects. The cyber-learning network shown in Figure 3 will be created to disseminate the content through secure internet sites. The K-12 students as well as their teachers will access these sites to obtain instructional material or engage in interactive sessions with the engineering faculty responsible for the course content. The cyber-learning network will benefit the schools and school districts as follows:

- (1) enhance the laboratory experience of the student
- (2) interact with the engineering faculty to motivate and broaden the learning process
- (3) overcome the inability of the students and teachers to commute to Gannon University due to the weather or other unforeseeable reasons
- (4) engage remote school districts with no means to bus the students to the Gannon campus
- (5) possibly reduce/eliminate scheduling conflicts within the regular day by organizing the laboratory session after school hours

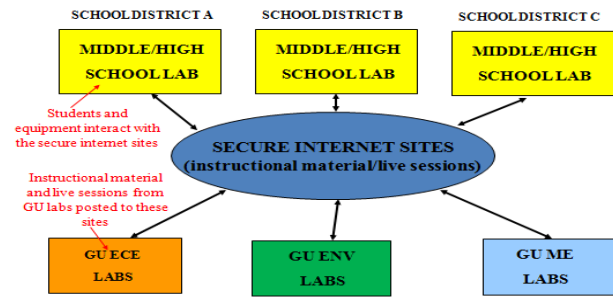


Figure 3. Cyber-learning network.

SECTION 4: PROGRAM EVALUATION & DISSEMINATION

The program evaluation comprises *external* and *internal* evaluation. The external evaluation will be conducted by a qualified STEM program evaluator. The internal evaluation will consist of *formative* and *summative* evaluation plans based on surveys created for each activity in the direct and extended outreach components of the initiative. The *summative evaluation for direct outreach* will consist of short-term and long-term survey analysis. The surveys will be administered as part of each project activity. The program will be disseminated through (a) laboratory manuals (b) the cyber-learning network (c) conference presentations and journal publications (d) community news.

SECTION 5: CONCLUSIONS & FUTURE WORK

The "Engage K-12 students in engineering" program promotes outreach and partnership between the undergraduate engineering institution and K-12 schools through engineering project activities for the K-12 students. The outreach comprises the implementation of direct and extended outreach aimed at year-round engagement with the K-12 STEM schools in order to inspire and guide the K-12 students toward undergraduate engineering education and careers in engineering disciplines. Future work includes completion of the set up of the cyber-learning network.

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Viewing K-12 Mathematics and Science Standards through the Lens of the First-Year Introduction to Engineering Course Classification Scheme

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Abstract— While there have been efforts to integrate engineering into K-12 through the planned development of standards, only recently have these plans come to fruition, albeit with seemingly little progress to appropriate integration. While the Common Core State Standards and the Next Generation Science Standards (among others) have provided a preliminary attempt to bring engineering into K-12, the research within this paper invites a different perspective on evaluating the preparation students are receiving for the first year of engineering. The hypothesis surrounding this review suggests that there exists a mapping of topics found in a first year engineering course, the classification scheme, into the Common Core State Standards for Mathematics and Next Generation Science Standards. Such a mapping would be multifaceted, enabling the construction of lessons tied to not only to Common Core, but also to the topics in the Classification Scheme. This paper will present the argument for the flexibility between the documents. Discussion on applications to advance K-12 Engineering Education will also be included with particular attention to the use of the Classification Scheme for First Year Engineering Courses as a foundation for the STEM pathway curriculum.

Keywords—K-12; curriculum; taxonomy; standards

I. INTRODUCTION

The Common Core State Standards for Mathematics and Next Generation Science Standards are recent attempts to standardize the knowledge expected of a high school graduate in the United States [1, 2]. These educational standards have been adopted or modeled after in multiple states and define the learning objectives for students in K-12 [3]. Separate standards for Engineering within K-12 have been considered, but have been deemed unsustainable given the current pool of teachers with the sufficient qualifications to integrate the subject into their classrooms [4]. Teachers who have attempted to incorporate engineering into their courses have often struggled due to the time constraint of covering the required standards by which students are formally assessed. In spite of a teaching force largely unprepared to teach engineering [5], there is considerable interest in creating pathways to success in a STEM degree program through the existing curriculum [6].

We will begin by examining the educational standards themselves and the current status of engineering in K-12. Then, methods of STEM integration will be discussed along with best practices associated with the idea of integration.

A. Educational Standards

The prevailing educational standards in use are the Common Core State Standards for Mathematics and the Next Generation Science Standards. From an organizational standpoint, the structure of Common Core and the Next Generation Science Standards are fundamentally similar, but differ in areas. For instance, the Common Core State Standards for Mathematics document is divided into two distinct sections, namely the Standards for Mathematical Practice and Mathematical Content Standards [1]. The Standards for Mathematical Practice (SMP) define eight skills that are expected to be developed throughout the student's mathematical career (which were inspired by the *Principles and Standards for School Mathematics*) [7]. All eight of the standards are listed below:

- SMP.1) Make sense of problems and persevere in solving them.
- SMP.2) Reason abstractly and quantitatively.
- SMP.3) Construct viable arguments and critique the reasoning of others.
- SMP.4) Model with mathematics.
- SMP.5) Use appropriate tools strategically.
- SMP.6) Attend to precision.
- SMP.7) Look for and make use of structure.
- SMP.8) Look for and express regularity in repeated reasoning.

The Mathematical Content Standards contain specific statements of skills that students must master. The skills are specified by grade level for grades K-8. Beyond these grades, the High School section of the content standards elect to split into six categories of topics: Number and Quantity, Algebra, Functions, Modeling, Geometry, and Statistics & Probability [1]. In order to compensate for varying curricula and student ability, the separated topics tend to be much easier to apply rather than topics grouped by grade level. To illustrate, the

following excerpt from CCSS.MATH.CONTENT.HSN.TF.C.9 (this is a code identifying where the standard is placed by section, grade level, domain, and specific standard) in the context of the Common Core State Standards:

“Prove the addition and subtraction formulas for sine, cosine, and tangent and use them to solve problems.” [1]

and another example from the Number and Quantity section:

“Explain why the sum or product of two rational numbers is rational; that the sum of a rational number and an irrational number is irrational; and that the product of a nonzero rational number and an irrational number is irrational.” [1]

It should be made clear that these individual statements of proficiency are more complex and expect a particular performance from students on the associated standardized assessments unlike simplistic bulleted topics of the past. This is highlighted in the action verbs used to identify the level of competency expected from the student: prove, explain, and so on (reminiscent of *Bloom’s Taxonomy*).

The Next Generation Science Standards are structured in a slightly different fashion and the topics themselves are primarily inspired by the National Research Council’s *A Framework for K-12 Science Education* [2, 8]. A topic begins with the performance objectives, as one would see if reading through the Common Core State Standards for Mathematics. A reader would then see what are called “Foundation Boxes” with the following headings: Disciplinary Core Ideas (DCIs), Science and Engineering Practices, and Crosscutting Concepts [2]. Figure 1 provides a general layout of how the boxes appear in the Next Generation Science Standards.

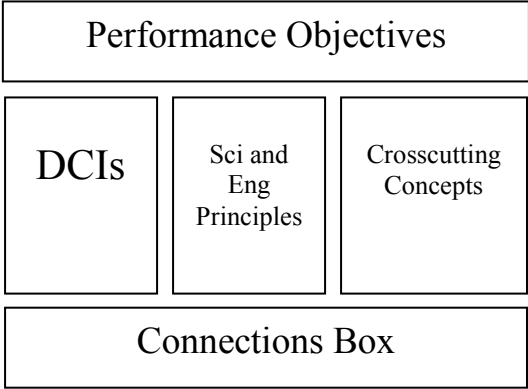


Fig 1: Layout of the Next Generation Science Standards

The Disciplinary Core Ideas are fundamentally the same as the performance objectives, albeit some additional clarification provided by the writing team after “unpacking” main ideas from the science disciplines. Any performance objectives that could be used to construct the Disciplinary Core Ideas are listed in the Science and Engineering Practices category. Finally, Crosscutting Concepts contains relevant performance objectives that highlight the dependence that science has on engineering and vice versa.

Moreover, the last section associated with each broad topic is the “Connection Box” which is also separated into three boxes: connections to other DCIs in this grade level, articulation of DCIs across different grade levels, and connections to the Common Core State Standards [2]. “Connections to other DCIs in this grade level” is self-explanatory; a list of related performance objectives are given. “Articulation of DCIs across grade levels” lists the DCIs related to other DCIs which provide either a foundation for the given topic or build on DCIs for later grades. The “Connections to the Common Core State Standards” contains standards from Common Core English Language Arts & Literacy and Mathematics that are directly related to the performance objectives. This particular section will be revisited later in the paper.

Beyond Common Core and the Next Generation Science Standards, separate standards for Engineering within K-12 have been considered and implemented such as the Massachusetts State Standards for Engineering and Technology [9], but others have been typically unsustainable on a larger scale [4].

B. Engineering in K-12

Often existing outside of the standard curriculum, particular portions of STEM do not reach a large population of students. A few notable engineering, or pre-engineering, programs do exist and have been successful over the past few years since their creation.

Project Lead the Way (PLTW) is likely the most visible program that is prepackaged with existing professional development opportunities [11]. Another advantage is the common assessment associated with the Project Lead the Way curriculum. The Tufts Center for Engineering Education and Outreach with LEGO Education offer the LEGO Engineering program to be integrated into the curriculum at any feasible age group [12]. Unlike Project Lead the Way, this particular attempt at integration is done through a familiar medium which is naturally hands-on. The familiarity can be exploited particularly in lower grades due to the average age of students, but this can certainly be effective in higher grades [13]. While LEGOs can be flexible in some respect, there are a few limitations – mostly in design freedom.

Another leader in engineering curricula, the Boston Museum of Science, developed what is currently known as Engineering is Elementary. This outreach rivals the Project Lead the Way program by also offering professional development opportunities in addition to rich methods of assessment for student learning [14]. Also, as a program built from the ground up, the Engineering is Elementary curriculum is aligned to the set of standards native to the Boston Museum of Science, namely the Massachusetts State Standards.

Schools created outside of the traditional K-12 systems often focus on project based learning; for example, MC2STEM High School in Cleveland is one such school [15]. Other than project based learning, other methods of integrating engineering include problem based learning and model eliciting activities. These three different, but related, types of activities and pedagogies are all applicable for instilling a

STEM state of mind. A brief summary of these three topics are as follows:

1) *Project Based Learning*

Within the context of project based learning, students react to a real-world, authentic scenario. The teacher guides the students through a plan beginning with preliminary research, followed by analysis, and concluding with performing the design process. The key to project based learning is requiring the students to present to an authentic audience once the project is complete [16].

2) *Problem Based Learning*

Students begin with the presentation of a problem, which is the primary motivation. Problem based learning is similar to project based learning in the sense that the problem is wholly dependent on an authentic real life scenario. Another similarity that can be drawn from project based learning is the ill structured nature of the problem, where not all of the information is given. Students are required to research and use appropriate resources at their disposal in order to solve the problem [17].

3) *Model Eliciting Activities (MEAs)*

This type of activity is far more involved than both problem and project based learning. Similarities to the previous two pedagogies are obvious, such as using an authentic scenario - preferably an appropriate application in STEM. Students are required to develop a model, either physical or purely mathematical, in order to solve a real world problem. The set-up of MEAs are purposely designed to be as realistic as possible, even to the point of having memos from their "customer" delivered to the students at the appropriate times. The rigor is the distinction with an MEA, both in creating and implementing them. Plenty of MEAs already exist, but finding adequate classroom time is the issue [18].

Through these three different avenues to incorporate STEM, particularly engineering, into the curriculum, we turn to the guiding principles for K-12 Engineering Education [19]:

Engineering design should be emphasized – As a centerpiece of engineering, design needs to be the focus of modeling and analysis when dealing with what we would call an "engineering problem."

Appropriate STEM knowledge and skills should be incorporated – Without a strong basis of skills in the context of STEM, we cannot expect students to succeed in the higher level tasks within science, math, engineering, or technology careers.

Engineering habits of mind should be promoted – The "habits of mind" refer to the necessary skills for the 21st century citizen: systems thinking, creativity, optimism, collaboration, communication, and ethics.

C. *Integration of Engineering in K-12*

The report by the National Academy of Engineering, *Standards for K-12 Engineering Education?*, defines *infusion* as incorporating learning objectives of one discipline in standards for another discipline [10]. In this case, it is simple

to bring the guiding principles for K-12 engineering education into the mix of the current curriculum. Another approach, called *mapping* in the report, involves drawing attention to how and where main ideas from a discipline naturally relate to the standards of another discipline [4].

By combining these two methods, the principle of infusion can be successfully used in order to allow engineering content to be more prominent in STEM standards, better communicate the relationship between engineering and other disciplines, and – as a result – engineering would be included in the standards for assessment. After a successful mapping, different connections that the developers of the standards did not see can be revealed, and the likelihood of engineering being used as a motivation tool can be increased.

In *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*, the Committee on Integrated STEM Education summarizes three key implications for STEM integration initiatives: (1) integration should be made explicit, (2) knowledge of individual disciplines should still be supported, and (3) more integration is not necessarily an improvement [20]. Issues primarily begin in the urge to string various concepts together in the name of making connections between subjects. We now turn to a tool which can facilitate making connections to engineering while following the guiding principles for K-12 engineering education and the Committee on Integrated STEM Education's recommendations.

II. A DIFFERENT LENS FROM FIRST-YEAR ENGINEERING

While *not* a set of standards by nature, The *Classification Scheme for First Year Engineering Courses* is a taxonomy that outlines the possible topics that can be found in a first year engineering course [21]. Created with support from a National Science Foundation grant, the scheme allows instructors to classify the content of their courses using a common tool [21]. In addition, students transferring to one university from another can be awarded accurate credit for an introductory course based on the classification results.

For organizational purposes, the taxonomy is divided into eight primary aspects, or main topics: Communication (COMM), Engineering Profession (ENPR), Math Skills and Applications (MATH), Design (DESN), Global Interest (GLIN), Professional Skills / Latent Curriculum (PROF), Academic Success (ACAD), and Engineering Specific Technology/Tools (ESTT) [22]. These main topics are each given by a four letter code, as shown. A topic that is listed under a main topic is given a Roman numeral and sub-topics related to the one level above are given letters. Any topics under a sub-topic are given numbers.

To illustrate the ID assignment, *Empirical Functions*, which is under Math Skills, is given the following way:

Main Topic MATH, Topic IX, Sub-Topic A, Specific Topic 1.

Using the organizational methodology, this piece's ID would be MATH IX.A.1. Notice that the structure is reminiscent of Common Core and the Next Generation Science

Standards. Thus, a convenient mapping between the taxonomy and the other educational standards is feasible. In fact, a fair amount of work has been done to map between various sets of standards already.

A. Mapping Standards

Plenty of efforts have attempted to make explicit connections between standards. One such attempt was presented by Palincsar in her argument for meeting objectives of Common Core State Standards for Science and Next Generation Science Standards simultaneously. This is primarily achieved by using principles of literacy and oral language to facilitate the learning of concepts [23]. Another exploratory study by Mayes and Koballa provides an alignment between the Standards for Mathematical Practice (SMP) and Scientific and Engineering Practices (SEP) as defined in the Next Generation Science Standards [24]. The eight Scientific and Engineering Practices are taken from *A Framework for K-12 Science Education* [8] and are listed below:

- SEP.1) Asking questions (for science) and defining problems (for engineering).
- SEP.2) Developing and using models.
- SEP.3) Planning and carrying out investigations.
- SEP.4) Analyzing and interpreting data.
- SEP.5) Using mathematics and computational thinking.
- SEP.6) Constructing explanations (for science) and designing solutions (for engineering).
- SEP.7) Engaging in argument from evidence.
- SEP.8) Obtaining, evaluating, and communicating information.

The connections drawn by Mayes and Koballa are shown in Figure 2.

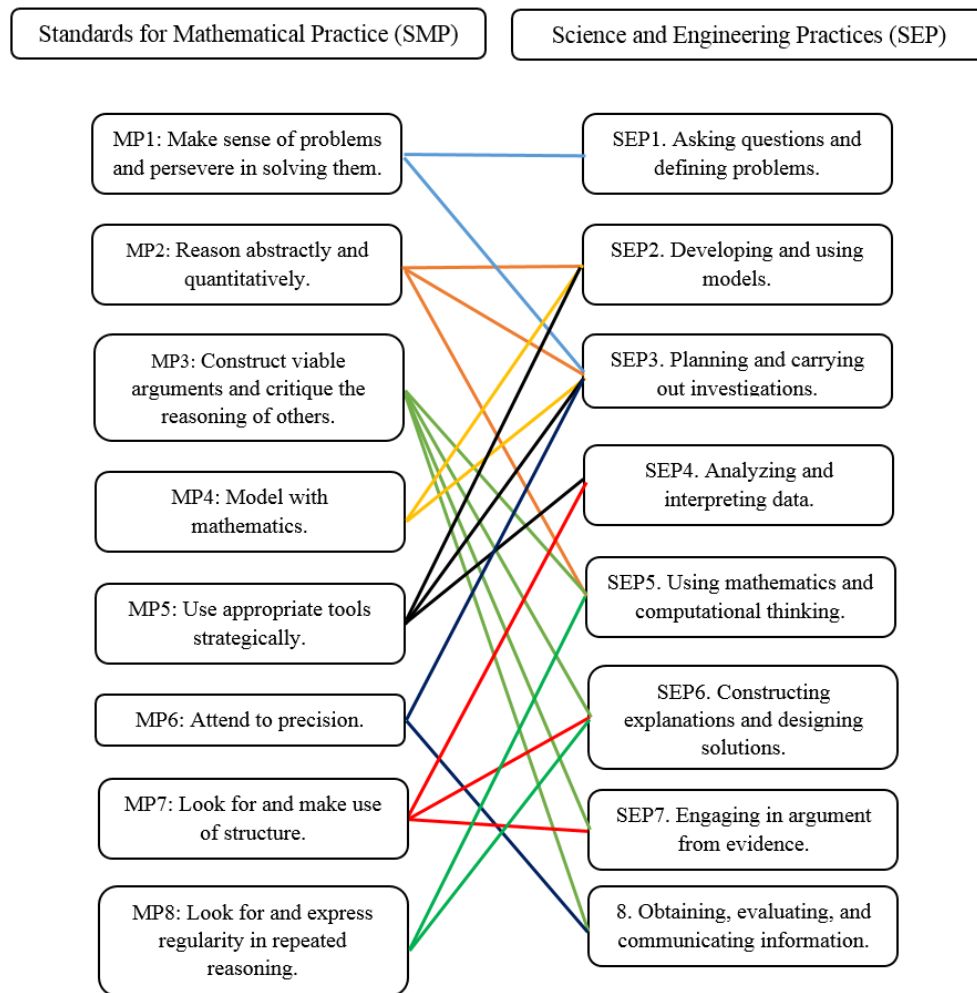


Fig 2: Mapping of Alignment between the SMP and SEP [24]

Another model is offered by Stage et al. which connects Common Core State Standards for English & Language Arts, Mathematics, and the Next Generation Science Standards [25]. To some respect, the model can be considered an expansion of Mayes and Koballa with the distinction being that the Science and Engineering Practices are not directly mapped to the Standards for Mathematical Practice. However, due to the lack of a direct mapping, Stage et al. claims that the intersection of math and science is merely the use of models and mathematical/computational thinking while Mayes and Koballa assert that the relationship is much tighter [24,25]. In addition to the external studies, the authors of the Next Generation Science Standards provided a mapping of their own into the Common Core State Standards.

In Appendix L of the Next Generation Science Standards, the authors noted more obvious connections to the Common Core State Standards for Mathematics [2]. The authors claim that three particular standards for mathematical practice are related to science: “Reason abstractly and quantitatively” (MP.2), “Model with Mathematics” (MP.4), and “Use appropriate tools strategically” (MP.5). The authors then proceed to define connections that are more explicit.

III. UTILIZING THE CLASSIFICATION SCHEME FROM A CURRICULUM EVALUATION PERSPECTIVE

First-year programs across the nation typically feature an introductory curriculum featuring a semester or yearlong “Introduction to Engineering” course or course sequence [21]. Upon examination of these courses, variation in content is prevalent [26]. For instance, a course from one institution could focus on MATLAB programming while a course at a different university could emphasize technical communication. Through the development of the taxonomy, the composition of first year engineering was distilled into predictable topics that could appear within an introductory course. The process of filtering through the taxonomy is referred to as “classifying a course,” naturally. Most applications of the classification scheme have been with the intention of program evaluation [21], but data has been collected in an attempt to define a *typical* first year engineering course [26].

Statistically, the summary described in [26] is limited to the sample from which the courses were taken; however, there is some insight that can be culled from the preliminary results in the context of preparing a STEM pipeline. In the previously reported study, a sample of 28 classified courses from 24 different institutions were used from an NSF sponsored workshop at the First Year Engineering Experience Conference in Pittsburgh in 2013 [26]. In the analysis, the total number of times each topic was marked as covered in the course was recorded on a separate document; the five number summary (minimum, first quartile, median, third quartile, and maximum) was calculated for each of the eight main topics.

For the sample, communication and professional skills were emphasized, but mathematical skills were surprisingly absent – likely due to the fact that courses such as Calculus are taken at the same time.

As a reflective piece, we invite K-12 educators and administrators to examine their definition of engineering and

how well they believe their students are being prepared for the first year of engineering. As evidenced in the literature, the perception of engineering is generally not on mark, which serves to spread myths about the profession. Moreover, the development of students as proficient communicators is of considerable interest when considering the sample since emphasis appears to be placed on team-based and professional communication. Finally, preparation in mathematics is of concern. Thus, the following guiding questions are offered for those interested in using the *First Year Engineering Classification Scheme* as a tool for curriculum evaluation:

- 1) *How well does the curriculum address the subject of engineering?*
- 2) *How well does the curriculum develop effective communicators?*
- 3) *How well does the curriculum develop students that are proficient in mathematics?*

The taxonomy provides a convenient bridge to these questions using *keywords*. Recall that the Common Core State Standards and the Next Generation Science Standards are phrased in such a way that keywords can be pulled and tied.

The topics outlined in the taxonomy are deliberately lumped to simplify the classification of courses and reduce statistical variables, which creates a useful correspondence to the domains found in the Common Core State Standards. For instance, CCSS.MATH.CONTENT.HSF.TF, the domain on Trigonometric Functions perfectly maps to MATH I.0.0 (Trig Review) in the classification scheme. In the Next Generation Science Standards, the most relevant section would be HS-ETS1, “Engineering Design.” Indexed under this is the first performance expectation HS-ETS1-1, “Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.” [2] Plenty of topics from the taxonomy will map to this such as GLIN I.0.0 “Grand Challenges,” GLIN II.0.0 “Concerns for Society,” and DESN IV.0.0 “Criteria and Constraints.”

IV. IMPLICATIONS

Simply using the taxonomy as a guide to integrate engineering while simultaneously covering standards should be a welcome tool for the K-12 environment. To reiterate, the report, *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*, the Committee on Integrated STEM Education provides three key implications for STEM integration initiatives, one of which is that integration should be made explicit [20]. Much of what K-12 currently does can be reframed as engineering; this is the concept of “mapping” discussed earlier.

One distinct benefit of the mapping is bringing awareness to the community of K-12 educators and demystifying the profession. Knowing what can be found in the context of first year engineering can aid in the reforming of curricula in order to feed competent students into the STEM pipeline.

In addition, much of engineering lends itself to the Standards for Mathematical Practice – especially modeling. Making sense of problems and reasoning abstractly and quantitatively are naturally engrained in the process of creating design solutions. The students need to “construct viable arguments and critique the reasoning of others” to decide on the most feasible design to realize, and so on. Engineering is hidden in the K-12 curriculum, it is hoped that this mapping will aid in solving the subject’s identity crisis.

Possible actions for first year engineering programs could include using the classification scheme in order to determine what is covered in their courses in terms of the topics and codes. Becoming more familiar with the K-12 standards can also be advantageous by adjusting expectations for incoming first year students in terms of their math and science skills. Both schools and universities can use the scheme for curriculum development and evaluation, but with the realization that covering all of the topics listed in the taxonomy is not feasible in a single course.

V. CONCLUSION

The *First-Year Introduction to Engineering Course Classification Scheme* is a tool that was developed and validated through testing with multiple institutions. The taxonomy has been a useful tool for departments assessing the content of their introductory curricula.

This literature review suggests that there exists a clear mapping of topics found in an arbitrary first year engineering course, the classification scheme, into the Common Core State Standards for Mathematics and Next Generation Science Standards. This mapping would be flexible in order for the construction of lessons tied to all three documents naturally.

It is hoped that K-12 finds the taxonomy to be a useful tool for the examination of curricula and tying appropriate standards to lessons.

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Effects of the Butterfly Diagram Education in Primary and Secondary Schools on Contradiction Problem Solving Ability

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Abstract—In the history of science and technology, many creative and innovative cases were found in contradiction problem solving. However, most research about creativity has rarely paid attention to contradiction solving so far. This paper introduces the way how adolescent solves contradiction problems with the Butterfly diagram, and shows the effects of the Butterfly diagram education in primary and secondary schools on contradiction problem solving ability. The Butterfly diagram uses symbolic notation and systematic representation for solving contradiction problem. It shows the structure of a given contradiction problem visually. Drawing a Butterfly diagram for solving a contradiction problem can reduce the problem space because it helps to figure out the problem structure and the problem type of the given problem. In the three experiments of this paper, we analyzed the effects of the Butterfly diagram education on contradiction solving ability. The students who learned the Butterfly diagram have awarded for 9 years (2007~2015) in a row when they participated in invention festivals. Three primary school students, 12 secondary school students, and 46 college students have awarded in invention festivals so far. Among them, 5 middle school students, 4 high school students, and 15 college students, and one graduate school students have registered 18 patents.

Keywords—creative problem solving; The Butterfly diagram; contradiction problem solving; TRIZ

I. INTRODUCTION

In the history of science and technology, many creative and innovative cases have solved contradiction problems. For example, James Watt made a break-through in Newcomen steam engine by solving the contradiction that the cylinder of the engine should be hot and cold at the same time [1]. The second example can be found in the public key infrastructure. When two parties communicate with each other trustworthily on the internet, the two parties should share a private key to construct a secure channel. However, the private key should not be opened to others due to security. Thus a contradiction occurs in this problem. The private key should be opened and not be opened for secure communication. In 1976, Diffie and Hellman proposed the innovative public key concept. E-Commerce became possible due to their idea by separating

key roles into two: one is locking with a public key and the other is unlocking with a private key [2].

Duncker's radiation problem has been a well-known problem in the area of problem solving psychology. It is described as follows [3]:

“Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at a sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue?”

Duncker's solution was dividing the intensity level of the ray into high and low. In other words, for destroying the tumor, the ray at the high intensity level was used, whereas for avoiding harmful effect to the healthy tissue, the ray at the low intensity level was used. Duncker's radiation problem has a contradiction that the intensity level of the ray should be high and low at the same time to solve the two conflicting problems. However, many research works on Duncker's radiation problem did not examine the problem from the contradiction resolution point of view [4][5][6].

Most research about creativity has rarely paid attention to contradiction problems so far because the western science since Aristotle has regarded contradictions as false, wrong thing, and empty set [7]. Due to this tradition, problem solving psychology in the west has classified problems into well-defined problems and ill-defined problems, or analytic problems and insight problems [8]. Many western researchers did not examine the problem from the contradiction resolution point of view [1]. Simonton, who had performed a lot of research on scientific discovery, explained that logic plays a secondary role in the generation of highly creative ideas. He argued that serendipity is important in truly original ideas and scientific discovery than logic [9]. He considered that creative

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idea cannot be solved by an algorithm consisted of a set of pre-determined steps.

Simon proposed that in order to solve complex problems, it is important to grasp problem types and to represent them appropriate [10][11]. The appropriate symbols and systematic representation enhance the problem solving ability of a problem solver [12][13]. So far, most of the research and the models for creative problem solving were descriptive [14]. However, the Butterfly diagram of this research proposes a systematic representation about contradiction problem using symbolic notation. The Butterfly diagram was motivated from TRIZ [14][15][16][17] originally. However, it overcame TRIZ's limitations, and the logical proofs about the Butterfly model was given in [1]. The Butterfly diagram helps to decide the right solution strategy for contradiction types by showing trade-off and contradiction relations of the given problem. The diagram contains the trade-off relation between the functions of a given problem and the contradiction relation between the system states generated for performing the functions. It shows the structure of a given contradiction problem visually [1]. The Butterfly diagram for contradiction problem solving can reduce the problem space by figuring out the problem structure and the problem type of a given problem [11][13].

This paper describes the way how adolescent applies the Butterfly diagram to contradiction problem solving, and shows the effects of the Butterfly diagram education in primary and secondary schools on contradiction problem solving abilities. In order to achieve these objectives, we performed three experiments to examine if the Butterfly diagram education affects the students' problem solving ability.

The first experiment is as follows: we selected the contradiction problems of the cannon ball and the installation art for measuring the students' contradiction problem solving abilities. The number of the students was 129. They solved one problem before they learned the Butterfly diagram. And then, they solved the other problem after they had learned the Butterfly diagram. Next, we analyzed the effects of the Butterfly diagram education on contradiction solving ability. The second experiment is as follows: we chose Duncker's radiation problem [3]. We analyzed the difference in the ratio of solving the radiation problem between the students who learned the Butterfly diagram and the students who did not. The third experiment checked if learning how to solve contradiction problems with the Butterfly diagram affected the students' growth mindset positively [18][19]. In Dweck's self-theory, people's mindset types are divided into 2: the fixed mindset and the growth mindset. According to the theory, people who have the growth mindset usually have a tendency to embrace challenges and to learn from failure [18].

The rest of our paper is organized as follows. In section 2, we review the drawbacks of TRIZ [14][15] and the mindset theory proposed by Dweck [18][19]. In section 3, we define a steps of our experiment. In section 4, we describe the results of the experiment. Finally, we conclude our paper in section 5. We discussed the reason and the practices about the students' increased contradiction problem solving ability in section 5.

II. BACKGROUND

A. TRIZ

TRIZ is the Russian acronym for the "Theory of Inventive Problem Solving". It was developed by Altshuller and his colleagues [14]. They found out that innovative inventions had something in common. The common thing was that the inventors had resolved contradictions without compromises [15].

We can find an example contradiction from a home bar link of a refrigerator produced by Samsung [20]. Recently, in many refrigerators have home bars (small doors) to take something out of the refrigerator easily without open the big door of the fridge. After opening the home bar, in order to prevent the home bar open fully and to close the door easily, GE invented home bar links and attached the links to the both edge sides of the home bar as shown in Fig. 1 (a). The links are expensive, but they are needed to open and fold the home bar door. In fact, there was a trade-off relation between function efficiency and manufacturing cost of the home bar link. Since Samsung had paid a lot of loyalty to GE for home bar links [20], Samsung started to develop a new method to open the home bar safely and to improve its aesthetic appearance with TRIZ researchers. Samsung Electronics eliminated the home bar link as shown in Fig. 1 (b) [21]. Samsung modified the home bar so that it performed the link's function by itself (Self-service principle of TRIZ 40 principles [22]). Samsung solved the contradiction by extending the latch of the home bar door behind the joint. There was no need to install links any more.

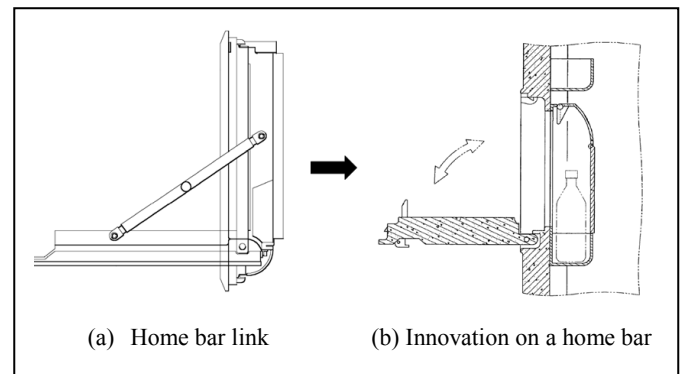


Fig. 1. A home bar innovation of refrigerator [21].

Even though TRIZ has contributed to problem solving area, it has a few limitations. Firstly, Altshuller and his colleagues established TRIZ having a set of rules found by inductive patents analysis not deduction [14]. Secondly, since they did not define TRIZ terminologies exactly, many researchers have defined the terms arbitrarily. Thirdly, TRIZ experts have insisted that TRIZ can avoid trial-and-errors such as Brainstorming, but this is not true. ARIZ-85c, the algorithm of inventive problem solving, has many steps [15]. Among them, the step 6.3 specifies "Go to step 1.4 and analyze another alternative if the chosen method cannot solve the problem correctly". This step tells us that TRIZ still has many trial-and-errors (a brute-force method) like other creative problem solving algorithms [23]. Fourthly, Altshuller

recommended that learners study more than 80 hours in order to apply TRIZ to the real problem in the preface of ARIZ-85c. It seems a long time for teenagers to learn TRIZ at schools. If we have a tool for teaching TRIZ easily to teenagers, then the teenagers will enhance their creative problem solving ability.

B. The Butterfly Diagram and the Butterfly Model

Every proof in mathematics consists of a chain of deduction. Deductive reasoning reaches a new true fact based on the already identified premises. The certainty of mathematics came from deductive proofs. Euclid published 'Elements' about 2,300 years ago. Euclid's Elements is innovative because it followed the proof systems that if an premise is true, then the conclusion is also true by using the deductive reasoning [24].

As Euclidean geometry derived 465 theorems based on 23 definitions, 5 postulates, and 5 axioms, the Butterfly model defined the components of the model firstly based on classifying contradiction problems into 9, and then performed a logical proofs about the optimal solutions of the 9 types of contradiction problems [1]. This approach is to adopt the method which divides a complex problem into a set of small problems, and then solve from the simplest problems to the most complex one like Descartes method.

The Butterfly diagram is a component of the Butterfly model described in [1]. The Butterfly diagram assumes the interconnectivity of a system that when some part of a system gets better, other part of the system gets worse, and vice versa [16][17]. It represents the interconnectivity with the relations caused by required functions required by a given problem. Fig. 2 shows a net. In the net, when a person pulls the area w , the area u shrinks on the contrary. In addition, there are a trade-off relation and a contradiction relation for a given problem in a Butterfly diagram[1]. The trade-off relation in a diagram can be depicted in rectangles containing two functions, w (wanted function) and $\sim u$ (not unwanted function), whereas the contradicting relations between two system states, s and $\sim s$. We explain the trade-off relation with a seesaw as shown in Fig. 3. Fig. 3 represents the importance of the fulcrum of the seesaw. In order to perform a specific function between the two functions of a system, it is important where to set the fulcrum. If the fulcrum is located closer to w (wanted function) than u (unwanted function), then the function w will be improved, and vice versa. Thus, the definite cause for generating a trade-off relationship depends on the location of the fulcrum (s or $\sim s$), where s and $\sim s$ have a contradiction relation [1]. The Butterfly diagram helps to select the right solution strategy for contradiction types by showing trade-off and contradiction relations of the given problem visually [16][17].

Next, the Butterfly diagram uses symbolic notation and systematic representation for solving contradiction problem [7]. Let us explain the necessity of symbolic notation and the systematic representation. Symbolic logic has advantages that eliminate the ambiguity of natural language and simplify the logical structure of a given problem. As a result, symbolic notations and systematic representations enhance the problem solving ability. If we know the structure and the type of a

given contradiction problem, we can solve the problem easier by using the representation [13][25].

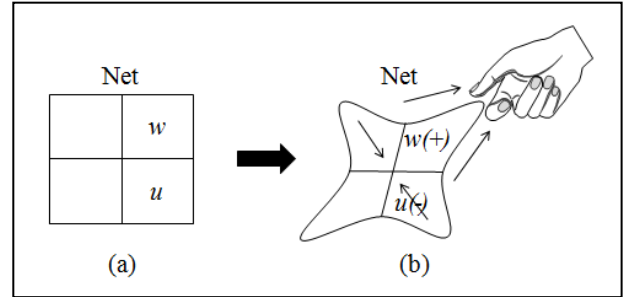


Fig. 2. Interconnectivity between two areas of a net.

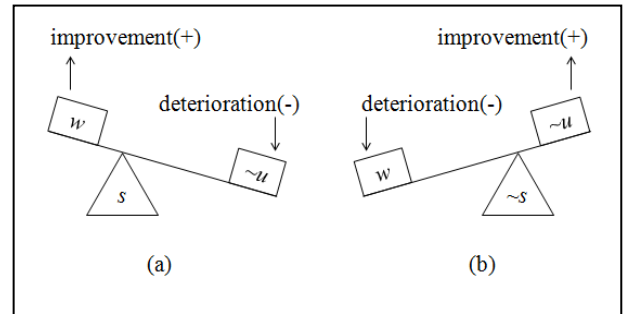


Fig. 3. The importance of the location of the fulcrum.

The conditional proposition ($w \rightarrow s$) in logic is equivalent to ($\sim s \rightarrow \sim w$) by the contraposition law. Therefore, for the relationship among conditional propositions with w , s , and u , we have a logical equivalence such that ($w \rightarrow s$) \equiv ($\sim s \rightarrow \sim w$), ($s \rightarrow u$) \equiv ($\sim u \rightarrow \sim s$). Base on these equivalences, we can draw a Butterfly diagram for the relationship among w , u , and s as shown in Fig. 4. In Fig. 4, let w be the wanted function to solve a given problem and s be the state caused by performing w . We describe it as $w \rightarrow s$. Next, let u be the unwanted function cause by the state s and $\sim u$ be the contradictory function of u . At this point $\sim u$ should make a trade-off relation with w . Then, $\sim u$ causes the state $\sim s$ by the contraposition law, and s and $\sim s$ have a contradiction relation by nature. The examples about Butterfly diagrams will be presented in the following section.

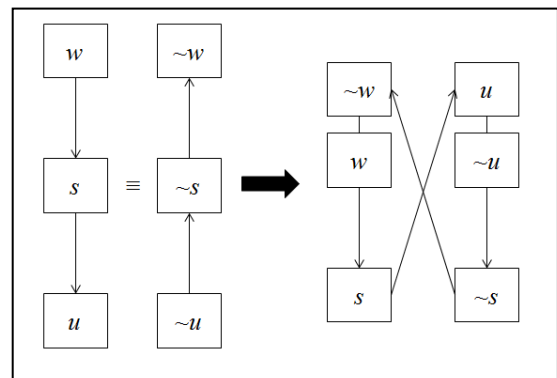


Fig. 4. Components of a Butterfly diagram.

The Butterfly model defines a problem, P , as a system, S , which is composed of 6 components, w , $\sim w$, u , $\sim u$, s , and $\sim s$ [26]. In the model, w is a wanted function of S , $\sim w$ is the contradictory function of w and u is the harmful function caused by satisfying s and the contradictory function of $\sim u$. $\sim u$ is the function that have a trade-off relation with w , s is a condition for supporting w , and $\sim s$ is a condition for supporting $\sim u$. At this moment, system state s and $\sim s$ have a contradiction relation. In summary,

$$P = S(w, \sim w, u, \sim u, s, \sim s).$$

In the Butterfly model, a contradiction relation is more concrete, and thus it has narrower problem space than trade-off relation. And then, the Butterfly can find out the solution strategy for the given problem easily by combining its trade-off relation and contradiction relation. After finding out its solution strategy, according to the type of the problems, the appropriate system states are applied to derive the problem solutions more precisely. The process of the Butterfly model as shown in Fig. 5.

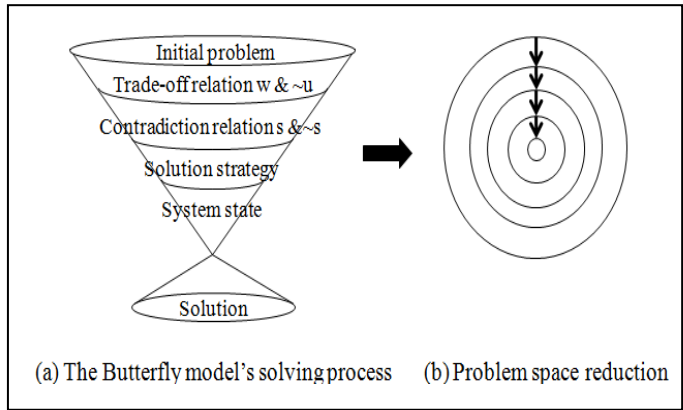


Fig. 5. The Butterfly model's solving process and its problem space reduction

III. EXPERIMENTS

In this paper, we examined if our students' contradiction problem solving ability and their growth mindsets were affected positively by learning the Butterfly diagram. In order to achieve the research objective, we surveyed three times and describe in detail in the following. The respondents of each experiments are different each other. In experiment 1, the average age of the primary school students was 12, whereas the one of the middle school students was 14. In experiment 2 and experiment 3, both of the average age of the middle school students were 14. Our learning process is as shown in Fig. 6.

A. Experiment 1

In the first experiment, there were 59 primary school students (37 males and 22 females) and 70 middle school student (45 males and 25 females). They were all gifted students attending a university's science gifted education center. The student selection standards do not discriminate gender and residential district, and the selection methods are recommendation and interview. Or, the students who are

included in the top 10 percent in schools have a chance to apply.

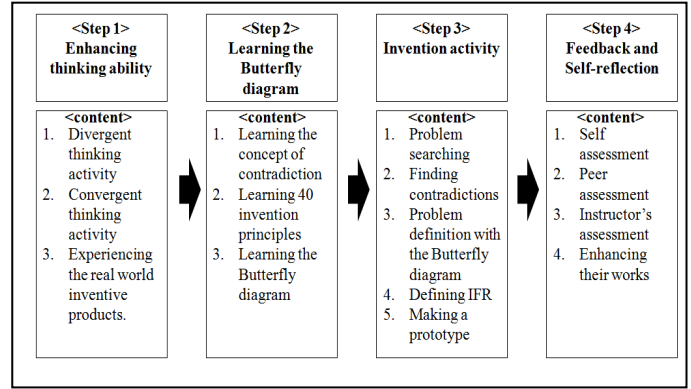


Fig. 6. The learning process.

To the students, we gave two problems. One was Armour-piercing fin-stabilized discarding-sabot (APFSDS) and the other was Bill Culbert's Bulb Box Reflection 2. The APFSDS problem is as following: if the size of a cannon is big, then the destructiveness of a shell will increase due to the explosive force of gunpowder in the cannon. However, since the size of the shell increases due to the size of the big cannon, the shell cannot fly further due to the heavy weight of the shell. In order for the shell to fly away, the size of the shell should be small. Thus, there exists a contradiction in this problem, i.e., the size of the shell should be big and small. The APFSDS solved the contradiction by changing the size of the shell shown in Fig. 7. and Fig. 8.

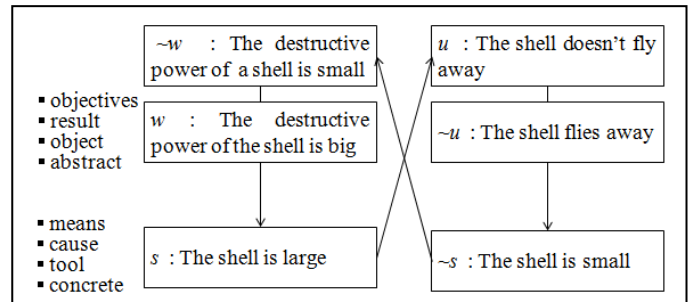


Fig. 7. The Butterfly diagram of the APFSDS problem.

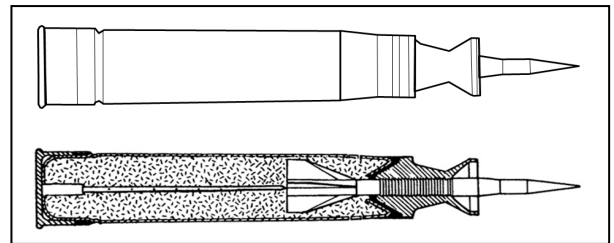


Fig. 8. The solution of the APFSDS problem. The small shell is put on the top of the big shell. The big shell contains huge amount of gunpowder.

The other contradiction problem was Bill Culbert's Bulb Box Reflection 2. In the Bill Culbert's Bulb Box Reflection 2, the bulb's reflection in a mirror is alight while the actual bulb

itself is not. The mirror reflects the opposite side except the light bulb (See also Fig. 9) [27].



Fig. 9. Bill Culbert’s Bulb Box Reflection 2.

In 1975, Culbert installed two light bulbs and one-way mirror between the two light bulbs. If the light bulb in the box is turned on and the light bulb outside the box is turned off, then the one-way mirror reflects not only the light bulb outside the box in the mirror, but also projects the light from the box at the same time. Culbert displayed this work successfully by using the one-way mirror’s contradiction feature. Fig. 10 represents the Butterfly diagram for Bill Culbert’s Bulb Box Reflection 2.

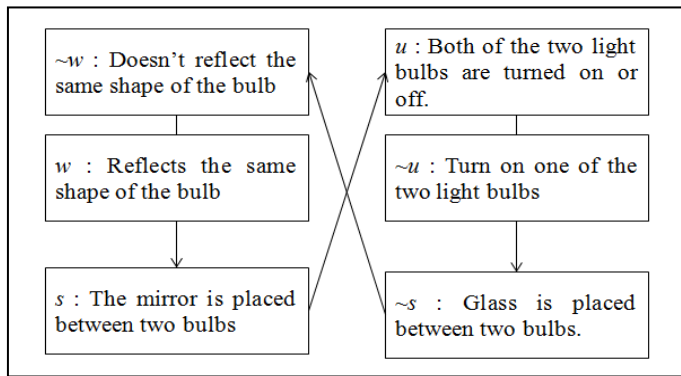


Fig. 10. The Butterfly diagram for Bill Culbert’s Bulb Box Reflection 2.

Before the students learned about the Butterfly diagram and the principles, the students solved one problem. And then, the students learned the theory for 4 hours, and then solve the other problem. The experiment design model is as follows (See also Table I) :

TABLE I. THE EXPERIMENT DESIGN MODEL

Primary school student	O ₁	X	O ₂
Middle school student	O ₂	X	O ₁

O₁ : To solve Bill Culbert’s Bulb Box Reflection 2 problem
O₂ : To solve APFSDS problem
X : To learn the Butterfly diagram

B. Experiment 2

In the second experiment, we provided Duncker’s radiation problem to see how many students solved the problem correctly after the students learned the Butterfly diagram. Duncker’s radiation problem has a contradiction between ‘to destroy the tumor’ (w) and ‘not to destroy healthy tissue’ (~u). We draw the problem with a Butterfly diagram as shown in Fig. 11. In the diagram, in order to destroy the tumor (w), the intensity level should be high (s). However, if the intensity level is high, then the healthy tissue can be destroyed (u). Not to destroy the healthy tissue(~u), the intensity level should be low (~s) [1]. ‘To destroy the tumor’ and ‘Not to destroy the healthy tissue’ have a trade-off relation, whereas ‘the intensity level of the rays is high’ and ‘the intensity level of the rays is low’ have a contradiction relation. The solution for Duncker’s problem is to use the weaker beams from each side so that it doesn’t harm the tissue, but the total power of the beams will meet at the tumor, enough so that it will destroy it.

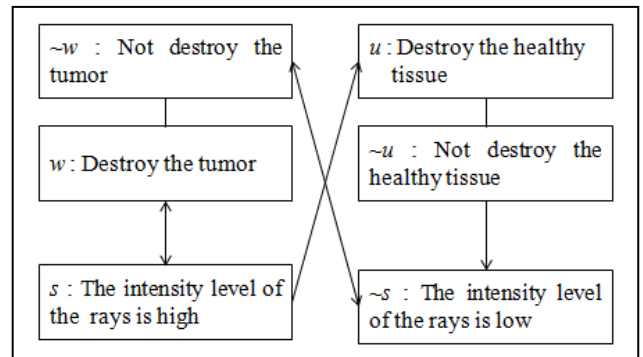


Fig. 11. The Butterfly diagram for Duncker’s radiation problem [1].

In the second experiment, there were 41 middle school students in total, and they were all the gifted students in the same university’s science gifted education center mentioned in the experiment 1. We divided the students into two groups: one was consisted of 15 7th grade students who are in the computer science class and learned the Butterfly diagram for 15 hours. The other was consisted of 13 physics class students and 13 biology class students. They did not learn the Butterfly diagram.

C. Experiment 3

In the third experiment, there were 44 middle school students. We taught the students with the same learning content. However, the 33 students did not learn the Butterfly diagram (24 mathematics class students, 9 physics class students), where as 11 students (computer science class) learned the Butterfly diagram for 17 hours. They were all the gifted students in the same university’s science gifted education center mentioned in the Experiment 1. After the education, we measured the growth mindset level of the students if there exists any difference between the experimental group and the control group.

IV. EXPERIMENTS' RESULTS

A. Experiment 1

We firstly performed an two-way ANOVA to check if there existed a mean difference between two student groups (primary and middle) for APFSDS problem and Bill Culbert's Bulb Box Reflection 2 problem (the bulb problem). If a student's answer was absolutely wrong or no answer, then the answer was scored as 0 point. If the answer was perfectly correct, then the answer was scored as 3 points. And, if the answer was slightly better than the zero-point answer, the answer was scored as 1 point. Similarly, if the answer was slightly worse than the 3-point answer, the answer was scored as 2 points.

For the primary school students, the mean value of the bulb problem was 1.03 ($SD = 0.72$) (before education), while the mean value of the APFSDS problem was 1.54 ($SD = 0.80$) (after education). On the other hand, for the middle school students, the mean value of the APFSDS problem was 0.57 ($SD = 0.79$) (before education), while the mean value of the bulb problem was 1.39 ($SD = 0.87$) (after education).

According to the result of the two-way ANOVA for solving the contradiction problem solving, the main effect of the Butterfly diagram learning presence was significant ($F(1, 254) = 43.83, p < 0.001$). The main effect of the difference between the bulb problem and the cannon ball problem was not appeared ($F(1, 254) = 2.34, p = 0.127$). The interaction effect between the learning presence and the problem type was also significant ($F(1, 254) = 9.60, p = 0.002$) as shown in Fig. 12. Table II shows the results of the two-way ANOVA with the interaction effect between the learning presence and the problem types.

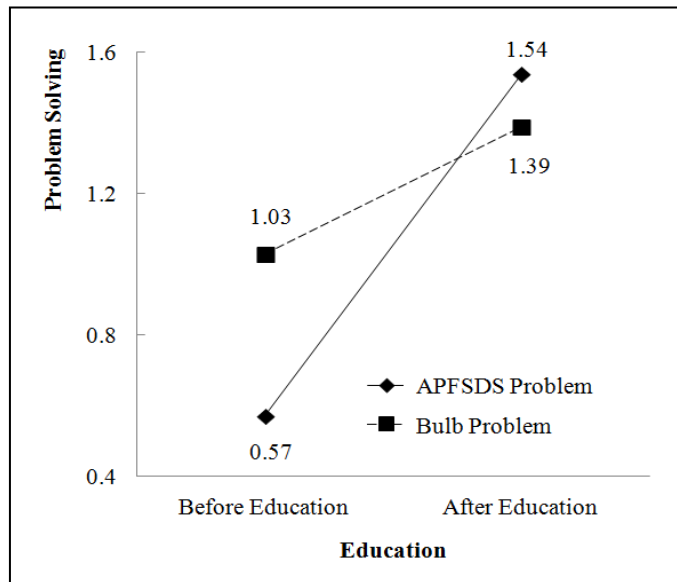


Fig. 12. The result of the two-way ANOVA.

Next, we performed a paired t-test to examine if there was the enhancement of program solving ability for each student. For the primary school students, the result of the paired t-test was statistically significant ($t(58) = -4.26, p < 0.001$). For the

middle school students, the result of the paired-t test was also significant ($t(69) = 5.20, p < 0.001$). It means that there existed the enhancement of the problem solving ability after the students learned the Butterfly diagram.

TABLE II. THE RESULT OF TWO-WAY ANOVA

Source	Sum of square	df	Mean square	F	p
Education (A)	28.01	1	28.01	43.83	< 0.001
Problem Type (B)	1.50	1	1.50	2.34	0.127
A * B	6.14	1	6.14	9.60	0.002
Error	162.31	254	0.64		
Total	197.96	257			

B. Experiment 2

In Duncker's research, the number of people who solved his radiation problem was 2. It was only possible after Duncker gave them hints. When a person is facing a given problem, getting a hint from somebody is not a realistic situation [28]. In the previous research of analogical problem solving with Duncker's radiation problem, when the researchers gave no hint, they got the solving ratios as follow: (1) In Gick and Holyoak's first experiment 0%, their second experiment 8%, their fourth experiment 7%, their fifth experiment 10% [5], (2) In Spencer and Weisberg's first experiment 7%, their second experiment 4% [29], (3) In the Pedone, Hummel, and Holyoak's first experiment 13%, their second experiment 11% [30]. In summary, the average problem solving ratio was 7.50% ($SD = 4.11$).

This research examined if there existed the difference in contradiction problem solving ability between the students who learned the Butterfly diagram and the students who did not. In experiment 2, the number of male students who did not learn the Butterfly diagram was 20 (76.9%) and the number of male students who learned the diagram was 11 (73.3%). Firstly, for Duncker's radiation problem, the problem solving ratio for the students who did not learn was 8%, whereas the ratio for the students who learned the diagram was 33%. It was the higher value than the previous experiments. In the Gick and Holyoak's 4th experiment, they gave a hint to the participants. As a result, they got the 20% problem solving ratio [5]. Also, Catrambone and Holyoak's first experiment showed 16% problem solving ratio with a hint to the participants [31]. Our ratio is much higher than them. As a result, we verified the educational effect of contradiction problem solving on the Butterfly diagram.

C. Experiment 3

In experiment 3, the number of male students who did not learn the Butterfly diagram was 28 (84.8%) and the number of male students who learned the diagram was 8 (72.7%). In order to avoid the respondents' answers that were desirable to the authors of this paper, a graduate student helped us by saying that she wanted their answers for her paperwork. The respondents firstly answered the questionnaires to measure their time perspectives for about 5 minutes. And then, they answered three questions that are developed by Dweck

[18][19] as follows: (1) Your intelligence is something about you that you can't change very much (reverse coded). (2) As much as I hate to admit it, you can't teach an old dog new tricks. People can't really change their intelligence (reverse coded). (3) No matter who you are, you can significantly change your intelligence level.

The first 2 questions are about the fixed mindset, whereas the third one is about the growth mindset. By using the 3 answers of the questions, we obtained the mean value of the growth mindset. And then, we defined this value as the growth mindset value. The Cronbach's alpha (α) was 0.83. It means that the 3 questions had an internal consistency, and were reliable as a measurement. Next, we performed a t -test between the student group learned the Butterfly diagram and the student group not learned the diagram with the growth mindset value as a dependent variable. Fig. 13 shows the result.

The growth mindset value of the students who did not learn the Butterfly diagram was 4.65 ($SD = 1.28$), whereas the growth mindset value of the students who learned the Butterfly diagram was 5.55 ($SD = 0.69$). The result of the t -test was statistically significant (Levene test $F = 4.14$; $p = 0.048$, $t = 2.95$, $p = 0.006$) (See also Fig. 13).

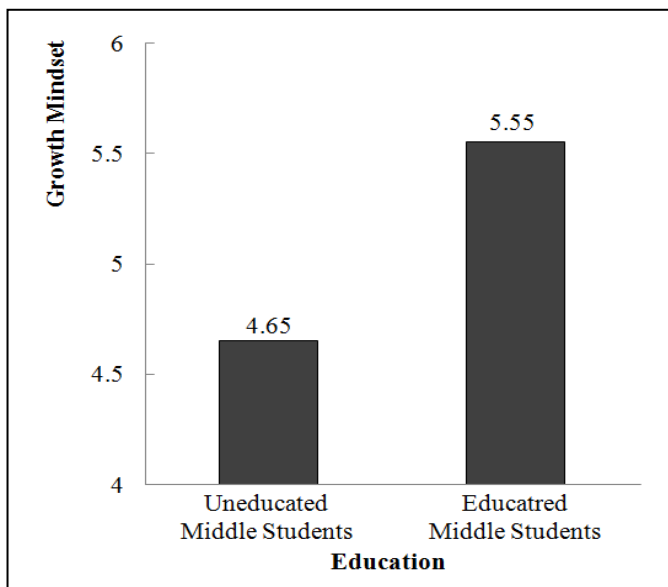


Fig. 13. The result of the t -test for the growth mindset mean value

V. CONCLUSIONS

In order to solve problem well it is important to represent the problem appropriately. If the type of a problem is determined, then the type of its solution can also be found easily [11][12][13]. So far, contradiction problems have been classified as difficult puzzles. A lot of problem solving psychologists dealt with Duncker's radiation problem for a long time, however almost everyone didn't examine the problem from the contradiction solving point of view [4][5][6]. In addition, there has rarely existed the research that classified contradiction problems and derived the solution

strategy for the contradiction problems. Unlike the existing research that treated Duncker's radiation problem as an ill-defined one, the Butterfly diagram of this research analyzed the radiation problem, and then converted it to a well-defined problem. This research introduced the Butterfly diagram that represents contradiction problems as symbolic logic, and then verify if the Butterfly diagram education affected students' problem solving ability.

If we figure out the structure and the types of contradiction problems, then we can solve the problems easily due to the reduced problem space [13]. In addition, when students are confronted with difficult contradiction problems, they are inclined to try to solve the problems. And, when they solve the problem finally, their mindsets become growth mindsets with their experience [18][19]. In this research, we conducted three experiments that analyzed the differences in the growth mindset and the problem solving ability between the students who learned the Butterfly diagram and the students who did not learn. The first experiment examined the problem solving ability about the Culbert's bulb problem and the APFSDS problem. The result of the first experiment was that the students solved better when they had learned the Butterfly diagram. The second experiment was about Duncker's radiation problem. In the previous studies, the average problem solving ratio about Duncker's problem was 7.5% ($SD = 4.11$). However, in this study, we got 33% by the Butterfly diagram education. Finally, the third experiment surveyed the students' growth mindset level after the Butterfly diagram learning. In other words, the growth mindset of the students who learned the Butterfly diagram was higher.

The reasons for enhancing students' contradiction problem solving ability with the Butterfly diagram are as follows:

Firstly, Gocłowska et al. found in their experiment that when people met the word thinking outside of the box such as 'female mechanic', their creative levels became higher [32]. When we determine a solution strategy for a given problem as satisfying two conflicting functions at the same time, the gap between the given solution strategy and the common and ordinary solution strategy becomes bigger. It leads us to increase counterfactual thinking ability [33]. As a result, problem solvers can overcome their psychological inertia. In other words, contradiction solving can reduce the problem solvers' fixed idea and increase the opportunities about creative problem solving [34].

Secondly, when the direction of a problem solving is given by others, the problem solvers think more creatively. When the direction of the problem solving is defined by themselves, it is difficult to overcome their fixed ideas [35]. The students who learned the Butterfly diagram had opportunities to think differently from their fixed ideas. The unfamiliar solution strategy given by the Butterfly diagram made the students more creatively. Thinking in the opposite direction increases the possibility of innovation [36].

Thirdly, the contradiction relation found by the Butterfly diagram is more concrete than the trade-off relation of the Butterfly diagram. During learning the Butterfly diagram, the students' thought about the solution of a problem changed from abstract to concrete. As a result, the students could have

a reduced solution space, and then they could find out the solution more quickly.

On the other hand, in the learning process, the students felt stressed and frustrated while defining problems and classifying the problem types with the Butterfly diagram by themselves. However, their iterative challenges and accomplishments to solve the problems enhanced their increased growth mindset.

The students who learned the Butterfly diagram awarded for 9 years (2007~2015) in a row when our students participated in invention festivals. During this period, 3 primary, 12 secondary, and 46 college students were awarded in invention festivals. And then, 5 middle school students, 4 high school students, and 15 college students, and one graduate school students registered 18 patents. In the 2014 Invention Idea Competition Festival, two primary school students who learned the Butterfly diagram were awarded one of 578 ideas in total. Furthermore, the college students who taught the two primary school students were also awarded one of 3,961 teams with 7,990 ideas. The students were also awarded in the Korean Science Creativity Festival. It showed the validity of the Butterfly model as a contradiction resolving model and the effectiveness of the educational content the students had learned.

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An Engineering Student Leadership Development Model for 21st Century Engineering

Using Sociocultural Theory to Inform Practice

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Abstract— To meet the demand for increased engagement of diverse engineers who possess 21st century skills, a leadership program was established in 2011 at a majority Hispanic four-year institution with an aim to develop engineers who work effectively with others in both public and private sectors through ideating, innovating, and thinking holistically through a systems approach to engineering problem solving. Designers of the program drew on leadership theory combined with situated learning theory to design and develop the program. Two theories of leadership informed our blended design: the relational model of leadership and the distributive actions theory of leadership. Situated learning theory, a sociocultural theory of learning, informed the programmatic implementation emphasizing learners' participation in authentic activities and the social relations in which they are embedded. Integral to the development of the leadership program model was a mixed methods research design to investigate its efficacy in relation to student development, which was structured in part to emphasize awareness and self-realization of various leadership skills. Qualitative research findings show that students associate their participation in situated learning activities of the leadership program with greater initiative and efficacy in their engineering classes. These findings corroborated the findings of the quantitative study.

Keywords—*leadership theory, sociocultural theory of learning, engineering education research*

I. INTRODUCTION

With funding from the U.S. Department of Education, the College of Engineering at the University of Texas at El Paso [UTEP] established its first leadership institute—Hispanic Engineering Leadership Institute [HELI]—in 2011 to support leadership skills development of engineering and computer science (hereafter referred to as engineering) undergraduates as a mechanism for persistence and ultimately success in preparing the 21st century workforce. HELI's emphasis on leadership was in response to the 2004 report of the National Academy of Engineering *The*

Engineer of 2020: Visions of Engineering in the New Century, which recommended a new paradigm for educating engineers to meet the nation's competitiveness and improve the quality of life from a global perspective [1]. To meet the demand for increased ingenuity and innovation of engineers, it is imperative to expand the engagement of diverse individuals who can contribute across disciplines and ensure continuous advancement in engineering. With the rapid growth of the Hispanic population [2] the need to tap into this underrepresented segment of the U.S. population is vital. [3] further emphasized the need to retain engineering students in the pipeline and to systematically address gender and ethnic equity. Following the recommendation from [4], we responded to developing a new paradigm for educating engineering leaders of the 21st century. The research reported here is part of that effort.

II. CONTEXT

A. About UTEP Engineering

UTEP is a minority institution located on the U.S./Mexico border serving a largely Hispanic population in a region of Texas with the lowest median income in the state [5]. Residing in the bicultural and bilingual community of El Paso on the U.S./Mexico border, UTEP is one of the largest binational universities in the world and, given its demographics, is unique among research institutions. UTEP enrolls over 23,000 students, of which approximately 78% are Hispanic, and 55% are the first in their families to attend college. Since its beginnings as a small mining school in 1914, UTEP has been committed to providing access and excellence in higher education. Today, the University offers 81 bachelor's, 81 master's and 17 doctoral degrees, with others in development. With over \$60 million in annual research spending, UTEP is classified as a Doctoral/Research-Intensive institution.

The UTEP College of Engineering offers undergraduate degrees in computer science and in civil, industrial, mechanical, electrical and computer, and metallurgical and

materials engineering. Its undergraduate enrollment of engineering majors is almost 2,000, of which 19% are female and 79% are Hispanic. The UTEP mission is to provide access and excellence to a non-traditional community of learners in the University region. This mission is coupled with a commitment to excellence in preparing students to make significant contributions to their professions, communities, and the world. Furthermore, a core belief of the UTEP College of Engineering is "diversity drives innovation." The nation's future depends on its ability to be a global leader in innovation, and advancing diversity is a key to innovation.

B. About HELI

The *Hispanic Engineering Leadership Institute* (HELI) is an integrated research and programmatic initiative with an aim of increasing the number of underrepresented groups, particularly Hispanic women and bilingual students, who persist in and graduate from UTEP's undergraduate engineering program possessing a competitive advantage through purposeful development of leadership skills. Two major components of HELI are (1) leadership curriculum designed for students to develop 21st century professional skills, and (2) field-based professional opportunities for students to practice and refine developing skills.

III. THEORETICAL FRAMEWORK

In designing the Hispanic Engineering Leadership program, the literature indicated a paucity of research in this particular area. Thus, we drew on leadership theory combined with situated learning theory to design and develop the program. Two theories of leadership informed our blended design: the relational model of leadership [6] and the distributive actions theory of leadership [7]. The relational model of leadership emphasizes the importance of developing (1) strong interpersonal skills; and (2) an inclusive, empowering, and ethical stance. In a similar manner, the distributive actions theory posits a cooperative framework to enable team members to work together effectively in order to establish and maintain effective working relationships and interdependence in meeting individual and team goals. Likewise, we drew on situated approaches to teaching and learning, which emphasize learning through practice and social interaction [8] to construct program activities that encouraged meaningful interactions among students as well as hands-on practice with leadership skills.

Together these informed our design in purposefully and intentionally targeting skills development with an expectation that engineering students would further seek and participate in internships, study abroad, cooperative education experiences, undergraduate research, and other co-curricular experiences to use their skills in authentic and meaningful interactions with others.

[These theories of leadership] emphasize the mutual goals and motivations of both followers and leaders, and elevate the importance and role of followers in the leadership process. In other words,

these theories posit, leadership is not just something that a leader does to followers; rather, leadership is a process that meaningfully engages leaders and participants, values the contributions of participants, shares power and authority between leaders and participants, and establishes leadership as an inclusive activity among independent people [6, p. 53].

Thus, we specifically encouraged English Language Learners and females to join our institute; we were successful in maintaining a higher percentage of females in our leadership than UTEP engineering enrollment. The skills we identified and targeted were managing conflict, oral and written communication, building trust and trustworthiness, understanding personality traits, being proactive, and actively listening.

IV. RESEARCH DESIGN, FINDINGS, AND CONTRIBUTION

Integral to the development of the leadership program model was a mixed methods research design to investigate its efficacy in relation to student development, which was structured in part to emphasize awareness and self-realization of various leadership skills. The driving questions informing the data collection were: (1) What challenges do Hispanic women and English Learners (ELs) face in undergraduate engineering programs? What are the most suitable mechanisms of support for academic success? (2) What components of HELI are most conducive for academic support? What aspects can be improved? (3) Does participating in HELI have better outcomes compared to other groups?

A. Participants

Overall, 59 HELI members (33 males, 26 females) were active in the program over three years with 92.3% self-identified as Hispanic or Latino/a. With respect to language background, 50% of students reported that Spanish was their native language, and 32.69% of students reported both Spanish and English as their native languages. Only 13.46% of students reported English as their native language.

B. Method

We drew on mixed methods, though primarily qualitative methods, to understand and assess the experiences of participants, especially women and ELs, in HELI. The focus of this paper is on the research design and findings of the qualitative study.

Five primary sources of data were collected: (1) a demographic survey soliciting background information related to language, gender, and academic supports; (2) focus groups with all HELI participants; (3) more than 54 hours of observations of HELI workshops; (4) a final evaluation survey of participants' experiences in HELI; and (5) in-depth interviews with participants in the language of their choice. For some participants, initial and follow-up interviews were conducted. In addition, we also conducted a phone survey with seven participants who discontinued participation in HELI.

Most participants agreed to be interviewed (36 of the 59 active members), and 17 were interviewed a second time. All of the interviews were uploaded and analyzed in NVivo10 qualitative data analysis software. The interviews were analyzed with an “open coding” and a “focused coding” approach [9] in NVivo10. Particular instances (codes) were identified in which the participants talked about HELI, HELI expectations, HELI and leadership engineering, and HELI and engineering.

C. Key Findings from Focus Groups and Interviews

This section outlines key findings from the systematic analysis of the qualitative data collected during the program. In analyzing the participant feedback provided in focus groups and individual interviews, several important themes emerged, each of which will be explored in detail in this section.

1) Impact of HELI on Engineering Leadership Skills

a) Communication

Improving communication skills was an important theme that emerged from female participants' interviews. For example, Adela expressed how HELI helped her with her confidence, saying “Well, finally, HELI with Dr. Elsa (HELI facilitator) and the group has helped a lot like in my confidence like in my leadership positions...During class like I feel more comfortable like taking the initiative, so I feel like I've learned a lot not only how to express myself and how to communicate with others.” Another female participant, Carolina, mentioned how HELI has helped her gained confidence to speak in English, “Well, I would say that I've learned many things. Before I was very nervous to speak to someone in English.” A third female participant, Adriana, highlighted the importance of communication skills in engineering leadership, saying that “an engineering leader [should] be able to talk to people because they have this stereotype that engineers are not like social persons they try to avoid people; and, if you do want to be an engineer, you have to break through that stereotype.”

b) Teamwork

Being able to work in teams was another important theme that emerged from the interviews. Both females and males expressed the need to work in teams. For example, Graciela mentioned that she learned in HELI the importance of listening to other peoples' ideas and trust. Adriana talked about how the workshops showed her how to work with different types of people and accomplish goals when working in teams. Similarly, Cristian and Andres mentioned the importance of trusting others when working in teams.

2) Application of engineering leadership knowledge in other contexts

Several female participants expressed how they have applied what they learned in HELI in their courses and

work. One participant, Monica, specifically pointed out using what she learned from the workshop on conflict management in other contexts. Another participant, Donna, revealed how she noticed that she had started to take initiative and become the leader in group projects associated with courses, which she attributed to her participation in HELI. Several male participants also expressed how they have applied the knowledge in their summer internships and classes. Leonardo said, “everything I applied from HELI in the summer definitely got me noticed the primary reason I was asked to come back but getting introduced to the petroleum industry and NASA.” Similarly, Luis talked about reaching out to younger students in his internship, “it was an engineering/internship so I had to put an example to high school students and talk to them about college and future plans”. Javier emphasized that he has used his knowledge in courses as well, saying “in class, I mean if I'm working in teams if I don't see that somebody has the capacity, or just by [my own] nature I take the lead of the team”.

3) Unique conceptions of engineering leadership

Two participants had conceptions of leadership engineering that differed from the other participants. For example, Carolina had a view of engineering leadership as a way of having a balanced life. In her interview she said, “I say that leadership is power, enjoy what you are doing in college, to have, to have I don't know the time for your homework, your projects, your classes, without neglecting other priorities that we may have.” Likewise, Leonardo saw engineering leadership as both knowledge of the business aspect and the technical aspect: “I would consider a leader engineer to be like the middle point of everything um how to get a technical aspect and how to relate it in business terms and to make sure that's the right thing so that it succeeds”.

4) Impact of HELI on Students' Engineering Identities and Professional Preparation

a) Professional preparation

Another theme that emerged from the interviews was the perceived benefit that being part of an organization had on their professional trajectories. For instance, Carolina compared herself to students who were not part of an organization, saying that she was prepared for career fairs and had her resume ready while her friends were not ready. Another participant, Andres, highlighted his professional trajectory as a key reason for deciding to be a part of HELI: “That's why I joined this student group, because I think that being part of this leadership group is going to help me in my future.” Cristian also compared himself with other students who were not part of an organization, saying that participating in HELI put him at an advantage in the job market.

b) Research opportunities

A common theme among males and females was how they benefited from HELI with respect to research opportunities. Some participants mentioned the chance to work in the summer because of HELI (Adriana, Graciela, Karina, Andres, Javier, Roger, Roberto, Cristian). Graciela and Javier said that they heard about the COURI program in HELI. Roger said during an interview, "I really like HELI and I got to do a research project over the summer because I was in HELI." Cristian also said during an interview "This program actually it has helped me a lot, I consider it a valuable opportunity that I got to be part of this group because I think that being part of this group opened the door for me to get a job in the summer."

c) Developing professional networks

Meeting faculty and other contacts was a theme that emerged from the interviews. Several females reported meeting engineering faculty as one of the key benefits of HELI. One female participant said that she felt that meeting HELI director and workshop facilitator Dr. Villa opened many doors for her, such as the opportunity to go to London (Karina); another mentioned getting a recommendation letter through HELI (Adela). A third participant mentioned how she was able to meet people with different interests (Monica). Finally, another participant, Adriana, said that being part of HELI helped her develop friendships with other members. This theme was not mentioned by any of the male participants.

IV. SUMMARY OF FINDINGS

Students found the skills of communication and teamwork to be significant; and were able to identify the application of engineering leadership knowledge to other spaces. Thus, students associated their participation in situated learning activities of the leadership program with greater initiative and efficacy in their engineering classes. Findings also strongly suggest how HELI was influential in further development of their engineering identities through the opportunity it provided in their professional preparation, in undergraduate research, and developing their professional networks; these are opportunities suggested by [10].

V. SIGNIFICANCE AND RELEVANCE

The recent shift emphasizing professional skills development of engineering students is evidenced by the release of a call for proposals under the National Science Foundation Directorate for Engineering, Engineering Education and Centers *Professional Formation of Engineers: Research Initiation in Engineering Formation* [NSF 15-539]. This program recognizes both the technical and professional skills development of engineers are critical for the future workforce, particularly with its inclusion of an ethical perspective.

Thus, HELI is one model for developing professional skills intentionally and purposefully using sociocultural approaches that emphasize social interaction and participation in meaningful leadership engineering

activities; participating students recognize and value professional skills development.

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Documenting students' faulty schema and misconceptions about combinations and permutations

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Abstract— STEM educators have devoted increasing attention to discrete mathematics in recent years due, in part, to its strong connections with subjects like computer science, probability and statistics, and business management. Combinatorics problems, in particular, while useful for modeling concrete situations, are often considered to be tricky for students. To develop a better understanding of students' conceptions regarding problems involving permutations and combinations, a secondary data analysis using a grounded theory approach was performed on transcripts of student interviews obtained during an earlier study. Participants had recently completed a college-level discrete mathematics course with a passing grade. Analysis focused on answering two research questions: 1) What patterns of responses do students generate while producing solutions to combinatorics word problems? 2) What underlying conceptual ideas lead to these patterns?

Keywords—combinatorics, permutations, combinations, student conceptions/misconceptions

I. INTRODUCTION

Education researchers in STEM fields have devoted increasing attention to discrete mathematics in recent years due, in part, to its strong connections with subjects like computer science, probability and statistics, and business management. The National Council of Teachers of Mathematics (NCTM) devoted their 1991 yearbook to the topic [1]. The importance of combinatorics, in particular, has been increasingly emphasized in the mathematics education literature [2-5] as well as K-12 standards documents [6]. However, while combinatorics problems are known for modeling concrete problems, they are often considered to be tricky for students. In the next section we present a brief review of the literature on college students' difficulties with introductory combinatorics. Subsequent sections are devoted to our research questions, study methods, and results/discussion.

II. LITERATURE REVIEW

We restrict our focus to the post-secondary literature. See [7] and [8] for detailed reviews of the K-12 literature. There are only a handful of peer-reviewed papers published at the post-secondary level examining students' understanding of combinatorics. Several of these articles focus on more

advanced topics than we will be addressing here [9-11] or use combinatorics problems as a context in which to study other issues such as cooperative problem solving [12], metacognition [13, 14], and semiotics [15].

Recently, four unpublished thesis dissertations have examined the learning of combinatorics at the undergraduate level. In the first of these [16], Smith employed a multiple case study approach to study how students, with varying levels of experience, approached solving basic counting problems of the four basic types appearing in Table 1. Note that a *permutation* is a particular ordering of k objects selected from among n distinguishable objects ($k \leq n$) whereas a *combination* is a selection of a particular subset of k of those n objects without regard to their order.

TABLE I. FOUR BASIC TYPES OF COUNTING PROBLEMS

	Permutations (ordered)	Combinations (unordered)
No repetition allowed	$\frac{n!}{(n-k)!}$	$\binom{n}{k} = \frac{n!}{k!(n-k)!}$
Repetition allowed	n^k	$\binom{n+k-1}{k}$

Smith found that the permutation problems (both with and without repetition) were easy for students, whereas combination problems were difficult. Furthermore, students approached the permutation problems from a more conceptual perspective based on the use of the multiplication rule, whereas formula recall was the strategy of choice for combination problems. Smith warned, however, that students' conceptions of permutations were rigid and resistant to generalizability beyond the simplest of counting problems. Additionally, Smith found that students' understanding of the notion of ordered/unordered sets was tenuous. Students had no problem connecting ordered sets with permutations and unordered sets with combinations. However, when asked during interviews to elaborate on the distinction, most participants appeared to

believe that the distinction had to do with whether the problem allowed repetition.

In the second dissertation [17], Kavousian presented college-level discrete-mathematics students with an unfamiliar (and somewhat complicated) definition and a corresponding set of tasks chosen to help reveal their concept image of the new mathematical object. The study revealed that, when attempting to understand the new concept, most students did not generate their own examples (rather, they expected examples to be provided for them by the teacher), and, while many students could eventually find a formula for counting these new objects after being exposed to related tasks, they did not make many of the anticipated connections to prior knowledge (e.g., knowledge of combinations and of the binomial theorem). Furthermore, students that generated pictorial representations of their new understanding did not consider these significant in their understanding. On the contrary, an algebraic representation was considered by students to be a necessary (and often sufficient) form of understanding.

In the third dissertation [18], Lockwood conducted *think aloud* interviews with advanced undergraduate and graduate students who were asked to solve difficult counting problems. The interview data was used to develop a model of combinatorial thinking in which students tend to relate algebraic *formulas/expressions* (like those contained in Table I) to *sets of outcomes* (the collection of objects being counted) via *counting processes* (the active mental and/or physical processes of enumeration). Lockwood also noted, however, that students frequently ignore the set of outcomes in counting problems, unless specifically prompted to address it. She later used the model as an analytical tool for interpreting her data as well as other researchers' data [19]. In a separate study [20], Lockwood also examined some of the spontaneous connections that students make between different combinatorics problems. Lockwood's is (to our knowledge) the only of the four dissertations to have resulted in peer-reviewed publications.

In the final dissertation [21], Halani studied the ways in which four Arizona State students, who had no prior experience with counting problems, conceived of the sets of outcomes in combinatorics problems. Halani identified three broad categories of ways that students think about solution sets which she labeled *subsets*, *odometer*, and *problem posing*. The subsets category involves envisioning the solution set as a union of subsets, while the odometer category involves holding an item (such as a digit in a number or character in a string) constant and varying the other items systematically. The problem posing category involves the spontaneous generation of a new problem whose solution set is somehow related to the solution set of the original problem.

III. RESEARCH QUESTIONS

Evidently, there are many gaps in the post-secondary literature on combinatorics education. In particular, among the studies we reviewed, several do not focus specifically on combinatorial concepts [12-15]. And those that do tend to focus on difficult problems [9, 10, 17] or examine populations of students with a great amount of mathematical experience

[11, 18-20]. The exceptions are the studies by Smith [16] and Halani [21]. However, Smith focused only on the most basic counting problems (those of the form listed in Table I), and Halani's study involved students who had had no prior instruction in combinatorics.

As a result, little has been done at the college level with problems that are just a bit more difficult than those represented in Table I. For example, little is known about how students in possession of basic knowledge of permutations and combinations (but not much more than that) approach a problem that naturally lends itself to the use of both a permutation and a combination or a problem requiring a simple combination but with an added restraint. Such problems would not lend themselves to the "order matters implies permutations" and "order does not matter implies combinations" schemas. In light of Smith's [16] claim that the notion of ordered/unordered sets is problematic for students as well as his claim that students' models of permutations are inflexible and resistant to generalizability, one would expect these intermediate level problems to be a rich site for study. With these considerations in mind, we pose the following questions:

- 1) What patterns of responses do students generate while producing solutions to combinatorics word problems that are slightly more complex than those in Table 1?
- 2) What underlying conceptual ideas lead to these patterns?

IV. METHOD

In this study, we performed a secondary data analysis of data originally gathered by different researchers in the University of Illinois at Urbana-Champaign's Computer Science Department. The data was part of a larger project to construct assessment tools to measure students' understanding of discrete mathematics concepts used in theoretical computing. The only portion of the project that will be discussed here is the part directly relevant to the current research on students' conceptions regarding combinatorics problems. The first subsection below will describe the data collection process that was carried out by a team that did not include any of the individual researchers involved in the present study. The second subsection will describe the data analysis process that was carried out by the researchers involved in the present study.

A. Data collection

Here we detail the data collection process, including details about the participants, the interview process, and the interview questions (by which we mean the combinatorics problems to be solved during the interviews).

1) Participants

In the spring of 2009, eighteen undergraduate volunteers from the University of Illinois at Urbana-Champaign enrolled in the study by responding to an email sent to recent "CS173: Discrete Mathematical Structures" students whose course performance merited a grade of B or C. Of these, there were

five women and thirteen men, all but two of whom were majoring in the mathematical sciences or engineering. The other two were undeclared. Fourteen were domestic students. Ten of the eighteen were computer science or computer engineering majors who are required to take a course on discrete mathematics. Students were paid \$15 for their participation. Students with grades B or C were targeted as they were more likely to generate error-prone solutions. It should be noted, however, that Illinois has a highly competitive engineering program, and the average ACT score of the students who participated was 32.6 (the 99th percentile). Of the eighteen participants, only eleven of them attempted to solve one or more of the interview questions specifically involving combinatorics, and, therefore, the present study included only those eleven students. Since the data had been anonymized prior to having been given to the current research team, there is no way to know which of the original eighteen students are included in the present study.

2) Interview process

Prior to being interviewed, students were briefed about the goal of the study, which was to understand how they think through various topics in discrete mathematics. They were warned that they would frequently be asked to expand on what they were writing or saying as they solved problems and were told not to expect feedback about the correctness of solutions. Participants were then interviewed for one hour about their understanding of a variety of discrete mathematics problems. They were instructed to “think aloud,” vocalizing their thoughts as they solved problems and answered questions [22]. Students’ work was recorded using a document camera. Audio was recorded with a microphone. The interviewer was an advanced-undergraduate computer science major. Participants were provided with a “cheat sheet” that contained basic notation and definitions that participants were free to consult during the interview. The portion of the “cheat sheet” relevant to the counting problems contained reminders of the notation for permutations and combinations as well as the formula for combinations with repetitions (the bottom-right formula from Table 1), though none of the problems actually required the use of this formula. All interviews were transcribed verbatim, and notes regarding what students wrote and when were included in the transcripts. All student work was scanned and stored electronically for future analysis.

3) Interview questions

The interview questions were a collection of fifteen discrete mathematics problems, four of which were basic counting problems involving permutations and combinations that will be discussed in the present study. These problems resembled those that the participants were likely to have previously encountered in CS173. Not all students answered all of the questions due to time constraints. Students were allowed to pick and choose which problems to attempt. The four counting problems are listed in Table II along with possible solutions. They are labelled Problem 3 through Problem 6 since these were the original labels of the combinatorics problems among the complete set of 18 discrete math problems.

Notice that, while Problem 3 and Problem 4 each have a potential “permutation only” solution (represented by the expression on the right of the equality sign in the solution), the contexts of these two word problems lend themselves strongly to a mixed approach that involves using a combination and a permutation (represented by the expression on the left of the equality). Also notice that, while the form of the solution is the same for both problems, the questions being asked appear quite different. In Problem 3 there are eight crayons being arranged in a box, some of which happen to have the same color. Problem 4, by contrast, involves a total of twelve crayons, none of which have the same color and from which only eight are being selected for later arrangement into the box. So, while a mathematician would tend to view these two problems as isomorphic, a novice might not.

Smith’s (2007) study suggests that combinations alone are difficult for students, so Problem 5 is a simple combinations without replacement problem (as in Table I) in a context in which it is clear that order does not matter. Problem 6, on the other hand, is a combinations without replacement with an additional constraint—the three red crayons cannot all be next to one another. Furthermore, the context of Problem 6 is a situation in which the order of the crayons in the final arrangement clearly matters even though the most natural solutions involve the use of only combinations. This apparent contradiction is resolved by noting that the unordered selection of several slots in which to place crayons of one color can be done in exactly the same number of ways as there are to arrange the eight crayons. It is worth noting that this problem is most easily solved indirectly by counting *all* arrangements of the crayons, then counting the six “disallowed” arrangements, and, finally, subtracting to find the number of “allowable” arrangements. It is possible to solve this problem by focusing only on the allowable arrangements (see the expression on the right side of the equality in Table II), but this approach makes the solution process much trickier, and we would expect a lower rate of success for students who choose this approach.

TABLE II. INTERVIEW QUESTIONS AND SOLUTIONS

Problem Statement	Solution
Problem 3: Suppose we have 8 crayons, three of which are the exact same color of red, and the others of which are different. Now how many ways are there of arranging the crayons in the box?	$\binom{8}{3} 5! = \frac{8!}{3!}$
Problem 4: Now suppose we have 12 different colored crayons, and a box that holds only 8. How many different arrangements of 8 crayons, selected from the 12, can be put in the box?	$\binom{12}{8} 8! = \frac{12!}{4!}$
Problem 5: A bundle of crayons is a collection of colors in no particular order. How many different bundles of 5 crayons can be made from a set of 8 uniquely colored crayons?	$\binom{8}{5} = \frac{8!}{3! \cdot 5!}$
Problem 6: Suppose you have a box of eight crayons, three of which are red, and five of which are blue. How many ways are there to arrange the crayons in the box so that the three red crayons are not all next to each other?	$\binom{8}{3} - 6 = 2 \binom{6}{2} + \binom{6}{3}$

B. Data analysis

Three researchers at the University of Illinois participated in the data analysis: a graduate student studying math education (the author), a professor, Geoffrey, specializing in engineering education, and an advanced undergraduate, Tom, majoring in computer science. A grounded theory approach [23] was used to analyze the interview transcripts and students' written work (hereafter referred to simply as "interviews"). First, each researcher individually coded the interviews, line by line, without any predetermined coding scheme. "Codes" were essentially annotated comments that referred to a specific line (or lines) or piece of written work. This approach allows theory to arise from the data, rather than force-fitting data to a predetermined theory. Second, the researchers met to discuss one another's coding, negotiate potential differences or disagreements, and eventually produce a single document containing all agreed upon codes. (Agreement on the application of the codes was essentially universal.) Next, Tom and the author reexamined all of the coded interviews to identify and come to agreement on any themes that were appearing in the data. A list of these themes were produced and then later discussed with Geoffrey present to ensure agreement. Finally, the author reexamined the interviews in an attempt to synthesize the thematic elements and develop theories that might help explain what contributes to students' difficulties in solving counting problems.

V. RESULTS AND DISCUSSION

One issue that became apparent while studying the transcripts was that the interviewer allowed his teaching instincts to interfere with the interview protocol (especially in earlier interviews). During uncomfortable moments when a student was struggling, the interviewer frequently asked leading questions, confirmed (or disconfirmed) students' work, or simply had the student move on to the next problem. At other moments, when students indicated that they were finished with a problem, they were allowed to move on without their solution being challenged or more deeply explored. This interference complicated the analysis of the transcripts as it was no longer possible to determine what the student would have done "naturally" (without the interference). As a result, we report only on findings that we believe hold up to scrutiny *in spite of* the interviewer interference.

Each subsection below, with the exception of the first, will focus on a theme that was identified in the data and was considered noteworthy of discussion. Segments of interview transcripts are used to provide vignettes that demonstrate each theme. Participants are referred to as Student 1 through Student 11. The five themes are summarized in Table III while the results are summarized in Table IV (located the end of this section) which indicates the presence (or lack thereof) of each theme for each student/problem pair.

A. A note on overall success rates

Problems 3, 4, 5, and 6 were attempted by 11, 9, 6, and 8 of the students, respectively, for a total of 34 attempts. Of

these attempts, 15 (or 44%) were found to be successful. By problem, there were 5, 4, 3, and 3 successful attempts, respectively, giving success rates between 37.5% and 50%. These rates are likely upper bounds as students were allowed to skip problems and likely skipped problems that they felt they would be unable to solve. It is also worth noting that 11 of the 15 successful attempts were made by just three of the students (Students 1, 7, and 8) who succeeded on every attempt they made. These numbers indicate (in agreement with the literature) that counting problems involving combinations are quite difficult for many students.

TABLE III. LIST OF THEMES

Problem assumptions: Student questions inherent problem assumptions. Four types of assumptions that were questioned included: the shape/capacity of the crayon box, the distinguishability of crayons, the importance of order, and the number of different crayon colors were implicated in a problem statement.
Dichotomous solutions: In the context of Problems 3 and 4, the student indicates that the solution should involve a permutation or a combination only, but not both.
Allowable arrangements: For Problem 6, the student employs a solution strategy that involves focusing on the enumeration of the allowable arrangements of crayons, rather than the simpler approach of counting all possible arrangements and then subtracting the number of disallowed arrangements.
Related constraints: For Problem 6, the student fails to notice that the arrangement of the crayons of one color within the box will necessarily constrain the number of possible arrangements of the crayons of the other color.
Use of diagrams: Simply indicates whether a student used a diagram in their solution attempt. Note that a string of characters indicating a particular arrangement of crayons (e.g., RBBRRBBB) as well as any visual representation of "slots" to be filled (e.g., use of underscores to represent slots) were all counted as diagrams.

B. Understanding the problem assumptions

One of the most common patterns we noticed was that novice counters tended to question problem assumptions more than "experts" (students who were most successful at solving the interview problems¹). Four types of assumptions were questioned: the shape/capacity of the crayon box, the indistinguishability of crayons of the same color, the importance of order, and the number of different colors of crayon contained in a problem. The first and last will not be elaborated upon any further as they seemed to reflect ambiguities in the wording of the interview problems more than conceptual difficulties regarding counting.

1) Distinguishability of crayons

Several students questioned whether crayons of the same color were distinguishable from one another as demonstrated by the following exchange that occurred during an attempt to solve Problem 3:

Student 4: [...] you have two ways of deciding whether or not the, whether or not the crayon's arrangements are different. For example, if you have

¹ We are careful to note, therefore, that "expert" behavior used in our sense is not necessarily meant to refer to behaviors characteristic of an instructor or professor.

a box of eight, um, if these three are the exact same shade of red, you could count them as essentially the same crayon, and then not care where those are placed in the box. And that would lead you to one answer. If you count them as distinct crayons, then it would be pretty simple. [...]

Interviewer: Well we give you that they're the exact same color. So...

Student 4: Yeah, but they're *different* crayons.

Student 4 is caught up on the distinguishability of the three red crayons and notes that, while they are all red, they are still "different" crayons. In the "real world" different red crayons are, ultimately, distinguishable, but the more expert problem solvers in this study tended to more readily "buy into" the intended problem assumption that the red crayons are indistinguishable.

2) Importance of order

The most common assumption that students' questioned or clearly misunderstood based upon their given solution was whether "order matters." Technically, this condition refers to the order in which distinguishable objects are arranged. However, students often ask, rather vaguely, "whether order matters" without any real indication of precisely what set of objects has its "orderability" being called into question. In a particular problem it may be the case that order both matters and does not matter depending upon what you are referring to. For example, in Problem 3 and Problem 6 the order of the overall arrangement of crayons matters while the order of the reds or blues alone does not matter.

Issues with order came up for each of the four problems. In the following example, Student 3, having just finished reading the statement of Problem 3, vaguely questions the issue of order using non-normative language:

Student 3: Would this be um, according to sequence, or just combinations?

Student 9, solving the same problem, seems to have a conflict between "order mattering" and "distinguishability":

Student 9: And the order matters, so I don't see why it points out that there are three [crayons] of the same color, well kind of.

In contrast, Student 6, while solving Problem 5, and in direct violation of the problem statement, counts the number of "bundles" as though order mattered:

Student 6: This is the same as the last one, isn't it? [Writes down 8 choose 5 times 5!] I mean it's the same idea from the last one, you're choosing 5 crayons from a set of 8, and then put that set of 5 crayons in a specific order.

More examples of order issues will be apparent in the discussion of the closely related "dichotomous solutions" theme to be discussed below.

Consideration of these implicit problem assumptions allows us to begin to grasp the cognitive complexity that combinatorics problems require of a novice. We found that most instances of questioned assumptions occurred during a failed solution attempt. If, for each student, we count each questioned assumption only once per problem, then there were 16 such instances. Of these 16 instances, 13 occurred during a

failed solution attempt by one of six different students. In particular, all but one of the seven instances in which the "order matters" assumption was questioned occurred during a failed attempt.

Students with incomplete conceptions regarding distinguishability and order were prone to developing unstable interpretations of problems that impeded progress toward a solution. This observation suggests that students may need more time than is typically devoted to discussion of the meanings of various assumptions about properties like order and distinguishability and how they relate to various problems. In the author's experience, students are typically presented with a table of basic counting formulas like the one in Table I very early on in combinatorics instruction and focus quickly moves on to more "interesting" problems in which these formulas are taken as "given" knowledge. More time is likely needed for students to develop mental models for the various counting processes represented by these formulas and how these processes are related to various types of problem assumptions regarding order and distinguishability.

C. Dichotomous solutions

We previously alluded to a schema that students often employ that dictates that permutations are to be used when "order matters" while combinations are to be used when order "does not matter." By *dichotomous solutions* we refer to an extension of this schema which further dictates that the solution to a counting problem must use either a permutation or a combination, but not both. Or, said differently, for a given counting problem either order matters or order does not matter (in some vague overall sense), but not both. We found evidence for the existence of this schema in solution attempts for Problem 3 and Problem 4—the two problems most likely to solicit solutions that involve both a permutation and a combination.

Four of the eleven students (Students 4, 6, 9, and 10) demonstrated this schema, and one demonstrated it on both problems (Student 10), giving a total of five instances. Note that none of these students were any of the three highly successful students (Students 1, 7, and 8). Consider first the following which occurred after Student 4 had abandoned a first solution attempt of Problem 3 and was starting on a fresh solution:

Student 4: OK. [Reading from the cheat sheet.] Number of ways to choose elements from a set of size N ... ok. So yeah, there's...yeah. The three that are the same and five that are distinct. Um...so I guess for each, each individual slot, you are choosing, for eight slots you're choosing on of...six possibilities it seems like, because these [referring to the 3 red crayons] are all counted as one possibility, um, so it might be eight choose six...umm, we have to choose R elements, oh nevermind, that doesn't take into account order. So it would be, because you care about order, it would be a permutation of...out of eight, six. [Writes " $P(8,6)$ "] Yeah. Cause there's six distinct elements. And you want to choose all the possible ways of arranging them.

Notice that this student begins by fixating on the notation for combinations contained on the cheat sheet and continues by using choosing language ("you are *choosing*, for eight slots

you're *choosing* one of..." and "so it might be eight *choose* six...umm, we have to *choose* R elements"). But the student abruptly abandons the use of combinations because they do not "take into account order" and decides to go with a permutation, which is this student's final answer.

As another example, here is Student 6 struggling with Problem 4:

Interviewer: [Student writes 12 choose 8.] And that counts what?

Student 6: How many ways to choose 8 from the 12. And then, that's pretty much it, isn't it?

Interviewer: Well, what do you think?

Student 6: [Repeats problem statement aloud.] Well this will count how many ways you can pick 8. Then, how many different arrangements of eight crayons is 8 factorial. So would it be times 8 factorial? No. No, that's right, because you're still counting... This is gonna count all the arrangements you can get from 12, how many different ways you can get 8 from the 12, That should be fine, shouldn't it? Just 12 choose 8?

Interviewer: Ok, that's it for you?

Student 6: Well, I guess, we have 12 different colored crayons, wait, no no no. 12 different colored crayons in a box that holds only eight. Do I still use 12 choose 8? Cause it's different crayons. So if its 12 choose 8, that means, that wouldn't, that's unordered. And then we have to choose 8 that *are* ordered. Which is 8 factorial.

Interviewer: Do you mean that there are two different "choosing processes" happening?

Student 6: I'm, I think so. Kind of, because it's first we're choosing 8 random crayons from the 12, and then, which is kind of, unordered I guess, because you don't care which 8 you choose. Well, do you? No, yeah. I can't use 12 choose 8, because that means, ah damn. I'm confusing myself. So, they're all different colored crayons, so if you have 8 crayons, they're different colors, so there's gotta be 8 factorial in there. Errg.

The interesting thing about this attempt is that Student 6's instincts are ultimately leading to a correct solution, namely, $C(12,8) \cdot 8!$. However, the dichotomous solutions schema is preventing the student from accepting it as it mixes permutations with combinations. The student is sure at first that $C(12,8)$ must be part of the solution, but later the student realizes that $8!$ must be part of the solution since order matters and reneges on the combination. This student goes on to offer $C(12,8) \cdot 8!$ as a final answer but does so with reluctance and admits that he or she is unsure if it gives the correct number or not. (Unfortunately, the interviewer immediately confirmed the answer rather than probing further.)

As illustrated by Student 6, the dichotomous solution schema tends to result in unstable interpretation of the problem assumptions. As students seesaw back and forth between wanting to use permutations and wanting to use combinations, they must also toggle between the assumptions that order matters and that order does not matter. This toggling, in turn, creates dissonance with students' intuitions (rooted in the physical context of the problem) that *both* assumptions appear to be true.

We speculate that the dichotomous solution schema is likely induced (at least partially) by instruction. Language

including statements like "use permutations when order matters and use combinations when order does not matter" is probably common in instruction. It is also implicit in tables like Table I that are contained in most introductory combinatorics and discrete math textbooks. Consequently, it may be a good idea to encourage students to think of Table 1 as a collection of counting *techniques* rather than a collection of solutions to counting problems (though they are that too). Perhaps there would then be less of a tendency for students to believe that they are mutually exclusive in the solutions to counting problems. Also, as students build more robust notions regarding the concept of "order mattering"—in particular as they develop the understanding that it is not a global feature of a counting problem but, rather, a local feature that can differ for various aspects of the problem—they probably become more likely to discard the dichotomous solution schema.

D. Focus on allowable arrangements

Recall that Problem 6 has a solution (the one on the right side of the equality in Table II) that is obtained by focusing on the enumeration of "allowable" arrangements of the crayons, rather than enumerating all possible arrangements and then subtracting the number of "disallowed" arrangements (the six in which all three red crayons are adjacent to one another). The former strategy leads to a more difficult solution process as it is easier to describe and count the disallowed arrangements than it is to describe and count the allowed ones. Nevertheless, this strategy was tempting for students. Perhaps this result is not surprising as the strategy involves inspecting the actual solution set (that is, the set of different arrangements whose cardinality is the answer to the counting problem) as opposed to two sets which are not the solution set but that happen to be closely related to it. Four students (Students 2, 4, 6, and 7, making up half of the students who attempted Problem 6) tried to enumerate allowable arrangements directly. Only Student 7, who solved all problems correctly, was successful in using this approach.

The following vignette is notable in that Student 4 continues to focus on an allowable arrangements strategy, even *after* having computed the number of disallowed arrangements and after stating that the strategy is not "very slick" (emphasis ours):

Student 4: So, um, there's one two three four five six, six total possibilities, where it's not allowed, essentially. And there's a total of, the permutations of, oh no, that's not right. Let's see. Can't do a simple permutation cause they're not distinct elements. The six is, the six was where there's not...for each, for each place it...for the first place you have two choices, red or blue, and if it's red...that's not a very slick way of doing it. And I'm not...once again, lazy, so I don't wanna go and draw out all possible combinations and just count them. Uhhh...but. *How many ways are there...so that the three crayons are not all next to each other?* Alright. Now I just have the impulse to talk, so that I am not leaving a big space on the transcript, but, nothing is actually coming into my mind at the moment, so...

Having computed that there are six disallowed arrangements, Student 4 attempts to connect this information back to the original question. But, in doing so, has reverted to a

permutation-centric approach that draws the student's attention back to the allowable arrangements of red crayons. This approach leads to a rather convoluted analysis that leaves the student wondering whether his/her focus should instead be placed on the blue crayons—at which point the interviewer intervenes in an attempt to refocus the discussion on the disallowed arrangements (emphasis ours):

Student 4: How would I count that...I would put down the well I'd put down the red one's first. Um, so, I'm starting with one there's, you know there's eight choices on the first one. And then there's seven choices on the second one. So the first one, put down here [first spot], second one, just go ahead and go straight across. The third one, there's not this choice [red], but there's all the rest of the choices, so there are five choices for the remainder. And I think that's going to always be true. It's gonna be eight choices for the first one, if you're putting in red first, seven for the second one, and then five, well I guess if you put a red one in the middle...red one in the middle, one two three four, five six seven eight, and then there, a red here [to the right of the middle red crayon], and then there's, if that's in the middle then those two are both invalid [the spaces to the side of the two middle crayons], so it's possible that it could be eight, seven, and then four. *So I guess the other way to say that the three red crayons are not all next to each other is that, there is, um, there is some gap in the blue ones. That not all five blue ones are continuous.* So it could be blue, blue, I guess, yeah.

Interviewer: OK, so what did you count before? When you were doing, you know, the written count of the...

Student 4: *The original count was the, was all the possible illegal placements of red.*

Interviewer: OK. So you counted that. So what are you currently trying to count?

Student 4: I'm trying to count the total number of placements², using three and, five separate elements [...]

Thus, some students more readily focus attention upon the set of arrangements evident in the problem statement at the expense of the other closely related sets (e.g., the set of all arrangements and the set of disallowed arrangements) that simplify the counting process. While this finding is not particularly surprising, it does suggest that the technique of examining related sets that are not explicitly mentioned in the statement of a counting problem should be focused on as an explicit goal of instruction rather than simply being an implicit aspect of the solution process of particular problems.

E. Related constraints

Another theme that was highlighted in the context of Problem 6 was students' failure to recognize "related constraints" on the arrangements of crayons. In the vignette above Student 4 recognized the constraint on the red crayons would result in a related constraint on the blue crayons (but mischaracterized it). Student 2, in contrast, never perceives this related constraint. Frustrated with examining allowable arrangements of red crayons, this student shifts focus to the blue ones in the following excerpt (emphasis ours):

Student 2: Yeah, um, well I don't think this is a good strategy, cause I can't really, cause these are different...I could split these up into containers, red red red red...ok. Little stuck here. So I can have, this [Draws new arrangement of red crayons], I can have like...this, [Draws another arrangement], I can have...[Draws another arrangement]...ok, well, I'm gonna think about it a different way now, *let's just ignore the reds for now*, and I know that I have five other spaces that I can choose. Blues. *So I have no restriction on where I put the blues in.* Or anyway, I can say, for the blues...order doesn't matter, so I could just do, so there's five places [Student spends some time doing calculations.] alright no, I'm stuck. *I'm trying to figure out how I can arrange just the blues in, and not worry about the reds, so...*

In the next vignette, Student 3 does not seem to realize that, once the reds have been placed, the placement of the blues is determined and continues counting the number of ways to arrange the blues (and, further, counts permutations of the eight crayons as though they were all distinguishable):

Interviewer: So, what were you just counting there?

Student 4: I was just counting um, how many positions it is possible for three of them to be together, and it's six. So I know to eliminate that. In the...

Interviewer: Eliminate it from what?

Student 4: From the thing I'm trying to calculate. So from that...it's...just...eight...[Writes, "8C3*8C5"... then tacks on, "8C3*8C5*8! - 6"]

Interviewer: So, where did you get the eight choose three times eight choose five times eight factorial?

Student 4: So eight choose three would be basically choosing three of the crayons, the three reds, and multiplying it with the five...

Interviewer: So it's, so the eight choose three counts the number of ways to place the three red crayons?

Student 4: Right right. And...

Interviewer: And, and what is the, the eight choose five counts the ways to place the blue crayons?

Student 4: Right. Um, and then this factorial is for the arrangement of all of those. And minus six is to...

Interviewer: To, yeah, take away the invalid cases.

Student 4: Right.

F. Use of diagrams

An unexpected finding was that the use of diagrams was associated with unsuccessful solution attempts. A diagram was produced during 19 solution attempts (representing all four problems), only four of which were successful attempts. Almost all diagrams were some sort of a representation of the slots in the crayon box (e.g. a string of horizontal dashes or squares or tick marks) or a representation of an arrangement of crayons (e.g., a string of R's and B's). So one reason for this association could be that students who are unsure of what to do may be more likely to draw specific arrangements of crayons/colors. It may also be the case that students with more counting experience develop a gestalt-like connection between the counting process and the algebraic formulas and, therefore, no longer need to use diagrams. Future research that examines

² Here the student is referring to the total number of arrangements allowed subject to the given restriction on the reds.

the use of diagrams in a more nuanced fashion³ could potentially provide valuable insight into the problem solving process for counting problems.

TABLE IV. SUMMARY OF RESULTS

Understanding Assumptions / Other Themes				
	Problem 3	Problem 4	Problem 5	Problem 6
Student 1	B/-	-/-		-/D
Student 2	O/D	C/D	-/D	-/DER
Student 3	O/D	-/D		OI*/DR
Student 4	BI/D2		-/-	B/DE
Student 5	B/DE			
Student 6	IO/-	-/2	O/-	-/DE
Student 7	-/-	C/-	-/-	-/DE
Student 8	-/-	O/-	-/-	-/-
Student 9	-/D	-/2		
Student 10	-/2	-/D2	O/D	-/D
Student 11	-/D	-/D		

Table IV Key: Understanding Assumptions - **B**: questioned shape of box, **I**: questioned indistinguishability of crayons (**I*** - though not explicitly mentioned out loud, this student's solution implicitly implied distinguishable, same-colored crayons), **O**: questioned importance of order, **C**: questioned the number of crayon colors. Other Themes - **2**: dichotomous solution schema present, **E**: enumeration of allowable arrangements, **R**: failure to perceive related constraints, **D**: drew a diagram. Note: '-' indicates absence of questioned assumptions/other themes. Green/Red indicates successful/unsuccessful solution attempts. White indicates the problem was not attempted.

VI. CONCLUSION

The five themes discussed above (understanding problem assumptions, dichotomous solutions, focus on allowable arrangements, perception of related constraints, and use of diagrams) highlight various difficulties that students experience when solving basic combinatorics problems involving permutations and combinations. Many of these difficulties are attributable to overlooked subtleties regarding the problem assumptions in combinatorics problems. We have tried to highlight some of these thorny issues via the vignettes presented in the previous section and, in some cases, have offered suggestions about how some of the difficulties might be mitigated (or at least not encouraged) by instruction. We have specifically called attention to students' difficulties with understanding problem assumptions and dichotomous solutions because instructors are more likely to be blind to these difficulties as their expertise blinds them to what assumptions they are making during their own problem solving [24].

³ More nuanced than just a binary code for whether a diagram was used or not as was done for this study. Different types of diagrams, for example, could be distinguished and details regarding how they are produced and used during the problem solving process could be studied.

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Taxonomy of Faculty Assumptions about Students

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Abstract—If you are part of a faculty meeting, a committee, or a learning community of instructors, you will sooner or later hear the same conversation - the conversation that begins with complaints about students. The attributions about lack of engagement, focus on grades, or the entitlement of this generation are common, and though typically unexamined such complaints are not completely ungrounded. This narrative creates a community around a shared “problem.” This camaraderie is natural, but what are the consequences? Beyond whether such statements are “true,” we believe these assumptions about students are affecting student learning. There is a phenomenon in education known as “self-fulfilling prophecy” where what we believe about students becomes manifest in part because instructors behave in ways that bring about what the instructor initially expects. As a first step in exploring these assumptions, 150 participants in a Teaching Professor Conference in May 2014, generated a list of assumptions they held about students. These assumptions were categorized into four dimensions: Motivation, Behavior, Preparation, and Systems with each dimension having a continuum. This paper describes the taxonomy and references theories to support the organization. The paper will give examples of the assumptions and discuss the next steps to validate the ideas.

Keywords—Faculty assumptions, teaching, psychology

I. INTRODUCTION AND BACKGROUND

Organizational theorists have long recognized that the assumptions held by the humans in the system determine the systemic outcomes [1] [2]. It is no different in engineering education. The connections between our assumptions and actions is made clear by Ambrose [3] where she explicitly states “Because assumptions influence the way we interact with our students, which in turn impacts their learning, we need to uncover and at times questions those assumptions.” (p 181). In the 1950’s Carl Rogers introduced some radical views on education [4]. Rogers articulated the assumptions on which the educational system was based and in so doing was able to illustrate the conflict. For instance, from page 171:

- The student cannot be trusted to pursue his [or her] own ... learning
- The ability to pass examinations is the best criterion for student selection and thus judging professional promise
- Presentation equals learning: what is presented in the lecture is what the student learns
- Creative scientist develop from passive learners

As a contrast to these assumptions, Rogers, Maslow [5], and others [6] used a constructivist approach [7] [8] and an emphasis on the innate drive and ability of people to learn. Rogers argues that individuals can and will grow when there is a safe environment present. This developed into his philosophy of “unconditional positive regard” which he extended to education [9]. In this model, the role of an instructor is to provide structure, inquiry, and space to explore while holding positive assumptions about the individuals ability to grow and change. Many others have also endorsed the importance of this disposition [3] [10] [11] [12] [13] [14]. Some of these ideas made their way into schools in experiments on “self-directed learning” in the 1970’s and 1980’s. Bellanca, et al [15] provide a vivid glimpse of a high school program in the 1980’s that embraced benevolent assumptions.

When reviewing literature on instructor assumptions we quickly become aware of a concept referred to as “self-fulfilling prophecy.” Most of the research on this particularly named phenomenon has been done in elementary schools [23]. In 1968, Rosenthal and Jacobson [24] performed an often quoted experiment and wrote about it in “Pygmalion in the Classroom.” They identified randomly chosen students and told their teachers that these students had been tested as “spurters,” an imaginary label, and could be expected to make great gains in school. After a year, they tested these students and found that indeed the “spurters” had made significant higher gains in ability when compared to the gains made by the control group. Later this was referred to as the “self-fulfilling prophecy” [16] [25]. Others have called it “teacher expectation bias” or “perception bias” [26].

Although people have been thinking about the role of assumptions in personal change, and to some extent in the K12 classroom, those that explicitly look at higher education are fewer. An exception is a study by Scheurman [16] using King and Strohm-Kitchner’s [17] framework for critical thinking through reflective judgment to study both faculty and students’ espoused and practiced thinking patterns. Interestingly they found that faculty assume both that students have a less mature reflective judgment than students actually have, and faculty themselves believe faculty have a more mature reflective judgment than faculty actually practiced in the classroom. The authors argue that the assumptions about student’s lower maturity lead to easier assignments and less engagement by students, which actually reinforces the

faculty's belief that the students are unable. This faulty feedback serves to amplify a lower level of learning in the students, the self-fulfilling prophecy.

Another study done in higher education in Physics classes looked at six instructors [18] to produce a very detailed mental model of the instruction process. The study highlights the importance of the initial classification of students in the instructors mind (assumptions) into two groups: "students who can improve" and "typical students." This initial classification leads to dramatically different instructional techniques and interactions, and presumably learning.

Carol Dweck's [19] [20] and other researchers' earlier work [21] [16] on Mindset concepts also have the same premise of self-reinforcement. These researchers assert that there is a role for the instructor to help change mindset from a fixed one to a malleable one, but the mindset held by a particular instructor influences the effectiveness of this instruction. This is consistent with the dynamics of self-fulfilling prophecy. As another example Rattan, Good and Dweck [22] argue that instructors who comfort struggling students in math might be reinforcing a fixed mindset and thus limiting potential achievement.

Some of these concepts have been extended to biases for under-represented groups such as women in engineering amplifying stereotype threat [27] [3]. Many studies validate that the expectations of significant others including parents and teachers does impact student performance [22] [28] [29].

One particularly interesting study on college classroom "incivilities" by Boice [30] connected negative classroom activities to poor learning for students and discouragement for teachers. He used observational studies, surveys, and interviews over a five-year period. He was able to observe incivilities of both students and faculty and found these had a direct impact on learning. The vicious cycle of misunderstanding is illustrated in his quote: "Faculty who struggle with CI [classroom incivilities] in their classrooms mistakenly believe that the students can only be won over with pandering - easy assignments, tests, and entertainment in place of serious classroom material. In the usual vicious cycle that follows, faculty often find ways to confirm the misbelief when they alternate distant, demanding styles with periodic bouts of lower standards, students quiet, but only temporarily" (p. 480).

The arguments we make here about the need to understand instructor's assumptions, certainly apply to all of education, but we believe engineering education probably suffers more from a pervasive negative bias. The roots of engineering are set in the military and in the orientation toward progress [31]. Although this has produced great results, there is some evidence that the persistence of a culture based on these assumptions is one not at all hospitable to under-represented groups like women, Latinos, or African Americans [32]. Studying engineering faculty's assumptions with the potential to intervene in the system may have great impact on STEM education.

It is clear to us that the assumptions we hold about students could impact the methods used in the classroom, which could in turn impact learning. As a first step to investigate this we are asking: "What are the types and range of assumptions that we hold as instructors?"

II. METHODS

In order to gain insight into the various assumptions held by faculty, one of the authors facilitated a workshop at the Teaching Professor Conference in Boston in May of 2014. 150 participants collaborated in small groups and generated a list of nearly 100 assumptions that we as faculty hold about students. These were collected on a "Sticky Wall." During the conference the assumptions were sorted into *negative* and *benevolent* assumptions. The conference participants debriefed the assumptions and many commented on how easy it was to think of negative assumptions while it was hard to come up with the more benevolent beliefs. The whole of the assumptions were later sorted into categories to create the taxonomy.

Figure 1 shows this taxonomy of faculty assumptions. It is important to remember these are assumptions that faculty hold about students, and not the traits of the students. The assumptions do map onto exiting psychological theories (explained below) indicating these assumptions probably do have a correlation to actual students traits, but our interests in this work in progress paper is in laying foundational work around the range of assumptions that faculty hold.

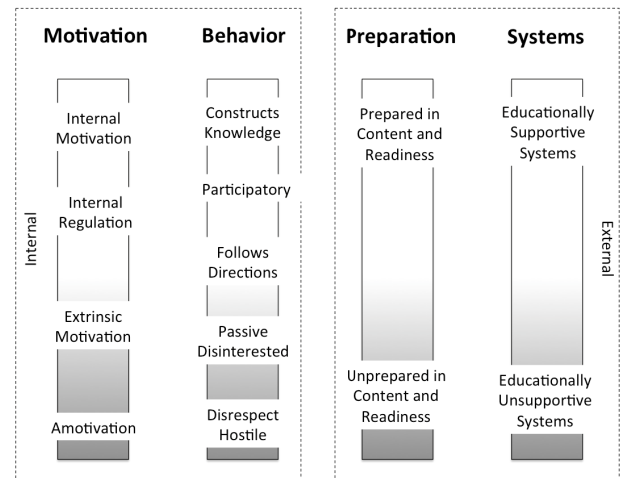


FIGURE 1: TAXONOMY OF ASSUMPTIONS

There are two general categories of assumptions: *Internal* influences and *External* influences. Within Internal we have identified *Motivation* and *Behavior*, and within External, there is *Preparation* and *Systems*. Below we explore each of these categories within the context of psychological theory.

III. PSYCHOLOGICAL THEORIES

To set a framework for exploring the assumption categories, we wish to be clear that although the taxonomy is presented as isolated, discrete groupings, in actuality they are mutually influential. Although each of the four categories are presented in order, across the domains there is interaction,

interdependence, and sway upon one another that yields a more complex process than the presentation might suggest.

A. Motivation

In their work on self-determination theory, Deci and Ryan [33] articulate a system ranging from motivated (defined as “energized or activated toward an end”) to unmotivated (defined by “no impetus or inspiration to act”). The authors further suggest that motivation can be distinguished in terms of *level* (quantity) and *orientation* (type), where the latter distinction relates to goals and attitudes.

Motivation is guided by attitudes and expectations about tasks, which are in turn directly related to goals and achievement behavior. Students’ motivation can vary in terms of whether they are striving to achieve due to a desire for positive outcomes (e.g. getting an A grade), which is an *approach* orientation, or because they are trying to *avoid* negative outcomes (e.g. not getting “bad” grade). Elliot and McGregor [34] further this distinction in describing what many have discussed as *mastery* and *performance goals*. Ryan and Deci [35], suggested this differentiation might be based on personal interest and curiosity versus seeking approval and recognition, respectively.

Intrinsic motivation relates to personal investment and leads to proactive behavior, depth of learning, retention of information, creativity, and is oriented to the mastery of a domain. Extrinsic Motivation conversely is derived from outside forces. In a learning context, this form of motivation relates to compliance and, worse yet, coercion where students engage in learning processes and assignments because they have to, not because of personal interest. Extrinsic motivation can lead to the same level of achievement as intrinsic, but the former form typically results in compromised retention of information because goals tend to be short-term. To clarify, the orientation of motivation as presented here suggests a dichotomous ordering, whereas in actuality the types are not mutually exclusive and may operate in combination or proportion.

Exploring how motivation ultimately translates into action adds complexity. We might consider motivation as related to potentials, whereas behavior is the actualization of motivational energy. For example, in taking the *Disrespect/Hostile* pole of the Behavior continuum, we understand it to be a predictable behavioral outcome as explained in Ryan and Deci’s [35] work. The authors assert that, “Students can perform extrinsically motivated actions with resentment, resistance, and disinterest... [which is] the classic case of extrinsic motivation” (pp. 55).

B. Behavior

Observable behavior can be considered as selection from a virtually infinite array of options. In theorizing about the influence perceptions of personal control have on behavior, Julian Rotter [36] posited the notion of *behavioral potential* to account for the litany of options for action available to each of us in any given situation. Rotter explained that *expectancy* of reward or punishment and *reinforcement value* decide our

actions. Regarding expectancy, students’ learning behavior depends upon their expectations of success or failure on exams and projects. Reinforcement value on the other hand relates to whether or not good grades and/or mastery of information are important to students. If neither of these outcomes matters to a student, or if more desirable alternatives are available, learning behavior will be undermined.

In providing a more balanced account, Kurt Lewin [37] challenged such one-sided notions in asserting that behavior (B) is a function (*f*) of both the person (P) and the environment (E): $B = f(P, E)$. More specifically, P symbolizes that which is internal to the individual (motivations, thoughts, and feelings), and E symbolizes the influential factors in the environment (setting, cultural factors, physical and social climate, interpersonal and sociopolitical histories). Lewin held that the person and the environment influence one another such that neither are passive recipients and that each responds to and influences the other. Dewey and Bentley [38] suggest, “A behavior is always to be taken transactionally: i.e., never as if the [student] alone, any more than of the environment alone, but always as of the [student]-environmental situation, with [students] and environmental objects taken as equally its aspects (pp. 290).”

All this is to stress the point that we have a role in students’ academic behavior. Our attitudes, interpersonal styles, and beliefs about teaching, learning, and students influence the environmental facets of the behavioral equation. As instructors, we must ask ourselves, “What is the environment of my classroom?... my campus?... and what is my role in that?” Learning, as well as teaching, is a social and relational event. If we do not endorse and embrace the fact that our behavior impacts the behavior of our students we miss the opportunity to reflect upon how our teaching assumptions and practices either facilitate or compromise students’ potential and learning.

C. Preparation

Student preparation can be divided into two broad categories; 1) that of information and skills derived from completion and retention of prerequisite course work (content knowledge), and 2) that of a broader level of readiness for college in general terms of cognitive strategies, transition knowledge and skills, and learning skills and techniques [39]. In reaching back across the previous two categories of the taxonomy, Gaertner and McClarty [40] assert that college readiness, related to content, is most notably impacted by students’ behavior and motivation. Conversely, the more general learning and transition skills relate more to readiness in terms of being able to navigate the college experience as a whole.

Preparation is increasingly discussed in terms of “non-cognitive” factors [39]. The ever expanding literature on First Generation College Students helps to highlight the specific challenges some students face in navigating the transition to college and the difficulty of engaging and thriving in a foreign environment. Often, the skills that got them to college are not

sufficient for subsequent success in and through degree completion. First generation students are simultaneously tasked with learning both discipline specific content as well as general college success skills, whereas second generation college students and beyond, the unwritten rules of college life and success are typically passed on from parents to children. In terms of utilizing resources, the example of instructor office hours comes to mind. There is a change that occurs in the shift from high school to college, wherein the former context “going to the office” typically holds a negative connotation, whereas in college utilizing office hours is viewed as a proactive behavior and often interpreted by instructors as a sign of engagement and motivation. Conversely, when instructors observe by way of performance that a student is struggling and reflect that the student has not sought help during the allotted office time, instructors may errantly interpret the lack of seeking out help as disengagement or laziness.

D. Systems

The systems dimension in the taxonomy reflects the external factors impacting students in their learning. Bronfenbrenner’s [41] widely applied ecological model accounts for the various systemic levels and their interactions in describing the educational contexts of students. At the center of the systems model, the *microsystem* addresses immediate interpersonal relations between a student and those she encounters in various academic or social settings which might include family, friends, classmates, and instructors. Next, the *mesosystem* refers to the interrelations and interactions between these specific groups. It is still rather immediate but occurs “around” the student more than always at the immediate transactional level where the student is central to the interaction. *Exosystems* are yet another step removed from personal engagement and denote major social structures that influence the individual broadly, yet not directly. They influence the other systems the individual is more intimately involved in. Finally, the *macrosystem* occurs at an overarching cultural level and is more abstract in housing the values learning that shape behaviors.

Beyond these broad categorizations, we must also address that many students face competing agendas for their resources of time, energy, and attention. From a diversity standpoint in terms of socioeconomic status, the funded, full-time, student-only lifestyle appears to be on the way out. Many students come from families who cannot afford to fund their education and as such must work part- or full-time jobs on top of being full-time students. In accord, we must be cautious in interpreting student grades as pure and equal markers for all students because not all students have the luxury of what may be assumed “typical” college reality in that academics are the primary focus of students’ lives. Finally, there are systems-based issues related to the climate of individual disciplines, such as engineering, as well as for the university at large. Research on college students’ sense of belonging [42] has been positively correlated to their identification with university and college life in a broad sense, as well as for

engagement and performance in coursework specifically. A systems perspective is broad yet necessary in understanding the range of both academic and nonacademic factors that impact students.

Given the list of assumptions and the above psychological theories we hypothesize that the assumptions we hold will map onto these categories. Figure 2 shows some of the actual assumptions collected at the Teaching Professor conference in May 2014 mapped onto the categories.

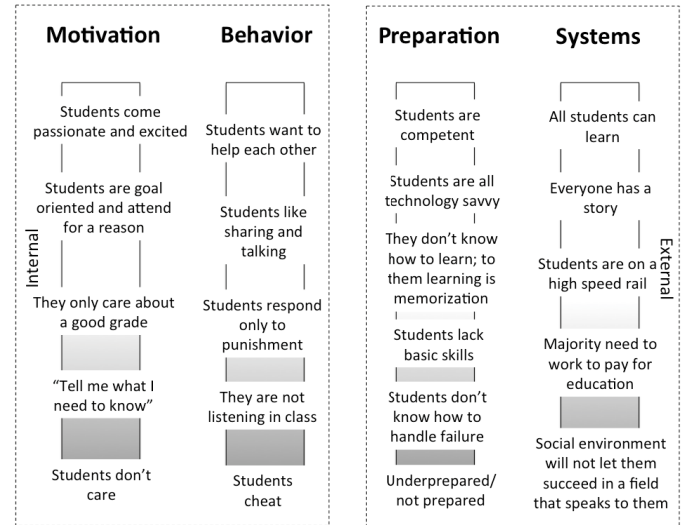


FIGURE 2: ACTUAL ASSUMPTIONS MAPPED ONTO TAXONOMY

IV. CONCLUSIONS AND NEXT STEPS

We are convinced that the assumptions faculty hold are influencing learning, in some cases these influences could be positive in others the assumptions held might be decreasing students learning. As a deep intervention into the system of education we are examining the assumptions we as faculty members hold about students. This work in progress paper is a first step in that direction. It is our intention to use this foundational taxonomy based on theories to continue investigating this issue. Our next step is to interview faculty and attempt to map an individual faculty’s assumptions onto this taxonomy. These individual taxonomy maps will serve to inform individuals as to where their assumptions fall on the full range of possible assumptions. We also hope to develop a collective picture of faculty as a whole.

We also are pursuing other research questions such as “How are pedagogical choices related to a faculty’s held assumptions?” or “Is there a correlation between faculty’s assumptions and actual students traits?”

We feel this is exciting and potentially transformative work in the area of psychology and engineering education that could potentially influence all of higher education.

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Sociocultural approaches to teaching and learning in engineering education: Research-based applications in a pre-engineering course

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Abstract— In this paper, we propose a sociocultural approach as an alternate model of teaching and learning to replace existing and often ineffective models of direct instruction in engineering education. We discuss preliminary findings from a project funded by the U.S. Department of Education Minority Science and Engineering Improvement Program to demonstrate the implementation of a sociocultural model of teaching and learning in a freshmen pre-engineering course at a large, Hispanic serving institution located on the US-Mexico border. Specifically, we highlight four features of sociocultural teaching and learning as applied within the context of key activities in this course. These four features include: peer-scaffolding, learning-in-practice, distributed expertise, and engineering-specific writing. Findings from student interviews and focus groups, as well as classroom observations, show that student learning and engagement are positively impacted by class activities that are constructed with an emphasis on small-group social interaction and participation in authentic engineering tasks.

Keywords—sociocultural theory; situated learning; authentic engagement; participation; hands-on learning; student-centered learning.

I. INTRODUCTION

The National Academy of Engineering (NAE) identified student learning as a top priority to 21st century engineering education [1]. Specifically, this "new frontier" in engineering education aims to change the paradigm for the teaching and learning of engineering at the foundational level by moving away from lecturing, what is often referred to as a "sage on the stage" approach. In this paper, we propose a sociocultural approach as an alternate model of teaching and learning to replace existing and often ineffective models of direct instruction in engineering education. While there is emerging interest in the field of engineering education [2]-[4], few empirical studies have examined the ways in which sociocultural approaches impact student learning and engagement in actual engineering classrooms. In this paper, we discuss preliminary findings from a project funded by the U.S. Department of Education Minority Science and Engineering Improvement Program to demonstrate the implementation of a sociocultural model of teaching and learning in a pre-engineering course at a large, Hispanic serving institution located on the US-Mexico border.

At the center of sociocultural theory is the idea that learning is a social and cultural phenomenon rather than solely individual [5]. In other words, while "sage on stage" approaches to teaching and learning focus on cognition as an individual process that takes place solely within the learner's brain, sociocultural approaches to learning focus on social interaction, authentic engagement and the learning environment. Some of the principal characteristics of a sociocultural model include: the importance of authentic activities to promote learning; the importance of the collaborative construction of knowledge; the need for coaching and scaffolding at critical moments; and the importance of reflection to encourage the formation of abstractions [6].

In what follows, we illustrate how these features of a sociocultural model were visible in three key course activities and highlight how these activities facilitated student learning in the freshman pre-engineering course. The three activities that we present are: (1) peer math groups; (2) a robotics project; and (3) the use of engineering notebooks. It is worth noting that our use of the term "activity" rather than assignments is purposeful and merits a brief definition given the focus of this paper. According to sociocultural theories of learning and teaching, in particular *cultural activity theory* [7]-[8], *activity* is a foundational component to socially situated sense making interaction and engagement. Within the context of our study, course activities were the primary unit of analysis to explore the role of sociocultural approaches to learning in engineering education.

II. METHODOLOGY

This study is part of a larger funded project aimed at fostering metacognitive practices to support the persistence and timely completion of students who are historically underrepresented in engineering, namely Hispanic women and English Learners [ELs]. The project represented a collaborative effort between educational researchers in the College of Education and researchers in the College of Engineering at the university. Drawing on the tradition of educational anthropology, we employed an ethnographically-informed qualitative approach to identify and analyze the role of sociocultural approaches in promoting student learning in a freshman pre-engineering course at the center of the project.

With the goal of describing and interpreting the social world, ethnography involves immersion into the everyday interactions and experiences of participants in order to “see firsthand how people grapple with uncertainty and ambiguity, how meanings emerge through talk and collective action, how understandings and interpretations change over time, and how these changes shape subsequent actions” [9]. By being immersed in the freshman pre-engineering course as participant observers, we were able to observe and describe the actions and interactions of students within this one particular setting, and then make sense of those actions in light of sociocultural theories of learning.

Data were collected across two sections of the pre-engineering course during the Fall 2014. Four primary sources of data were collected: (1) a demographic survey soliciting information about language and schooling; (2) participant observations during class meetings; (3) in-depth interviews with select participants; and (4) focus groups with all participants. The in-depth interviews conducted with select participants included one interview at the beginning of the semester and a follow-up interview towards the end of the semester. In order to have a diversified group of students to be interviewed, students were selected based on their language background, location of K-12 schooling (e.g. Mexico or U.S.), and gender. Individual interviews were conducted with 12 students, seven females and five males. Nine of these students attended K-12 schooling in the United States, while three attending K-12 schooling in Mexico. In addition, ten of the selected students reported both English and Spanish as their native languages while one student reported only English and another reported only Spanish as their native language. The focus groups, which were conducted with all participants in both course sections, lasted 60 minutes on average. Finally, more than 50 combined hours of classroom observations took place over the course of the semester by all three authors.

All interview and focus group data were transcribed and coded in the qualitative software NVivo 10 using an “open coding” and a “focused coding” approach [9]. A total of 22 interviews as well as the two focus groups and observational notes were analyzed and coded for themes and patterns that emerged across the data sources. For this analysis, we focused on the three principal activities of the course – peer math groups, the robotics project, and the use of engineering notebooks - to examine students’ perspectives on and experiences with these activities in relationship to their learning. Key themes (codes) that emerged in NVivo included *students as resources*, *student collaboration*, *student negotiation*, and *problem-solving*. The authors of this paper participated in a series of data analysis sessions at each stage of analysis to discuss emerging themes, which ultimately led to the presented findings below.

III. FINDINGS

A. Peer math groups

Peer math groups were the first activity introduced in the pre-engineering course. Specifically, expert-novice groups were formed to promote mathematical learning on six pre-defined pre-calculus topics: polynomials, functions,

exponentials, logarithms, unit circle, and trigonometric functions. These topics were chosen because the majority of students enrolled in the course were simultaneously enrolled in pre-calculus. Using a random process of assignment, six “expert” teams were created. Each of the six expert teams was responsible for developing expertise in one topic. Expert teams used multiple resources to facilitate their becoming “experts” on their math concept. For example, expert teams consulted math texts, online tutorials and other experts, like the course instructors, family members and friends. Additionally, students in each of the expert groups had varying degrees of prior expertise on the math concept. In sum, expert teams drew on a range of resources and competencies to develop shared expertise on the topic.

Novice teams were formed by randomly assigning one student from each expert group to a novice group so that each novice group included one “expert” in polynomials, one in functions, one in exponentials, one in logarithms, one in unit circles and one in trigonometric functions. Once the expert-novice groups were formed, students worked in their expert group to acquire expertise with fellow expert group members on the assigned math concept during one week and then on alternate weeks students would work in their novice group. Within the novice group, each student was responsible for “teaching” the math concept from their expert group to the rest of the novice group.

A central sociocultural feature of the expert-novice groups was *peer-scaffolding*. Scaffolding is shorthand for the *zone of proximal development* (ZPD) in sociocultural theories of learning [10]. ZPD is the idea that learning occurs through socially situated interactions with peers or adults who have different levels of understanding relative to a given task or concept. In keeping with a “societal” perspective of ZPD [11], the math groups constitute a collective activity in which learning represents “the changing relations between newcomers and old-timers in the context of a changing shared practice” [11].

By designing collective activity systems, like these math groups, novice students were able to learn new math concepts as a consequence of the interactions and authentic engagement with expert or “old-timer” students. For example, during an interview, Clara, a Latina student, described herself as “not good at math,” “really slow with math,” and “not as smart as” other students in her math class; at the time of the interview she was enrolled in a pre-calculus college course, even though she had taken a semester of calculus in high school. She also indicated that her pre-calculus professor “teaches by just writing it out” with little to no explanation, about which she said, “I’m not used to this.” However, in contrast to the “sage on the stage” approach of this professor, Clara talked enthusiastically about how the high levels of engagement and interactions in her novice-expert math groups had a positive impact on her understanding of math concepts. Specifically, she explained that she learned “a lot more” from the math-novice group than from her pre-calculus class, stating “...because I was seeing it, I was doing it, and the way we would have to teach it... it helped me learn more.” She also emphasized the importance of interactions in her math expert-novice group, drawing a contrast with the note-taking that took

place in her more teacher-centered pre-calculus course: "...when the other groups present it also kind of kept my attention 'cuz of the way they would present it and the way they would interact with us. That also helped a lot for me to memorize...those [concepts]."

Importantly, data from this study also demonstrate that a sociocultural rather than an individual approach to learning benefits students at all stages of understanding and not just novices. For example, Ana, another Latina student, talked about the effects of engaging as the "expert" in the context of the novice-expert groups on her learning, "I can learn hands on and visual as well but I also learn by explaining to others and I think that's something that a lot of us should do more often because then we actually know and understand the material better."

While it is beyond the scope of the current paper to explore other sociocultural features that were a part of the math groups, we want to highlight the significance of ZPD or peer-scaffolding as forms of authentic engagement and social interaction rather than more traditional models of teacher-centered lecturing.

B. Robotics project

The second key activity in the pre-engineering course was a small-group robotics project. This project took place in the second half of the semester following the math expert-novice groups. In this project, small groups worked together to design and build their own robot using Lego Mindstorms. The small groups were formed randomly, using different configurations of students than the math expert-novice groups. Like the math expert-novice groups, this activity illustrated the ways in which participation in authentic engineering activities contributed to student engagement in learning. Two sociocultural features were particularly visible in this activity: *learning-in-practice* [11] and *distributed expertise* [12].

Learning-in-practice makes reference to the ways in which learning is facilitated by engagement in authentic tasks and activities and participation in the social practices tied to those activities [11]. One student, for example, describes the trial-and-error process that was involved in creating a soldier robot to replace human soldiers as part of their Systems Engineering project: "we started building a robot and well first we like I don't know it just kind of developed because like as we were building our robot we realized we kind of needed a tank and then like we were just experimenting." Learning in this instance did not occur solely in the abstract or in the minds of students; rather, it occurred through participation in the social and material act of constructing a robot. From a sociocultural perspective, the building of a robot represented "learning [as] doing" within a particular context [3].

While the physical artifact of the robot served as an important tool for learning, such learning transpired primarily through peer-to-peer interactions within and across robotics groups, which consisted of 3-5 students each. These groups became an important site for "distributed expertise," which emphasizes the ways in which knowledge and expertise can be spread among participants in a given setting, and the ways in

which participants "mutually appropriate" such expertise through social interaction [12]. Within these groups, students had to negotiate their roles in order to accomplish the robotics task at-hand. In both interviews and focus groups, several students from different groups highlighted the ways in which different team members contributed different skills to the design process. One student, for instance, described the importance of role and tasks within his group: "What helped a lot was knowing what each teammate has to do, I mean, to move fast because every teammate has a specific function within the group and I mean if you do that you can finish your project..." Several other students highlighted the need for specific programming knowledge to complete their robots. In one group, two participants volunteered to be the programmers, thus offering a particular skill set in the robot development process. If no group members held that expertise, participants looked to known programming experts from other groups. Such practices illustrate the ways in which expertise was distributed both at the small-group activity level as well as the classroom level.

C. The use of engineering notebooks

The third key activity in the pre-engineering course was the use of engineering notebooks as part of the robotics project, where students documented their robot design and development process. The use of engineering notebooks represented an engineering-specific writing task situated within the robotics activity. This task can be seen as a key illustration of writing as a form of social action tied to authentic settings and tasks, in this case, the engineering-specific task of designing a robot [4], [12]-[13].

All of the robotics groups in the pre-engineering course utilized the engineering notebooks, but the notebooks took on different meanings to different groups. In one group, for example, the engineering notebook played an important mediating role as the four group members negotiated the type of robot they would build. One group member, Daniela, explained in an interview that the rest of her teammates, all male, wanted to build a very complex robot, "something really big, something really spectacular." Concerned about time constraints and also about not wanting to make a decision "in an authoritative way," Daniela encouraged her team to brainstorm different possibilities for robots. The group used the engineering notebook to draw and discuss models of different robots; Daniela reported that, through the process of brainstorming ideas in the engineering notebook, the group discovered that some of their original ideas were "too complex [and] maybe not so useful for engineering." They instead chose to pursue a robot of simpler design, one that prevented accidents by "cleaning up" color-coded hazardous waste materials.

In addition to playing a mediating role in some groups, the engineering notebooks also played an instrumental role in many groups, serving as a mechanism of communication between group members. Several groups reported using the notebooks to document their progress on the robot and to communicate about next steps needed in the process, as

different configurations of group members met at different times. In all of the groups, the writing that occurred through the notebooks was closely tied to the task at hand; in other words, students participated in authentic forms of engineering communication that were situated in an authentic engineering activity [4].

IV. DISCUSSION

In this paper, we highlighted four features of sociocultural teaching and learning as applied within the context of key activities in a freshman pre-engineering course. These four features included: peer-scaffolding, learning-in-practice, distributed expertise, and engineering-specific writing. We showed the ways in which peer-scaffolding in math expert-novice groups better facilitated student learning of fundamental pre-calculus concepts in ways that differ substantially from traditional “sage on the stage” approaches. We also showed how student engagement in the hands-on development of a robot encouraged learning by trial-and-error through participation in an authentic engineering task (learning-in-practice) and paved the way for different group members to contribute different kinds of knowledge to complete the task (distributed expertise). Finally, we demonstrated how the use of engineering notebooks as part of the robotics project represented a form of authentic engineering communication tied to an authentic task. Findings from student interviews and focus groups, as well as classroom observations, show that student learning and engagement were positively impacted by class activities that were constructed with an emphasis on small-group social interaction and participation in authentic engineering tasks.

In total, these findings highlight the ways in which undergraduate courses can be designed using sociocultural principles in order to foster greater student learning and engagement. Following, this study also illuminates the need for more systematic research on the implementation of sociocultural approaches to teaching and learning in engineering education. The shift from individualized notions of cognition and learning to social understandings of distributed cognition and learning through participation holds great promise not only for engineering education. Such approaches are especially critical to broadening the participation of traditionally underrepresented students in engineering education, who stand to gain the most from teaching and learning that actively promotes collaboration over isolation..

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Qualitative Assessment of the University of Texas System Louis Stokes Alliance for Minority Participation Summer Research Academy Abroad: An International Experience in Research and Culture

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Abstract— Since 1993 nine universities in the University of Texas System and several affiliated community colleges have worked collaboratively to promote STEM undergraduate research through the Louis Stokes Alliance for Minority Participation. In 2012 the Alliance was recognized as a model Senior Alliance by the National Science Foundation and to expand on its work an international research component was added: the Summer Research Academy Abroad (SRA-A). Our first cohort of eight students travelled abroad during the summer of 2014. The students participated in an intensive undergraduate research experience for eight weeks and thus became part of the global STEM community. Prior to their departure these students enrolled in a spring 2014 online seminar to prepare them for both the scientific and cultural components of the SRA-A experience. They learned to operate with confidence in new, unfamiliar environments and gained a multicultural perspective. They also acquired early membership and credibility in the global science arena and began to understand the competitiveness that drives the international research community. This paper discusses program details, participant profiles, and assessment after the program's first year of operation.

Keywords—undergraduate research, international experience, underrepresented minorities

I. INTRODUCTION

The demographic landscape in the state of Texas is changing at an astonishing rate. According to the US Census Bureau, in 2010, African Americans and Latinos accounted for nearly 50% of the Texas population. However, enrollment of and degrees received by underrepresented minorities (URM) in postsecondary education have remained below targets set by

the Texas Higher Education Coordinating Board. Given these disparities in educational attainment, the University of Texas System is taking steps to close these gaps for low income and URM students. The University of Texas System Louis Stokes Alliance for Minority Participation (UT System LSAMP) was inceptioned to improve enrollment, retention, performance, and graduation of URM students in Science, Technology, Engineering and Mathematics (STEM).

As a senior alliance we have three main goals: (i) enhancing our Summer Research Academy (SRA) to include national laboratory and international experiences, (ii) matriculation to STEM programs at UT System universities for participating community college students, and (iii) creating synergy with other NSF research training projects. These goals will prepare our students to be more competent and competitive for graduate studies or in the STEM workforce. The SRA-A is our response to the need for true globalization of higher education. These goals will allow us to continue providing URM STEM students with valuable research opportunities at UT System universities, US Department of Energy National Laboratories, and international research sites.

II. PROGRAM DESCRIPTION

The following description of the program reflects lessons learned from the first cohort of participants. Planning for the SRA-A begins a year in advance of the participants' time abroad. Potential applicants are informed about the program details and application deadlines via email and through various presentations. In addition, interested students are encouraged to access weekly blog posts by previous SRA-A participants. Recruitment efforts also take place at the annual LSAMP conference held each September. Previous SRA-A participants are prominently featured at the conference and are available to speak individually with interested students. The

application deadline is set for mid to late October of each year, allowing time for students who attend the conference to submit the required application materials.

After the application deadline the individual campus directors evaluate applications submitted by students from their home institutions. With fourteen partner institutions and eight funded placements each summer, each campus can send one of their students abroad nearly every two years. Students are notified of the offer by email in mid-November and given two weeks to accept or decline.

Following acceptance in November, an individual video conference is held with the program coordinator and each participant. The goals of the meeting are to:

- Test-run/troubleshoot the video conferencing technology employed;
- Introductions and discussion of roles and expectations;
- Review the program timeline and confirm availability for the mandatory spring seminar;
- Discuss research interests, plan strategies, and assign the next steps for securing a research placement;
- Address potential barriers to participation such as obtaining a passport, family concerns, and time conflicts.

This initial meeting is critical as the search for the research placement abroad starts almost immediately. A discussion of roles and expectations at the outset clarifies that the student and the program coordinator are partners in planning for the time abroad. The student understands that s/he must take ownership of preparations and that the program coordinator will act as a coach, providing support, guidance, and expertise.

Searching for the research placement abroad is the first task students undertake as part of the pre-departure process. Each participant secures a placement in a research group or laboratory abroad that fits both the student's area of interest and his/her country or language preference. There is no list of prearranged placements or mentors; however, students are encouraged to take advantage of previously-formed connections made by prior SRA-A students. For the application, students select their top three destinations from a list of approved countries. If a student wants to secure a placement in a country not on the list, the student needs to demonstrate that costs are within budget, that the appropriate visa can be obtained, and that the country is not on the US State Department Travel Warning list.

To reduce anxiety and uncertainty about the process, on-going communication is key. To ensure this communication takes place, participants are required to send a brief email update to the program coordinator each Friday until the placement is confirmed. This informal check-in creates an additional opportunity for trouble-shooting, devising next steps and strategies, and building the partnership between the student and the program coordinator.

To facilitate communication with potential supervisors abroad, students are given an LSAMP program information sheet which outlines the program and expectations and is written with the potential research mentor in mind. Sample introductory email messages are also provided as templates to use when contacting faculty abroad.

There are three possible strategies for securing a research placement:

- The student consults with their current research supervisor at their home institution to consider international placement with a research collaborator abroad.
- The student searches the web on his/her own for research groups and labs doing work in-line with interests, identifies appropriate faculty members to contact, and makes initial contact.
- The program coordinator asks LSAMP campus directors, faculty members at the home university, and faculty supervisors abroad who have hosted SRA-A students in prior summers for advice and leads.

The first approach has proven to be the most efficient means of securing a placement that is a good fit for the student, although students have been successful finding excellent placements by searching and contacting potential supervisors on their own. Placements will preferably be confirmed for all participants by January, before the start of the preparatory seminar.

From February to May students participate in a weekly, one-hour, non-credit seminar via video conference from their respective campuses. The seminar prepares participants for the time abroad, and also creates a virtual space for the students to create a community. Topics include:

- Course introduction: Introductions; review of the syllabus; research placement updates and next steps;
- Program expectations: Behavioral expectations; code of conduct; drug and alcohol policy;
- Travel planning and budgeting: Scholarship funds; how to create a budget; tools for estimating expenses; currency exchange; emergency funds; how to book the flight; how to find housing;
- Culture, language and country specific information: Learning about the host country (culture, language, history, geography, government; racism, sexual orientation, gender);
- Health and safety, emergency preparedness: Staying safe while abroad; immunizations, medications, International SOS, international health insurance, US and in-country emergency contacts, US State Department STEP program;
- Expectations at the home university: Informing the local university study abroad office of the LSAMP program and the trip abroad, purchasing of international health insurance; providing all required documentation;

- Research readiness: Final preparation for the research experience, communication with the faculty mentor abroad;
- Flight/day of arrival: Travel tips, transportation from airport, jet lag, notifying family of safe arrival;
- Communication and summer blog: Connecting with family, cellular telephone coverage, internet access, blogging expectations;
- Final check-in: Packing tips, troubleshooting last minute details.

Each participant receives \$7,150 in support: \$3,800 for travel, room/board, and a \$3,350 stipend. Funds are disbursed as two scholarship payments. The first, for \$3,800, is paid in late February so students can purchase flight tickets and pay housing deposits. The participants receive the second payment, for \$3,350, at the beginning of May, giving them sufficient time to deposit funds prior to departure.

Participants must meet the requirements for travel abroad set by their home institution's Study Abroad office. These requirements vary by campus, but usually involve providing emergency contact information, an itinerary, and arranging for international health insurance coverage. In addition, by April 30th participants must provide the SRA-A program coordinator a document with the following: research placement information, including name, email, phone and address for the faculty supervisor; flight itinerary; student's cellular phone number and physical address while abroad; name, address, phone of emergency contact person in the US (usually a parent, friend, or spouse); name, address, phone of emergency contact person in the host country (usually the research supervisor); and contact information for their home university study abroad office.

The primary focus during the summer is participation in the eight-week international research experience, dedicating approximately 40 hours per week to the effort. Additionally, students are required to blog about their time abroad, writing about their experiences both in and out of the lab.

Upon their return in September, participants present their research at the annual UT System LSAMP conference. They also participate in a panel discussion about their international experience. Finally, they are required to complete a post-program survey and participate in focus groups.

The 2014 SRA-A program included a total of eight student participants; seven male and one female student; five seniors, two juniors and one sophomore; three Latinos, one African American, two multi-racial, and two Caucasian students. The students came from a variety of academic disciplines: engineering and computer science, life/biological sciences and chemistry. The students traveled to four European countries: England, Germany, Italy, and Switzerland. With the exception of the student in England, none of the students were fluent in the language of their assigned locations.

III. PROGRAM EVALUATION

In order to assess the impact of the SRA-A program on the participants, the students were required to take a survey and participate in focus groups upon their return.

A 32-question survey queried the students about their level of satisfaction with the just-completed SRA-A experience and their perceived gains in six pre-determined categories. Of the eight participants in the 2014 SRA-A there were six valid surveys; one student did not take the survey and another registered for it but did not answer any of the questions. It is unknown why these two students did not complete the survey. All the students were participating in their first international student experience. Below are some interesting trends and data tables that explain the important facets of the survey.

An important consequence of participating in the SRA-A is the ability of the students to focus ahead more sharply and make better choices for further studies and career plans. In every instance, the majority of the students found that the experience had a positive and helpful impact on their graduate school plans. Other survey questions revealed that before participating in the 2014 SRA-A, three of the students definitely planned to go to graduate school and two had thought about going to graduate school. After the SRA-A, four of the students planned to definitely go to graduate school and one was considering doing more research abroad. Two planned to pursue a doctorate and one a masters in a STEM discipline; one planned to earn an MD/PhD; and another an MBA. Three of the students were not sure where they would pursue graduate school, but two were planning to attend their present institution and three had not yet decided.

The focus group, with *all* eight SRA-A participants in attendance, lasted approximately 1.45 hours. During the focus group meeting, the students were very open regarding their impressions, experiences, and recommendations for future SRA-A cohorts and placed particular importance on sharing these thoughts. The general agreement was that, albeit some glitches, each of them would go through the experience again. It is important to note that the time spent during the focus group on the discussion of the topics listed below was extensive and considered very important by the participants, thus overshadowing any extended discussion of other areas, which to them were less important. Following is a summary of the participants' most salient and emphatic comments:

- The Alliance must start the whole process of preparation and coordination earlier, possibly even before students leave for their winter break so that they can use that time to research and work on their preparations; students found the blog to be very useful;
- The program coordinator and students must pay special attention to the "comparative perceptions" of the same field in a different country: for example, is the definition of industrial engineering the same in Italy as it is here?

- The program coordinator must better explore the housing issue, especially the possibility of university housing at area institutions;
- Students need better training regarding money exchanges and finances; especially about the cost of living in the host country and the different rates of exchange, which dictate how far the stipend can stretch;
- Although students found that language issues were not relevant in the lab setting, they would benefit from some type of language training for emergencies and basic needs, and some additional language training suggestions should be provided;
- All students agreed that they should develop “what if” strategies to address possible problems, and that there needs to be a “back-up” plan in case the assignment does not work out to enable the participant to switch to a more meaningful experience mid-stream, if necessary.

Level of agreement with the following statements regarding the SRA-A experience					
	Strongly Agree	Agree	Disagree	Strongly Disagree	n/a
My SRA-A exceeded my expectations	3	1	1		
Instructions I received were very helpful	3	2			
I was happy with living arrangements	3	2			
I was happy with my research assignment	2	2		1	
My staff supervisor was excellent teacher & mentor	3	1		1	
My faculty mentor provided excellent guidance & direction	3	1		1	
Working with the other students was best part of summer	3	1		1	
I will definitely seek to participate in another	4				1

SRA-A					
I would recommend the experience	5				

My SRA-A experience has allowed me to . . .						
	Strongly Agree	Agree	Disagree	Strongly Disagree	Neither	n/a
Improve my overall research skills over the summer	2	2		1		
Be more ready to cope with the demands of a project	2	2	1			
Enhance my familiarity with research tools	4				1	
Improve my ability to analyze data	3	1	1			
Improve my skills in analysis results interpretation	3	1	1			
Improve my laboratory techniques	1	3				1
Better manage information	2	2			1	
Improve understanding & interpretation of literature	2	2	1			
Be more open to the discovery of new ideas	2	2				1

IV. CONCLUSION

The data demonstrates that SRA-A is providing a valuable research experience and a global perspective. It is also allowing participating students to identify professional options to solidify their future career plans. A new group of seven students is doing research abroad during the summer of 2015, and data will be collected and analyzed by mid-September. Recruitment for SRA-A 2016 began in June and the application will be available until October. The UT System LSAMP SRA-A team will begin publishing and disseminating the results of this work to identify partners and opportunities for funding beyond the current phase and future institutionalization.

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Landscape Analysis as a Tool in the Curricular Change Process

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Abstract— The Center for Engineering Pathways to Innovation (Epicenter)'s initiative for faculty development and institutional change – called Pathways to Innovation (Pathways) – is working with U.S. engineering schools to embed innovation and entrepreneurship learning opportunities into the undergraduate experience. Pathways' program design is grounded in the literature that identifies "best practices" in faculty development and institutional change. Each participating institution begins its work with a process of documenting resources (assets) and identifying gaps at their school to create a "landscape analysis." That analysis then becomes the basis for identifying well-defined objectives for focused work to create meaningful change over a short period. The mapping process itself becomes a vehicle through which a large number of stakeholders throughout the institution are engaged. While this process of asset mapping is well-referenced in change literature, its application to curricular change is novel. The specific objectives of the Epicenter project are to increase the access to innovation and entrepreneurship learning opportunities for undergraduate engineering students; however, aspects of the landscape analysis process are relevant to a much wider audience of faculty and administrators seeking to implement curricular change beyond one instructor and/or one course. This paper reviews the research underpinnings of the landscape tool and describes its evolution based on early formative evaluation. Further, the paper illustrates the tool's use in more than 35 engineering schools with widely-varying profiles (*i.e.*, public/private, small/large, rural/urban) and reports on how the tool has been used by teams to identify appropriate change strategies and increase engagement in their project by stakeholders. Finally, the paper identifies future directions and uses for the tool as well as possible topics for future research.

Keywords—*institutional change, curricular change, entrepreneurship, innovation, faculty development, evaluation*

I. INTRODUCTION

The Pathways to Innovation program (Pathways) is a faculty development and institutional change initiative of the Engineering Pathways to Innovation (Epicenter) project, funded by the National Science Foundation and managed by Stanford University and VentureWell (formerly NCIA). Epicenter's aim is to equip engineering students with the knowledge, attitudes and skills needed in a world marked by rapid technological transformation. Based on a preliminary

literature review of effective strategies for faculty development and change in higher education [1], Pathways uses a team-based guided change process to help faculty and institutions introduce and embed innovation and entrepreneurship (I&E) into curricular and cocurricular educational experiences for undergraduate engineers.[2]

Schools participating in Pathways assemble a team of faculty and administrators (and students in some cases) to explore exemplary models for including I&E in engineering and then implement appropriate strategies on their own campuses. The two-year process is highly context-specific; the program provides teams with a range of possible opportunities and avenues and provides coaching as they select and combine those most appropriate.

II. GOALS FOR THE TOOL

The literature review identified key themes for staff to incorporate into the program, two of which became the goals for a tool to support teams in their work.

The first theme emphasizes context-specific changes, rather than the "imposition" of a single approach. The tool should therefore foster strategic change by providing teams with a clear assessment of their environment and the institutional strengths they might leverage in the service of a range of approaches.

The second theme is the need for a mechanism to provide outcomes-based feedback to Pathways institutions themselves, Pathways program staff, and evaluators. Ideally the mechanism would be a tool and accompanying process that efficiently, systematically and (where possible) quantifiably documents the state of the institution before and after the program intervention. By describing the status of the campus at a point in time, it could also serve as a mechanism to confirm campus awareness of said institutional changes. The tool should also evaluate the degree to which Pathways provides effective tools and processes for effecting change on a campus.

III. RESEARCH UNDERPINNINGS

Higher education institutions typically employ a number of different assessment strategies. One mechanism that often lies underneath such assessments is the rubric; rubrics improve the reliability of scoring assessments, and foster self-assessment and reflection, which leads to improved learning outcomes.[3]

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Rubrics need not be restricted to learning outcomes, as illustrated by the PULSE “Vision and Change Rubrics”[4] which is used to help institutions gauge the degree to which recommended curricular innovations in life sciences are happening on their campus. A rubric’s ability to improve reliability, while also fostering reflection and enabling the assessment of change undertaken, led to the use of a rubric-type approach as a starting point for the type of evaluation tool sought.

However, a rubric is not intended to help teams leverage aspects of a multi-faceted environment; for this purpose an approach known as “asset mapping” is a more appropriate starting point. While not a part of educational institutions’ traditional planning processes, asset mapping is readily recognizable in other disciplines, particularly community development and public health. There is a body of knowledge around its use and impact in those settings [5], much of which is relevant to higher education.

Asset mapping has its roots in geographically mapping an organization’s physical assets. Kretzman and McKnight [6] extended the approach by transferring the conceptual framework to the civic sector, where it became known as a cornerstone of “asset-based community development (ABCD)” or one of its variants, including the appreciative inquiry facilitative approach.[7]

Asset mapping avoids a deficit-based perspective that focuses primarily on what is lacking and yields mixed results: incremental improvements but no significant transformation. Instead, asset mapping takes as a starting point the collective knowledge of a community or institution, with the aim of subsequently building on those strengths (assets), to create change. Beyond forming a repository of information, the process of asset mapping is a collective activity and itself becomes a vehicle for developing social capital and a basis for consensus about future actions.[8] Crucially, it shifts the locus of control for change from a positional leader to the community being engaged in the mapping process.[9] The customary role of the facilitator or organization leading the planning process also shifts from one of control to one of partnership in a form of “action research.” [10]

The qualities of asset mapping that make it effective for community development are also useful toward the Pathways goal: change that goes beyond an isolated course or program and change that is widely embraced within the institution. In a university setting, no one individual - even the president - can mandate changes that will be adopted across the institution.[11] Asset mapping acknowledges this reality and helps equip a larger campus network to effect change rather than relying on positional leaders. The Pathways team serves as the nucleus of this new network. The landscape process also accelerates the formation of a “community of practice”[12] with social capital, including connections (especially across departments or colleges) and relationships characterized by trust and mutual obligation, and a common vocabulary.[13]

By combining a rubric-type approach with asset mapping, the landscape tool provides a strategic and context-appropriate starting point for each institutions’ plans to integrate innovation and entrepreneurship, a mechanism for growing the network of

stakeholders attached to the change initiative, and may also provide an evaluation feedback loop.[14]

IV. TOOL DEVELOPMENT

When developing the landscape tool, the PULSE rubric, with its focus on institutional change in a STEM discipline, was influential. Several themes found in the rubric were highly relevant: faculty development and training, development of learning spaces that support desired outcomes, and leadership support of faculty professional development.

Another source of inspiration when developing the landscape tool was the the Kern Engineering Education Network’s (KEEN) “Activity Matrix” that documents the strategies initiated by schools that form part of that network.[15] The KEEN matrix is not a rubric *per se*, in that there is no assessment of outcomes. Rather, it provides a format for cataloging the presence or absence of different curricular and infrastructure components at institutions, rendering it similar to the asset mapping approach outlined above. These different components aligned well with the different components of the innovation and entrepreneurship (I&E) ecosystem that Pathways was interested in fostering and measuring (*i.e.*, co-curricular and curricular programming, learning spaces, faculty training).

The resulting tool was a spreadsheet comprised of six worksheets, each cataloging different parts of an institution’s ecosystem that might foster I&E knowledge, skills, attitudes and experiences. In the “Courses,” “Programs” and “Extra-curricular” sheets, teams documented curricular offerings; in the “Spaces” sheet teams listed physical spaces that foster I&E learning; in the “Leadership” worksheet, teams captured initiatives and strategies emerging from either central administration or engineering that could ultimately foster I&E education on campus (*e.g.*, incentives for new course or program development, or faculty professional development); in the “Champions” worksheet, teams identified individuals that might have the enthusiasm, skills, knowledge and time to assist teams in their efforts. In keeping with the assessment goals of a traditional rubric, a “scorecard” column was included on each sheet, along with the number of students served by different programs where appropriate.

Given the Pathways focus on the integration of I&E, various concepts deemed critical to this field of study were also incorporated. The tool included recommended definitions for innovation and entrepreneurship to promote a common understanding of the two terms, given the myriad of definitions currently in use.[16] [Also included were matrices that invited institutions to consider whether their institution focuses more entrepreneurship or innovation, and the overall degree to which classes are taught using experiential learning, an approach deemed critical to effectively teaching and learning entrepreneurship.[17] On a more granular level, the “Co-curricular” and “Spaces” worksheets included drop down boxes to select the types of assets that promote I&E learning.

The resulting spreadsheet was shared with the team leaders of the first participating schools at a one-day training workshop at the project’s launch in January 2014, with an accompanying short training overview. Team leaders were asked to complete

the tool with their teams over the next month and to bring the completed tool with them to the project's next event, an in-person gathering of all twelve teams at which they would draft a strategy for integrating I&E into their engineering programs by identifying specific ways in which existing strengths could be amplified or leveraged to address gaps in educational offerings.

V. EVOLUTION OF THE LANDSCAPE TOOL

While many teams found the process of completing the landscape inventory challenging, evaluation feedback revealed that the tool provided them with the hoped-for foundation for planning. However, observations of the way the landscape tool was completed, along with an increased understanding of what was important (and conversely unimportant) for the teams to document, pointed out several shortcomings of the tool.

First, completion of the landscape tool is intended to be a group activity, consistent with its roots in asset mapping. However, the static Excel spreadsheet format made this difficult, as members could only contribute information asynchronously unless they were physically in the same room. This meant that often a single individual entered most data, or

the data entered was limited to information that could be easily recalled, and/or made readily available to group members during a meeting. Additionally, the completed landscape tools contained an enormous amount of data, but it did not provide a summarized version of their data along any of the dimensions collected, or tools to compare an institution's own landscape with another school's or aggregated across all the Pathways schools. Finally, soon after the release of the tool, the project staff and evaluators began to grapple with the fact that while the landscape provided a robust baseline, it did not incorporate any mechanism for tracking changes over time, other than a general intention to have the teams update their tools at a later date. In response to these observations, the tool was revised in several ways and introduced to the second group of participating schools in January 2015 (a screenshot is included as Fig. 1):

The tool was converted from a standalone Excel document to a cloud-based spreadsheet using Google Sheets. All members of the Pathways team from a school are given access to the document and can work on it, synchronously if desired, from their own computers. This approach also facilitates the process of knowledge sharing[18] across the team. By ensuring the landscape tool can be completed by a broader group, teams

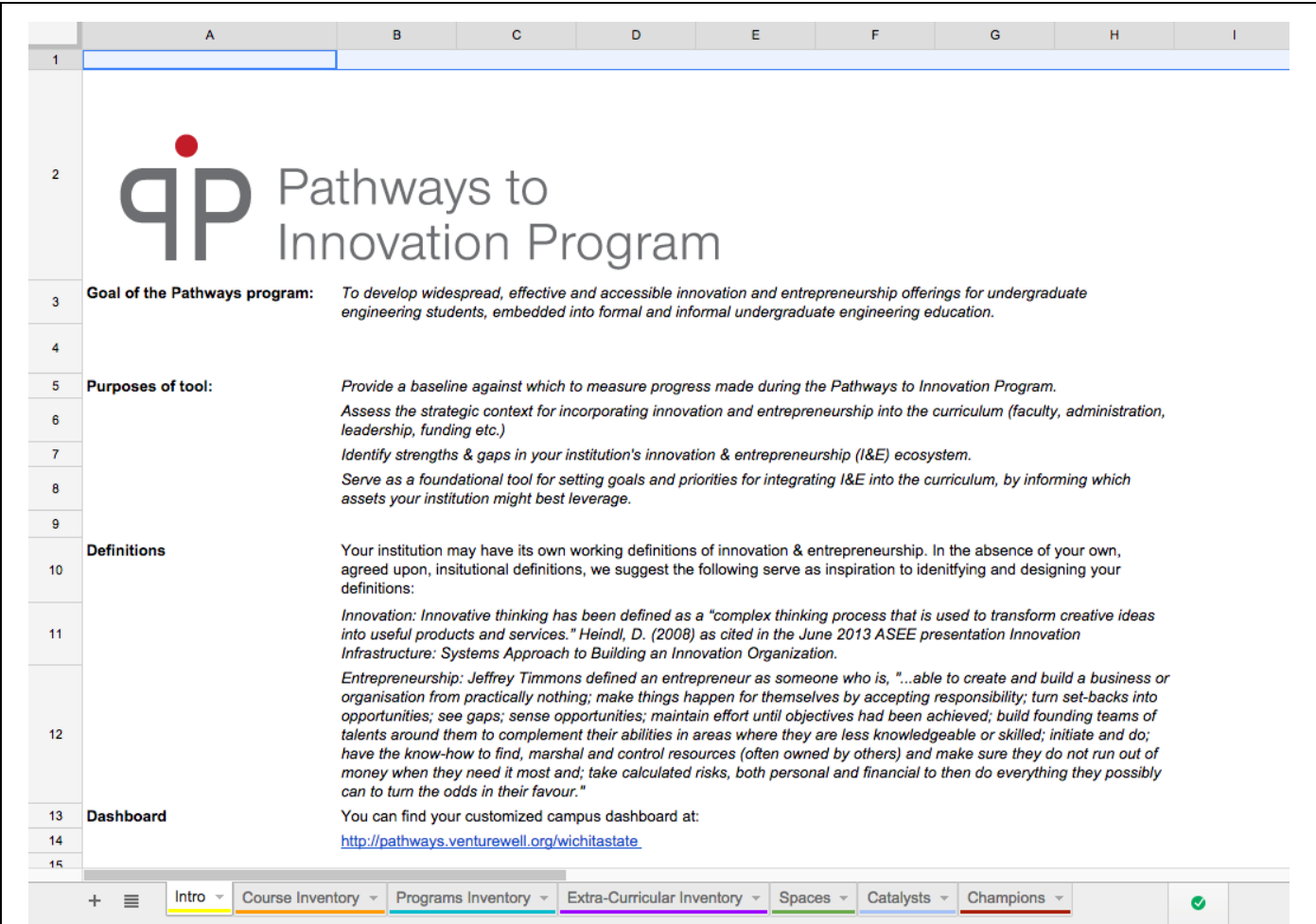


Fig. 1. Screenshot of Landscape Tool

are also better able to engage those beyond the core team, including faculty from other disciplines, students on campus and possibly even off-campus partners in this process. By engaging a broader group in the landscape completion process, the team members may develop a more expansive view of their campus ecosystem, an increased understanding of the opportunities available to students and the possibilities for cross-campus strategic collaboration.

A data visualization capability was added. This was deemed critical for two reasons: (1) given the complex nature of the tool, institutions, Pathways program staff and evaluators needed a way to be able to efficiently draw broad conclusions about the data, and (2) staff and evaluators needed a process for capturing and quantifying changes in the landscape over time. The resulting landscape data is now aggregated in a separate file and reviewed for accuracy before being stored in the cloud. Pre-defined queries on this data create data-driven websites with “snapshot” visualizations for each team that illustrate the status of their campus ecosystem on key dimensions using pie charts (a sample, illustrating the affiliations of individuals a team has identified as champions, is shown in Fig. 2). The visualizations also compare their institution to the entire group of Pathways schools on these dimensions.

An update capability (and supporting data structure) was introduced. The landscape data is now stored together with the date of any changes made including modification to existing assets and new assets. This allows teams to make changes to their landscape, both in real time if they discover new information, but also at designated times for evaluative purposes. Those changes are presented in updated charts in the dashboard, and are also available to the teams and to program staff and evaluators to measure the impact of the program at individual institutions as well as in the larger cohort of participating schools.

I&E-specific modifications better aligned the tool with the project’s underlying theoretical base and with teams’ information needs. Some data points collected in the original sheets were deemed too granular and removed. The recommended definitions for entrepreneurship and innovation became suggested rather than imposed, to encourage a team conversation about their institutions’ definitions. Other elements were more fully incorporated into the tool because

they were considered important to the work being undertaken. For example, teams now identify where each individual course lies on Duval-Couetil’s “innovation education continuum”[19] and the degree to which each course and program listed integrates active learning. To ensure teams consider change strategies that move beyond changes to curriculum and space, Graham’s characteristics of a balanced and effective entrepreneurial university [20] were incorporated with specific focus on student-driven change, collaboration with the off-campus ecosystem and campus policy and culture..

VI. CURRENT USE OF TOOL

The updated tool and user feedback from teams (and the significant technical assistance that was required from staff to assist teams) - informed changes in the way the tool is introduced and supported. The team leader workshop now includes a more comprehensive overview of assets and how a wide range of assets might be used to implement change. In the introduction to the tool, the basic architecture of the tool is described, with attention to how the categories of items collected are aligned with Graham’s taxonomy of successful university entrepreneurship ecosystems. Participants “try out” the tool’s categories with a hands-on exercise in which they identify a set of activities already underway on their campus and place each within the corresponding category.

After the team leaders return to campus, they meet with their team and decide on a plan to populate the tool with the activities at the institution. Leaders are encouraged to make the process one that takes advantage of the cloud-based character of the tool and include all team members in the collection process (however, even with a cloud-based tool, not all team leaders choose to approach the task in this way).

The team has approximately one month to complete their landscape in preparation for the meeting of all Pathways teams in which each crafts a strategy for embedding I&E in undergraduate engineering. During that meeting’s opening session, the teams open their landscape documents and review the (newly-added) data visualizations of both their school’s information as well as the aggregated data. Teams reflect on how (and why) their school’s profile might be similar or different from the aggregate.

With that learning as a backdrop, over the course of the next two days, teams are exposed to a wide variety of different approaches for integrating I&E on campus - all presented by faculty from institutions with robust I&E programming. Teams follow this exposure by identifying ways that they can adopt and/or adapt a set of these models to address a strategic objective, while simultaneously identifying ways they can “link and leverage” one or more of the assets on their landscape[21] to help teams quickly take actions to launch the change process.

Now that an update capability has been added to the landscape tool, teams will be asked to update their tool before they attend the next in-person Pathways workshop in October 2015. This data will be drawn into the aggregated data file, allowing teams, program staff and evaluators to measure what impact the team’s work might have had in expanding I&E activity on each campus. Activities directly attributable to the

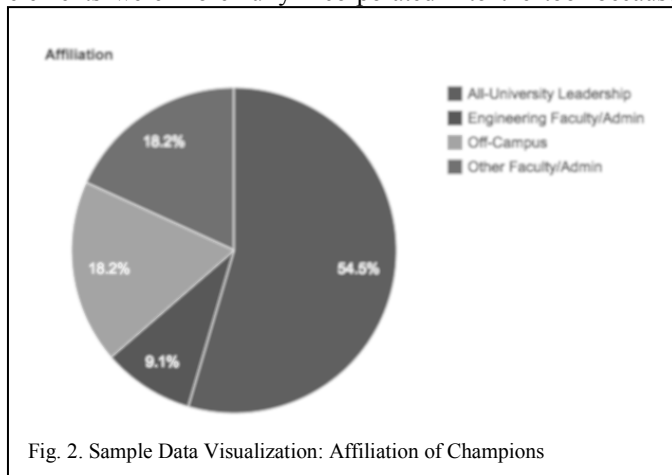


Fig. 2. Sample Data Visualization: Affiliation of Champions

team's work, such as a new course are considered, but also less-direct results, such as a general increase in participation in I&E courses or extra-curricular activities are incorporated. This data will also help teams to think strategically about how best to grow and sustain their efforts

Findings from this pilot update process will be result in further refinements to the tool, the update process, and team line for subsequent updates.

VII. THE LANDSCAPE AS A STRATEGIC TOOL

The landscape tool helps teams identify many different kinds of opportunities for intervention on their campus by identifying a wide range of existing strengths/assets to build on. That knowledge can then be employed to address the institution's needs – some of which may have already been known by the team, but also those that might be revealed by the tool itself. The information in the completed tool may:

- highlight the lack of a particular kind of asset, such as a makerspace;
- reveal specific existing assets that could be targeted for improvement - *ie*, those rated by the team as “needs attention”;
- provide guidance on the degree to which courses were (and were not) being delivered using active learning strategies;
- identify individuals and organizations (both on- and off-campus) that could be engaged to support the team's efforts;
- show areas in which the campus was significantly “out of step” with the larger Pathways community; and
- identify a lack of strategies that fall outside of the more typical faculty driven intervention like curriculum and space (*e.g.* students driven efforts, departmental policy initiatives and off-campus collaborations).

At the team planning workshop and beyond, teams match these observations to potential program models to formulate a strategy for change, characterized by a series of projects chosen by the team. This process continues over the course of the two years - teams complete tasks, start new ones, and adjust strategies based on new information about their campus as well as increased knowledge about possible interventions. Regularly scheduled virtual meetings provide a window into implementation as each team starts with a single modest project and then expands their work rapidly as they gain momentum and attract other faculty and administrators to their efforts.

This context-specific, asset-driven approach results in the pursuit of a wide variety of projects as shown in Table 1. The data includes projects from both schools that began the program in 2014 and those new to the program in 2015. Potential impact reflects the total number of undergraduate engineering students at the campuses pursuing each type of strategy.[22]

TABLE 1.

<i>Project^a</i>	<i>Completed</i>	<i>In Development</i>	<i>Potential impact (total undergraduate engineering enrollment at schools using strategies)^b</i>
New or redesigned courses	13	25	53,139
New or renovated makerspaces	7	20	36,816
Credentials (minors, certificates or degrees)	1	12	22,325
Infrastructure (new classrooms, IP policies, champion development)	7	12	36,088
Non-credit learning (workshops, internships)	9	12	30,406
Competitions	10	6	27,110
Consolidations of I&E activity across campus	5	5	17,738
Other	1	4	7,903

^a Projects shown are current as of June 2015.

^b Integrated Postsecondary Education Data System (IPEDS), Fall 2012.

VIII. THE LANDSCAPE AS AN EVALUATION TOOL

While still in the early stages of using the landscape as an evaluation tool, its usefulness in that regard is already apparent. Having a baseline snapshot of the campus landscape allows evaluators to determine the degree to which institutions have created I&E change since joining the Pathways program. Pre-determined response options also allow for easy comparison across institutions and time points, so that data can be analyzed in an efficient, systematic and quantifiable fashion.

Once updates to the landscape are collected, these updates will contribute to answering key evaluation questions including: “Is the Pathways program an effective process for affecting change in I&E offerings on a campus?” and “How are participating campuses’ I&E ecosystems changing as a result of their participation in the project?” In the interim, landscape categories have guided the evaluation team in the development of interview protocols aimed at capturing some of the ‘what’ and ‘how’ behind their institutional change projects.

Although the I&E changes at the institution level cannot necessarily be attributed directly to involvement in the Pathways program, updated landscapes will provide a mechanism whereby these causal links can begin to be explored. Programmatically, the tool will also contribute directly to program outcomes identified in the program's logic model, including a mechanism for cross-referencing whether

“school leadership understands the current I&E environment at their school.”

The combined programmatic and evaluation benefits of the landscape tool provide teams, program staff and evaluators with a large body of knowledge to inform their associated roles..

IX. POTENTIAL ENHANCEMENTS AND EXPANSIONS TO THE TOOL

While the landscape tool provides for the knowledge sharing, team-building and evaluation needs initially outlined, there are enhancements currently under consideration that would improve and/or extend the usefulness of the tool.

First, it is becoming increasingly important to find ways to onboard faculty, students and administrators that join Pathways teams after the initial landscape training. A self-paced orientation is in development that will orient teams to the landscape tool, its uses and the process for completion.

The next enhancement under consideration relates to security. The data visualization process is currently a cloud-based solution that takes full advantage of the Google ecosystem. These tools are free and offer many built-in advantages including free management of hosting, security updates, service outages and backups. However the approach can also be problematic from both a security perspective and in terms of what one can achieve with the data. Use of a server would eliminate security concerns and would also maximize the potential uses of the data. School data could, for example, be anonymized and schools could search for landscapes of schools fitting various criteria.

Moving beyond these initial refinements, more ambitious ideas include the development and design of a data warehouse. The warehouse could incorporate the landscape data along with historical information about other activities the institutions have engaged in; IPEDS data could also be incorporated into the data warehouse. These kinds of technical modifications would enhance the end user experience by providing access to more extensive and customizable data sets. More sophisticated graphical outputs could also be incorporated to enhance the end user experience.

To date the landscape tool has been conceived of as something that provides only Pathways teams, program staff and evaluators with information to better understand a campus ecosystem. However, the data collected could also be used to inform other campus constituents about I&E resources and spaces, for example through the design of self-service interactive campus maps that highlight I&E hotspots.

The final change under consideration would add value to the Pathways program, but poses significant challenges: designing a component that helps track and “grade” the outcomes of team’s campus-specific interventions. The project’s external evaluators currently gather this data through surveys and interviews with team members, and manually map the teams’ efforts to the assets in their landscapes. Integrating this process into the landscape tool is under consideration.

X. OPPORTUNITIES FOR RESEARCH

The rich set of data gathered across institutions and over time presents many exciting research possibilities. An immediate opportunity is the examination of the growth of campus entrepreneurial ecosystems over time and the degree to which location, institution size, public or private status, Carnegie classification and an institution’s initial assets impact that trajectory and the kinds of strategies undertaken. As part of this examination, one could, for example, canvas a suite of institutions of a similar Carnegie classification and determine which offerings are most prevalent and use these findings as a springboard for rich qualitative investigations into how and why this might be the case. Such research might also inform best practices for modifying a campus ecosystem: for example, whether a school should undertake a more modest grassroots approach first, such as the launch of an extracurricular project, or a more ambitious project, like the launch of an entrepreneurship center.

Further research into how the landscape is used might also be undertaken. Some teams adopt a collaborative approach, while others treat it as a solitary task. One team used the tool as a foundation for creating a visual representations of their campus ecosystem. Another institution shared their landscape with high level administrators to realize a goal of strategically combining spaces and creating a new position. Additional research into these and other practices will increase the understanding of best practices for completing and sharing the landscapes.

If the more ambitious enhancements to the tool are undertaken, the research possibilities broaden. For example, through the inclusion of IPEDS data, one might research the extent to which I&E activity impacts retention and graduation rates.

XI. CONCLUSION

The development and deployment of a landscape tool has proven to be a highly useful strategy in helping faculty teams plan and implement curricular changes in the domain of innovation and entrepreneurship education for engineering students. The data gathered through the tool will provide ample opportunities for ongoing research, particularly as the tool is enhanced and expanded in future versions. While some of the data collected through the tool is specific to this domain, the underlying rationale for the tool - to collect a robust array of information that can inform decision-making while also developing the social capital and team behavior that will enable implementation of change - is broadly applicable to many of the challenges in engineering education.

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Fostering the Entrepreneurial Mindset in the Junior and Senior Mechanical Engineering Curriculum with a Multi-Course Problem-Based Learning Experience

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Abstract— This paper presents a multi-course problem-based learning (PBL) experience to foster the entrepreneurial mindset in the junior and senior mechanical engineering curriculum. Previous senior project students designed, fabricated, and validated a fluid-powered gantry crane that exhibited areas for improvement. To improve upon the project gantry crane, junior- and senior-level students implemented concurrent problem-based learning activities in three courses: Fluid Mechanics, Heat Transfer, and Mechatronics. Even though the PBLs targeted both technical and entrepreneurial objectives, only the results of entrepreneurial mindset attributes are discussed in this paper. Assessment results including student commentary are detailed and discussed in the paper. Preliminary results indicate extensive student practice of entrepreneurial skills.

Keywords—*problem-based learning; entrepreneurial mindset; multi-course; mechanical engineering.*

I. INTRODUCTION

In collaboration with the Kern Entrepreneurial Engineering Network (KEEN), Lawrence Technological University seeks to instill in engineering students an entrepreneurial mindset ^{[1][2]}. The entrepreneurial mindset includes many facets, and KEEN has identified example behaviors (i.e., outcomes) which include the ability to integrate information from many sources, persist through and learn from failure, apply creative thinking to ambiguous problems, apply systems thinking to complex problems, work in teams, convey engineering solution in economic terms, substantiate claims with data and facts, and fulfill commitments in a timely manner ^{[3][4]}. Previous work has shown the effectiveness of problem-based learning (PBL) in improving these qualities in students ^{[5][6]}. By its very nature, a well-posed PBL exercise includes an ambiguous, complex, team-based problem, requiring the students to synthesize material from a variety of sources, while persisting through pitfalls and "wrong turns." Therefore, as part of Lawrence Tech's six-year process to foster the entrepreneurial mindset in the engineering curriculum, courses throughout the Colleges of Engineering and Arts and Science have been modified to incorporate PBL ^[7].

Unfortunately, PBL in a specific course often does not convey the complex or multi-disciplinary nature of an engineering problem; the PBL assignment will focus on the content of that particular course. Recently, a PBL assignment with a common theme was identified that can be incorporated across multiple required courses in Lawrence Tech's BS Mechanical Engineering program. In particular, the PBL exercises are focused on a fluid-powered gantry crane. Originally funded by a teaching grant from the National Fluid Power Association, a prior year's senior project team designed, fabricated, and experimentally validated a gantry crane that used fluid power for material handling ^[8]. During fabrication and testing of the fluid-powered gantry crane, a number of areas for improvement of the student design were identified. Among these were the inclusion of a control system to limit load swing, redesign of the fluid distribution system, redesign to reduce friction and binding between the trolley and crossbar, and new design of a heat sink for cooling the electrical system. Rather than fixing the deficiencies with a second capstone project, PBL exercises were developed to target both technical and entrepreneurial objectives in courses including Mechatronics, Fluid Mechanics, and Heat Transfer. In turn these PBL activities emphasize the multi-disciplinary nature of an engineering design, while allowing a single theme to span multiple semesters. As a result, many facets of the entrepreneurial mindset are emphasized.

Following concurrent PBL implementation in two sections each of Mechatronics, Fluid Mechanics, and Heat Transfer courses, student surveys were used to quantitatively and qualitatively assess the effectiveness of the PBL in fostering the entrepreneurial mindset. Rubrics were used to directly assess student performance. Assessment results, including student commentary are detailed and discussed in the paper.

II. DESCRIPTION OF THE PBL MODULE

Senior mechanical engineering students designed and fabricated a fluid-powered gantry crane (shown in Fig. 1). A number of areas for improvement were identified during the fabrication, assembly, and testing processes. Based on this real-world design exercise, multi-course modules are developed and

carried out in three different courses: Mechatronics (2 sections), Fluid Mechanics (2 sections), and Heat Transfer (2 sections) taught in Fall 2014 to instill entrepreneurial mindset learning for junior and senior students. The PBL activities are briefly summarized below. The detailed assignment description and guidelines are presented in a previous publication [9].

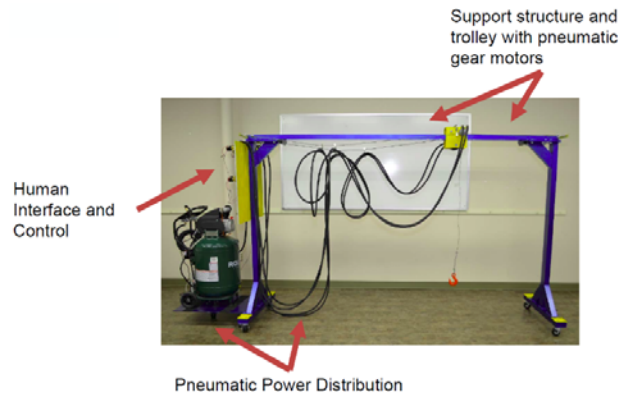


Fig. 1. Student-designed fluid-powered gantry crane

A. PBL activities in Mechatronics

Three thematically connected PBL exercises were created to augment lecture and lab material in four topic areas: modeling and analysis of dynamic systems, integration of mechatronic systems, and feedback control systems. Students were provided with a mix of lecture and lab time to work in teams, however additional work outside of class was required. PBL exercise deliverables included a team report, confidential individual peer evaluations, and individual surveys for indirect assessment of student learning in both technical and entrepreneurial dimensions.

Scenario: The Joint Systems Manufacturing Center (JSMC) is a government-owned, contractor-operated facility which makes armored vehicles such as the M1A2 Abrams main battle tank. During the fabrication process, workers weld together thick steel plates to form the vehicle hull, turret, and side walls. The JSMC uses an overhead gantry crane system to move extremely heavy armor sections from the staging area into a work cell and then to move completed turrets, hulls, and sidewalls from the work cells to an assembly area (Fig. 2). The crane is operated by a trained worker who uses a handheld pendant to control motion of the load in six axes. You are tasked with addressing the following questions:

1. Under what circumstances could a suspended load swing beyond the intended pathway?
2. Could any single fault in the crane control systems have caused the injury?
3. Can the faulty crane operation be demonstrated in a dramatic fashion?



Fig. 2. An overhead gantry crane system

B. PBL activity in Fluid Mechanics

Fluid Mechanics is a junior-level course and two sections were taught in Fall 2014. During the final four weeks of the course, students were tasked to work in a self-selected team of three (with some teams of two) to design the fluid system of a hydraulic gantry crane. Each team was required to submit one technical report describing their detailed design.

Scenario: Your rich uncle, Mortimer, has built a large storage that contains many of his prized possessions. His snowmobile happens to be in a far corner of the garage behind his 2002 Ferrari Enzo. He has asked you to design the fluid system for a hydraulic gantry crane that can lift and move the snowmobile out of the corner. You must keep in mind that Uncle Mortimer is miserly with his expenses; he did not get rich by wasting money. If you can design an efficient and cost effective system, you will not only be paid well, you will likely inherit some of the garage contents!

C. PBL activity in Heat Transfer

Heat Transfer is a senior-level course covering the principles and applications of heat transfer by conduction, convection and thermal radiation. Two sections were taught in Fall 2014. During the final four weeks of the course, a problem-based learning project was assigned and students were tasked to work in a self-selected team of three to address a solution to overheating transistors on a gantry crane. Each team was required to submit one technical report describing their detailed solution.

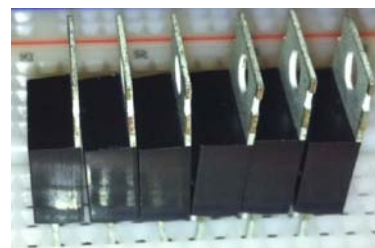


Fig. 3. Transistors stacked together causing poor heat dissipation (illustration to students)

Scenario: Once Uncle Mortimer started using his gantry crane, he noticed that the electronics package is poorly designed (multiple transistors are stacked together as illustrated for the students in Fig. 3). The electronics package heats up quickly and causes failure. After learning of your vast new knowledge of heat transfer, he has asked you to design a system that would

keep the surface temperature of the electronics at a maximum temperature of 40° C.

III. ASSESSMENT METHOD

In order to evaluate the outcome of the PBL modules and collect valuable feedback for future improvement, a survey was distributed to students to acquire their perceptions and suggestions about their design process. The students were given the following statements and were asked to provide their perception in five scales:

1. Strongly disagree
2. Disagree
3. No opinion
4. Agree
5. Strongly agree.

Survey question statements:

- a. My project design satisfied the customer's needs and goals.
- b. I consider the results of my project successful.
- c. I found my work on the project to be satisfying.
- d. The real-world application of the project motivated me to do my best work.
- e. The open-ended nature of the project motivated me to do my best work.

The students were asked to answer questions in regards to example behaviors of the entrepreneurial mindset (directly addressing the KEEN student outcomes), in the format of "During the course of this project, to what extent did you:" with answers provided in 5 scales:

1. None at all
2. Slightly
3. On some occasions
4. Many times
5. Throughout most of the project

Survey questions:

- f. Integrate information from many sources to gain insight.
- g. Assess and manage risk.
- h. Persist through failure.
- i. Apply creative thinking to ambiguous problems.
- j. Apply systems thinking to complex problems.
- k. Understand the motivations and perspectives of others.
- l. Convey engineering solutions in economic terms.
- m. Substantiate claims with data and facts.

Following the questions above, the students were also asked about their team dynamics:

- n. To what extent did you work as a team?

Answers are provided in 5 scales:

1. Almost never
2. Rarely
3. Sometimes
4. Often
5. Almost always

Besides evaluating the students on entrepreneurial mindset learning, they are also directly and indirectly assessed for

technical skills [9]. A problem-based learning rubric [10] [11] was used for evaluating the quality of the problem solutions. There are a total of 9 rubric criteria, which are graded as five scales:

1. No demonstration
2. Attempted demonstration
3. Partial demonstration
4. Proficient demonstration
5. Sophisticated demonstration

Problem based learning rubric criteria:

- o. Identification of problem
- p. Data collection
- q. Representing data
- r. Verify and evaluate information
- s. Draw conclusions and make appropriate applications
- t. Justify and support decisions, strategies, findings and solutions
- u. Communicate purpose and/or main idea for audience
- v. Organization
- w. Supporting details and/or visuals

The students were also asked to provide commentary statements about their problem-based learning experience. They were asked what they liked or appreciated about the project, what should be changed, and any other additional comments/observations.

IV. RESULTS AND DISCUSSION

The data shown in Table 1 are the student feedback to the three PBL activities implemented in Mechatronics class. As shown in the Table, these three activities allowed students to gain various practice of entrepreneurial skills. For example, the students agreed that during the first PBL exercise they were able to "integrate information from many sources to gain insight" (average feedback of 4.0 to question "f"), and also worked as a team more than often (average feedback of 4.2 to question "n").

Table 1. Survey results in Mechatronics Class

Q #	Modeling and Analysis		Sensor and Actuator Integration		PID Controller Design	
	Mean	SD	Mean	SD	Mean	SD
a	3.7	1.14	3.9	0.77	3.87	0.74
b	3.6	1.09	4.0	0.52	4.00	0.50
c	3.6	0.96	3.9	0.44	3.87	0.64
d	3.7	1.01	4.1	0.62	4.07	0.46
e	3.1	1.26	3.6	1.02	3.47	0.99
f	4.0	0.63	3.81	1.05	3.93	0.88
g	3.3	1.16	3.13	1.31	3.53	1.13
h	3.9	0.89	3.63	0.89	3.93	0.80
i	3.9	0.77	4.00	0.65	3.67	0.62
j	3.9	0.96	3.80	0.86	3.87	0.74
k	-	-	4.40	0.63	4.00	1.13
l	2.4	0.91	3.80	0.94	3.67	1.11
m	3.1	0.85	3.60	1.06	2.20	1.08
n	4.2	0.66	3.87	0.52	3.79	0.97

Student feedback to the same survey questions in Fluid Mechanics and Heat Transfer classes are shown in Table 2. It is clear that collaborative activities in both classes greatly facilitate team work (average feedback of 4.38 and 4.06 to survey question “n”). The Fluid Mechanics project particularly addressed the student outcome of “substantiating claims with data and facts” (average feedback of 4.29 to survey question “m”), while the Heat Transfer assignment greatly helped students to “understand the motivations and perspective of others” (average feedback of 4.32 to survey question “k”). Overall, the PBL exercise in Fluid Mechanics class received the most positive student feedback.

Table 2. Survey results in Fluid Mechanics and Heat Transfer Classes

Q#	Fluid Mechanics		Heat Transfer	
	Mean	SD	Mean	SD
a	4.05	1.02	3.82	0.95
b	3.95	1.00	4.24	0.56
c	3.81	1.08	3.94	0.83
d	3.81	0.93	3.94	1.09
e	4.00	0.77	3.41	1.00
f	4.19	0.81	3.88	0.70
g	3.81	0.68	3.06	0.83
h	4.19	0.68	3.65	1.06
i	4.05	0.80	3.65	0.93
j	4.19	0.68	3.56	1.17
k	4.00	0.63	4.32	0.85
l	3.81	0.93	3.65	0.93
m	4.29	0.64	4.12	0.60
n	4.38	0.74	4.06	0.75

The results from direct assessment are summarized in Table 3 (Mechatronics class) and Table 4 (Fluid Mechanics and Heat Transfer classes). The students in Mechatronics class performed well on criteria “q – representing data” and “v – organization”, evaluated as average of 4.6 and 4.4 respectively. The students in Fluid Mechanics and Heat Transfer classes learned to use a variety of supporting details to help with the audience’s understanding (average evaluation of 4.1 and 4.0 to criteria “w”). However, note that the direct assessment results in Tables 3 and 4 are not individual performance, because evaluation was through team design reports. Therefore, less deviations were observed in the data.

When asked to comment about their learning experience through the PBL exercises, many students mentioned that they liked applying theoretical knowledge from class to a real-world problem, and they appreciated the open-ended nature of the problems, which exactly addressed survey questions d and e. Several student comments are listed as examples:

- “There is no exact answer for the question, but you should find one that best fits.” (Mechatronics, part 1)
- “Working as a group, work well as a team. Learning more about options for motion control was a rewarding/valuable experience.” (Mechatronics, part 2)

- “Project created dialogue among students in engineering topics.” (Fluid Mechanics)
- “I prefer learning through projects because we are not confined to a ‘box’ in our problem solving like a test. It represents real world engineering.” (Fluid Mechanics)
- “It related to everything we learned in class.” (Heat Transfer)
- “I appreciate the idea and concept behind this project. It gives me a real world problem, gives me a chance to understand problems which are not completely set up/lead for me.” (Heat Transfer)

Table 3. Direct assessment rubric results of PBL in Mechatronics Class

Criteria	Modeling and Analysis	Sensor and Actuator Integration	PID Controller Design
o	3.0	4.0	4.0
p	3.5	3.8	4.8
q	5.0	4.8	4.0
r	3.0	3.5	3.8
s	3.3	3.8	3.8
t	4.3	3.3	3.3
u	3.8	4.0	2.5
v	4.5	4.3	4.5
w	3.8	3.5	3.5
Average	3.78	3.86	3.78

Table 4. Direct assessment rubric results of PBL in Fluid Mechanics and Heat Transfer Classes

Criteria	Fluid Mechanics	Heat Transfer
o	3.4	4.0
p	3.7	4.0
q	3.8	4.0
r	3.4	3.5
s	3.8	4.0
t	3.6	3.5
u	3.7	4.0
v	3.8	4.0
w	4.1	4.0
Average	3.68	3.89

V. CONCLUSIONS

Based on a student designed fluid-powered gantry crane, problem-based learning modules were developed and implemented spanning across the junior and senior Mechanical Engineering courses including Mechatronics, Fluid Mechanics, and Heat Transfer. These collaborative learning activities allow students to work in teams, integrate information from many sources, and apply creative thinking to ambiguous problems. Assessment results indicate that students gained extensive practice in various aspects of entrepreneurial skills.

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Assessing situational curiosity and motivation in open-ended design electives

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Abstract— Our institution has recently committed to develop five new entrepreneurially-minded elective courses called “IDEAS studios”. The entrepreneurially-minded aspects of IDEAS studios include close interaction with industrial partners and an emphasis on topics such as value proposition, opportunity recognition, intellectual property, and customer engagement. We hypothesize that in addition to specific topics and competencies these courses facilitate develop *attitudinal* skills needed for an entrepreneurial mindset. Such skills—which include persistence, curiosity, conscientiousness, optimism, and self-control—typically cannot be measured using standard assessment methods.

In this work-in-progress, we have identified seven structural attributes of IDEAS studios which we hypothesize support the courses’ ability to foster the attitudinal aspects of an entrepreneurial mindset. We have designed and are in the process of conducting a study of students enrolled in these courses to assess the impact of both the courses as a whole and the individual attributes on students’ situational motivation and curiosity. We hypothesize that the open and student-centered nature of IDEAS studios will foster greater curiosity and intrinsic motivation than will courses that lack these seven attributes. This paper reports on a pilot study of students enrolled in IDEAS studios to assess the impact of these seven structural attributes on students’ situational motivation and curiosity.

Keywords— *entrepreneurial learning; motivation*

I. INTRODUCTION

IDEAS courses were developed with the goal of instilling an “entrepreneurial mindset” in engineering students. Our operational definition of this mindset is that students will display curiosity, make connections, and create value (3 C’s) [4]. IDEAS courses are two-credit-hour elective studio-based engineering courses that have been designed to foster these

outcomes. We identify seven core attributes of IDEAS courses that will compliment course content in instilling the 3C’s:

- 1) The class is voluntary;
- 2) In the course, students create a physical artifact;
- 3) Student work is motivated by real problems;
- 4) Students apply broad perspectives to their work;
- 5) An open-process is applied to create solutions;
- 6) The course environment contains an interdisciplinary mix of students;
- 7) The number of students in the class is small.

Ultimately, six sections of four different courses will be taught, each on a different topic but all embodying the seven attributes listed above. The exact manner in which these characteristics are realized will vary slightly from instructor to instructor, but in general items 1, 6, and 7 are controlled through the course registration process. Items 2-5 are introduced through use of problem- or project- based learning as the main pedagogy for the course. The problem or project based upon on or more open-ended design problems, typically created in collaboration with an outside customer. For example, the customer for on IDEAS course was a surgical research team at a hospital. In the context of IDEAS course projects, students are encouraged to consider broad perspectives through topics including value, societal benefit, cost, scale, and marketability.

Our conceptual framework is that intrinsic motivation is key to development of students’ ability to achieve an entrepreneurial mindset. We expect that fostering students’ intrinsic motivation in a course based on entrepreneurial thinking will result in students who are most curious, best able to make connections between disparate ideas, and create value based on their insight. Using self-determination theory as our guide [5], the seven course characteristics were developed to

create an environment favorable for intrinsic motivation. Self Determination Theory states that motivation stems from autonomy, relatedness, and competence [5]. In the IDEAS courses, attributes 1, 4, and 5 relate to autonomy, attributes 2, 3, and 4 relate to relatedness, and items 2, 6, and 7 relate to competence. While these attributes are not entirely unique to these courses, we believe the combination of all of them might be, and might therefore be essential to creating the attitudinal change we are seeking in the students.

The data from this study are being analyzed to determine the impact of IDEAS courses overall on curiosity and motivation as well as determining the impact of each structural attribute on these outcomes. The results will serve as a pilot to design a larger study that considers other additional attitudinal skills and that seeks to understand the relative importance of the class' attributes.

II. METHODS

The study used a sample of convenience. Students enrolled in the Fall 2014 IDEAS course were invited to participate in the study. All 13 students elected to participate and signed an informed consent form. Both the study and the form were approved by the Bucknell IRB. Students were compensated for their participation: \$10 for each of the four surveys completed, plus a bonus \$10 if all four were completed.

Students were asked to consider their situational curiosity and motivation in both the IDEAS course and a "control" course designated "Course X". Course X is independently and anonymously selected by each student as a course in which they are concurrently enrolled that, in their opinion, shares as few of the IDEAS attributes as possible. Students were asked to select their own Course X for a number of reasons. The most significant reason is that students enrolled in the IDEAS course are from a variety of majors, there is no one other course in which they are all enrolled. In addition, because the student perception of the course may be different from the faculty intent, we felt students themselves would be the best judge of which other course is most different from their IDEAS course, with respect to how those differences impact their own attitudes.

Approximately every four weeks the situational motivation survey and situational curiosity survey were shared. Existing scales developed by Guay, Vallerand, and Blanchard [3], as applied by Stolk, Gross, and Zastavker [6] for situational motivation (SIMs instrument) and Chen, Darst, and Pangranzi [1] for curiosity were used. The combined survey consists of 5 items on situational curiosity from the Chen, Darst, and Pangranzi [1] instrument, and 16 items from the SIMs instrument, plus demographic questions. Students completed this twice during each instance – once, thinking of their IDEAS course, once thinking of the course they had identified as Course X.

At the very end of the semester, the "wrap up" survey was shared. This survey asked about each of the seven characteristics given above and the extent to which they were perceived to be present in both the IDEAS course and Course X.

Analysis of student responses used the item groupings for the SIMS questions as identified by [3]: Intrinsic-motivation; Identified-Regulation (I'm doing this because it's good for me); External-Regulation (I have to do this); and Amotivation (I don't know why I'm doing this). Item responses for both scales is a "strongly agree" (=5) to "strongly disagree" (=1). For the present preliminary analysis, the mean sum of all students' responses for each question group is presented.

III. PRELIMINARY RESULTS

Of the planned three-semester study, one semester has been completed, yielding student survey results (n=13) for one IDEAS course. As such, results are considered preliminary. By the conclusion of this study, we expect an n>100. The current sample is 69% male, and 69% white, consisted of 6 juniors, 6 seniors, and one sophomore, and 8 mechanical engineers, 3 computer/electrical engineers, and 2 biomedical engineers.

There are apparent differences in motivational state and curiosity between students when they are in the IDEAS course and Course X, as can be seen in Table 1. Table 1 combines responses for IDEAS and Course X for all three survey instances and all 13 students throughout the semester. Students' intrinsic motivation, identified regulation, and curiosity are all higher for the IDEAS course, consistent with course design. Students report higher external regulation for Course X, which is consistent with it being a required course (the case for most students, see Table 2).

TABLE I. MEAN STUDENT RESPONSES

Average of all questions in group (5-point scale) n=13		
Motivational State	IDEAS Mean(std.dev.)	Course X Mean(std.dev.)
Intrinsic motivation	18.39(1.76)	13.15(3.56)
Identified regulation	17.92(1.75)	14.92(2.33)
External regulation	6.85(2.41)	12.92(4.86)
Amotivation	6.31(2.10)	10.15(3.13)
Curiosity	22.15(1.73)	18.39(4.75)

Using a Wilcoxon test, the differences between the IDEAS course and Course X in intrinsic motivation, identified regulation, external regulation, and amotivation were all significant at the $p<0.01$ level. The difference in intrinsic motivation is consistent with our initial hypothesis, that intrinsic motivation would be fostered by the IDEAS course environment. The difference in identified regulation was not as expected, but seems consistent with the design of the IDEAS course to be driven by "real problems", giving students a sense of importance – they recognize that they will benefit from doing course work. Course X has a significantly higher score for external regulation and amotivation, which suggests that students in required courses do not always see the ultimate goal of their study. The curiosity result was significant at the $p<0.05$ level with the same test, suggesting students were more curious in the IDEAS environment.

A Wilcoxon Signed Ranks Test is the appropriate test for results with multiple modes and small sample size, as was seen in this case [2].

At the end of the semester, students were asked to characterize both the IDEAS course and Course X according to the seven attributes. Note one student chose not to participate in this survey. We anticipated when students selected Course X at the start of the semester, they might not have sufficient information to completely judge its similarity to the IDEAS course, therefore the request to characterize the course in terms of the seven attributes was at the end of the semester. We also asked students to characterize the IDEAS course to inform us if the student perception of the course design aligned with our intent.

TABLE II. COURSE ATTRIBUTES

Course alignment with 7 attributes		
List of attributes	IDEAS	Course X
1. Voluntary	Yes (12) No (0)	Yes (3) No (9)
2. Physical artifact	Yes (12) No (0)	Yes (5) No (7)
3. Multidisciplinary	Yes (12) No (0)	Yes (6) No (6)
4. Agreement: Real problems	4.8 / 5.0	3.4 / 5.0
5. Agreement: Broad perspectives	4.3 / 5.0	3.0 / 5.0
6. Agreement: Open-ended	4.8 / 5.0	3.2 / 5.0
7. Class size	15	25

There is a high level of agreement that the students perceived that the IDEAS course embodied the seven characteristics, as intended. These data also suggest that while Course X was dissimilar from the IDEAS course in some ways, for most students it was not entirely dissimilar.

The ultimate goal of this work is to not only characterize the differences in motivational and curiosity state for both IDEAS and X courses, but to use responses to these attributes

to determine the importance of each to students' motivational state. For example, because there are students who had attribute 3, an interdisciplinary mix of students, in IDEAS and in Course X, we should be able to assess the extent to which this attribute correlates with motivational state and curiosity. By the end of the study, we should have over 100 students' responses, which will enable this examination.

In conclusion, this preliminary study suggests that IDEAS courses are better environments for fostering students' situational motivation and curiosity than more typical courses. This observation is consistent with self-determination theory, where the greater levels of autonomy, purpose, and mastery are expected to result in higher levels of intrinsic motivation among students. As the study continues, we will see if this observation continues to be borne out with a larger sample size.

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“Innovative Office”: Building Future for Young Engineers

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Abstract — This paper shows the course designed by COPEC – Science and Education Research Council education research team, for engineering students what is called “working with communities course”, which provides the students of engineering in 3rd year the chance to work with consultancy for the entrepreneurial community, in the region. It is for an engineering school of a private university and the goal is provide the needed resources to enable interdisciplinary efforts to prepare engineering students to tackle real-world challenges in engineering, entrepreneurship and new business ventures as professionals. The process is designed in order to offer a space that has been named after “innovative office”, where local entrepreneurs go with a problem or project to discuss and to find sustainable solutions under the consultancy of young engineers. So far the program has been working well and is opening doors for young engineers.

Keywords — *Entrepreneurship; sustainable solutions; project development; innovative office; working with communities.*

I. INTRODUCING

At the present engineers with technical skills must also learn how to work in interdisciplinary teams, how to develop designs rapidly, how to manufacture sustainably, how to combine art and engineering, and how to address global markets. It is imperative to provide future engineers opportunity in the work market has become now part of university formation, as a way to assure also the future of university. Enterprises and universities have still in many places difficulties in working together, it is up to the engineering schools and universities to have the initiative to enhance their programs, to assure the proper formation for future professionals that can perform in this mutant work

environment of 21st Century. In accordance with the National Academy of Engineering, USA report “The Engineer of 2020” paints a picture of a dynamically changing and evolving world: “The successful future engineer will need strong analytical skills, practical ingenuity, creativity, good communication skills, business and management knowledge, leadership, high ethical standards, professionalism, dynamism, agility, resilience, flexibility, and the pursuit of lifelong learning”, the report says.

Presently the opportunities for professionals seem to be very narrow once economic crisis is impacting countries and communities worldwide, as the result of a natural cyclic wave of economy until a new economic model starts to work somehow. To provide future professionals an opportunity in the work market has now become part of university training as a way to assure the future of university.

This paper describes a course designed by COPEC – Science and Education Research Council education research team, for engineering students which is called “Working with Communities Course”, providing 3rd year engineering students the chance to work with consultancy for the entrepreneurial community in the city. The goal is to offer a space that has been named “Innovative Office”, which local entrepreneurs can refer to with a problem or project to discuss and to find sustainable solutions.

Engineering students then work using their creativity to design and present solutions within the constraints of ethical practice grounded in science and engineering methods and standards. The process involves face-to-face meetings and discussions with entrepreneurs of the city, from the presentation of the problem until the delivery of the plans.

Once engineers are part of society it is important that they have a stronger interaction with the wider public. So the goal of including this course in the program is to provide students the opportunity to work closely with the real local entrepreneurship environment. Apart from this, engineers need to develop broad fundamental understanding of their professional responsibilities as well as the need to be entrepreneurial in order to understand and contribute in the context of market and business pressures. If engineers can work with the public to explain how engineering can help address their problems, and to help them to decide which are the most effective and affordable ways to address their concerns, the community can make great progress and improvements. It will surely be a great acquisition for the city business community as well as for the students themselves, once they can get a glimpse of what it is to engineer in real world. This project is being developed in partnership with a City Hall as a way to improve entrepreneurship in the region, aiming at fostering employment and private initiatives to change the community's profile.

II. DISCUSSIONS ABOUT EDUCATIONAL ASPECTS

New work environment takes place worldwide and today millions of professionals are also unemployed, even in advanced economies. On the other hand, businesses in advanced economy countries claim that they often are not able to find workers with the required skills. It is a fact that this is a symptomatic dysfunction due to the structural changes that are transforming the nature of work and reshaping employment opportunities. This shows that organizations and policies are not keeping up with the changes in business practices and new technologies that are defining what kind of jobs will be created and where they will be located. So there is a need for companies to redefine how and where different tasks have to be carried out requiring new skills and new employer and employee relationships [1].

Another aspect is that globalization has been expanding access to low-cost talent professionals and creating a greater need for workers with higher levels of education and specific skills in order to perform in advanced economies. Under skilled workers are disappearing due to automation and low-cost labor market abroad. In this world scenario, education and training should be seen as vital economic priorities by governments. However, it is still possible to observe the neglect of some nations, perhaps due to lack of political interest other than electoral. Although governments need to invest in the entire system that builds workforce skills, in some places it is up to private initiatives to offer opportunities for young ambitious talented professionals, who can cooperate for a better future of generations to come. There is no better place than universities to offer these opportunities, pushed by the enterprises. It is important for nations to train highly skilled native-born citizens as well as to attract highly skilled immigrants in order to be competitive in a global scale and assure a future for the people [2].

Finally, govern agents should be aware of the fact that if there is no production system there will be no financial resources to maintain social assistance system. This idea of an innovative office will help generate more quality services for the betterment of service industry as well as the productive

system generating opportunities and generation of jobs, which is a need everywhere in the world today [3].

III. COPEC: SCIENCE AND EDUCATION RESEARCH COUNCIL

COPEC's history started with an idea shared by some scientists of creating an organization to foster the research mainly in sciences and education. This idea seized larger proportions and after some meetings the Council became reality. This is a group of scientists, professors and professionals whose vision of future has driven them to start this work.

The main mission of COPEC is to promote the progress of science and technology for the welfare of humanity. Through its activities, COPEC maintains relations with universities, institutions of education, enterprises and the society of several countries for the discussion of sciences, technology and education directions. COPEC - Science and Education Research Council has been very active and has developed many achievements of great importance for the Country in which it is located. The Council is an organization constituted by scientists of several areas of human knowledge committed with education and the development of science and technology.

Its members believe that education is the main beam in the construction of a better society and that sciences and technology are the main agents in fostering progress to promote the welfare of human being [4].

IV. METHODOLOGY

The whole process has been developed in steps and it required a person in charge of the project, which in this case is the professor specially hired as the Head Director of "The Innovative Office" since the very beginning. The Head Director will keep the project working and collect all data for enhancement of the process throughout its development.

The project starts with adding a course named "Introductory Economics Topics" which may include an overview of: economic theory, econometrics, macroeconomics, microeconomics, economics research methods, economic policy, game theory and mathematical methods for economic analysis. The main goal is for students to have a glimpse of economics aspects necessary to understand and boost the economic commonwealth of the region. The hired teacher is a professional who is also prominent in his field in order to attract students and enhance the quality of the program. The model chosen is the one-week intensive class about the topics, in order to provide them the basic knowledge and the means to research further information when necessary. This step will take nine weeks before the students can start their journey in the project.

The legal aspects are up to the consultancy of law office of City Hall in order to assure that some other issues related with legal actions and measures are avoided.

The research team proposes to offer this course for all engineering programs of the Engineering School of the university involved in the project, to have a critical mass of specialties to perform in the consultancy field for the

community. However students are invited to join the project, which in fact reduces the number of interested students. The key is to have really interested students involved in a first stage, so that it can be expanded to all school programs as a way to increase the quality of the program [5].

FIG I. WORKSPACE



Once the number of students interested from all the programs of the referred engineering school is established, the next step is to hold a meeting with students and define a schedule for the activities to be held at the office, located in the City Hall building which is offering this service to the community. The workspace is basically a clean, neat room with tables, chairs, computers and a telephone line.

It is up to the City Hall to advertise the service offer “The Innovative Office” to the local community. The university is responsible for providing the students and the necessary laboratories. In case a laboratory is used, a fee is charged to the consultant to cover basic material and energy. There is another professor in charge of mentoring the students’ team for a determined period as volunteer work, in order to help refining their proposed projects to their clients.

Next step is to have students working in teams at the offices, available to receive possible clients. The students welcome the client; start a professional relationship and work in order to solve the presented problem. Their work starts with a visit to the enterprise where the business takes place, collecting all data, followed by the search for ways to best solve the client’s issue. This means that they have to work hard in teams to find out “The Best Solution” for the presented problem in a “Certain Period of Time”, which the team can establish and must honor. It is a simple concept that works because of the commitment of all people involved in the process. Both the university and the City Hall are committed to provide this service for a determined period of time in a first moment and the enlargement of this service, if there are conditions for it. An agreement is signed between both organizations for a certain period, which can be terminated by mutual decision. The implementation of the project started in 2013 and the office started working effectively in August 2014, mainly due to City Hall bureaucracy.

V. DETAILS OF THE ENTREPRENEURSHIP

The students interested in the project register for economics classes. After three weeks of classes they take part in a training class and learn how to cause a first good impression with their future clients. This is followed by a period at The Innovative

Office, in the City Hall. Their work starts when they register for the project, which is an opportunity of intensive internship early in the program.

The main aspect of the project is that students have to be committed with sustainable and feasible simple solutions for medium and small business problems and as low cost as possible. These are the headlines and main idea of the entire training that they have prior the practical period.

FIG II. MEETING



Once at The Innovative Office, for a period of at least four months, students have to establish goals and work towards achieving them. Students are challenged to start a professional relationship with a possible client, leading them to be open and honest. They will start identifying a problem, and then find a theoretical background and a methodical approach to solve the problem within a realistic time frame towards the completion of the project and at reasonable expenses. This is followed by the implementation period and the refinement of procedures in order to solve the problem and deliver the project.

After the accomplishment of the project, students send a report to the Head Director of The Innovative Office to be included in both the program’s and the students’ portfolio.

VI. SCHEDULE FOR 2015/2016

The maximum number of groups per period is 5 with an average of 4/5 students each. Each group can work with maximum 2 clients in order to have a good performance once it is submitted to the availability of the students because of the classes and studies in the university. The project must be delivered at least before the end of their period at the office.

FIG III. SCHEDULE

1st period	March/April/May/June	4 groups with 4 people
2nd period	July/August/September/October	5 groups with 3 people
3rd period	November/December/January/February	3 groups with 4 people

It is important to have the office working all year round, so that students can choose the best suitable period. In any case, the schedule is up to the Head Director of The Innovative Office to set together with the students.

VII. OBJECTIVES OF THE PROJECT

The project objectives are essentially the development of engineers with skills to perform in the future work market especially in economics, as high skilled professionals are a demand in every country, which widens their job opportunities. The following skills are important once they are already required:

- Broad knowledge of different fields in economics;
- Enhanced research skills for researching for clients;
- Entrepreneurial skills;
- Knowledge of theoretical and empirical approaches to economics;
- Management skills;
- Solid understanding of economic practices, principles and theory;
- Strong command of economic models, tools and techniques including particular statistical techniques;
- Strong numerical and analytical skills;
- Strong oral and written communication skills, including preparation and delivery of professional, technical and non-technical reports and presentations;
- Time management skills.

At the end of the period the students will be able to understand the real economic and social impact of engineering in this century. Another target goal to be achieved is to foster among them the entrepreneurial mind to pursue other opportunities than find a job in a company [6]. Another aspect is that for the university the goal is to attract more students and enlarge the number of students in engineering programs. For the City Hall, this is another community service funded by federal government, which could be turned into votes for future elections.

VIII. PROJECT STATUS

The groups and the director of the project as a type of swot are doing the assessment of the project in order to identify the weak and strong points in order to make adjustments for future activities.

Presently the project has worked relatively well. Student groups are working hard and the results have been positive. Customer satisfaction has been very good. This information is based on the result of a research that is completed at the end of the project in participant companies. The students claim that the project is a very good opportunity to know their own limits and capabilities. The difficulties they face are related to the fact that they have to combine the project work with studying hard to accomplish the engineering program. They have provided good feedback and are working hard to finish the engineering program, certain that engineering is what they want to do in life.

The City Hall evaluates it as a good service offered to the community and intends to keep "The Innovative Office" open for another year. The constraints are related to the political environment, meaning that the project will last as long as there is political interest by the current government bodies at least until 2016.

IX. CONCLUSIONS

May be the best outcomes of the project are the skills that the students develop along the process in the "Innovative Office", along the perception that they have to take risks and turn today's failures into the seeds of tomorrow's successes. A first result seen during this process is that the project helps the students to experience what it is to be an engineer early during their studies.

Another relevant conclusion is that they can evaluate their own performance and make adjustments. Furthermore, they develop skills such as human interaction, work in team, and work under deadlines and how really to engineer for sustainable, feasible solutions.

The pedagogical aspects of the program are the key factor for its success, which are the extra courses of economics taught by specialists and the research practice that students have to develop in order to get the basis for project development.

It is a very rich experience for students and shows them that they need to be very much self disciplined and to avoid procrastination.

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Task Choice, Group Dynamics and Learning Goals: Understanding Student Activities in Teams

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Abstract— In this work-in-progress research paper, we explore the task choice of students in first-year, team-based engineering design project courses, with the goal of gaining insight on how to best structure and scaffold team projects so that all students have a positive, effective experience. What factors affect student task choice? Do students select tasks that they feel the most confident about completing, or do they challenge themselves to learn new skills? Do gender or team dynamics or self-imposed roles affect how students participate? If students are asked to develop individual learning goals for the project, does that influence the activities that they engage in, and does articulating learning goals lead to a more beneficial project experience? We are using a mixed-methods approach to investigate the experiences of a small cohort of students engaged in a first-year design project, in order to better understand how students choose to undertake different tasks in team projects.

Keywords—confidence; first-year; project-based learning; self-efficacy; teams

I. INTRODUCTION

Team projects can be beneficial learning experiences for students, encouraging the development of both technical and non-technical skills, allowing students to take on authentic, open-ended problems that cannot be completed individually. They also provide students with engineering “mastery experiences”, one of the main contributors to engineering self-efficacy, the belief in one’s ability to succeed in engineering tasks [1], which is associated with motivation, retention and persistence in the field [2].

However, it has recently been observed that the effects of projects on student engineering self-efficacy is non-uniform, including being affected by the gender of students [3]. Team projects are typically designed with the expectation that all students will engage similarly in both technical and non-technical tasks. However, student participation varies, both within the project as a whole but also with regards to hands-on engineering tasks within the project [4], [5]. Male students take on more engineering tasks (non-personal, goal-focused, and technical), while female students are more likely to take on group-focused, organizational, non-technical tasks [4]–[6]. Students with lower engineering self-efficacy may not take on more technical engineering tasks. Differences in personality can cause some students to assert themselves and take on the

tasks they most enjoy, leaving less assertive students to take on the roles that need to be filled. Finally, a “learning goal” orientation (as opposed to a “performance goal” orientation) can encourage students to participate in tasks that they want to develop skills in, rather than focusing solely on completing the project [4], [7]. Student task choice in team projects is therefore likely to result from a complex interaction of these factors.

This study is part of a larger project focused on the development of engineering self-efficacy in hands-on courses, which includes data collected on students across several universities and a range of courses. The work presented here is a mixed-methods analysis of a small cohort of students to investigate task choice. Was it based on where their existing confidence or self-efficacy lies? Was it based on the roles they played within the team, or perhaps the roles they desired to play on the team? When students are assigned to develop learning goals, do those guide their task choice? Are there gender differences in task choice or roles?

II. METHODS

A. Participants

This analysis focuses on 19 first-year student participants enrolled in a hands-on engineering design course at a small, private engineering college. The course consisted primarily of two projects: the first was an individual project to build a small mechanical toy and the second was a team project to build a more complex toy, suitable for fourth-graders, which typically contained both an electrical and a mechanical component. Teams consisted of 5-6 students and were structured based on reported student interest. Most teams were mixed-gender. Nine students identified as male (students A, D, E, K, L, M, N, O, R, S), nine as female (B, C, F, G, J, M, P, Q, T), and one student did not report gender (H). Six students participated in 2013 (students B, D, M, N, P, and T) and the rest participated in 2012, with an identical project structure and a similar set of course instructors in both years.

The course design incorporates two key learning interventions. One, the carefully scaffolded individual project allows students to develop engineering design skills, regardless of their background. Two, students were asked to formulate individual learning goals for the team project, to share these

goals with their teammates, and to design project plans that addressed each team member's individual learning goals.

B. Data Collection

Participating students were asked to complete pre- and post-course surveys, weekly activity logs, and post-course semi-structured interviews.

The pre-course survey included questions about demographics, personality (using the Big 5 Personality Test [8]), and prior engineering experience and exposure. Both the pre- and post-course surveys included instruments for students to self-assess their commitment to and confidence in completing an engineering degree, their academic self-confidence in open-ended problem-solving, math/science skills, and professional/interpersonal skills [9] and their self-efficacy in engineering and in "tinkering," or hands-on tasks [10]. Each instrument asked students to rate their agreement on a Likert scale from 0-7 (the academic self-confidence instruments) or 0-5 (all other instruments).

Students used weekly activity logs to report time spent on the course in total and on forty different project tasks (with the opportunity to write in tasks that were not listed).

Semi-structured interviews provided further insight into the students' project experience, with a focus on teaming. Students were asked questions pertaining to their perceptions of engineering, their experience with their team, and about factors that may affect their self-efficacy or confidence (including social affirmation and role models). Students were also asked to identify roles played by each team member, including themselves, using "role cards," which named fifteen potential roles they could have played on their team: mechie (focused on the mechanical design), planner, helper, CAD person, eclectic, finisher, servo person (focused on the servo motor/electrical system), communicator, idea person, scheduler, artist, shepherd, leader, builder, and cheerleader (students could also name roles not listed on the cards). Students were then asked how they felt about roles, and which roles they wished they had played on the team but had not. The students were also asked to identify their learning goals for the project, and to assess whether they achieved those goals.

C. Data Analysis

This study used a concurrent triangulation mixed-methods approach to analysis, relating quantitative factors from surveys and activity logs to student descriptions of their individual learning goals and their teaming experiences from the interview data.

a) Quantitative Analysis

Activity logs were analysed to determine the proportion of time devoted to tasks relative to the total time reported for the project. The tasks were grouped into twelve "activity clusters:" brainstorming (ideation), calculations, communication with peers, documentation, hands-on work, modeling/CAD, preparing and giving oral presentations, project management, research, sketching (2D and 3D), teamwork, and preparing a written report. The tasks were also divided into five "mastery clusters," each of which map onto a specific instrument used in

the pre- and post-course survey to measure self-confidence or -efficacy: academic self-confidence in open-ended problem solving, academic self-confidence in math and science skills, academic self-confidence in professional and interpersonal skills, engineering self-efficacy and tinkering self-efficacy. Pearson's correlation tests were performed between relevant parameters, with statistical significance set at $p < 0.05$.

b) Qualitative Analysis

For this study, we focused on aspects of the students' interview data related to task choice: which roles they played on the team, which roles they wished to play, and what their learning goals were, to determine if students are completing activities in line with their original learning goals or their perception of their role aligns with the activities they performed. This qualitative analysis (students' descriptions of learning goals and team roles) was then related to quantitative data from the activity logs. In order to relate this data to what the students were reporting in their end-of-course interviews, we assessed the following: if the student spent a large proportion of their time on a particular task compared to other tasks, if a task cluster was within the top five clusters in which they spent the most time or how the time on task compared to the average of all students. In line with our emphasis on the individual student experience, we did not compare specific students to each other.

III. RESULTS

We first analyzed how students reported spending their time. Fig. 1 shows how each student divided their time among tasks, in terms of proportion of total project time devoted to each of the thirteen activity clusters. Every student spent the most time on tasks within the Hands-on Work cluster (ranging from 17% to 48% of their total time). Students also spent a large proportion of time on Modeling, Brainstorming or Project Management tasks. Students generally spent the lowest amount of time on the Written Report, Documentation, or Calculations activities.

We then considered this data within the context of the students' experience to investigate how they related to the tasks undertaken in the team project: were they based on their incoming self-confidence or self-efficacy levels, the roles they played or wished to play within the team, their learning goals, or gender roles?

A. Academic Self-Confidence and Self-Efficacy

To investigate if students chose tasks based on their confidence or self-efficacy levels, we determined the Pearson's correlation coefficient between academic self-confidence or self-efficacy and the proportion of time spent on different tasks. Although there were several correlations between incoming confidence or self-efficacy levels and time on tasks, there were no direct correlations between any confidence or self-efficacy measure and the corresponding mastery task. For example, academic self-confidence on professional and interpersonal skills did not correlate to spending more time on professional tasks, but did correlate to spending more time on math and science tasks.

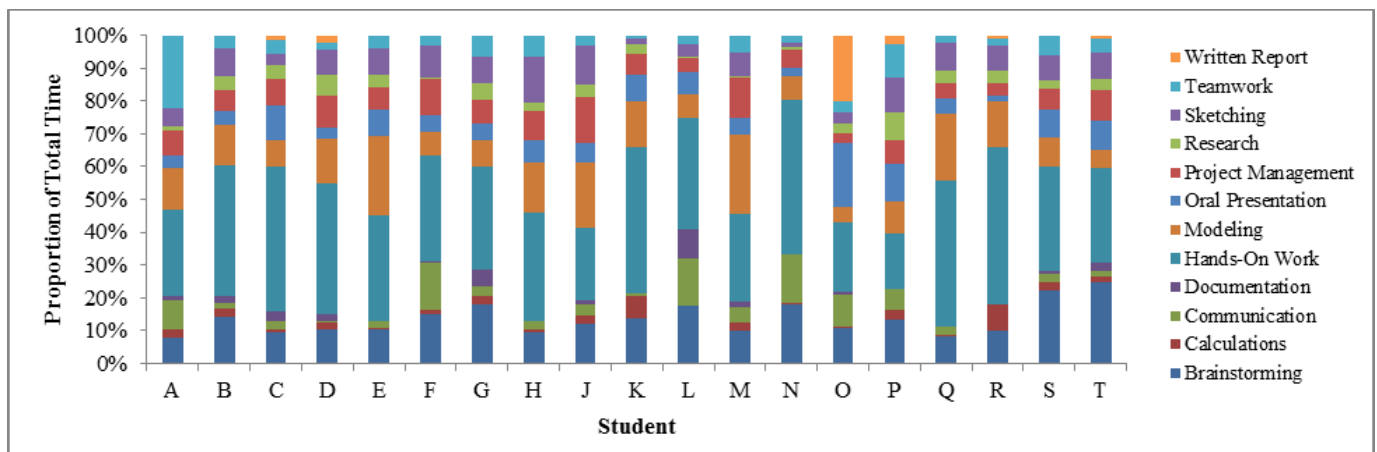


Fig. 1. How students divided their time on activities throughout the project. A, D, E, K, L, M, N, O, R, S identified as male; B, C, F, G, J, M, P, Q, T as female.

B. Roles

As part of the semi-structured interviews, students were asked to identify one to three roles that they played on the team, and roles that they wished to play on the team but did not. These answers were compared to how students reported spending their time on the project.

Students most often identified themselves as a helper (7 students), idea person (7), builder (6), CAD person (5), servo person (5) or planner (5), which corresponds to the high proportion of time reported spent on Hands-on Work, Brainstorming or Modeling tasks. Almost every student demonstrated consistency between their self-described roles and the tasks that they chose. For example, students B and M identified as ‘CAD person’ and spent a large proportion of their time on Modeling activities; it was their third and second most time-intensive activity, respectively. Students B, C, and R identified as ‘idea person’ and spent the second, second, and third largest proportion of their time doing Brainstorming tasks. Student H identified as artist and spent much of his time in Sketching and Modeling tasks. The only apparent discrepancies were with students who self-identified as taking on organizational roles such as planner, scheduler or communicator who in fact spent a relatively small proportion of their time on Communication (or Project Management) tasks compared to more technical tasks like Hands-on Work or Modeling. However, these students did spend much more time in these roles than their counterparts who did not identify themselves with these roles. For example, student F identified as a scheduler and planner and spent 14.3% and 10.8% of her time on Communication and Project Management, respectively, compared to averages of 5.1% and 7.4%, respectively. Student D identified as a Communicator and spent 9.6% of his time on Communication; he explained his role trying to be a planner and communicator for his team: “It was—at the end it was very busy... So I think running from team to team did take a lot out of me...” Even though students did not report spending a large *proportion* of their time on these task clusters (perhaps because of the nature of the work required), the students were likely correct in reporting that they took on these tasks to a greater degree within their team.

Students were also asked what roles they *wished* to have played on their team: “Ideally, which roles would you want to describe you?” Students answered with both the roles they did play as well as identifying other roles. For example, student B identified as a CAD person, idea person, and helper and wished to be more of a CAD person and mechie:

“My role...I was a bit of the CAD person...and then I guess I was an idea person...I guess I was overall, like, a helper...I’m happy with the roles that I played, though I think I could’ve done a bit more. But I think the issue was also because we didn’t have a lot of time...I would have liked doing a little more CAD than what I did and then being a mechie...”

Students most often wanted to be a CAD person (4 students), finisher (3), idea person (2) or in an organizational role such as leader (3), planner (2), or scheduler (1). There were also relationships between the roles that students wished they played (but did not identify themselves as taking on) and the tasks that they performed. Students G and K, who wished they played the CAD person role, did in fact spend much of their time on Modeling; students E and P wished they were more of an idea person, even though they reported a relatively high proportion of their time spent Brainstorming. Students who wanted to play organizational roles actually spent a higher proportion of their time on Project Management tasks compared to their peers. For example, students A, D and T wished to be a leader, planner, or scheduler and spent 7.6%, 9.6% and 9.4% of their time within the Project Management activity cluster, respectively, compared to the average of 7.4%.

C. Learning Goals

During the interviews, students were asked to share their learning goals for the course and to assess whether they achieved those goals. While some students identified vague goals (“learning how to do stuff was my biggest goal”) or simply wanted to complete the project “make something that worked”), many students identified specific and achievable goals, and seemed to consider them throughout the course. For example, student L stated early on in his interview:

One of my goals, I don’t know if you know, we had to make goal statements in the beginning of the course saying what we

wanted to accomplish and I did that. So I accomplished my goals. So I wanted to work more on drawing and the CAD.

There was a clear relationship between learning goals and tasks undertaken. Seven students mentioned wanting to get hands-on building experience or learning about mechanical systems, which they accomplished (all students spent the most time in Hands-on Work). Eight students had a goal of learning how to CAD, and most of these students did spend a large proportion of their time on Modeling. Less common goals also matched up with reported tasks: student A had a goal of “learning how the group dynamic worked” and student H had a goal of “teamwork” and they reported spending 21.9% and 6.4%, respectively, of their time on Teamwork, compared to the average of 5.0%; student D wanted to gain experience “managing a team” and spent 9.6% of his time on Project Management compared to the average of 7.4%; Student J wanted to “be an idea person” and Brainstorming was within the top five activity clusters that she devoted time to.

D. Gender

Pearson’s correlation coefficients between gender and the proportion of time spent on tasks were also calculated. Although previous studies reported gender differences between the tasks completed by different team members [4], [5], in this cohort, the only task that correlated with gender was the proportion of time spent on research, which was higher for female students.

Gender differences in the roles that students played within their teams were more pronounced. More male students identified as a helper (five male students versus two female students) and in more technical roles, like builder (four versus two), servo person (four versus one), or mechie (three versus none). Male student O, who self-identified as a builder, idea person, artist, and helper, did not identify with a non-technical role, despite spending far more time on the Written Report and Oral Presentation tasks (19.5% and 19.0%, respectively) than average (1.4%, 6.8%). More female students identified as playing less technical roles, like idea person (five female students versus two male students), communicator (two versus one), and scheduler (three versus none). Female student J self-identified as a communicator and idea person, but spent 19.4% of her time on Modeling and 11.8% on Sketching, far more than the averages of 12.3% and 7.1%. This suggests that gender schemas may influence of student’s self-perception of the role they played.

There were few gender differences in the roles that students *wished* to have played: interest in both technical roles (builder, mechie, CAD person) and non-technical roles (leader, scheduler, planner) were similar. The learning goals of students were also similar. Many students wanted to learn how to build (four women, three men) or CAD (five women, three men). However, only male students reported a goal of “learning how to design”, and only female students wanted to “be an idea person.”

IV. DISCUSSION AND PRELIMINARY CONCLUSIONS

Our original hypothesis for this research project was that incoming academic self-confidence or self-efficacy levels

would significantly affect student engagement in project tasks. No clear correlations were observed, however, and the evidence is that many factors affect tasks students undertake, including team and gender dynamics. As well, activity log data cannot be used to distinguish between productivity or difficulty: a large proportion of time spent doing CAD, for example, may mean that the student was efficiently completing many CAD tasks or that they took longer to do each task.

However, there is evidence that the learning goal intervention, originally designed to reduce gendered task choice [4], is having the desired effect. The relationship that we found to be the most distinctive was that between proportion of time spent on tasks and the students’ reported pre-project learning goals. The effects of goal-setting have been well-studied in other fields [11]; here, formulating and sharing goals provides students with the opportunity to focus their project time. This intervention can easily be implemented in project-based learning experiences; the shift from a ‘performance orientation’ to a ‘learning orientation’ meant that students took on personally meaningful tasks or roles.

The tasks that students completed during the project not only seemed to align with the roles that they felt they played on the team (as expected) but were also consistent with the roles that they wished they had played on the team. This may align with our original hypothesis: having performed these tasks extensively over the course, students may have higher self-efficacy in those tasks, and thus be more inclined to continue to take them on. However, it may also be because students were struggling with some tasks, and they wished to have the opportunity to improve.

Finally, while no gender differences in how students engaged in tasks were observed, male and female students differed in their self-perceived roles. Although the activity logs demonstrated that there was no significant gender differences in students’ self-reported time-on-task data – men and women participated equally in technical and non-technical tasks – female students were still more likely to think of themselves as taking on non-technical, organizational roles while male students placed themselves in technical roles (mechie, builder). This suggests that gender schemas around the perceived “male” nature of technical roles may still be prevalent.

These findings from a cohort within a larger project suggest that is the result of a large number of interacting factors, of which self-efficacy is only one. However, the learning goal intervention implemented in this course seemed to have a pronounced effect on task choice, at least in this specific academic setting. Analysis of data collected on the experiences of students from other academic environments and types of project courses is ongoing.

ACKNOWLEDGMENT

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The Impact of a Peer Learning Strategy on Student Academic Performance in a Fundamental Engineering Course

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Abstract—One of the main reasons that engineering students withdraw from their major programs is the discouraging academic performance in fundamental engineering courses. It not only limits students' access to advanced engineering courses, but also diminishes students' attitudes toward engineering. The purpose of this pilot study is to investigate the effect of the proposed peer learning strategy on students' learning of Dynamics, a fundamental engineering course. Research questions of this study include: Q1: To what extent does the proposed peer learning strategy improve students' understanding of engineering dynamics? Q2: To what extent does the proposed peer learning strategy change students' attitudes toward engineering?

Seventy students who enrolled in the Engineering Dynamics course in the fall 2014 and spring 2015 participated in this study. Students' performance by question type (PQT) were defined and analyzed to identify students' academic needs and to assign peer learning teams. Results suggested that peer learning strategy proposed in this pilot study had positive impact on students' learning of dynamics and attitudes toward engineering. Limitations and future studies were discussed at the end of this WIP.

Keywords—Peer Learning; Academic Performance; Engineering Attitudes; Engineering Dynamics

I. INTRODUCTION

Engineering mechanics dynamics is a core course for many engineering undergraduate students. It introduces numerous engineering concepts and is the foundation for advanced engineering courses, such as thermodynamics, solid mechanics, machine design, and structural design. It is also acknowledged as a challenging course because it not only requires applications of mathematics skills (i.e. algebra, calculus, and differentiation equations), but also covers a broad spectrum of engineering concepts and principles [1-2]. For example, students need to learn through kinematics and kinetics principles of Force and Acceleration, Work and Energy and Impulse and Momentum for particles and rigid bodies within 15 weeks of time frame. Many students indicated that they "remembered" and "understood" the principles learned in Dynamics; however, they had difficulties in applying the learned principles into problem solving. In the standard Fundamentals of Engineering examination in 2009 in the

U.S.A., the national average score on the dynamics exam was only 53%.

Relatively low engineering self-efficacy and motivation are the other primary reasons that lead to high attrition in engineering. Studies showed that self-efficacy is significantly correlated with students' tenacity, persistence, and achievement [3]. It determines students' confidence and use of cognitive strategies in learning [4]. In addition, high self-efficacy leads students to set new challenging goals for themselves [5]. Santiago and Hensel [6] reported students' reasons for transferring majors from engineering at colleges and universities and the #2 reason was "I don't think I can succeed in engineering."

Peer learning strategy in this study refers to learning activities that involve intellectual interactions of a group of students. Students' interactions are often emphasized in collaborative/active learning. For example, Stump et al. [7] issued a survey to 150 mechanical and aerospace engineering students in sophomore through senior level core courses to determine the effects of peer learning. The survey consisted of questions evaluating through student perceptions of classroom knowledge-building (SPOCK) which focuses on knowledge building, teacher directedness, and collaborative learning, and motivated strategies for learning questionnaire (MSLQ), the portion of which used in the study focused on self-efficacy. Results to these surveys were scaled and analyzed using multiple regression to compare student opinion with performance. These scores indicated a significantly positive correlation between collaborative learning and self-efficacy, knowledge building, and course performance, and a correlation between self-efficacy and knowledge building, course grade, and teacher directedness. The study also predicted course grades based on collaborative learning and the results suggested students participating in collaborative learning performed better in the course than those working independently.

Another example is the study conducted by Freeman etc. [8] to test the influence of lecturing on learning. The examination scores or failure rates in undergraduate STEM courses reported in 225 studies were meta-analyzed. The results indicated that the average examination scores were 6% higher in studies with active learning than others, and students

learned through traditional lectures were 1.5 times more likely to fail than those in active learning. It is believed that collaborative/active learning increases knowledge transfer between students, strengthening each other's weaknesses, and increases overall student performance.

However, these studies assessed the overall effect of collaborative/active learning, including interactions between students and/or the instructor. This study focuses on the role of peers, referred to as peer learning strategy in this paper, in the learning of an engineering course.

II. VALUE OF CURRENT STUDY

A number of studies have investigated the effectiveness of peer learning in different student groups. Some studies suggested that interacting with peer students at the same cognition level, while in other studies, interactions happened among non-competent students. Both strategies have been found beneficial to the students [9-10]. However, asymmetry of knowledge exists among competent peers. Few studies have explored peer learning among competent students with asymmetry of knowledge.

The primary research questions of this pilot study are:

- 1) To what extent can peer learning affect students learning of Engineering Dynamics when team with competent peers with asymmetry of knowledge?
- 2) To what extent does the proposed peer learning strategy change students' attitudes toward engineering?

III. RESEARCH METHOD

Students enrolled in the engineering dynamics courses in fall 2014 and spring 2015 semesters participated in the pilot study. Students in the fall 2014 semester were in the control group and those in spring 2015 were in the experimental group. The following paragraphs describe the research method step by step.

Step1: Collected baseline data from the two groups through a 30-minute pre-test. The pre-test includes 11 multiple-choice questions and 4 open-ended questions that align with ABET's requirements on problem identification, interpretation, formulation, and mathematical application [11].

Step 2: Calculated the grades of students in each category mentioned in Step 1 in the pre-test

Step 3: Strategically grouped students into teams according to their total points and achievement in each category in the pre-test. Each team consisted of 3-4 students with similar total points (points differences were smaller than 2 out of 15 points) while asymmetry points in at least on category.

Step 4. Students in both control and experimental groups were provided with one problem for practice during each lecture in the engineering dynamics course and ten practice questions covering key knowledge at the end of each chapter. Students in control group did individual work on the practice questions; while those in the experimental group worked as teams with emphases on problem analysis and identification. The teams in the experimental group

- summarized the theories/principles they had learned in the dynamics course,
- described the patterns and/or features of the theories/principles,
- identified the situations that confirmed or contradicted with the pre-assumptions,
- applied proper theories/principles to solve problems,
- analyzed advantages and disadvantages of a potential solution with peers, and
- explored and analyzed other options to solve specific types of problems with peers.

Step 5: Compared students' performance in the experimental and control groups in the three exams in dynamics. Both groups used the same questions. The questions were designed with the guidance of ABET requirements and the textbook of Engineering Mechanics Dynamics [12]. To control the validity of the two exams in two continuous semesters, questions were reviewed in class using the projector within one week after each exam. No exam questions were released to the students after the exams.

Step 6: Investigated students' attitudes toward engineering using engineering attitude survey. The survey was adapted from the author's previous study on students' engineering attitudes [13].

IV. DATA COLLECTION

Quantitative data were collected from students in Engineering Dynamics at a public 4-year engineering school in the State of South Dakota. As shown in Table 1, a total of 70 students were involved in this pilot study.

TABLE I. STUDENT DEMOGRAPHICS

Groups	Genders		Majors ^a		Grades ^b		
	Male	Female	ME	CEE	SO	JR	SR
Control Group	23	1	23	1	10	11	3
Experimental Group	45	1	43	3	20	22	4
Total	68	2	46	4	30	33	7

^a ME: Mechanical Engineering Department; CEE: Civil and Environmental Engineering Department

^b SO: Sophomore; JR: Junior; SR: Senior

In response to the ABET criteria, the practice activity was designed with 3 problem identification questions, 4 problem interpretation questions, 5 problem formulation questions, and 3 mathematical application questions. Table 2 shows the distribution of questions in the pre- and post-tests in the four categories as described above. Students' responses to the pre-test were graded with the same weight for the 15 questions. For example, a student can gain 1 point for answering one question completely correctly or 0 points for an incorrect answer.

TABLE II. DISTRIBUTION OF THE QUESTIONS IN THE FOUR CATEGORIES

Category	Question Number
Problem identification	6, 8, & 9
Problem interpretation	1, 3, 5, & 11
Problem formulation	2, 4, 7, 10, & 12
Mathematical application	13, 14, & 15

Students in the dynamics course filled the Engineering Self-Efficacy Survey at the beginning and the end of the spring 2015 semester through Qualtrics, an online survey platform. Students with more than 10% of missing data were excluded from the assessment of Engineering Self-Efficacy.

V. RESULTS

Fig. 1 compares students' achievement in the pre-test in the control and experimental groups. To compare the performance of the students in the two groups, the following criterion is defined as (1) in this study:

$$\text{Percentage of correct response (PCR)} = \frac{\text{(The average number of students who selected the correct answer to questions in one category/ Total number of students in the group)}}{\text{Error! Reference source not found.}} \times 100\% \quad (1)$$

For example, assume 15 out of 30 students answered question A correctly and 10 for question B. Question category I consists of question A and B. The average number of students who selected the correct answers to the question category is $(15+10)/2 = 12.5$; while the PCR of question category I is $12.5/30 \times 100\% = 41.7\%$.

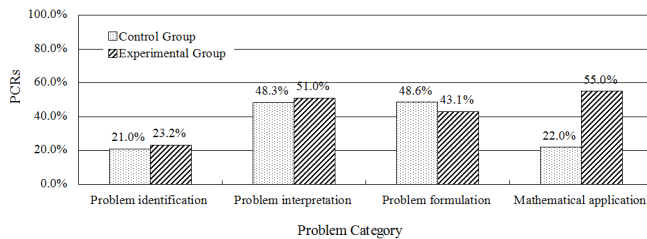


Fig. 1. Comparisons of the PCRs of pre-test.

Data indicate that, on average, students in the experimental group were at similar cognition levels than those in the control group at the beginning of dynamics course, except for mathematical application.

The average of students' academic performance in the three exams are compared in Fig. 2.

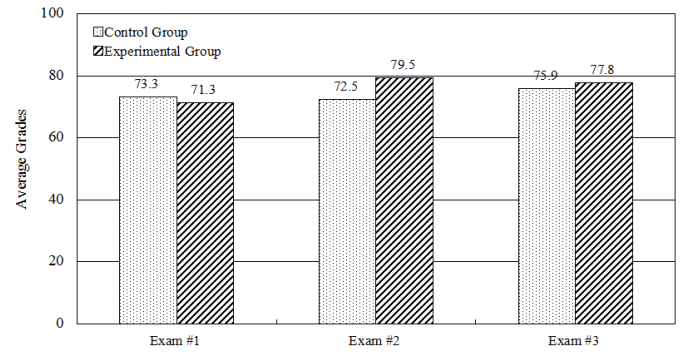


Fig. 2. Comparison of average exam scores.

A total of 34 students at the beginning and 32 at the end of the spring 2015 semester filled the engineering self-efficacy online survey. As shown in Fig. 3, no significant differences were found in a 95% confidence interval in students' self-efficacy, perceived inclusion, intrinsic motivation, or extrinsic motivation. However, considering the small sample size and short treatment (one semester), we adopted a 90% confidence interval and students had higher self-efficacy and perceived inclusion in the post-test ($p < 0.1$).

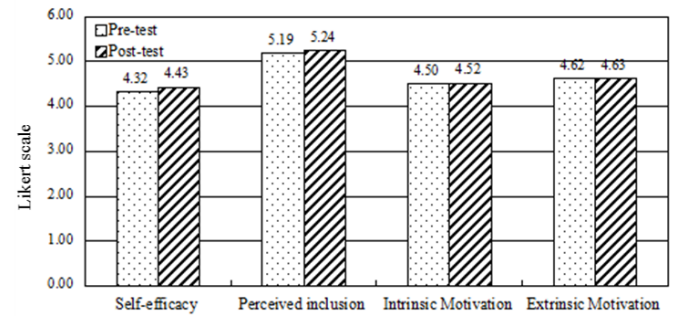


Fig. 3. Comparison of students' attitudes toward engineering.

VI. DISCUSSIONS

The preliminary results showed above suggest that the proposed peer learning strategy can improve engineering students' learning of dynamics and attitudes toward engineering. Although the students in the experimental group had higher average PCR in mathematical application, they did not achieved higher average score in the first exam. Two potential reasons are discussed in the following paragraph.

First, the students were not familiar with peer learning strategy and they were not benefit much from it at the beginning of the semester. One of the authors noticed that many students did not put much effort in analyzing the problem nor discussing with team members during in-class practice time in the first two weeks of the semester. Fortunately, the situation was significantly improved at the end

of the first month and most students actively involved in the discussions.

Second, although mathematical application skills are necessary to learn dynamics, it is not a sufficient factor. A student needs to apply mathematics based on skills in terms of problem identification, interpretation, and formulation. Limited by the three skills mentioned above, students in the experimental group could not succeed in dynamics, as shown in the results of exam #1.

Students in the experimental group had slightly higher self-efficacy and perceived inclusion after one semester of peer learning experience; however, no differences were found in intrinsic and extrinsic motivation in engineering. Considering the improved academic performance in dynamics and self-efficacy as well as perceived inclusion, motivation in engineering can be improved through the proposed peer learning strategy if adopted for more than one semesters or multiple courses.

By the time of submission of this pilot study, the students in the experimental group have not taken the post-test yet. Comparisons of the pre- and post-tests of the control and experimental groups will be conducted in the future study.

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Checkable Answers: Understanding Student Behaviors with Instant Feedback in a Blended Learning Class

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Abstract—Online learning platforms can provide automatic instant feedback on students’ activities with formative assessment tasks such as homework assignments. However, the various ways that students interact with feedback features add to the uncertainty of the effectiveness of automatic immediate feedback on student learning. We study student behavioral patterns with an instant feedback feature: “checkable answers,” powered by the edX learning platform. We show how these behavioral patterns are related to student course performance and other factors such as self-efficacy and student perceptions of the utility of the course for their future.

Keywords— *immediate feedback; learning analytics; edX; blended learning*

I. INTRODUCTION

Feedback serves to close the gap between learners’ current understanding and the desired understanding [1]. Timely and informative feedback can keep students from holding onto misconceptions, actively engage learners in knowledge acquisition, and increase confidence and motivation to learn [2], [3]. Yet, in the context of higher education, it is usually not possible for instructors to provide timely feedback to every individual student. Online learning platforms offer a solution to provide students automatic instant feedback on their interactions with online formative assessment tasks. However, how students choose to interact with these features and how these features have influenced students’ learning experiences are rarely well understood, especially in blended learning [4].

We utilize rich quantitative data including a large volume of server tracking log data of students’ interactions with the online platform, survey results regarding student perceptions of the checkable answers and self-efficacy to perform in the course, and student course performance metrics. The findings provide implications for improvements to instructional practice in blended learning for STEM courses.

II. FRAMEWORK AND RELATED LITERATURE

A. Conceptual Framework

Based on social constructivism learning theory [5] and numerous theoretical and empirical studies of how people learn

[6], we know that students develop their understanding of a concept based on their prior knowledge and experiences. Feedback plays an important role in closing the gap between current understanding (built from prior knowledge) and the desired goal, enhancing student performance and achievement.

To understand the effect of feedback on learning, we need to first understand the levels and timing of feedback. Hattie and Timperly [7] conducted a thorough review of studies on feedback effects, and they proposed four levels of feedback, from specific to generic: (1) feedback on task execution, (2) feedback on learning strategies, (3) feedback on metacognitive skills, and (4) feedback on the self as a person. Studies note that there is an interactive effect between feedback on task execution and learning strategies [8]. Feedback at the task level can help students who already demonstrate metacognitive awareness develop appropriate learning strategies on their own. Though the “checkable answers” in the course we study only provide simple corrective feedback at the task execution level, it is reasonable to assume that students with strong metacognitive awareness could develop effective learning strategies because the task level feedback is available.

In terms of the timing of feedback, much debate exists in the literature over the effectiveness of immediate versus delayed feedback. Proponents of delayed feedback refer to the superiority of delayed over immediate feedback as the Delay-Retention Effect (DRE) [9]. However, many recent studies argue against DRE, which may be more effective in laboratory settings [10], [11]. In the context of this study, “checkable answers” provided automatic immediate corrective feedback on students answers’ to online homework problems.

B. Background Literature

1) Blended learning

A blended learning class in post-secondary education is usually defined as a class that has a significant online component, while the students and instructors still meet face-to-face regularly [12]. Researchers argue that the blended learning format combines the “best of both worlds” [13] and could support deep and meaningful learning [14]. However, empirical studies report mixed evidence of the effectiveness of the blended learning format [12], in part because there are

virtually countless instructional and platform design possibilities for blended learning classes in various contexts. As [4] states, and we concur, studies merely answering “big” questions such as “is blended learning effective” yield few actionable insights for educational practices. This current study does not intend to justify whether blended learning is effective or not. Rather, we take a very focused approach to understanding and improving blended learning, here, by studying the component of immediate feedback within a blended learning context.

2) *Student behaviors in online learning platforms*

Solely understanding the effect of feedback on student learning is not enough to provide practical guidelines for the design of automatic instant feedback features. Even if we provide the right level of feedback at the right time, there can still be numerous ways in which students interact with these feedback features online outside of the controlled classroom environment [15]. In a work-in-progress study [16], the researchers seek to develop measures for students’ “productive persistence”—strategic behaviors that benefit learning in an online learning platform. Such measures could be used by instructors for pedagogical improvement. Similarly, in our study, we investigate whether we could identify student instrumental vs. strategic behaviors using the “checkable answers” feature, and we estimate the relationship between these behaviors, course performance, and self-efficacy.

C. *Research Questions*

Based on our conceptual framework and existing literature, we ask three foundational questions in our study: (1) How can we characterize the behavioral patterns that students demonstrate while using the “checkable answers” feature? (2) How are these behavioral patterns related to students’ performance? (3) How are perception, attitudinal, or self-efficacy factors related to student behaviors using the instant feedback feature?

III. DATA

The course studied in this paper is a residential physics course, “Classical Mechanics,” required for all first-year students at an elite private university in the northeastern United States. In Fall 2014, a total of 474 students were enrolled in this course. The course was a blended learning course, including active learning face-to-face class sessions during the week and a large number of learning materials and assessments online powered by the edX learning platform (www.edx.org). This current study focuses on the rich quantitative data from students’ interactions with the course platform, survey results, and student performance.

A. *“Checkable Answers”*

Using an instant feedback feature called “checkable answers” on the edX platform, the students could check an unlimited number of times whether their answers to the online homework problems were correct indicated by a green check mark or a red cross mark. No answer or hint was available before the due date. There were 22 online homework problems over the semester, and students had 10 days to work on each

problem before the due date. In total, online homework problems were worth 2% of the course grade.

B. *Data Sources*

1) *Tracking log data*

From September 1st to December 31st, 2014, students’ interactions with the edX course website resulted in more than 30 million interactive events. These interactive events include students’ interactions with all kinds of online materials and assessment tasks: the e-textbook, lecture slides, videos, and homework problems. One event with the “checkable answers” is referred to as a “check”. In total, with 22 problems, students made 58,422 checks. The total number of correct checks is 9,545, and that of incorrect checks is 48,877: only 16.3% of the checks were correct.

2) *Survey data*

During November 2014, we administered a Qualtrics survey to the students. The survey measured, using a 1-7 Likert scale, students’ perceptions of the utility of the “checkable answers” feature (e.g., whether the feature helped their learning by “helping me check for errors”); their self-efficacy to perform in this course; and the perceived utility of this course for their future. For each of the three metrics, we constructed a scale (average score of items to which one student responded). The within-scale reliability for the new scale of perceptions of the utility of the checkable answers is high (Cronbach $\alpha=0.98$). The self-efficacy measure and the measure for students’ perceived utility of this course for their future are adapted from [17] and [18], respectively.

Out of the 474 students, 266 students completed the survey, resulting in a response rate of 56.12%. Tests show that students who completed the survey performed significantly better in both cumulative and final exam grades ($p<0.01$). These systematic differences between students who did or did not complete the survey represent a limitation to our study.

3) *Performance metrics*

We collected cumulative grades and final exam grades for all students enrolled in this course. Besides final exam grades, the cumulative grades take into consideration students’ homework scores, quiz scores, reading assignment scores, and participation in problem-solving sessions and experiments, therefore representing students’ effort more broadly [19].

IV. METHODS

We extracted 10 variables from the server tracking log data to describe student behaviors with the “checkable answers”. We supplement behavioral data with the survey results as described above and run appropriate correlations.

A. *Extracting variables*

For each homework problem, a student submitted a set of answers, to which the system returned a set of True (T) or False (F) symbols indicating the correctness. Different students had different numbers of Fs and Ts on each homework problem, with different time intervals in between. We constructed the following ten basic variables for each student on each homework problem to summarize the the student

behaviors in their use of the “checkable answers”: (1) the time between the first check and the homework due time; (2) the number of Ts; (3) the number of Fs; (4) the total number of checks; (5) the ratio of the number of correct checks out of the total number of checks; (6) the time between the first check and the last check; (7) the time between the first check and the second check; (8) the average time interval between each check; (9) is the first check a T?; and, (10) is the last check a T? With 22 homework problems, we have 220 descriptive variables for each student.

B. Analyses

We normalize each feature by a “difficulty” proxy for all students within each homework problem before proceeding to the correlation analyses. For variables 9 and 10 above, which are binary, we weighted using the total number of incorrect checks for each homework problem. Our logic is to use the total number of incorrect checks for each homework problem across all students to approximate the difficulty level.

For each of the 10 normalized or weighted variables, we then found the mean value over the 22 homework problems for each student. Then, we calculated the Spearman rank correlation coefficients between the mean values of each feature and each students’ final exam scores and cumulative grades. For students who completed the survey, we also calculated the correlation between the 10 variables and the scale scores.

V. RESULTS

Initial results indicate that some of the student behavioral variables are significantly related to performance and attitudinal outcomes, though only a few are strongly so.

A. Descriptive statistics

The maximum number of checks for a homework problem summed across all students is 6,127, while the minimum number is 579. The average number of checks for a homework problem across all students is 2,656. On average, one student checks each problem 5.6 times. Fig. 1 is a stacked bar graph illustrating the number of correct and incorrect checks for each student (ordered based on total number of checks). We can see that students who checked more than 300 times had a relatively lower percentage of correct checks. We might hypothesize that the students who checked more than 300 times are demonstrating frequent guessing behaviors, and their performance might be hurt by this behavior. However, as we will show in correlations, frequent checking in this blended learning context does not appear to hurt student performance.

B. Skewness

Fig. 2 demonstrates that the distributions of the variables are skewed, which is the case for the other 8 variables as well. This is the rationale for our choice to use Spearman rank correlation instead of Pearson correlation in our analysis.

C. Correlations

We show a correlation coefficient visualization in Fig. 3. The order of the 1-10 variables is the same as the ordering in the list we describe in section IV.A.

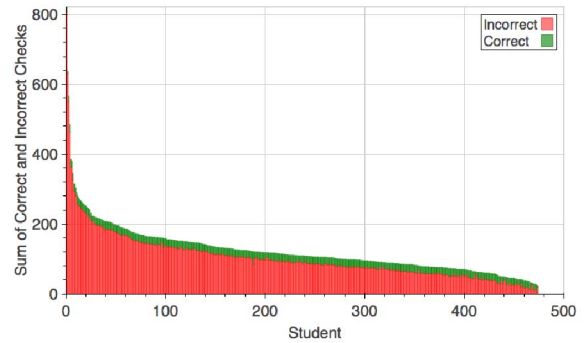


Fig. 1. Total number of correct and incorrect checks for each student over all 22 homework problems (Stacked)

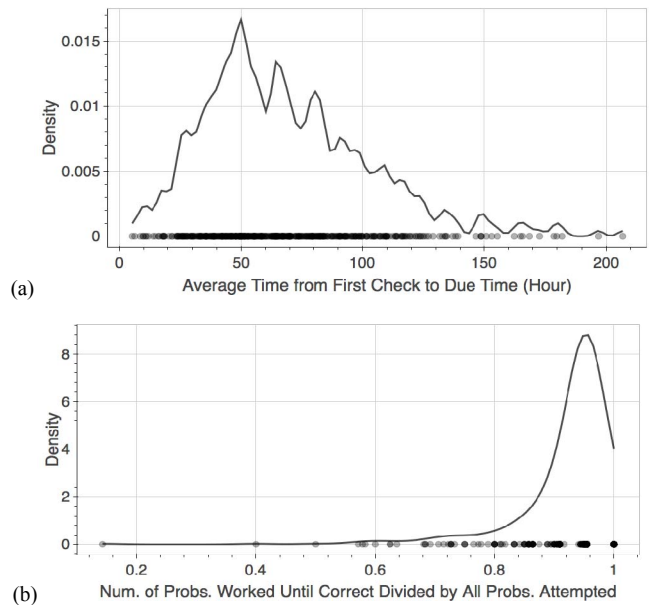


Fig. 2. Density plots for (a) the average time the first check to the homework due time for a given student (variable 1) and (b) the ratio of number of problems where the student worked until correct divided by number of all problems attempted (variable 10)

VI. FINDINGS

We find that some of the behaviors that research has shown to be important in face-to-face classrooms (e.g., conscientious study strategies) are also significant in the blended classroom. We also find that higher engagement with immediate feedback in the simple ways in which we measure this construct is positively related to achievement in the course.

A. Student behaviors using “checkable answers” feature

We observe a great deal of heterogeneity in the range and types of behaviors students demonstrate as they engage with the “checkable answers” feature. Although these behaviors represent a great deal of diversity and demonstrate a high level of skew, they are not as notably skewed or widely varied as behaviors in the MOOC context [20].

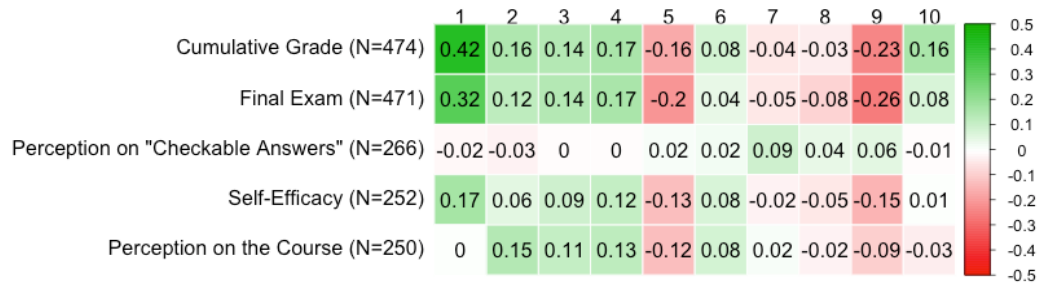


Fig. 3. Spearman correlations between the 10 variables and student performance and attitudinal scores (see section IV A. for descriptions of the 10 variables)

B. Relationship to student course performance

From Fig. 3, we can see that many of the behaviors we study are related to achievement in the course. Some are significantly related to student attitudes or perceptions. Further, some, but not all, of the relationships are in the direction we had hypothesized.

The time between the first check and the homework due time is the metric most strongly related to students' course performance. This indicates that "early starters," on average, perform well. This may be due to their higher level of metacognition or more mature study strategies. Our subsequent multivariate regression models will help us better parse out the variance attributable to different student behaviors.

Number of checks, no matter whether it is the number of correct, incorrect, or total checks, has a positive correlation with student performance. We hypothesize that this might indicate that, even if a check is incorrect, the student receives feedback on his/her response and can utilize that feedback, which may then result in higher learning outcomes. The positive relationship between number of checks and achievement may also be a proxy for the student's effort, which would positively contribute to performance compared with no check at all [19].

We had hypothesized that students getting the correct answer on their first tries (variable 9) might be a proxy for higher prior knowledge of the course content, which would likely positively correlate with performance. However, our current results show the opposite. It is actually students working until they get the correct answer (variable 10) that is more important and beneficial for achievement than getting the correct answers on the first attempts.

C. Perceptions and self-efficacy

We find that some of the behaviors are related to the three key survey scale metrics: students' self-efficacy to perform in the course, their perceptions of the utility of the course for their future, and their perceptions of the utility of the "checkable answer" feature. These key attitudinal metrics may be related to both student performance directly and also to the way in which students use the feedback feature, which could in turn mediate their learning.

Interestingly, students' perception of the utility of the "checkable answers" feature is not actually correlated with any of their actual behaviors with the "checkable answers." This

may reflect the fact that, regardless of how students perceive the benefits of the tool, it is their realized behaviors and the ways in which they engage with the feedback system that ultimately impact their performance. On the other hand, students' self-efficacy scale scores are correlated with behavioral measures, and they follow the same positive/negative pattern of correlation as behaviors related to performance outcomes. In addition, students' perceived utility of the course for their future is positively correlated with their number of checks (perhaps a proxy for effort).

VII. DISCUSSION, IMPLICATIONS, AND LIMITATIONS

We find three key implications for instructors and platform designers across STEM undergraduate courses. First, "effort" as measured by the number of checks appears to be an important behavior, regardless of whether students get the answer correct or incorrect, and therefore, instructors should encourage or reward students' "trying" over their getting the correct answer right away. Also, the extent to which students start the homework before the due date is very strongly tied to their achievement, and instructors or platform designers could encourage or remind students to practice thoughtful study strategies in the blended setting as they ideally would in a face-to-face class. Finally, the lack of a correlation between students' perceptions of the utility of the "checkable answers" implies that instructors and designers should reconsider the way they gather student perception measures and ask corresponding research questions.

We highlight two additional limitations that we have not already mentioned. First, we did not have direct measures or strong proxies of crucial student background factors such as prior knowledge and metacognitive skills. And, second, we cannot actually observe everything that students are doing in between checks in order to affirm our hypotheses about why we observe the relationships that we find in our study. In future work, we will include student background factors in our analyses in order to look into students' other behaviors associated with the usage of "checkable answers" during the problem solving process.

ACKNOWLEDGMENTS

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Automatic Recognition of Misconceptions in Visual Algorithm Simulation Exercises

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Abstract—Visual algorithm simulation (VAS) is an activity in which students practice their understanding of algorithms: They simulate the steps of an algorithm by manipulating a bespoke visualization within a supporting software system. Multiple instances of a VAS exercise may be automatically generated for different learners or for repetitive practice by a single learner. In this work-in-progress report, we discuss how misconceptions might be automatically detected in students' solutions to VAS exercises and how misconception-aware feedback might be provided in VAS. We identify two strategies for producing multiple instances of VAS exercises and evaluate them against several criteria. The trade-offs so identified are also pertinent for similar process-simulation practice beyond VAS and computing education.

Keywords—*computing education, algorithm visualization, visual algorithm simulation, process-simulation practice, automatic assessment, feedback, misconceptions, individualized instances of exercises, input generation*

I. INTRODUCTION

Consider an activity in which a student is supposed to learn about a well-defined stepwise process, standard procedure, or algorithm. To this end, an exercise is provided in which students start with some input, practice applying the procedure on it, and, if all goes well, produce the intended outcome. The path they are expected to follow depends on the input and the procedure.

An example of this kind of learning activity within computer science education is *visual algorithm simulation* (VAS) [1]. In VAS, students use a computer to manipulate a visualization of a data structure in order to learn about how a particular algorithm works on that structure and to demonstrate their understanding. Since the algorithm is well defined, the activity can be automatically assessed and scales to online or blended courses with large numbers of students.

For a software system to support VAS or a similar form of practice effectively, the following features are desirable:

- The system should be capable of automatically generating numerous instances of the problem, i.e., different inputs on which the algorithm can be practiced.
- The system should be sensitive to common misconceptions of the algorithm that is to be learned. The generated instances of the activity should be such that a student with these misconceptions is unlikely to succeed unless they address the misconception.

- The system should provide formative feedback that targets particular misconceptions. This feedback should be generated as automatically as possible: it should be able to assess when a particular student might have a particular misconception.
- Ideally, the system would also aid teachers and developers in determining which student errors and misconceptions are common.

This article is a work-in-progress report. In it, we explain why the above goals make sense, highlight certain difficulties in achieving all of them at the same time, and promote a discussion on how to work towards them. In the following sections, we elaborate on visual algorithm simulation and empirical studies of it, present the above agenda in some more detail, and discuss two alternative strategies for generating inputs for VAS exercises. We then turn to the research community for advice.

II. VISUAL ALGORITHM SIMULATION

Although the problems of input generation and misconception-aware feedback in computer-supported process-simulation tasks arise in many contexts, our current interest in this topic revolves around computing education and, more specifically, algorithms courses and the *visual algorithm simulation exercises* [1] which may be employed in them. Visual algorithm simulation is an interactive form of *algorithm visualization*, and, more broadly speaking, of educational *software visualization* [2]. In the form that we discuss in this article, VAS requires a purpose-built software system that facilitates practice.

In a VAS exercise, a learner is asked to trace an algorithm by manipulating a given visualization of one or more data structures. Typically, these manipulations are carried out using the mouse on the visualization: clicking, dragging, and dropping, for instance. Learners produce a trace of a specific algorithm: Mouse events signal transitions between the states that constitute the trace. As the learner operates on the visualization, the corresponding modifications are made to real data structures in computer memory. The states of the data structures are recorded at each step.

An example of a VAS exercise is shown in Fig. 1: A new key has just been inserted into a Red Black Tree. In this example, the learner is supposed to click the nodes and

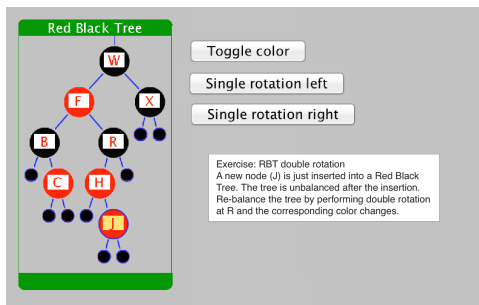


Fig. 1. A snapshot of a VAS exercise. The learner is supposed to insert a number of keys into an initially empty balanced search tree. A new key has been just inserted into a Red Black Tree (the red node *J*, in yellow). The tree is currently unbalanced (the rule “both children of every red node must be black” is violated at *H*). Next, the learner is to choose and perform the correct operations to re-balance the tree.

push buttons on the screen in order to re-balance the tree. The balancing is performed by selecting a node and choosing the correct push button. In this case, the learner is supposed to do a double rotation at *R* and the corresponding color changes. However, this is a complex operation that requires multiple steps (as this VAS exercise does not offer a double rotation operation as a primitive). The corresponding states produced during these steps constitute the trace. The correct re-balancing sequence begins with selecting the node *H* and performing *Single rotation left*, after which *Single rotation right* is required at *R* and *Toggle color* at both *J* and *R*.

VAS exercises can be embedded in instructional materials such as OpenDSA that is targeted for data structures and algorithms courses [3]. OpenDSA integrates a textbook with algorithm visualizations and a collection of “proficiency exercises” in the form of VAS. The learner can submit their answer — the sequence of states — to the back end simulation system and receive a grade and/or feedback.

The automatic assessment of a VAS exercise can be implemented as a stepwise comparison of learner-generated states with a model sequence; an example is shown in Fig. 2. Each state in the student’s sequence must match the model answer in order for the student to receive full points. Automatic assessment not only removes the burden of marking those exercises manually, but also makes it possible to give the students immediate feedback.

In existing VAS exercises [1], each exercise is typically initialized so that the system generates random input data within exercise-specific parameters. This has several benefits:

- The system can provide a model answer for each instance of the exercise: A student may request to see the model answer and compare their answer with it, and then start over with a new instance (fresh inputs) to try and gain the marks for the exercise. This provides an opportunity to students to learn from their mistakes, assuming they are able to understand the model solution.
- Students can practice on an algorithm using fresh data even after successfully solving the exercise once.
- The system can provide students with individualized instances of the exercise so that they cannot simply

copy each others answer directly. This may reduce cheating.

It is not trivial to choose the parameters within which inputs are generated. For example, consider the sequence of keys to be inserted into an initially empty Red Black Tree. The sequence should be such all the different balancing scenarios are covered. The snapshot in Fig. 1 covers only the case where a double rotation is needed. In a complete exercise, also a single rotation and simple color change scenarios should be covered. In addition, there is a case where the procedure needs to be recursively performed upper in the tree after a color change. Not all random input sequences feature such scenarios with a feasible small amount of keys and steps. We will return to this issue below.

III. RELATED EMPIRICAL WORK

Seppälä et al. [4] introduced an approach to recognize misconceptions related to the Build-Heap algorithm. They examined recorded sequences from a VAS exercise to discover misconceptions related to the algorithm. Afterwards, they manually implemented misconceived algorithm variants and matched student solutions to these. According to the authors, a relatively large body of incorrect student answers can be matched against these misconceived algorithm variants:

“Of all the incorrect answers, one fifth could be explained by the three most common [misconceived] algorithms alone. If algorithms that do not end with the heap property restored are considered, only one fourth of all submissions to the exercise were left.” [4]

Seppälä et al. also extended the idea of modeling misconceptions beyond manually implemented algorithm variants [5]. They made small changes — mutations — to the code of the implemented variant algorithms. This allowed subtle variation within the variant itself as well as modeling non-systematic behavior such as slips.

Karavirta et al. [6] also studied misconceptions in the context of VAS and found out that some VAS exercises have problematic input data: Some instances of exercises could be solved with full marks even by students with a misconception. This is possible if the correct trace does not include a state or step that is needed to reveal the misconception. For example, in the Build-Heap algorithm, the input could be such that swaps occur only with a parent and its child, but this “percolate-down” process (also known as sift-down or heapify-down) never continues at the lower levels. In other words, the tail recursion at the end of the algorithm never happens. Many well-known misconceptions are related to students’ weak understanding of recursive functions. In this case, the student might never realize the recursive nature of the algorithm if the input data is badly chosen.

Logged traces of student behavior in software simulations have also been found to be a potentially useful form of data in the context of *program visualization* (i.e., the visualization of concrete programs as opposed to general algorithms): Sirkiä and Sorva [7] explored students’ solutions to visual program simulation exercises and found evidence of multiple misconceptions of introductory-level programming concepts.

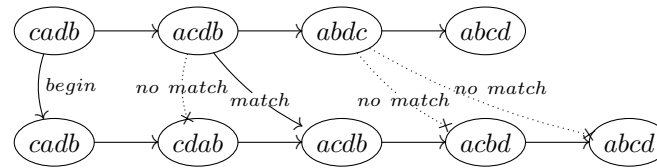


Fig. 2. A comparison of two selection sort sequences. The top sequence is the model solution, and the bottom sequence is an incorrect solution produced by a student. The comparison proceeds by stepping through the states of the model solution and trying to find the corresponding state from the student sequence. The process continues until either sequence runs out of states.

Beyond from computer science, specific processes that a student should follow and the related misconceptions have been studied in the context of mathematics education [8]–[10]. Work has also been done on the automatic analysis of students’ systematic stepwise processes in the context of chemistry education [11] and Lisp programming [12].

IV. TOWARDS MISCONCEPTION-AWARE VISUAL ALGORITHM SIMULATION

In this section, we first outline our goals, which are related to improving feedback in VAS exercises. With these goals in mind, we discuss four desirable characteristics of the input generation facilities of VAS systems. There are tensions between these requirements, which become even more apparent as we then consider some alternative strategies for implementing input generation.

A. Goal: Improving Feedback

There are two interrelated aspects to our overall goal of improving the automatic feedback given by VAS exercises: 1) detecting that a particular student might have a particular misconception and 2) discovering new patterns of incorrect solutions which are common among a student population. The first aspect is important from the perspective of teaching and learning; the second is additionally concerned with advancing computing education research.

1) *Targeting students with feedback:* Knowledge of students’ misconceptions is a part of pedagogical content knowledge (PCK) [13]; knowledge of common misconceptions improves the effectiveness of a teacher [14]. Some aspects of PCK may be encoded into software such as a VAS system.

We would like to have a system that analyzes students’ mistakes in VAS exercises, and, upon detecting a possible misconception, adjusts the feedback it gives to the student. This is challenging for a number of reasons. One challenge is that a single misstep is often not enough for reliable analysis, and a sequence of consistent mistakes may be required. Even then, there may be multiple misconceptions or other explanations for any given sequence of simulations steps. Some misconceptions may lead to inconsistent behaviors, and more research is needed to establish which misconceptions can be reliably detected.

Another topic for future research is the effectiveness of different forms of feedback. For instance, might it be useful to present code or pseudocode that represents the *incorrect* version of the algorithm that matches the student’s attempt

and to highlight the differences between that version and the correct one?

2) Computer-aided discovery of common error patterns:

Some misconceptions may be detected by observing students, discussing with them, or analyzing their answers to problems. Solution attempts to VAS exercises are one such source of data, one which has potential for the semi-automatic discovery of new misconceptions and other common sources of error such as usability problems in a particular VAS interface.

If we had a system that could group large numbers of erroneous solutions on the basis of their similarities, these groups could be then analyzed by a human researcher or teacher to form hypotheses about the misconceptions or other issues that led to them. Such analysis could take place after a course is finished, to improve future course offerings. Or it could even be carried out while a course is still running so that the teacher immediately writes feedback to students with a particular error pattern upon being informed by the system of a new common pattern. Other options could also be explored: For instance, in a massive online course, the system could automatically create threads on a discussion forum for common solution patterns and direct students to them. The resulting discussion could help them learn and also aid teachers and researchers in getting to the reasons behind the patterns. Even on a smaller scale, students could be automatically prompted to explain their reasoning in case they are getting an exercise wrong multiple times, consistently repeating an erroneous pattern.

B. Useful Characteristics of Input Sets

On the basis of the earlier studies reviewed and our own experiences, and targeting the goals just discussed, we describe four characteristics of that input sets of VAS exercises may have: 1) dissimilarity, 2) sensitivity to misconceptions, 3) randomness and 4) similarity. All of these characteristics are desirable in one way or another, but as the names already suggest, there are some trade-offs involved.

1) *Dissimilarity:* Each instance of a VAS exercise — each set of inputs, that is — should be different from the other instances seen by the same student. The chances of a student and their friend having an identical or near-identical instance should be small. In addition, there are benefits to allowing students to redo the exercise with different inputs. From the teaching and learning point of view, this is desirable for the reasons discussed above in Section II.

2) *Sensitivity to misconceptions*: Knowledge is commonly (or always) viable for some situations but non-viable for some rarer or more complex situations. Even many so-called misconceptions might be viewed as not incorrect as such but as a limited form of knowledge that work for some purposes [15]. For incorrect or limited knowledge to evolve into more generally useful knowledge, the learner needs to be placed in situations in which their earlier understanding is insufficient; we learn from difficulties [16]. Making mistakes can create dissatisfaction with existing knowledge and promote conceptual change. Taking all that to the context of algorithm simulation, we suggest that instances of VAS exercises should be carefully configured in such a way that the exercise is difficult to solve if the student has a known misconception about the algorithm. That is, knowledge about the algorithm that is not viable in a wide variety of contexts should also not be viable in the context of the exercise.

3) *Randomness*: From a research point of view, we need a wide variety of highly variable inputs spanning as many of the valid inputs of each algorithm as possible. This can help with the discovery of entirely new misconceptions as some misconceived algorithms will produce behavior different from the correct algorithm only when conditions specific to that misconception are met during the solving process.

4) *Similarity*: For research purposes, we might also benefit from students using the same or very similar input sets so that it is easier to categorize different solution paths within an exercise. If a group of students all solve the same exercise instance in an identical way which is notably different from the correct solution this is possible evidence of a misconception or a problem in the exercise itself.

C. Strategies for Input Generation

Input generation is the process by which a VAS system or a similar learning environment produces instances of an exercise for different learners to solve. We discuss two alternative strategies for input generation, which we will call the constraints style and the preconfigured templates style.

1) *Constraints*: In the constraints style of input generation, an input set is generated by choosing randomly among all valid inputs, then checked against exercise-specific constraints which invalidate certain kinds of input sets. The process is repeated until a valid input set is produced. The constraints are designed to prevent instances of an exercise from being too easy. (An already-sorted input for a sorting exercise is an extreme example of an excessively easy instance.)

Moreover, the constraints may be designed so that the exercise is sensitive to misconceptions. One way to achieve this is that each candidate instance is checked against a number of incorrect implementations of the algorithm which correspond to specific misconceptions, and only instances where incorrect algorithms produce different steps are accepted. One downside of this approach is that it multiple incorrect variants of the have to be manually implemented. A particular strength of this approach is that it can achieve a high degree of desirable dissimilarity. Current VAS systems [1] use the constraints approach in a limited, largely misconception-insensitive form, mainly to require that the problem instances require different aspects of the algorithms (e.g., a Red-Black Tree balancing

exercise covers all the different balancing scenarios: single rotation, double rotation, and color change, but possibly also recursive balancing if required after a simple color change).

2) *Preconfigured templates*: Dissimilarities between input sets can be grouped into 1) *superficial* ones: the inputs use different specific values, but lead to the same sequence of solution steps, and 2) *categorical* ones: the inputs require a different sequence of steps to complete correctly. This difference is exploited in the preconfigured categories strategy of input generation. In this strategy, teachers or system designers manually configure a small number misconception-sensitive *input templates* for each exercise. All possible instances that conform to a template are categorically similar to each other, but may be superficially dissimilar. Several templates can be generated for each exercise. The number of these templates should be large enough that a student can practice on multiple structurally different instances of each problem; prior work suggests that half a dozen categories per exercise might be enough (because students typically need between 1 and 5 attempts to solve a VAS exercise). To individualize the exercises, each actual instance that a student sees is generated from a template by randomly choosing the superficial features of the problem within the bounds of the template.

In many cases, generating instances from a template is fairly straightforward. If the input is, say, an array of keys to be inserted into a binary search tree, the keys themselves are not important for the purposes of the exercises, only their relative order is. Thus, we can, for example, substitute each key with its predecessor without affecting the correct solution sequence. This approach has the additional benefit (towards the goal of similarity identified above) that we can bring all the instances that match a template to a canonical form.

A downside of the preconfigured templates approach is that the generated instances do not necessarily span the entire space of valid inputs, which may hinder the discovery of new misconceptions. On the other hand, this method could also be used to test students with essentially the same random data and then look for possible new misconceptions where a group of students solve the problem in a new, previously unknown way.

V. CONCLUSION

In this work-in-progress report, we have highlighted issues in how visual algorithm simulation systems generate distinct instances of exercises and provide feedback to students. The discussion is also pertinent in the context of other similarly interactive forms of practice that target the learning of processes, procedures, or algorithms. We have outlined an agenda for improving the automatic detection of misconceptions in visual algorithm simulation exercises, and commented on two alternative ways to generate inputs suitable for misconception-aware exercises, each with their own sets of strengths and weaknesses. We invite the research community to discuss and improve upon these ideas and to share best practices in the design of computer-supported process-simulation exercises.

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Formulation of a predictive model for academic performance based on students' academic and demographic data

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Abstract— This work is based upon the results of an evaluation process applied over data mining techniques, in order to find the most adequate ones to extract classification rules from first-year students' academic and demographic data in relation with their academic performance. As a result of this, the formulation of a predictive model for academic performance is presented; model whose construction was achieved by analyzing, selecting and defining the classification rules that properly predict the academic performance of Systems Engineering students, at Universidad El Bosque in Bogotá, Colombia. Classification rules that make up the model are analyzed from a contextualized academic point of view; consequently evaluating the pertinence of the relationships between attributes contained within these rules and their ability to predict poor academic performance (through academic risk). Also their applicability to datasets from other academic programs is contemplated, in order to generate useful strategies to prevent academic desertion, being poor academic performance one of the most influencing factors over this phenomenon.

Keywords—educational data mining; classification; predictive model; academic performance; academic data; demographic data

I. INTRODUCTION

Academic desertion in higher education is understood as the situation in which a student cannot conclude its educational formation, and a deserter is an individual who exhibits no academic activity during two or more consecutive semesters [1]. Due to the impact that academic desertion has in society, Colombia has progressed in understanding and addressing the phenomenon through the National Education Ministry, which has successfully documented it [2] and generated specific strategies for its diagnosis and treatment. By diagnosing the phenomenon, it has been found that most of the desertion rates occur during the first year of university studies [2]. It also was found that low academic performance is one of the most influencing factors in student desertion [3].

At Universidad El Bosque the whole concept of academic desertion prevention has evolved into assuring students' success. For this, the Students' Success Program (PAE) was created [4], which aims to provide adequate learning environments in favor of the students' quality of life and

integral wellbeing throughout their formative process. It also aims to design and develop practices which allow for the improvement of retention and graduation rates. Within these strategies a follow-up is done over the students' academic performance in every one of the three major testing times along each semester. This way, according to the students' academic performance they are classified within defined risk levels: no risk, low-risk, medium-risk and high-risk. Accompaniment-related actions are triggered by these risk levels for students who have been classified within a high academic risk. Even though these accompaniment strategies are useful, they take place when the students' performance has already been evaluated and classified. This makes them post-facto, or non-preventive strategies.

Because of the above, it becomes necessary to obtain a profile of the students' academic performance anticipatedly, in order to generate preventive accompaniment strategies. These strategies should diminish the probability of student desertion when implemented, mainly through the first year of university studies.

Educational Data Mining (EDM) rose to be a very useful tool to analyze academic information to serve different purposes within educational scenarios [5]. EDM helps reveal relationships between data stored in institutional information systems, allowing the modelling of educational phenomena, such as academic performance. Several studies demonstrate how this technology is proven useful for academic performance prediction [6-16].

The objective of this work is to formulate a predictive model for first-year students' academic performance, from analyzing classification rules product of a data mining process applied over the students' academic and demographic data. In particular, the demographic data is provided by the students as they are admitted to the academic program. This paper is presented in four sections. The first one describes the conceptual framework and theories upon which this work is constructed. Next a methodological development is presented which is composed by the data mining process' execution and the predictive model's formulation. In the third section of this article the results obtained throughout the whole exercise are

analyzed, to finally establish some conclusions presented in the fourth and final section.

II. THEORETICAL FRAMEWORK

A. Data Mining and Educational Scenarios

EDM has been defined as an emergent discipline, concerned with developing methods for exploring the unique kinds of data that come from educational settings, and using those methods to better understand students and those settings in which they learn on [5]. Currently there are entities such as the International Educational Data Mining Society [17] and the Society for Learning Analytics Research [18], which are two very important hubs to the international research community. They provide a common ground for this field of study, educational and pedagogical analysis and exploration through data mining. EDM is an invaluable tool to educational institutions for it has allowed them to profile, predict and adjust students' academic performance as well as providing support in decision-making processes involving both teaching and administrative staff. It is possible to discover the reasons that lead to academic success by inquiring on the factors that cause students to fail academically [8].

Data mining provides an accurate and systematic way of inquiring and discovering knowledge in settings like educational institutions. "Data mining can be used effectively in educational institutes for leading education activities in an effective way, for watching students' performances continuously and directing students in course and profession choosing". Thus, "the level of students' success can be raised"[8]. Also "data mining is a powerful analytical tool that allows academic institutions to better assign resources and personnel, manage proactively students' results and improve the alumni's development effectiveness"[19].

B. Additional concepts and theories

Academic performance represents "the efficacy level in the consecution of the curricular objectives for a diversity of subjects, and is expressed through a qualifier" [20] which is a value within a numeric interval. In this work, academic performance is represented in four different values: the weighted average from all the students' first year grades, and three separate averages for different academic areas (professional, basic and complimentary areas). Each of the academic area averages is calculated using the grades of the subjects that make up each area in the study plan. Performance within each representation is presented as three possible values: outstanding, average or risk.

A model is understood as a theoretical scheme -generally in a mathematical form- that represents a system or a complex reality, that is developed to further study and more easily understand its behavior. In this work, the predictive model will be given by classification rule sets shown as logic propositions that relate academic and demographic variables with a determined academic performance level.

In the field of data mining, prediction addresses the ability to infer a singular aspect of data (predicted variable), from a combination of other specific data aspects (predictive variables)[21]. Therefore predictive modeling is a statistical

technique commonly utilized to predict future behaviors. Predictive modeling-based solutions are a form of data mining-based technology, that makes use of historical and current data analysis, in order to generate a model that predicts future outcomes[22].

There are diverse factors and variables –academic and demographic- that can influence the students' academic performance. Just as proposed, studied and demonstrated by Baha Sen and Emine Ucar, factors such as age, gender, type of high school education and kind of higher education (distance or attendance-based) have a direct impact on students' academic results[9]. Other studies have found important correlation between variables such as gender, age and academic performance on admission and graduation tests [23, 24]. In other investigations correlation between academic performance and other variables such as parents' educational level was found [25].

III. METHODOLOGY

The model's formulation is composed of two great phases. In the first one, a data mining process is executed using the J48 and PART[26] algorithms in order to extract an initial set of rules; all this bearing in mind what was learned in previous exercises on data mining, which allowed the recognition of the necessary procedures and adequate techniques for the data mining process. These addressed matters such as data extraction and preprocessing, relevant attribute selection and identification, data mining techniques for results optimization and the behavior of the J48, PART and Ridor algorithms (with the studied dataset). Secondly, the predictive model itself will be formulated by analyzing, selecting and defining the rule set –composed of the previously extracted rules- that will be included as part of the model. This selection will take into account factors such as classification coverage for each independent rule, precision of the data mining models generated and their accuracy to predict academic performance –particularly risk-.

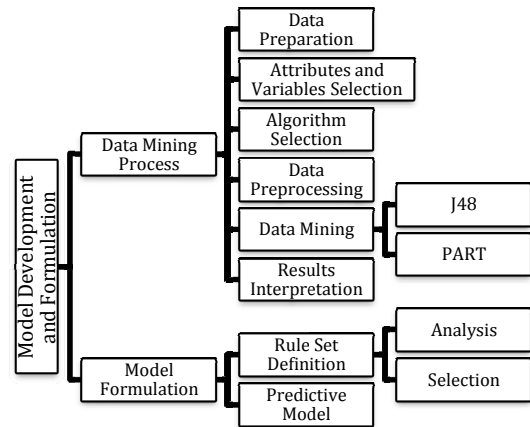


Fig. 1. Methodological development chart

A. The Data Mining Process

The algorithms selected to accomplish the data mining task were J48 and PART. J48 implements a C4.5 decision tree and PART implements a decision list. The latter uses separate-and-conquer techniques, builds a partial C4.5 decision tree in each

iteration and makes the "best" leaf into a rule [26]. These algorithms were selected due to their adequate mining results of the dataset in previous data mining exercises, rendering a classification and precision rates between 70% and 85%.

The data preparation step begins with its extraction from the database system that registers the students' information as they enter the Systems Engineering Program. The information corresponding to 932 students was selected, of which 61.38% where male students and 38.62% where female. Regarding the sample's socio-demographical characteristics, it was found that 6.65% of the students belong to higher social stratus, 73.07% belong to middle social stratus and 20.28% belong to lower social stratus. Also 19.74% of the students come from other cities, most of them are single (92.49%) and the majority of them don't have a job (71.56%).

The total dataset was split randomly in two subsets of 465 and 467 instances respectively, in order to obtain an experimental group to be used during the data mining process, and a control group for the predictive model's validation. Similarly, due to previous experience, the attributes selected for this study were the ones that remained of interest and behaved the best (as a group) throughout the data mining process. Said attributes are presented in Table I:

TABLE I. SELECTED ATTRIBUTES FOR DATA MINING

Student Demographics -predictive variables-	Student's ICFES test scores -predictive variables-	Classes/Output Variables -predicted variables-
<ul style="list-style-type: none"> • age • gender • distance to university • city of origin • social stratum[0-6] • marital status • day/night classes • job status • registers a mother [true/false] • mother's education level • registers a father [true/false] • father's education level • number of siblings 	<ul style="list-style-type: none"> • biology • philosophy • physics • geography • history • english • language (spanish) • mathematics • Chemistry • average ICFES score 	<ul style="list-style-type: none"> • basic area average • complimentary area average • professional area average • first year weighted average

Academic performance was characterized within three possible values: risk, average and outstanding (or above-average). In accordance with institutional policies at Universidad El Bosque, a student presents academic risk when its weighted average is below 3.3/5.0, so anything below this value defined the values for risk. The average weighted average for the Systems Engineering program was found to be around 4.0/5.0, therefore average performance was defined between 3.3/5.0 and 4.0/5.0. Thus, any scores with a higher value than 4.0/5.0 are defined as outstanding academic performance.

Additionally, academic performance was measured over four different aspects of the students' first-year academic grades: overall weighted average, basic area weighted average,

professional area weighted average and complimentary area weighted average. The later three aspects describe three different learning paths regarding the students' study plan. The basic area covers subjects like calculus, logic and algebra; the professional area covers programming courses and General Systems Theories; lastly the complimentary area covers subjects like academic writing and elective courses.

Having laid out the structure for the data to be used in this study, the data –which was loaded into a relational database engine- was normalized and standardized. Then the previously defined data subsets were extracted from the database in structured comma-separated-value (CSV) text files, which then were transformed into an Attribute-Relation File (ARFF) –the default file format used by the data mining suite *WEKA*- [26].

Once the data was loaded into *WEKA*'s *explorer* view it was preprocessed. First, instances without an output variable were removed quickly by hand. Then, instances that didn't contribute positively to the model were removed using the *removeMisclassified* unsupervised instance filter, using a non-parametrized J48 algorithm. Finally each algorithm was executed over each dataset several times –tweaking their parameters on each execution- until better results could not be obtained. Also, all algorithms were executed using tenfold cross-validation, as it is the standard for model metrics and validation [26]. These steps were performed on each data subset; each one of having a different output variable to be modeled for prediction corresponding to the four defined aspects for academic performance measurement.

Through cross-validation, *WEKA* is able to present metrics for the generated model's precision and accuracy, allowing the comparison between the results of different algorithm executions over the same dataset. In tenfold cross-validation "the data is divided randomly into 10 parts in which the class is represented in approximately the same proportions as in the full dataset. Each part is held out in turn and the learning scheme trained on the remaining nine-tenths; then its error rate is calculated on the holdout set. Thus, the learning procedure is executed a total of 10 times on different training sets (each set has a lot in common with the others). Finally, the 10 error estimates are averaged to yield an overall error estimate"[26].

The data mining process' results are presented in Table II:

B. Predictive Model Formulation

1) Relationship Analysis Between the Attributes Within Classification Rules

a) First-year Overall Weighted Average Prediction

Because of the result metrics obtained by both algorithms for this aspect, only the rules extracted by the J48 decision tree were taken into account. Regarding this classification rules, it was found that 53% of the correctly classified instances were predicted by combinations of the following conditioned attributes: *social stratum* = 3 and *marital status* = single. Such findings correspond to the characterization of the studied population. Within this classifier's subset, the variable *student_gender* appears in the next level of the decision tree, in which men account for 35% and women for 18% of these

correctly classified instances. Of the above men, 54% were attributed to have a *risk* level for their academic performance, and the rest were classified as *average*. Regarding the women, 15% of them were classified as *risk*, 69% as *average* and 15% as *outstanding*. In the next level of the decision tree, attributes such as *student_age* and some various *ICFES*

(standardized test similar to the SAT in the United States) test scores show up. Nonetheless they are not representative in terms of classification rate and don't seem to hold any important correlation with academic performance.

TABLE II. DATA MINING PROCESS SUMMARY TABLE

<i>Algorithm</i>	<i>Output Variable</i>	<i>Correctly Classified Instances</i>	<i>Kappa Statistics</i>	<i>Mean Absolute Error</i>	<i>Root Mean Squared Error</i>	<i>Precision for RISK prediction</i>
J48	Basic	73.63%	0.427	0.18	0.3767	0.829
	Complimentary	73.75%	0.5553	0.1968	0.3788	0.548
	Professional	85.36%	0.7795	0.124	0.2801	0.855
	Overall Average	82.41%	0.6963	0.1264	0.3062	0.851
PART	Basic	72.13%	0.3847	0.2274	0.3698	0.816
	Complimentary	64.70%	0.403	0.2573	0.3997	0.355
	Professional	68.29%	0.5217	0.2711	0.3969	0.694
	Overall Average	66.33%	0.4215	0.264	0.4061	0.683

In the other relevant portion of correctly classified instances, 24% of the students have a social stratum of 4 and are also single. For this subset, academic attributes like *ICFES* physics scores appear in the next level of the decision tree. This classifies students as having *risk* and *average* performance if the score is below or equal to 50; above this value classifies a student within *outstanding* academic performance. Contrasting these values with the admission requisites demanded by the Systems Engineering department for physics scores on the *ICFES* test, a minimum of 45 points is required.

According to these findings, in order to predict the students' first-year overall weighted average, demographic characteristics such as their social stratum, marital status and gender should be taken into account. Regarding academic attributes, *ICFES* physics score seem to be a determining factor for a student's weighted average. It should be noted, that the precision rates for *risk* and *average* performance prediction were over 80%, contrary to the rates for *outstanding* performance, which did not exceed 70%.

b) First-year Basic Area Average Prediction

Classification rules obtained for the prediction of this aspect with the J48 algorithm exhibit several notable characteristics. To predict academic performance in the basic area, one attribute appears as a great classifier splitting the subset in two: *day/night classes*. Rules for daytime students cover 49% of the instances, and rules for nighttime students cover 51%. It is then found that 24% of the male daytime students are attributed *risk* if their *ICFES* Biology score - which appears in the next level of the Tree- is below 40 points. This draws significant attention, for this *ICFES* score is not taken into account during a student's admission process to the academic program. The present variables in women's classification for this aspect exhibit very low relevance.

Only 15% of daytime students with an *ICFES* Biology scores greater than 50 points are classified as *risk*; these rules also include -non-significantly- other variables such as *ICFES* chemistry, philosophy and average score. 27% are classified within *average* performance, taking into account these same variables and their place of residence. The missing 16% of the daytime students are attributed *outstanding* performance in this area. Based on the precision achieved for each of the performance levels, the only dependable one is the one for *risk*, which exceeds 80%. The other levels exhibit a low precision.

Regarding the nighttime students, attention is drawn to the fact that -without the participation of any additional attributes- 42% of the students are immediately classified as *risk* for this area. This classification varies only in a 5% when age and place of residence are taken into account. Also, 5% of the nighttime students are classified as *average* in this area, and only a 2% are classified as *outstanding*. Even though -in comparison with the institutional context- there is no apparent reason for the high rate of *risk* classification, relevance should be given to this due to its precision rate of 82%.

c) First-year Complimentary Area Average Prediction

Precision rates for the PART algorithm were low, and error rates were high. In accordance with the rule set obtained by the J48 algorithm for this area, those students who register a father and mother in the system are attributed *risk*; 25% of the students with a social stratum of 3, mostly men (and a few with a social stratum of 4) are also classified as *risk* if their *ICFES* chemistry score is below 45. Bearing in mind that these are the variables that commonly describe the program's student population, these classification rules are non-important, especially when they exhibit a precision rate of 54% for this performance level. The PART algorithm also shows that the level *risk* is unpredictable for this area.

Instances predominantly classified as *average* are mostly selected by social stratum. 21% of them are those students with a social stratum of 2 and that currently don't have a job;

26% of them are males that have a social stratum of 3, and scored above 45 points in physics on their ICFES test.

TABLE III. CORRELATION FACTORS

Area	Predicted Academic Performance Level		
	Risk	Average	Outstanding
Overall Weighted Average	marital status (single) social stratum (2,3) gender(male) ICFES physics(<50)	marital status (single) social stratum (3,4) gender(male) age female (<=24) ICFES physics(<50)	marital status (single) social stratum (3,4,5,6) gender(female) age female (>24)
Basic Area Weighted Average	day/night classes(nighttime) ICFES biology(<=50)	Unpredictable (52% precision)	Unpredictable (50% precision)
Complimentary Area Weighted Average	Unpredictable(54% precision)	social stratum (2,3) gender(male) ICFES physics(>45)	doesn't register (father, mother) social stratum(3,4,5,6)
Professional Area Weighted Average	siblings(>1) job status(no)	siblings (0) job status (no) ICFES biology (<55)	Siblings (1) father's education level (university) job status(no)

Classification rules for the rest of the instances in this area are not representative and are related to attributes like gender, parents' education levels, ICFES English and physics scores. Noting the quantity of correctly classified instances, correlation for these variables rises in relation with *average* performance, but it's not significant (66%).

The fact that *outstanding* performance is attributed to instances that don't register a mother or father in the system, which represent 30% of the correctly classified instances for this particular model. Regarding those who do register said information, a higher correlation with the social stratum is achieved; here 7% of the instances have a stratum value of 2, 17% a value of 3, 12% a value of 4 and 12% account for the sum of stratum 5 and 6. From the above, it is logical that the precision rate for *outstanding* academic performance in this area is 83%, which makes of the variable *social stratum* a more reliable attribute for prediction.

In summary, for this particular area the *risk* level seems unpredictable and *average* is predictable with a 66% precision -through social stratum as a higher classifier attribute-. For the *outstanding* performance level, the fact that a student doesn't register parents in the system seems as a very influencing variable when accompanied by the social stratum.

d) First-year Professional Area Average Prediction

For this area, rules obtained by the J48 algorithm are accounted for. In these, an important correlation emerges

between the fact that a student has siblings and if he or she is currently unemployed. When a student has no siblings (6% of the total classified instances), his/her academic performance for this area is predicted as *average*. If the student has only one sibling it is immediately classified as *outstanding* if his/her father's educational level is *university studies*. However, if the student has more than one sibling, his/her performance classification will depend on this job status. The fact that a student does not have a job presents a higher correlation in the classification, for it directly classifies 34% of the students as *risk*, 19% as *average* and 19% as *outstanding*. 28% of the students that were classified without the use of this attribute (job status), present other determining factors such as gender and father's education level as important. It is worth noting that, within classification rules that mind if a student is unemployed, the attribute that then plays a relevant part is ICFES biology score for the *average* performance level.

2) Rules Selection and Definition

For each weighted average, factors that showed the highest correlation in prediction for the different academic performance levels are shown in Table III. Each factor's values that had the greater influence over each of the levels are shown in parentheses.

IV. RESULTS ANALYSIS

According to the results obtained in this study, the ruleset allows identifying -with an adequate confidence

level- the sociodemographic variables that influence academic performance prediction the most; these are marital status, social stratum, whether the student takes day or night classes, gender and number of siblings. The academic variables with the higher influence are ICFES scores for biology and physics.

In relation with academic risk prediction for the overall weighted average, this one impacts more over students with a low or medium social stratum, which corresponds with the historical students' academic performance information for the academic program –bearing in mind that most of the program's population belongs in these social strata-. It is valid that the students' ICFES biology score allows for academic risk prediction for the Basic Area subjects. What actually draws more attention is the fact that whether a student takes classes at night or during the day is the most influencing factor for this aspect.

When the social stratum ranges from medium to high, average academic performance is favored. The fact that ICFES physics and biology scores are also determinant attributes for this performance level must be carefully noted. Even though the siblings variable has a high correlation, it doesn't seem to hold any meaning within an institutional context.

Regarding outstanding performance levels, the same socio-demographical variables mentioned earlier reappear, but in this level for social strata in the range medium to high. No academic variables emerge in this level, which may suggest that there is no academic determinant in a student's career choice and its performance in it. Concerning prediction for this level, attention is drawn to the fact that situations such as having just one sibling and having a father with a university degree might be a influencing factor over academic performance.

By drawing a comparison between the variables that explain educational desertion as a phenomenon in Colombia's higher education system [2], and the variables found to influence academic performance –as an influencing factor for desertion-, academic risk is linked to a (subject) repeating rate; rate which implies the existence for an academic risk as it reflects an underachievement in a student's overall subject weighted average. ICFES scores also appear as an influencing factor in desertion, which for this case –and the Systems Engineering program- it's useful to pay particular attention to physics and biology scores. Both number of siblings and gender coincide as influencing factor for both phenomena (academic desertion and academic risk).

V. CONCLUSIONS

Taking into account previous works, and the results obtained by this study, it is proven that Data Mining is a useful tool when applied in educational contexts. It aids in comprehending phenomena that exhibit a variable behavior depending on the particularities of each educational scenario. Specifically, first-year academic performance prediction reduces the possibility for academic desertion. It also improves the quality of students' formative processes,

enabling the orientation of preventive accompaniment strategies for individuals with a real possibility of suffering academic risk.

The classification rules found in this study are useful contextually speaking and regarding this work's objective; however they must be improved for they encompass a very small set of instances, seemingly due to the absence of data in the instances discarded in the preprocessing stages.

As for future, work in the near future, verification experiments must be performed using the obtained rule sets. They should be applied over similar and larger datasets in order to evaluate their applicability to other formative processes and academic programs that gather similar information from their students. In the medium term, an application that allows to reutilize the model within the institution is expected to be developed; thus transforming it into an everyday tool that supports and aids in the University's Coordination for Academic Success.

Predicting the students' academic performance implies a conceptual change within the Colombian and Latinamerican educational systems, due to that their thought structure and actuation is mostly coercive; guided by post-facto strategies that pretend –in the best of cases- to correct any problem that might turn up within the system, instead of preventing them and thus diminishing costs.

The results here presented imply that the Institution, and particularly the Coordination for Academic Success, must start thinking about risk prevention strategies based upon students' socioeconomical classification for the Program's new students. Taking into account that the Basic Area of the study plan is one of the areas that represents the largest amount of effort and difficulty for Systems Engineering students, the ICFES biology score should be added as a relevant metric in the admission process; specially for students that attend nighttime classes.

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Elicited and Mined Rules for Dropout Prevention in Online Courses

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Abstract—This article presents an ongoing investigation that uses mining tools to analyze a large volume of data from students of online courses in a LMS platform to discover Association Rules used to identifying dropout situations. These ARs are used along with several explicit (formalized) rules elicited from course operators and are intended to be used by a software agent to detect individuals within a certain risk region, triggering a communication process to a student support team.

Keywords—learning analytics; distance education; knowledge representation; mining

I. INTRODUCTION

Dropout is a complex issue and even more critical on distance education. Prevention to it have included several resources, many based on ad-hoc or other tacit choices, and have progressed towards a formalization of the knowledge elicited from teachers, course authors, tutors and other operators involved with management of those courses. The widely spread use of Learning Management Systems and other technological learning platforms have amplified ability to record course activities to a point where unassisted inspection/analysis became impractical. In such context, the process of data mining has been used, with success, to find patterns and Association Rules (AR) in large educational datasets.

This article presents an ongoing investigation that uses mining tools to analyze a large volume of data from students of online courses in a LMS platform to discover Association Rules used to identifying dropout situations. These AR could be used by a software agent to detect individuals within a certain risk region, triggering a communication process to a student support team. For example, a software agent with the ARs found in this study would classify a student as a dropout before he actually becomes one (maybe in the middle of the course). With this information a teacher or tutor could take action and help the student before it is too late.

A real world dataset was obtained from a Brazilian Federal university. The platform used was Moodle-based and so it had logs of all actions within that environment – sending internal messages, reading forum topics, doing assignments and about 200 other that a fresh installation allows it. We were especially interested in actions related to interactions between students, some resulting from assignments plainly specifying collaboration. Some ARs were found mining the dataset and

have been tested with current course instances. Other rules were elicited from course operators and have been formalized as first order logic sentences. Both sets of rules (mined and elicited) are now being tried on courses of different categories with encouraging results and an agent-based service monitoring students will be integrated to the intelligent layer of an innovative web platform.

II. DROPOUT IN ONLINE COURSES

Investigation on student dropout in online courses reported in [1] and [2], describes some models people have used to explain dropout process. Among these, one of the more traditional is SIM (Student Integration Model), created from studies on traditional student behavior and focused on internal reasons leading to dropout. Another model is SAM (Student Attrition Mode) an improvement upon SIM that considers nontraditional students and emphasizes the effect of external variables on decision of persisting or dropping out a course. Another well-known model is CPM (Composite Persistence Model), capable of combining these two models in order to obtain a better balance among external and internal factors especially when dealing with students of online courses.

A revised and improved version of CPM outlining a theoretical framework for dropout on online courses is described in [3]. According to this framework, there are factors affecting the decision of dropping out a course, some of these factors are prior to the course, some are prior to the course and still persist during the course and other are present only after the course start. Factors also can be classified as external or internal to the course. Students' individual characteristics (age, genre, education degree, etc.) also affect dropout, although not at the same scale that internal and external factors. There is no strong empirical evidence that other aspects (learner skills, for example) affect decision on dropping out.

In Brazil, reports on distance education dropout like [4] and [5] have special interest on investigating this phenomenon in Learning Management Systems (LMS), the most used technological platform to that goal.

This work contributes with the discussion about dropouts in online course by approaching the problem in a novel way. The combination of educational data mining tools and expert knowledge about dropouts turns possible to foresee the problem before it happens. Currently, a dropout candidate

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might be identified through a slow process based in analysis of LMS statistics and subjective clues interpreted by a tutor or teacher, but with results from this work it would be possible to create rules to automate the detection of dropouts. This type of automation can imply in better use of materials and human resources required by distance learning education projects.

III. EDUCATIONAL DATA MINING

According to [6], Educational Data Mining (EDM) is a research area that applies tools and techniques from Data Mining (or Knowledge Discovery in Databases – KDD) in the context of education research. EDM aims to discover new information by identification of relations between educational data as a way to discover new knowledge and make scientific progress. As an example, is possible to use EDM to analyze the relationship between a teacher's method and students learning progress so that any new knowledge discovered can be used to make better new methods.

EDM is a multidisciplinary and still recent area involving several Computer Science subareas. There are, nonetheless, several works aiming at improving teaching and learning by mining data stored at online courses. [7], [8], [9] and [10] are examples where some gain was obtained. This shows that EDM can be used with relative success at exploratory research to answer questions in the area of education.

In this work, an EDM tool named Association Rule is used to analyze and generate useful knowledge about dropouts in the context of online courses. An approach that resembles the one presented here is described in [11]. The goal was to predict which students would dropout a regular course by using data mining, although there was no use of more recent techniques like Frequent Itemset to generation of Association Rules (AR).

IV. ASSOCIATION RULES

One of the main data mining techniques used nowadays is the formulation of Association Rules (AR) through the search of patterns in a database. An AR is a rule with the following format

$$A, B, C \rightarrow D$$

This rule can be interpreted like “if (A and B and C) is True then D is also True”. In this study, all variables A , B , C and D represent facts about the same student and the facts are extracted from a database of a online course. For example, a fact could be “Posted 10 messages in the forum One” or “Finished 2 assignments”. So, we can have rules like: If “Made 2 posts” and “Read lesson One” and “Attended chat session One” are True then “Finished Assignment One” is True. It is worth to note that the same rule can emerge more than one time, because it can be extracted again with respect to some other student.

To an AR be considered a “good” rule it should have attended two requirements. The first requirement is to have occurrence (number of times a rule shows up in dataset) greater than or equal to a predefined number S . S is called of rule support and can be expressed as a percentage. The second requirement is that occurrence of a complete rule on the

database should be high enough when compared to the frequency that the first part of the rule occurs in the same database – this characteristic is the rule confidence.

An example of AR in educational context is reported in [13], where they are used to associate students to companies with internship or full job opportunities linked to practical works developed at university.

As described in [12], ARs can be used in classification problems, and to detect dropout risk can be seen as a classification problem where students of a specific course are classified as either “dropouts” or “non-dropouts” and therefore we can use ARs to predict situations about a certain student.

V. METHODOLOGY

Mining and analysis of ARs expressing student dropout involved the following activities:

1. Analysis and selection of data repositories used in experiments
2. Selection of variable to be used to ARs generation. This task was not limited to choices given by the virtual environment but also included expert-described variables
3. Preprocessing on the database for data “cleaning” and normalization
4. Database transformation for a reduced format able to be used as input to data mining algorithm
5. AR extraction through data mining algorithm
6. Test and validation of AR with databases not used during generation phase
7. Results interpretation and evaluation

These activities are detailed throughout the next sections of this work.

VI. DATA SELECTION

For this work we have used databases from courses available at ColabWeb¹, a Moodle²-based LMS implemented at the Institute of Computing of a Brazilian federal university. ColabWeb is used to support courses carried out by that institute. It is left teachers and course organizers to balance between in-classroom and distance activities and so there are student profiles from both in-classroom and distance activities.

Firstly, all finished courses with more than 10 properly enrolled students were selected. That filter was necessary because we planned to use statistics of student interaction in data treatment and fewer students would imply less variation and more deficient data.

The next step was a search in the university records. The goal was to check grades and attendance of students at every selected course and to confirm dropouts. Initially we considered a dropout as a student who abandons a course. It

1 <http://colabweb.ufam.edu.br>
 2 <http://www.moodle.org>

was necessary to redefine this concept because to succeed at a course, a student must comply with two requirements: to attend more than 75% of classes and to have a minimum grade of 5 in a 0-10 scale. For this reason sometimes a dropout might be missed and wrongly marked as a low grade student. So, on the scenario of this work, a dropout is a student that failed to attend 75% of classes or got a final grade smaller than 3. This grade value was defined to accommodate situations with students that drop out towards the end of the course, due to a higher demand from tests and practical exercises. The effect of students giving up a course that way is not on attendance (most would reach the minimum level) but at the final grade. Grades bigger than this threshold value but smaller than the minimum allowed grade would only indicate a poor performance throughout the course.

Thus, 87 courses were initially selected, and further “filtering” stages were necessary to tackle problems like multiple accounts for a same user or users that rarely had accessed that environment (none or too few access to the environment suggests a user that has not effectively started the course) and so students with less than 10 operations recorded on the environment were not considered. After that, only courses with 10 or more students left (for reasons similar to the ones at the first filter) were considered to take part on the experiment. At the end, 27 courses were maintained with a total of 1421 students and 252 among them were dropouts (17,73%). From these courses, the more recent three were put apart and used to test ARs found and the remaining 24 were used in mining process.

VII. VARIABLE SELECTION

All variables used in our experiments were extracted from events recorded on the environment. However, for variable specification, two methods were adopted and their results combined.

The first method consisted of associating variables in the course log with events recorded and so variable names were changed to mirror event names and their values for each student was defined as the number of entries (records) of that specific student during the period of the course considered. An event was any action carried out by a student within the environment (for example: sending a message, uploading an answer to an exercise, consulting an assignment) and so the first variables obtained were total of messages sent, total of answers uploaded, total of logins in the environment, etc.

It is worth to mention that what was done was just a counting of the number of times an event appeared in the table log of Moodle. In some events it would be possible to extract more information, but even in those cases we still get only the total counting. For example, when we counted the number of times a student hands in an assignment it was possible to know if he was handing in a new assignment or a new version of a previous handed assignment, but in this phase we just got the total number of times he handed any assignment without care whether the assignment handed was one he already handed in

or not. The Moodle version used during experiments could record 183 events, generating 183 variables to each student.

For the second method it was reviewed information about a student that could be extracted from data in Moodle log. That large amount of data brought no useful insights and we decided to adopt expert opinion (from teachers, course authors, education managers, etc.) on which variables would affect (either in a positive or a negative way) student tendency to drop out. This elicitation process was done in two stages, as follows.

The first stage involved a literature review on educational data mining to survey which variables would be indicated on those reports. Although variable equivalence was not too easy to establish, we managed to find new variables to add to our experiment. The works described in [9] and [14] were the main source of indicators matching those variables available at ColabWeb, as shown on Table I.

TABLE I. VARIABLES ELICITED FROM [9] AND [14]

Variable	Description
<i>n_access</i>	Total of access
<i>n_post_forum</i>	Total of forum postings
<i>n_post_ans_forum</i>	Total of forums postings commenting/answering other students postings
<i>n_post_rev_forum</i>	Total of revisions/modifications upon previous forums postings
<i>avg_freq_access</i>	Frequency of students access to LMS
<i>n_days_first_access</i>	Amount of days between course start and the first access
<i>n_post_ask_stu</i>	Amount of posts replied/commented by other students
<i>n_post_ans_stu</i>	Amount of replied/comments done upon other students posts
<i>n_msg_ask</i>	Amount of messages received from other participants during the course
<i>n_msg_ans</i>	Amount of messages sent to other participants during the course
<i>n_msg_ask_teacher</i>	Amount of messages sent to the teacher/tutor during the course
<i>n_msg_ans_teacher</i>	Amount of messages received from the teacher/tutor during the course
<i>n_assign</i>	Number of assignments handed in

The second stage involved a review on factors reported as influencing dropout. Works reported on [4], [1] and [2] were the main source of discussion of this topic. To each one of factors pointed out as a main factor influencing dropout decision, a relevant new variable was defined, using data collected from the environment logs. Thus, the variables and factors shown on Table II, were added to our initial set.

TABLE II. VARIABLES DEFINED TO MATCH FACTORS FROM [4][1][2]

Variable	Factor	Collected Data
<i>avg_days_bef_due</i>	Difficulty with deadlines	Average of difference between deadline and actual exercise upload
<i>msg_ask_ans_teacher</i>	Difficulty with obtaining feedback	Difference between amount of messages sent to teacher/tutor and amount of answers received
<i>total_global_msg</i>	Interpersonal Relationships	Total of sent and received messages to/from other users in the environment

A total of 199 variables were used in our experiments.

VIII. DATA TREATMENT

The data was organized in a table format where each row represented a student and columns represented variables from this study. There were separated areas for each course. For clarification, an example is show in Table III.

TABLE III. VARIABLE ORGANIZATION

Course 1				
	Var1	Var2	Var3	...
Student 1	1	23	5	
Student 2	2	15	5	
Student 3	3	4	5	
Student 4	4	43	5	
...				
Course 2				
	Var1	Var2	Var3	...
Student 1	45	10	3	
Student 2	89	10	3	
Student 3	27	30	3	
Student 4	65	30	3	
...				
...				

For a more efficient mining of ARs in databases, it is useful to have variable values categorized in small sets. Assuming that we wanted to find differences between dropouts and non-dropouts, our categorization was based on a basic quartile separation. To each quarter a concept was associated, suggesting an adherence level to dropout influence.

TABLE IV. VALUES CATEGORIZATION

Quarter	Concept
1	LOW
2	MEDIUM
3	MEDIUM
4	HIGH

This categorization considers only value distribution within a course, not the distribution throughout all courses and so

after categorization, variables have only three possible values: LOW, MEDIUM or HIGH.

Applying this categorization to the example table the result is show in Table V.

TABLE V. VARIABLE ORGANIZATION (AFTER CATEGORIZATION)

Course 1				
	Var1	Var2	Var3	...
Student 1	LOW	MEDIUM	HIGH	
Student 2	MEDIUM	MEDIUM	HIGH	
Student 3	MEDIUM	LOW	HIGH	
Student 4	HIGH	HIGH	HIGH	
...				
Course 2				
	Var1	Var2	Var3	...
Student 1	MEDIUM	MEDIUM	HIGH	
Student 2	HIGH	MEDIUM	HIGH	
Student 3	LOW	HIGH	HIGH	
Student 4	MEDIUM	HIGH	HIGH	
...				
...				

After apply categorization on all selected courses, results were grouped in one single file and submitted to a last filter in order to optimize AR generation. That filter identifies variables with the same value for all students in the experiment and, since they have no variation on the entire universe considered, they were discarded. In the example table the variable Var3 should be removed from the experiment.

After all these processes, only 37 variables were used in our experiment.

IX. EXPERIMENT

When AR mining is in a planning phase, it is possible to make a choice in the process to find any type of rule or a specific type of rule called Class Association Rule (CAR). CAR are rules where the last part of the rule is compose of only one variable (the rule example showed in session IV is a case of a CAR). In this study the variable is the condition of be or not to be a dropout. Been more specific, the interest of this work is only when the variable is a dropout. Since dropouts are 17,73% of population in this study it is not possible to find a AR, useful in this work, with a support higher than this number. Because of this, AR mining was not done using standard data mining algorithms.

Normally, AR mining aims at high support and high confidence but in our case, it would not be possible to find AR with support higher than 17,73%. and smaller support rates also would imply significant increasing of processing times.

To resume, in our case we are interested in rules with low support (reduced occurrences in the database) but with high confidence, leading to the same results. This kind of rules are known by academic community like 'sporadic rules' and can be found with algorithms like Apriori-Inverse, described in

[15].

In this experiment we have used SPMF³, a open-source tool with several mining algorithms including Apriori-Inverse. SPMF's APriori was used with minimum support of 1% and maximum support of 18% and 205 AR were found with dropout condition. From these, the 10 rules with greatest confidence levels were selected for use. These rules are show on Table VI.

TABLE VI. HIGHEST CONFIDENCE RULES

N	Rule	Conf.
1	n_post_forum =MEDIUM AND <i>avg_days_bef_due</i> =LOW	0,8857
2	n_post_forum =MEDIUM AND <i>avg_days_bef_due</i> =LOW AND <i>assign_view</i> =LOW AND <i>assign_upload</i> =LOW AND n_msg_ans_teacher =LOW	0,8235
3	n_post_forum =MEDIUM AND <i>avg_days_bef_due</i> =LOW AND <i>assign_view</i> =LOW AND <i>assign_upload</i> =LOW	0,8148
4	<i>avg_days_bef_due</i> =LOW AND <i>assign_view</i> =LOW AND <i>assign_upload</i> =LOW AND <i>forum_add_post</i> =MEDIUM	0,8095
5	<i>assign_view</i> =LOW AND <i>assign_upload</i> =LOW AND n_msg_ans_teacher =LOW AND <i>forum_add_post</i> =MEDIUM	0,8095
6	n_post_forum =MEDIUM AND <i>avg_days_bef_due</i> =LOW AND <i>assign_view</i> =LOW AND <i>assign_upload</i> =LOW AND <i>forum_add_post</i> =MEDIUM	0,8095
7	n_post_forum =MEDIUM AND <i>assign_view</i> =LOW AND <i>assign_upload</i> =LOW AND n_msg_ans_teacher =LOW AND <i>forum_add_post</i> =MEDIUM	0,8095
8	n_post_forum =MEDIUM AND <i>assign_view</i> =LOW AND <i>assign_upload</i> =LOW AND n_msg_ans_teacher =LOW	0,7917
9	n_post_forum =MEDIUM AND <i>avg_days_bef_due</i> =LOW AND <i>assign_upload</i> =LOW AND n_msg_ans_teacher =LOW	0,7778
10	n_post_forum =MEDIUM AND <i>avg_days_bef_due</i> =LOW AND <i>assign_upload</i> =LOW	0,7742

On Table VI, variables elicited from [9] and [14] are printed in bold and variables mapping factors from [4], [1] and [2] are printed in italic.

Next, these rules were applied to three courses used for test. Each rule was tested alone to check its accuracy and the same

was done with a combination of the 10 highest and again with a combination of all 205 AR found.

Rule combination was done using OR operator between the rules, so to be considered a dropout, a student must be identified as such for any of the combined rules. For example the combination of Rule 1 and Rule 10 is show bellow:

$$(\mathbf{n_post_forum=MEDIUM} \text{ AND } \mathbf{avg_days_bef_due=LOW}) \text{ OR } (\mathbf{n_post_forum=MEDIUM})$$

The first group had a total of 23 students with 1 dropout. Table VII shows the results.

TABLE VII. ACCURACY OF RULES ON TEST COURSE 1

Rule	Real Positive	False Positive	Real Negative	False Negative	Accuracy
1	1	2	20	0	0,9130
2,4,5,6,7,8,9	0	0	22	1	0,9565
3,10	1	1	21	0	0,9565
10 highest	1	2	20	0	0,9130
All 205	1	18	4	0	0,2173

The second group had a total of 15 students with 1 dropout. Table VIII shows the results.

TABLE VIII. ACCURACY OF RULES ON TEST COURSE 2

Rule	Real Positive	False Positive	Real Negative	False Negative	Accuracy
1,2,3,4,5,6,7,8,9,10	0	0	14	1	0,9333
10 highest	0	0	14	1	0,9333
All 205	1	2	12	0	0,8666

The third group had a total of 26 students with 5 dropouts. Table IX shows the results.

TABLE IX. ACCURACY OF RULES ON TEST COURSE 3

Rule	Real Positive	False Positive	Real Negative	False Negative	Accuracy
1,2,3,4,5,6,7,8,9,10	0	0	21	5	0,8076
10 highest	0	0	21	5	0,8076
All 205	0	6	15	5	0,5769

X. RESULTS ANALYSIS

Our initial approach to use elicited rules was to apply them after AR mining. However, analysis of possible scenarios

3 <http://www.philippe-fournier-viger.com/spmf/>

suggested that elicited rules produce better results when embedded in the mining process as variables to be considered. To illustrate this, let us consider a simple elicited rule:

$$A \rightarrow D$$

We can interpret this rule as: if A happens it means that student will be a dropout (D). This is an association rule and if it is a good rule it will have a high confidence level, meaning that quite often when A happens, D also happens and AR mining would corroborate this with high confidence. If, on the other hand, this rule would not be found to be so good, a low confidence would be associated and so no harm was done and there appears to be no advantage to include this on the discovery stage as another variable.

However, to include elicited knowledge as a variable to be used at the discovery stage will increase probability of finding new rules associated to that elicited knowledge, for example:

$$A \wedge B \rightarrow D$$

A is the elicited knowledge and B some other condition present at discovery stage. This new rule could be better than A alone, because the confidence level could be higher. To explain this we can imagine the case where A happens in all dataset (i.e. have low confidence) and B happens more when D happens. In this case, the confidence level of the new rule is higher than the rule with only A . To not include A in the discovery stage is equal to discard the possibility of a combination of A and any other variable (including other elicited knowledge) be better than A alone.

Another aspect observed in this work was the high accuracy of the AR in most cases. Once these AR have been submitted to more tests, they can be transposed to some knowledge base and used by recommendation systems that would inspect records of students indicated as potential dropouts and act accordingly.

Several of the elicited variables were present among the 10 best rated AR. It is worth to emphasize that variable '*avg_days_bef_due*', obtained by mapping the factor "difficulty with deadlines", has appeared in 7 of the 10 best rated AR. This seems to confirm that factor as important indicator of dropout tendency and suggests that LMS would benefit of specific resources for this sort of monitoring.

Lastly, there is the question of using RA combination and the impact in the number of false negatives and false positives. The best case should be to eliminate both, but in our case that is not possible because AR generation do not assure a 100% match in the classification. So to deal with this problem we used the rationalization showed in [11] that shows for the problem of dropouts in courses a false negative is worse than a false positive. For example, when we mark a student not been a dropout when in reality he is (a false negative) the teacher or tutor will think that student is not in a risk situation and he will focus in others students marked as dropouts, so this student will probably turn in a dropout case. On the other hand if we

mark a student as a dropout when in reality he is not (a false positive) the teacher will focus in this student and in other students marked as dropouts, in this case the only problem is that the work of the teacher or tutor will increase. In this work we noticed that a search for a good tradeoff between the false positives and false negatives should be made through the number of RAs combined.

XI. CONCLUDING REMARKS

Reducing dropouts in online courses mediated through LMS is a relevant goal that would imply better use of resources specially where, like the case with Brazilian federal universities, classes are limited to a certain number of students.

In this scenario, this work shows how tools like APriori-Inverse algorithm can be used to support early detection of potential dropouts, allowing teachers/tutors to intervening.

Further research with more data is necessary to corroborate findings from this work and to establish what could be a good tradeoff to the problem of false negatives and false positives.

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xAPI-SRL: Uses of an Application Profile for Self-Regulated Learning Based on the Analysis of Learning Strategies

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Abstract—Self-Regulated Learning (SRL) is being promoted and adopted increasingly because of the needs of current education, based on competences and student centered. At the same time, the use of technology for learning is now usual and also increasing. Nevertheless, current learning software offers poor support for SRL. Learners use different tools to organize their learning, to visualize content, to submit assignments, to answer questionnaires, etc. These functionalities are useful, but they are not relevant from the SRL approach. Particularly, monitoring students' development of SRL strategies and students' self-monitoring are not well supported in existing systems. This paper introduces a proposal to improve monitoring support in e-learning systems. The proposal is based on Tin Can API or xAPI, a recent standard to record data about users' activity in learning systems.

Keywords—Self-Regulated Learning; Learning Strategy; Monitoring; Application Profile; Learning Analytics.

I. INTRODUCTION

The development of competencies is crucial in current education, especially in higher education, where the students are required a high degree of autonomy compared to earlier stages. In this student-centered context, Self-Regulated Learning (SRL) is an appropriate approach to achieve these goals and actually it is becoming popular. SRL contributes to the development of learning skills vital to become an efficient and effective learner [1]. A key point is the development of metacognitive self-regulation processes. The final goal is that learners become more accountable for their own learning.

Another trend in the current educational scenario is the increased use of learning software. It has increased a lot over the past few years and it is still increasing. The proof is that both blended learning and distance learning are very popular and they are being adopted for formal and informal learning situations. There are many learning software tools that support different learning approaches: blended, flipped, cooperative, collaborative, etc. But, what about SRL? We have found that this type of approach is not supported by most learning software. Actually, it is supported partially by just a few learning tools [2][3].

Learning software should adapt to the new teaching and learning approaches, but for some reason, this process is slow and it never catches up with current tendencies. In many cases, software developers do not know the needs of the teaching and learning communities, and even if they do, it is hard to translate the vision of teachers and pedagogues into suitable learning tools, especially from the learners' point of view.

Existing SRL-oriented learning tools seem to be developed attending to the SRL theory, resulting in a general, shallow support. This may be due to two main reasons: (1) the lack of agreement among SRL authors, which makes the SRL concept rather diffuse; and (2) SRL theory is not specific or detailed in terms of methods and actions, which is something critical to design any software functionality.

One of the most remarkable initiatives related to the technological support of SRL was the TELEpeers project [3][4]. This project was aimed at the evaluation of the "potential of Technology Enhanced Learning Environments (TELEs) to support self-regulated learning". It considers a very general view, not distinguishing specific areas or functionalities. After reviewing it we realized that a different approach was needed, more practical and realistic. Focusing on what is taught in SRL promotion courses [5][3] and on what learners actually use to learn in SRL contexts, we selected self-regulation and learning strategies as the foundations of our research.

Therefore, our general goal is to improve the possibilities of software to support the implementation of SRL strategies. The idea is to facilitate the development of proper SRL functionalities or specific tools that support the implementation of the strategies. We understand this as "reducing or eliminating the limitations when implementing learning strategies through a piece of software" [6]. In previous works we defined the software design criteria to offer this support [7] and created a questionnaire for the evaluation of SRL support in software [2]. Both are based on the analysis of SRL strategies.

In this paper we focus on a big limitation that we found when analyzing the SRL support in existing tools: monitoring. There are two main goals. The first one is to measure how

well students are self-regulating by monitoring their activity in software tools and analyzing tracking data. A main issue is that there is a lot of relevant information missing, because there are many basic SRL strategies that are not considered by typical learning software. Besides, monitoring data and functionality is usually intended to help teachers to monitor the performance of their students, but not to support learners' self-regulation. This is the second goal: supporting learners' self-monitoring by providing them with monitoring functionalities. Learners "use information of their own activity to see how they are doing, to modify their plan if necessary, etc." [6], i.e., to self-monitor and self-evaluate their learning. A software tool could ease that process by capturing and showing this information in an adequate manner, but it needs to get all the information first. A self-regulated learner may use different tools for planning, executing, self-monitoring and self-evaluating his/her learning. We need a common way to record all the events derived from the implementation of the strategies in different tools if we want to work with this data to extract information using adequate techniques (learning analytics, process mining, etc.). In [6] we presented our proposal for an extension of xAPI [8], a standard for activity recording, in order to "improve its capabilities for recording SRL-related actions". This extension is an application profile for SRL, and was called xAPI-SRL.

In this paper we present how using xAPI-SRL to record data from different sources can allow us to extract valuable information to facilitate self-monitoring and self-evaluation, and also enable SRL assessment for educators, using some of the ideas introduced in [9]. First, we introduce SRL theory in section II, focusing on monitoring in section IV. In section III we discuss about SRL oriented software. Section V is dedicated to related work. In section VI we briefly explain xAPI to introduce the xAPI-SRL application profile that is presented in section VII. Section VIII is dedicated to conclusions and future work.

II. SELF-REGULATED LEARNING

There are several definitions of SRL, depending of each author's perspective, but all of them share a similar vision. The most referenced models are the ones from Zimmerman and Pintrich. Zimmerman defines self-regulation as "self-generated thoughts, feelings and behaviors that are oriented to attaining goals" [10]. In the words of Pintrich, SRL is "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment" [11]. As we synthesized in [7], "the self-regulation process is based upon the students' consciousness about their possibilities and limitations, their task centered goals and their use of appropriate strategies. Students can improve their performance and academic success using strategies to control and regulate aspects of their cognition, motivation and behavior, to select and build learning environments and to set goals and monitor their compliance".

A. Self-Regulated Learning Model

We use a unifying model based on Zimmerman's and Pintrich's models, built following the conclusions of Solano

[12]. We consider three SRL phases, like in Zimmerman's model:

1. *Forethought, planning and activation.*
2. *Performance, monitoring and control.*
3. *Evaluation, reflection and reaction.*

"This is because the elements of each phase are concurrent within the learning episode" [13]. These phases work like a cycle that the learner performs for each task. Pintrich defined four phases, splitting phase two into monitoring and control, not specifying performance.

Following Pintrich's approach, we defined SRL areas. Pintrich defines four, considering cognition and metacognition as one. According to Solano, metacognition should be considered an area on its own as their processes are very different [12], so we have five: *metacognition, cognition, motivation/affect, behavior*, and (social and environmental) *context*.

B. Self-Regulated Learning Strategies

We can define SRL strategies as "the methods and procedures that the students can use to help them tackle their learning in the most effective and competent manner, to plan, monitor and evaluate the five SRL areas" [7]. There are many other definitions from relevant authors that were compiled by Gu in [14].

We selected and analyzed many strategies from different sources [5][15][16][17] and classified them into two big groups: *self-regulation strategies*, focused on self-regulation of learning; and *cognitive learning strategies*, focused on the acquisition and creation of knowledge [7]:

- *Self-regulation strategies* are metacognitive strategies (goal and task planning, self-monitoring and self-evaluation, prior knowledge activation, time estimation, etc.), behavior strategies (time management, help seeking, self-observation, etc.), motivation strategies (interest activation, reward, causal attributions, etc.) and context strategies (task changes and context conditions monitoring, evaluation of the task, etc.).
- *Cognitive strategies* provide a structure for learning for complex tasks aimed at managing and acquiring knowledge. Some examples are information strategies (selection, acquisition, transformation, etc.), memorization, problem solving, reading comprehension, etc. Many of these strategies are not easily embeddable in software as they involve "internal actions and interaction with external elements".

III. SOFTWARE AND SRL

In [1], Nussbaumer et al. affirm that "studies have shown that the application of SRL increases the effectiveness of education. However, this is quite challenging to be facilitated with learning technologies like LMSs that lack an individualized approach as well as a right balance between the learner's freedom and guidance". Those are interesting concepts, essential for a SRL approach with software. In

addition to that, LMSs in general do not offer support for the implementation of most relevant SRL strategies. These strategies, as we stated before, are what SRL learners use, so they are crucial.

Most tools offer partial support for some of these strategies, without offering full support for any of them or for any SRL phase or area [7]. For instance, LMSs are focused on educational content delivery and knowledge evaluation. Some LMSs have SRL features, allowing learners to reflect about what and how they did, but planning and monitoring are usually forgotten, and it is rare to find these features in learning software. Examples of LMSs with some SRL capabilities are ILIAS [18] and the ROLE Personal LMS, now ROLE sandbox [19], but both of them have their limitations. ILIAS is truly powerful and flexible, and supports partially some of the main SRL strategies with tools for planning, information management, note taking, etc. Full SRL support would require attention to detail in the implementation of the strategies, but ILIAS is a general purpose open LMS, not a specific SRL tool. The ROLE sandbox is based on widgets, and it has many SRL-oriented ones, but one of the main problems is that they are not able to communicate among them, preventing the system from being practical.

Another big problem is due to the confusion that this type of learning approach creates in non-experts when it comes to monitoring. Most tools get activity data, process it and then try to tell the learner what to do. A more appropriate approach for SRL would be to provide information that support learners drawing their own conclusions and reflecting about their learning processes, strategies and results. In this way, we can guide learners through this process at the beginning. The level of guidance is critical and should adapt for every student through time depending on his/her SRL skill level. We can learn from the gaming world in this aspect, which has focused on playability, usability and adaptability for years and has advanced a lot. For instance, it is very common to be able to select the difficulty level, to enable or disable hints depending on their type, to select the amount of hints when enabled, etc. At the same time, this guidance is offered at the beginning and tends to disappear progressively and automatically as the user gets more experienced, and users can reactivate or deactivate anything when they need it.

Another thing to consider is the use of reporting tools. Anyone would probably be able to name some task managers, LMSs, e-portfolio tools, etc., but, how many reporting tools do you know? Reporting tools are well known in the business world. They process raw data, usually coming from other software tools, and show information reports and graphs to the users. It is clear that a standard data format is needed in order to be able to share information and take advantage of these tools.

IV. MONITORING SRL AND SELF-MONITORING

Self-monitoring consists on tracking what you are doing as a learner and how you are doing it, what strategies you are using, whether if you are planning properly or not, whether if you are following your plan or not, etc. Self-monitoring refers specifically to this process performed by the learners themselves, tracking their own activity as part of the SRL

cycle, enabling control, reflection and evaluation, thus reaction.

Teachers can also monitor their students' activity in order to assess and guide them when they need it, and this process, in a SRL context, is known as monitoring. It is time consuming and not effective if learners use traditional tools (because teachers need to interview periodically each student to get the information they need to assess and guide) or even if they use common LMSs and/or e-portfolios (teachers need to read a lot of content from their students to do a qualitative assessment [20]). This process can be improved and optimized for both learners and educators using adequate software, with functionalities oriented to improve the implementation of the strategies and to track learners' actions focusing on the SRL process, especially if we have adequate and complete data from all SRL phases.

The monitoring system of any learning software tool "should provide both students and educators with useful information about the evolution of the learning process" [9]. It is very important to choose an adequate data set in order to be able to extract relevant information from raw activity data. In our case, we need to track the actions derived from the implementation of the SRL strategies, in order to know how learners are using them and help them to improve, and also in order to provide the learners with useful information that may help them with control, reflection and evaluation of their learning activities.

In [9] we presented our vision of a monitoring system that was embedded in a full modular system, and showed how to combine pieces of data to extract useful information. The problem there was that this monitoring system would not work outside that full system, and therefore we were missing important SRL information. This was because the whole system did not support some important SRL strategies, and therefore they had to be implemented in other tools. The system was not interoperable. To solve this, in [6] we presented the idea of a standard to get activity information from different learning tools, which may allow any compliant reporting tool to extract valuable information about the whole SRL process, performed in different software tools. We presented some examples of what to record and how to record it. The idea here is to specify that work and show how we can use activity data from multiple sources to get valuable information about SRL processes.

V. RELATED WORK

A. *SoftLearn*

One of the most interesting works about systems for monitoring SRL to ease assessment for teachers is the one presented in [20]. In their scenario, they chose a blended learning approach in which the students use ELGG as a PLE (Personal Learning Environment). ELGG [21] is an open source platform that "integrates an individual space and also a social network with forums, blogs, micro-blogging, details of the user profile, friend lists, activity screening, a personal wall, calendar, favorites and pages". One of the big problems of assessing SRL in this context is that "a rigorous monitoring process generates such a volume of information that it

becomes unmanageable: assessing a set of portfolios is much more complex than a simple note granting process". At the same time, the assessment is qualitative, and it "requires reading hundreds of inputs to know if the student has achieved the expected competencies", so it is "extremely time consuming".

SoftLearn is a process mining based tool that "automatically discovers and represents the learning process followed by the students". They tackled several problems: obtaining complete, precise and simple information about learning processes from large amount of traces, representing the learning process for visualization, etc. They obtained great results using process mining algorithms and creating their own visualization based on D/F-graphs. Using SoftLearn, teachers were able to save 54% of their assessment time.

B. The ROLE Project, BOOST and Learning Layers

Responsive Open Learning Environments (ROLE) [22] is a European collaborative project that comprises 16 research groups from six EU countries and China. It is aimed at supporting teachers in the development of open personal learning environments for their students where they can train their SRL skills. Their main outcomes are the ROLE PLMS (Personal Learning Management System) [23] and a big list of widgets available through a store. The PLMS was based on CLIX and allowed the integration of widgets that covered separately almost the whole range of SRL strategies. It is no longer available as it became a commercial enterprise oriented LMS. Widgets can still be used through the ROLE sandbox [19], a learning space whose functionality is provided by the widgets.

This widget-based system allows the students to build their own mashup PLE attending to their needs, but it has some limitations. The main one would be isolation. Although the system is powerful and tackles many tech-SRL common issues that other software misses, monitoring learners' activity is not really possible as we understand it because most widgets do not communicate between each other or record activity data in a common format so other widget or application could work with that data.

Other projects like BOOST [24] and Learning Layers [25] are also based in this concept and have improved the usability and the communication capabilities between the widgets used, but they are aimed at workplace learning.

VI. EXPERIENCE API

A. What It Is

Experience API, also known as Tin Can API or xAPI [8], is a specification for learning technology managed by ADL that "allows recording a wide range of experiences that a user can have in different technologies or tools" [6]. It is community driven and expandable, hence very adaptable. The way it has been designed makes it very flexible and versatile, being able to record any type of activity or event in different ways, which as we will see is an advantage and a disadvantage at the same time. It has many other advantages: activities are easy to code in it, statements are human readable, it has a layer to tackle the language issue, it is device independent, it

supports different technologies, it allows interoperability, records are traceable and quantifiable, it allows resumption across sessions (records the state of the activities), etc.

B. How It Works

It is based on statements in the form of "I did this" (noun, verb and object) that are recorded to or retrieved from a Learning Record Store (LRS). A LRS is a repository for learning records that can be accessed by any compliant software tool, including LMSs, reporting tools and other LRSs. Some of these possibilities are shown in Fig. 1, in which we can see several tools connected to different LRSs, also connected between them. The possibilities for sharing data are endless.

Activities are identified and described in the Activity Profile API, the state of each activity is managed by the State API and every user is identified through the Agent Profile API, even when using accounts from different tools.

C. The Statements

xAPI statements are JSON based objects comprised of a set of defined elements: UUID, actor, verb, object, context, result, timestamp, extensions, attachments, authority, stored and version. Some of them are commonly defined by the LRS: UUID is the identification of the statement generated by the LRS or by the activity provider, Timestamp stores the date and time when the statement is created, and is set by the LRS if it is not included by the activity provider, Authority indicates who asserts the statement, Stored represents the date and time when the statement is stored in the LRS and Version represents the version of the API.

The rest of the elements can be used to define the activity:

- *Actor*: The actor is who performs the action. It can be an agent or a group. It contains a name and an identifier, like and email, mbox, OpenID or an account (e.g. like a twitter account).
- *Verb*: The verb identifies the action. Past tense is used. Each verb has an URI that acts as a unique identifier. ADL created a list of recommended verbs that can be expanded if the action is not represented by any of the existing verbs. A display field shows a legible version of the verb in each language.
- *Object*: The object of the action can be an activity, an agent or a group, a statement reference or a sub-statement. Activity objects are the most common, and they are usually defined by the reporting systems. They have a type, a name and a description. Like the verbs, they are uniquely defined by an URI.
- *Context*: This allows us to add contextual information to a statement, and represents the context of the action, i.e., the instructor, the parent activity, the group, the platform, etc. All these elements are optional.
- *Result*: In these fields we can define the results of the action, if any. Here we can say if the activity was completed, if it was a success, we can define the score, etc.

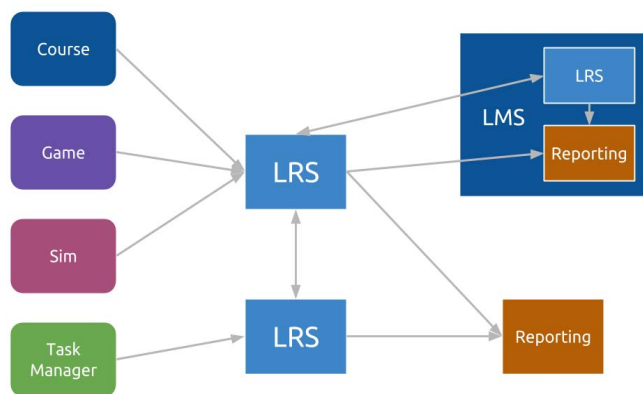


Fig. 1. Combinations for sharing learning activity records.

- *Extensions*: Activity definitions, context or results can be extended with custom elements for specialized use. This increases flexibility, but it must be used with care if we want others to use our activity records.
- *Attachments*: This object was created to define a list of files that will be attached to the statement. It has some required fields to identify attachment's properties like type, length, name, etc.

An example of a xAPI statement will be shown in the next section.

D. Tin Can Profiles and Recipes

Tin Can Profiles are best practice guides for certain scenarios or certain groups of actions. They can be seen as application profiles for xAPI. Application profiles are “schemas which consist of data elements drawn from one or more namespaces, combined together by implementers, and optimized for a particular local application” [26].

There are just a few profiles up to this date, including profiles for video experiences, checklists, SCORM courses, and for Open Badges. Each profile has recipes, activities and a list of linked identifiers. It is in the recipes where all the activities and extensions related to the profile are defined.

VII. xAPI-SRL APPLICATION PROFILE

A. What it Is

xAPI-SRL is an application profile for xAPI that defines how to record SRL actions derived from the implementation of SRL strategies.

Tin Can API allows you to record any action in several different ways. This way you will not need to modify the standard, just adapt the way you use it to your needs. The main drawback of this approach is that two different developers could decide to record the same action using different verbs or coding it differently in xAPI, creating a compatibility issue, despite using the same standard. Besides, if they cannot find an adequate verb or activity type for a particular action in the xAPI Registry [27], they may propose different ones. xAPI-SRL is proposed as a solution to these

problems, providing the developers with a standard for recording and reading SRL actions, allowing them to create interoperable SRL tools.

B. xAPI-SRL Development [6]

We studied a large number of SRL strategies in order to know what information could be generated through their implementation in software. We attempted to minimize the complexity and focused on the data that should be common to the implementation of each one of them, no matter what tool is used. In order to define how to record these actions we: (1) selected the most appropriate verbs, activity types, etc. for each action; (2) selected the most appropriate fields to record the strategy derived data; (3) extended xAPI with new verbs, activity types, extensions, etc. to record actions that were not represented in xAPI Registry, thus in the current xAPI specification. All the information that is not represented in the application profile, probably not related to SRL, can be considered as proprietary information (exclusive for that tool) and can be recorded using the extensions fields.

C. Building the xAPI profile

Tin Can Profiles and recipes need to be structured. This became another big issue when creating the profile: classifying the strategies' implementation records into recipes. We cannot use the classification of the strategies mentioned in section II.B, as the profiles are meant to be used by developers that do not have to know about SRL theory. This classification should be coherent with SRL theory and, at the same time, practical and usable by techs. In order to achieve this, each recipe is composed by groups of strategies that belong to the same higher level strategy, and at the same time are related by functionality, being the latter primary. For instance, there is a planning recipe, and a time management recipe. There are some time management strategies that are also present in the *goal planning* strategy (e.g. time estimation), but we included them in the time management recipe because they are closer to these group functionality and strategies.

D. Capturing the data

In a SRL technology enhanced scenario, a learner would use, at least, the following functionalities, provided by one or more tools (see Fig. 2): organization and time management (provided by goal/task or project managers), content delivery (provided for instance by LMSs or MOOCs), self-monitoring and self-evaluation (provided for instance by a reporting tool and a tool oriented to record reflections like an electronic portfolio). Following the xAPI standard, each tool records the activities that the learner performs, and sends the activity records to a LRS instantly or when the connection is available. That activity data can be retrieved from the LRS anytime by any authorized tool. This way, any tool with reporting capabilities could work with a complete set of activity information.

E. Recording the activity with xAPI-SRL

Here we show an activity record of a time estimation for a task that uses xAPI-SRL. The task is represented in the object as a reference of the statement in which the task was created.

```
{
  "actor": {
    "mbox": "mailto:david@example.es",
    "name": "David", "objectType": "Agent"},
    "verb": {
      "id": "http://uvigo.es/xapi/reg/verbs/estimated-time",
      "display": {"en-US": "answered"}},
      "object": {
        "objectType": "StatementRef",
        "id": "6gf47cxdi-cb53-34c7e-ae32-44982ef22df4"
        "extensions": {
          "http://id.tincanapi.com/extension/duration": "PT45M" }
        "timestamp": "2014-06-30T14:36:18.2435Z"}
  }
```

F. Selecting the data

Monitoring systems usually record almost each of the movements of the user when using the platform, that is, the little steps of each action. With xAPI, each record references a complete meaningful action, not paying attention to each click or small step, which eases the process. Despite this, the data generated in a single learning episode is abundant and varied. We need to filter it and select only the data that would give us the information we want, and organize it if comes from different tools. This process has several steps (Fig. 3):

- *Author*: we filter the statements to select the records from the selected author.
- *SRL*: we filter SRL related actions.
- *Time*: we select the time window and organize the records time wise.
- *Object*: we filter or organize (depending on the intention of the query) the statements attending to the object, grouping related ones.
- *Grouping and analysis*: we analyze groups of statements attending to their related strategy and how they relate to each other.

This last step is not trivial as it implies knowing the relationships of the verbs, activity types, etc. with the strategies, and also how they relate to each other in terms of object of the action, parent activity, etc.

G. Processing the data

In [9] we presented a monitoring system that analyzed raw data from a learning organizer combining related variables to obtain valuable information by using comparative equations. Comparison is the most common and simple method used to see differences between two elements. That is why we based most of our information graphs, calculations and reports on comparisons of two elements, along with a reference element that could be a sequence of tasks, goals, time, etc. The idea here is to select two variables that will create a meaningful comparison following the process described in the last subsection and analyze the data to extract values to compare. In some cases, this is trivial (for instance, time estimations are a field that can be retrieved as it is), and other cases need some processing (for instance, knowing the time spent on a task implies getting the timestamp from several records: activity start, activity pause or stop and resume if they exist and activity complete, and calculate the time with simple math operations).

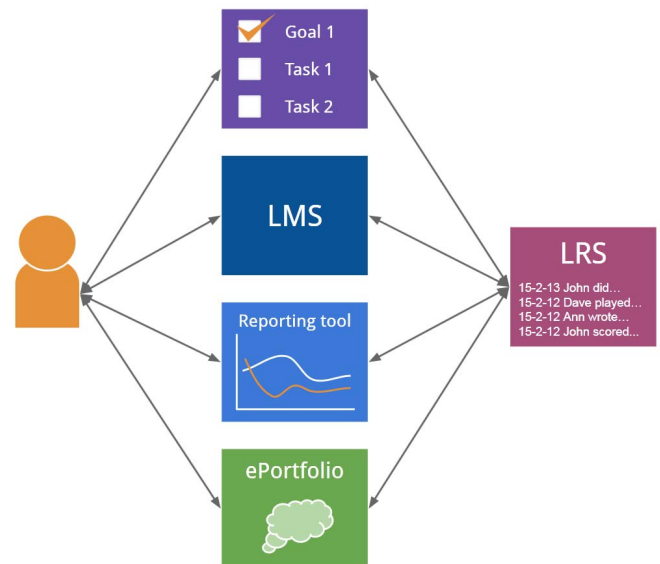


Fig. 2. SRL technology enhanced scenario.



Fig. 3. Data filtering and organization process.

The results that we obtain using this method are easy to understand and useful for both learners and educators. For example, in a scenario in which learners define their goals and plan their learning with subgoals and tasks, time estimations and results estimations are a common practice in SRL. Comparing these time estimations with the actual time used through several tasks or goals would give the learners an idea of how well they made their time estimations. Fig. 4 is an example of a comparative graph showing the time estimations for the tasks versus the time actually spent doing them. At the same time, it can show the details for each particular task or goal in the graph, the time difference in percentage and in this case, it has an option to record our reflection about the time difference. When focusing in each particular task, learners can see how well they performed (in terms of time use) compared to what they thought they would. This allow them to reflect about their performance with information to support their thinking, and would help them draw right conclusions.

Fig. 5 is an example of the number of doubts or reviews that the learner annotated for each goal, and it also shows their current state (pending or solved). It also shows the detail of a goal and how its doubts and reviews are distributed in its subgoals. This graph may help learners with: making decisions for their planning (they can see at a glance their most challenging goals or tasks, their pending doubts or items to review, etc.), reflecting about their evolution, focusing on their weaknesses, etc.

VIII. CONCLUSIONS AND FUTURE WORK

We need a standard way to record learners' activity if we want to share this information to use the most suitable tools for each purpose, specially reporting tools. This application profile would facilitate the creation of a common ground to work with SRL activity data and build tools with advanced learning process monitoring and evaluation support for both learners and educators. This work, along with the CESARAS questionnaire for SRL support evaluation [2] and the design guidelines for SRL that we provide could be a framework for developers to improve the level of support for SRL in software tools, and more specifically, for SRL strategies.

A. Validation

The validation process is not clear because there are no software applications that offer full support for SRL, and at the same time because there are no reporting tools for SRL purposes. The results will be partial in any case. Developing one or more applications to prove this is worthy is not an option for obvious reasons (the investment for the validation would be more than ten times the cost of the development of the standard), as it should include full functionality support, full activity data recording support and advanced reporting features, otherwise the validation would be partial. Using third party applications to validate it has its own problems, as the few existing SRL oriented applications do not use xAPI to record students' activities, but their proprietary solutions. Translating their data into the xAPI-SRL standard has its own problems, as we would need to fill the gaps not included in the original data, and the results obtained would be partial. We needed another approach.

This research was supported by pedagogy experts that provided a first conceptual validation. The next step towards a full validation is getting it published in the ADL website as a profile for SRL. ADL curators examine every proposal for profiles and recipes, suggest changes to the authors and publish their work once it meets their requirements. At present time, we have contacted ADL to start the process, which should resolve within the next months.

B. Future integrations

In the future, we plan to integrate this application profile and some SRL oriented functionalities in tools that we developed, and also to promote its use in the development community.

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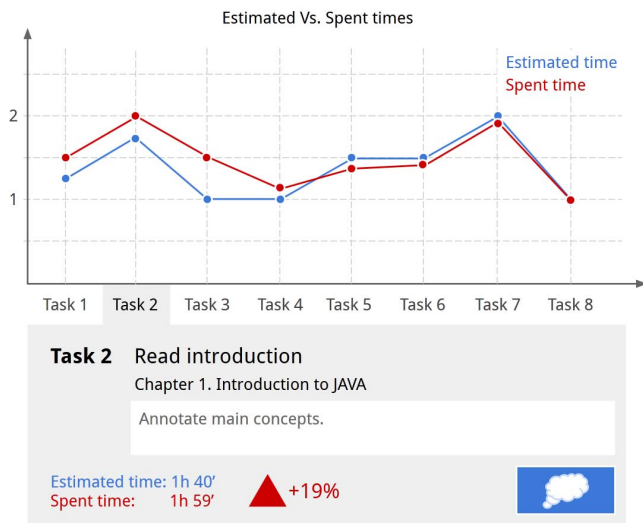


Fig. 4. Time estimation vs. time spent graph.



Fig. 5. Graph showing doubts and reviews pending or solved per goal.

These graphs show the power behind this concept. With adequate tools, learners would be able to implement the strategies using software, and that actions would generate activity records that, once processed, would give learners and educators means to actually use SRL techniques for monitoring and evaluation improved with software. It clearly enhances SRL phases 2 (performance, monitoring and control) and 3 (evaluation, reflection and reaction), supporting also phase 1 (forethought, planning and activation) as SRL is a cyclical process based on metacognition (with each iteration we increase our knowledge about how we learn).

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An Approach to Enhance Students' Competency in Software Verification Techniques

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Abstract— In this paper we present an approach used to enhance students' competency in software verification. Students were asked to apply software verification techniques to a complex formal specification system. The complexity of the system stems from its sophisticated requirements. Selecting such system for this study was intentional for the following two reasons 1) the system is difficult to understand and analyze because of the domain knowledge required to generate formal specifications in temporal logic and 2) the system is large and complex which lends itself to a wide range of applicable verification techniques, and thus highlights the differences in the capabilities of each of the software verification approaches. Students were assessed using multiple criteria including; examination in applying learned techniques, students' attitude toward the technique, perceived efficiency of the techniques in discovering software defects, and the ability of the technique to locate errors in the code beyond simply indicating their presence. The results of this work show that the students applied the learned techniques successfully and their attitudes towards software verification improved.

Keywords—Software Engineering, Computer Science Education, Debugging, Software Testing

I. INTRODUCTION

As our dependency on computer-based critical systems continues to increase, software systems will continue to grow in complexity and size. It has been reported that a significant number of software systems do not meet users' requirements and are of poor quality [13]. In addition a study from the National Institute of Standards and Technology revealed that software defects are so prevalent and detrimental that they cost the U.S. economy an estimated \$59.5 billion annually, or about 0.6 percent of the gross domestic product [14]. The estimated cost due to software errors in the aerospace industry alone was \$6 billion in 1999 [15]. Thus it is increasingly more important that efforts in software development focus on decreasing the number of defects within developed software systems. However, studies have found that senior-level college students and recent graduates lack adequate preparation in software verification, and have difficulty in testing software thoroughly [16, 17, 18, 19]. Therefore, there is an increasing demand for software professionals who have a strong background in software verification.

This paper presents the results of an approach in enhancing students' competency in software verification. Students are

asked to apply the techniques of interest to verify a system used to generate formal specification [7, 9]. The complexity of the system stems from its sophisticated requirements (specified using first order logic). The choice of such system was intentional for the following two reasons 1) the system is difficult to understand and analyze because of the domain knowledge required to generate formal specifications in temporal logic and 2) the system is large and complex which lends itself to a wide range of applicable verification techniques emphasizing the differences in the capabilities of each of the software verification approaches. Students were assessed using multiple criteria including; examination in applying learned techniques, students' attitude toward the technique, perceived efficiency of the techniques in discovering software defects, and the ability of the technique to locate errors in the code beyond simply indicating their presence.

The hands-on approach used in this work aims at exposing the students to the subtleties of each technique by allowing them to explore and learn by practice, and thus, gain expertise in software verification. This paper presents the results of the approach, focusing on the increased proficiency of the student's ability to leverage these software verification techniques in finding software defects and in the applicability of the chosen system in teaching these techniques..

II. BACKGROUND

One of the key aspects in software development is the assurance that the software behaves correctly, i.e., as specified by requirements. The most common software verification technique is that of testing. Software testing is the process of creating and applying test cases to a software system in order to check if the system's behavior was correctly implemented. A test must be efficient in such way that it either exposes a defect or gives some level of confidence on the absence of defects. The problem of determining efficient inputs for test cases has been tackled by different approaches, ranging from treating the system as a black-box [20] to white-box approaches [21].

A. Black-box Testing

In a black-box testing approach, which focuses on selecting input for test cases from the specified requirements and input ranges, it is easier to determine inputs for a test case, but a failed test case will not tell us the potential location of the

defect in the system. Our approach focuses on three black-box testing techniques:

Equivalence Class Partitioning. Equivalence class testing is a technique in which the input domain is partitioned into a finite number of valid and invalid classes. Input values within each equivalence class should behave the same. As such one test input selected from each equivalence class should be sufficient to determine the behavior of the whole equivalence class. By executing one test from each equivalence class, the amount of necessary testing is reduced.

Boundary Value Analysis. Boundary value analysis is a technique that selects tests from the boundary range of input values. These ranges can be defined from specifications or via equivalence classes. The test is selected from above, below and at the boundary of the range. Software defects are commonly encountered at these boundaries, and testing them is an efficient way to detect defects.

Pair-wise Testing. Software systems of any significance are, typically, too large to be tested for all possible input combinations. For these software systems, pair-wise testing [22] is useful because it focuses on testing all pairs of test case inputs instead of all combinations of inputs. The generation of test case input under pair-wise testing is mechanical in nature, only ensuring that each pair of input variables is accounted for from an orthogonal array of inputs. This leads to a automatic way of generating test case input data for the testing of a wide range of large systems.

B. White-box Testing

A white-box testing approach requires the analysis of the internal structure of a system in order to select sets of test input cases that provide adequate coverage of the source code. Determining test input data in white-box testing can be more difficult since it requires construction of control flow graphs (CFG) from source code to determine what input must be used to meet the desired coverage criteria. Because the executions paths are directly tied to the test case input, a failed test can provide the location of the defect.

Branch Coverage. A branch coverage criterion is one that requires that each branch of every control structure has been touched at least once by the testing. Test case input is selected by analyzing the CFG and determining what branches need to be tested. Test cases are created until every branch has been touched at least once. When every branch has been touched at least once, branch coverage reaches 100%.

Path Coverage. A path coverage criterion requires that every possible path is executed by testing at least once. In order to determine test case input, an analysis of the CFG must be done to generate test input data for every possible path that can be executed. This coverage criterion is deemed the most expensive type of coverage as the number of tests required grows exponentially with the number of conditions in the source code.

Def-use Coverage. A def-use coverage criteria focuses on generating tests that cover paths through the definition and use of variables in a program. The def-use requires that testing covers every path from every variable definition to every use

of that variable. This is done by examining the paths stemming from where a variable is first defined, down to every single use of that definition of the variable.

III. PROPERTY SPECIFICATION (PROSPEC) TOOL

A. Formal Specification Languages

Software specifications refer to properties that the system must adhere to. Specifications can be defined and used at the different stages of software development and can range in formality from completely informal (i.e., natural language) to completely formal (i.e., mathematical description). Informal specifications provide a simple mean by which stakeholders, who are, usually, not immersed in logic, can easily understand the desired system properties. On the other hand, formal specifications are more succinct and unambiguous. More importantly, formal specifications allow for the use of formal verification techniques such as model checking [1] and runtime monitoring [2].

There are numerous formal languages that can be used to express system behavior, e.g., first order logic, the specification languages Z and VDM, which have been used in the specification of software and hardware systems.

In the case of dynamic software systems, temporal logic has been used for many decades. In order to be able to describe truth in different moments of time, researchers have designated extensions of traditional logic called temporal logics. Linear Temporal Logic (LTL) [3] and Computation Tree Logic (CTL) [4] have been commonly used by formal verification techniques, especially model checking.

Formulas in LTL are constructed from elementary propositions (i.e., statements with truth value describing system conditions or events), and the usual Boolean operators for not, and, or, imply (\neg , $\&$, \vee , and \rightarrow , respectively). In addition, LTL provides the temporal operators *next* (X), *eventually* (F), *always* (G), *until*, (U), *weak until* (W), and *release* (R). These formulas assume discrete time, i.e., state s may be denoted as 0, or 1, or 2, or ... The meaning of the temporal operators is straightforward [3]:

- The formula Xp holds at state s if p holds at the next state $s + 1$,
- the formula $p U q$ holds at state s , if there is a state $s' \geq s$ at which q is true and, if s' is such a state, then p is true at all states s_i for which $s \leq s_i < s'$,
- the formula Fp holds at state s if p is true at some state $s' \geq s$, and
- the formula Gp holds at state s if p is true at all states $s' \geq s$.

B. Automated Support for Generating Formal Specifications

Specification Patterns System (SPS). A major reason for the lack of application of formal methods in software development is the difficulty in writing, reading, and validating formal specification, particularly those involving time. To assist users in the generation of formal specifications, Dwyer et al. [5, 6] developed the Specification Pattern System (SPS). The work defined a set of patterns to represent the most

commonly used formal properties and to guide the practitioner through the specification process. *Patterns* capture the expertise of developers by describing solutions to recurrent problems. SPS also defined a set of scopes of system execution where the pattern of interest must hold. Each pattern and scope combination can be mapped to specifications in multiple formal languages including LTL and CTL. Using the notions of patterns and scopes a user can define formal system properties without being an expert in the language.

The main patterns defined by SPS are: *Universality*, *Absence*, *Existence*, *Precedence*, and *Response*. The descriptions given below are taken verbatim from the SPS website [S6]:

- *Absence(P)*: To describe a portion of a system's execution that is free of event or state (P).
- *Universality(P)*: To describe a portion of a system's execution which contains only states that have the desired property (P). Also known as Henceforth and Always.
- *Existence(P)*: To describe a portion of a system's execution that contains an instance of certain events or states (P). Also known as Eventually.
- *Precedence(P, Q)*: To describe relationships between a pair of events/states where the occurrence of the first (Q) is a necessary pre-condition for an occurrence of the second (P). It can be said that an occurrence of the second is enabled by an occurrence of the first.
- *Strict Precedence(P, Q)*: To describe relationships between a pair of events/states where the occurrence of the first (Q) is a necessary pre-condition for an occurrence of the second (P). This pattern differs from the previous one in that in regular precedence the pattern is satisfied if both P and Q hold in the same state, while the *Strict Precedence* is only satisfied when Q holds in a state that *strictly precedes* the one in which P holds.
- *Response(P, Q)*: To describe cause-effect relationships between a pair of events/states. An occurrence of the first (P), the cause, must be followed by an occurrence of the second (Q), the effect. Also known as Follows and Leads-to.

In SPS, each pattern is associated with a scope that defines the extent of program execution over which a property pattern is considered. There are five types of scopes defined in SPS:

- *Global*: The scope consists of all the states of program execution.
- *Before R*: The scope consists of the states from the beginning of program execution until the state immediately before the state in which proposition R first holds.
- *After L*: The scope consists of the state in which proposition L first holds and includes all the remaining states of program execution.
- *Between L And R*: The scope consists of all intervals of states where the start of each interval is the state in which proposition L holds and the end of the interval

is the state immediately prior to one in which proposition R holds.

- *After L Until R*: This scope is similar to the previous one except, if there is a state in which L holds and proposition R does not hold, then the interval of the scope will include all states from and including the state where L last holds until the end of program execution.

SPS is presented as a website [6] with links to descriptions of the patterns. The website provides a mapping of each pattern and scope combination into different formal specification languages. For example, the property "A request always triggers an acknowledgment, between the beginning of execution and system shutdown." can be described by the *Q Responds to P* pattern within the *Between L and R* scope, where Q denotes "Acknowledgement is triggered.", P denotes "Request is made.", L denotes "Execution begins.", and R denotes "System is shut down.". Based on the selected pattern and scope combination, the LTL formula provided by the SPS website [S6] is:

$$G((L \ \& \ (!R) \ \& \ F R) \rightarrow (P \rightarrow ((!R) \ U \ (Q \ \& \ !R))) \ U \ R).$$

Composite Propositions (CP). Composite propositions (CP) [7] expand the expressiveness of patterns and scopes to include the specification of sequential and concurrent behaviors. In practical applications, we often need to describe properties where one or more of the pattern or scope parameters are made of multiple (i.e., composite) propositions. An example of such property is the one for sending data by a client and storing the data by the server. The English description of the property is "every time data is sent at state s_i , data is read at state $s_j \geq s_i$, the data is processed at state $s_k \geq s_j$, and data is stored at state $s_l \geq s_k$." Although SPS provides a significant support for property specifications, specifying such a property using SPS would require a significant effort by the user. In order to arrive at the formal specification for this property, the user will have to manipulate the different propositions within the property in order to make it fit the available patterns and scopes. This extra effort by the user might lead to erroneous specifications or user frustration, or both.

Even with the introduction of SPS' patterns and scopes, defining formal specifications for concurrent and sequential properties similar to the above example remains a huge obstacle in adapting formal methods in software verification. To describe such properties, SPS was extended by introducing a classification for defining sequential and concurrent behavior to describe pattern and scope parameters. Specifically, the work [7] defined the following CP classes along with their English description:

- *AtLeastOne_C*: At least one of the propositions in the set of propositions holds.
- *AtLeastOne_E*: At least one of the propositions in the set of propositions becomes *true*.
- *Parallel_C*: All propositions in the set of propositions hold.

- **Parallel_E**: All propositions in the set of propositions become *true* simultaneously.
- **Consecutive_C**: Each proposition in the sequence of propositions is asserted to hold in a specified order, one at each successive state.
- **Consecutive_E**: Each proposition in the sequence of propositions becomes *true* in a specified order, one at each successive state. Once they become *true*, their truth value in subsequent states does not matter.
- **Eventually_C**: Each proposition in the sequence of propositions is asserted to hold in a specified order and in distinct and possibly non-consecutive states.
- **Eventually_E**: Each proposition in the sequence of propositions becomes *true* in a specified order and in distinct and possibly non-consecutive states. Once they become *true*, their truth value in subsequent states does not matter.

The subscripts C and E describe whether the propositions within a CP class are asserted as conditions or events respectively. A proposition defined as a condition holds in one or more consecutive states. A proposition defined as event means that there is an instant at which the proposition changes truth value in two consecutive states. [7] Provides the LTL semantics for each of the CP classes.

Combining patterns and scopes with this notion of CP makes the formal specification of the sending/storing property above much easier. This property can be described using the *Existence of P* pattern within the *Between L and R* scope where *L* is defined with the proposition signifying “data is sent,” *R* is defined by the proposition “date is stored,” and *P* is a CP of type *Consecutive_C* composed of the two propositions p_1 and p_2 (data is read and data is processed, respectively).

One of the advantages of utilizing CPs in generating formal specifications is that it forces the user to consider the different possible relations among proposition within a property. This leads to more complete and correct specifications of sequential and concurrent behaviors which are characteristics of reactive systems.

Combining patterns, scopes and CPs. Although SPS provides LTL formulas for basic patterns and scopes (ones that use single, “atomic”, propositions to define L, R, P, and Q) and Mondragon et al. [7] provided LTL semantics for the CP classes described above., in most cases it is not adequate to simply substitute the LTL description of the CP class into the basic LTL formula for the pattern and scope combination. Consider the following property: “The delete button is enabled in the main window only if the user is logged in as administrator and the main window is invoked by selecting it from the Admin menu”. This property can be described using the Existence (Eventual_C(p_1, p_2)) Before(*r*) where p_1 is “the user logged in as an admin”, p_2 is “the main window is invoked”, and *r* is “the delete button is enabled”. As mentioned above, the LTL formula for the Existence(*p*) Before(*r*) is $[S6] \text{ “}(G \text{ !}r) \mid (! r \text{ U } (p \ \& \ \text{!}r))\text{”}$, and the LTL formula for the CP class Eventual_C, as described in [7], is $(p_1 \ \& \ X(!p_2 \text{ U } p_2))$. By replacing *P* by $(p_1 \ \& \ X(!p_2 \text{ U } p_2))$ in the formula for the pattern and scope, we get the formula: “ $(G \text{ !}r) \mid$

$(!r \text{ U } ((p_1 \ \& \ X(!p_2 \text{ U } p_2)) \ \& \ \text{!}r))\text{”}$. This formula however, asserts that either *r* never holds or *r* holds after the formula $(p_1 \ \& \ X(!p_2 \text{ U } p_2))$ becomes true. In other words, the formula asserts that it is an acceptable behavior if *r* (“the delete button is enabled”) holds after p_1 (“the user logged in as an admin”) holds and before p_2 (“the main window is invoked”) holds, which should not be an acceptable behavior.

As seen by the above example, the temporal nature of LTL and its operators means that direct substitution could lead to the description of behaviors that do not match the actual intent of the user. For this reason, it is necessary to provide abstract LTL formulas that can be used as templates for the generation of LTL specifications for all combinations of patterns, scopes, and CP classes. To address this issue, Salamah et al [8] defined a set of templates that can be used to ease the generation of LTL specifications for all pattern, scope, and CP combinations. The work defined nine templates to generate formulas within the *global* scope, 14 for formulas within the *before R* scope, and another five templates to generate the formulas within the *between L and R* and the *after L until R* scopes. The work in [8] also showed how formal proofs and software inspections were used to validate the correctness of the defined templates.

Using the templates defined by [8] allows for the generation of over 31,000 types of properties as described in the breakdown shown in Table 1.

The numbers for each combination of pattern/scope are results of number of possible ways to combine the different representation of P, Q, L, and R. For example, in the *Absence*

Table 1. Breakdown of Property Types

Pattern/ Scope	Global	Before R	After L	Between L and R	After L Until R	Total
Absence	8	64	64	512	512	1160
Existence	8	64	64	512	512	1160
Universality	8	64	64	512	512	1160
Precedence	64	512	512	4096	4096	9280
Strict Precedence	64	512	512	4096	4096	9280
Response	64	512	512	4096	4096	9280
Total	216	1728	1728	13824	13824	31320

of *P* pattern within the *Before R* scope, there are eight possible ways of presenting each of *P* and *R*, and as result there are 8x8 (64) combinations. On the other hand, the number of combinations for *Q Responds to P* within *Between L and R* is calculated as 8x8x8x8 to yield 4096 combinations.

Prospec Tool. The Property Specification (Prospec) [7, 9] is a prototype tool with a graphical user interface developed at the University of Texas at El Paso to help software developers create software specifications using SPS’ patterns and scopes as well as the aforementioned notion of composite propositions (CP). Prospec generates formal specification in Future Interval Logic (FIL) [10] and LTL. The tool guides practitioners in the creation of formal specifications by assisting the user in the identification and elucidation of

events or conditions that are used to specify behavior. Prospec makes use of decision trees to guide the user through a series of decisions to select an appropriate pattern, scope, and CP classes to match his/her property. □ □

C. Using Prospec in Teaching Software Testing

Considering the complexity associated with generating a large number of LTL specifications using the Prospec tool, we envision this as a perfect platform to teach software testing. The applicability of the Prospec tool stems from multiple factors:

1. The complexity of the LTL specifications generated by the tool requires significant domain knowledge in order for students to adequately test the generated specifications. This is typical of a real-world environment in which software quality assurance personnel must gain domain expertise in the system under test (SUT) before attempting to test such system.
2. The large number of LTL specifications (over 31,000 possible specifications) supported by the tool forces students to employ adequate testing techniques to select sets of test cases that provides appropriate coverage of the system.
3. The characteristics of patterns, scopes, and CPs considerably lend themselves to testing techniques such as equivalence classes and boundary testing. For example, in order to generate black-box test cases, students have to break the input domain into different possibilities, such as, a) the pattern holds but the scope does not, b) the scope holds, but the pattern does not, among many other cases.
4. The fact that the domain associated with the Prospec tool is that of formal specifications is an attractive one as it provides a way to introduce students to formalisms and formal specifications as part of formal methods within software development.

IV. APPROACH FOR USING THE PROSPEC TOOL IN TEACHING SOFTWARE TESTING

The Prospec tool and the associated patterns, scopes, and CPs were introduced as a semester project for the CS4387/5387 (Software Integration and V&V) course at the University of Texas at El Paso (UTEP) in Spring 2015. The course is a core requirement for students in the Masters of Science in Software Engineering (MSSwE) program at UTEP. However, the course also attracts students from other programs offered by the Computer Science Department.

A. Students' Profile and Team Structure.

The current addition of the course has a total of 22 students. Of those students one is a PhD. candidate in Computer Science, another is pursuing a Master's in Computer Science, two others are undergraduate students in Computer Students, and the remaining 18 students are MSSwE students.

Students in the class were assigned into five teams of four to five students. The course teams work on a semester long

project where they develop a complete test plan for a particular project. The test plan includes:

- Plans to test the system's requirements and design specifications as well as implementation using black-box testing techniques,
- Plans to perform white-box testing on system implementation, and
- Plans for system integration, and
-

B. Team Assignments

Using our approach, student teams were assigned three major assignments to verify correctness of LTL specifications generated by the Prospec tool. Below, we discuss each of these assignments, along with students' expectation, and actual students' performance in each of these assignments.

Using Pair-wise Testing. Each of the five teams in the class was assigned a pattern/scope combination where all four propositions are present. Namely, each team was assigned one of the following pattern/scope combinations:

- Q Responds to P, Between L and R
- Q Responds to P, After L Until R
- Q Precedes to P, Between L and R
- Q Precedes to P, After L Until R
- Q Strictly Precedes to P, Between L and R

According to Table 1, each one of these combinations yields a total of 4,096 possible LTL specifications. Because of the large number of formulas to consider when testing the system, students were introduced to the technique of pair-wise testing in which possible values of each pair of input are combined to generate a single test case. The students were asked to use pair-wise testing to reduce the number of candidate formulas to be tested under each combination.

While using pair-wise testing is part of the outcomes of this course, students were not required to manually generate the orthogonal arrays as part of pair-wise testing. Instead, students were asked to research tools that automatically generate pair-wise tests. All teams used the web tool Hexawise [11]. Using the Hexawise tool, each team generated a list of 78 formulas to consider for testing of their particular pattern/scope combination. The teams were also asked to verify that each pair of CPs representing the different proposition (*P*, *Q*, *L*, and *R*) is present in the 78 formulas suggested by Hexawise.

Black-box Testing. Once the teams generated a list of formulas to test using pair-wise testing, the generated formulas were divided among team members to test using black-box testing. As a result, each student was responsible for testing no more than 20 formulas.

Students were asked to use equivalence classes and boundary value testing techniques in testing each of their formulas. To start, the team as a whole was required to develop equivalence class partitioning for the general pattern/scope combination (without the introduction of CPs).

Considering the patterns and scope characteristics described previously, we can find a perfect symmetry with the conditions emphasized in equivalence class partitioning and testing boundary values. For example, scopes formally define the states of interest within system execution (i.e., define boundaries where a pattern is to hold). As a result, scopes characteristics provide sufficient examples to explain what constitutes a boundary value. For example, using the scope Before R, one can test whether the pattern of interest is upheld if that pattern holds immediately before the state where R holds, at the same state as R, and at the state immediately after R. In a similar fashion, patterns can be used to better understand equivalence class testing. For example, using the Q Responds to P pattern, we can think of multiple equivalence classes to choose tests from:

- P never holds, and Q holds,
- P and Q never hold,
- P holds and Q never holds,
- P holds and Q holds after P,
- P and Q hold in the same state,
- ...

Figure 1 shows the equivalence class partitioning and boundary testing of the Q Precedes P pattern within the Between L and R scope as produced by the designated team of students for that pattern/scope combination. The teams were required to provide multiple drafts of their equivalence partitioning and boundary test cases. The provided figure is a sample of the final breakdown of test cases after consultation with the teaching team (both authors). In Figure 1 the students used the notion of Traces of Computation to describe test cases and the behaviors accepted or rejected by a pattern and scope combinations. A trace of computation is a string representing a sequence of states that depicts the propositions that hold in each state. Each character in the string represents a state and a dash (-) implies that no proposition is true at that state. A letter symbol, e.g., P, Q, L, and R, denotes that the proposition is true in the designated state. Displaying more than one letter between parentheses implies that the propositions represented by the letters are valid at that state. For example, in the trace of computation “- - L - - R - - (QP) - -”, L is true in the third state, R is true in the sixth state, and both Q and P are true in the ninth states.

Once the candidate tests for each patterns/scope combination was agreed on, the students were then asked to provide equivalence partitioning of CP classes. For all CP classes the possible inputs fall into one of two cases; the CP holds or the CP does not hold. For example, in the case where P is of type EventualC (p1, p2, p3), possible equivalence classes are as follows (using traces of computations):

- P Holds:
 - p1p2p3
 - p1-p2p3
 - p1-p2-p3
 - p1p2--p3
 - ...
- P Does not hold

- p1-p2---
- p2-p1-p3
- p2-p3
-

Once both the equivalence partitioning of the simple pattern/scope combination and those for each of the CP classes was finalized, students were required to translate their original test cases (similar to those in Figure 1) into ones that consider CP classes. For example, the first test cases in Table 1 can be translated into the following case when both P and R are of type EventualC: “-----p1p2---p3-----r1r2r3”.

All the pattern/scope combinations had known defects to the teaching team but not the students. As is the case with any software system of significance, there are defects that are not obvious even for the original developers of the system. In the case of the Prospec tool, it is assumed that such unknown defects are present in the implementation. The expectations for students’ teams were that they will discover the majority of these defects. The teams discovered defects at the following rate:

ELUIVALENCE CLASSES ON P	TEST CASES WITH BOUNDARY ANALYSIS AND ELUIVALENCE CLASSES ON R	EXPECTED RESULT
Q Does not precede P in any state in the interval	1. The interval is not made: a) ----- P ----- R b) ---- (LRP) ----- c) ---- L ----- P ----- d) ----- P ----- e) R ----- P ----- L ----- 2. A single interval is made: a) L holds in first state: i. L - - - P - - - R - - - ii. L - - - Q - - - R - - - iii. L - - - P - - - Q - - - R - - - iv. L - - - (RP) - - - v. L - - - R P - - - vi. L - - - (PQ) - - - R - - - b) R holds in last state: i. ----- P L ----- R ii. ----- L - - - (RP) iii. ----- L - - - P - - - R iv. ----- L - - - P - - - Q - - - R v. ----- L - - - Q - - - R 3. Multiple intervals are made: a) L - - - R - - - L - - - P - - - R - - - b) L - - - R - - - P - - - L - - - R - - - 4. Nested intervals are made: a) - - - L - - - L - - - P - - - R - - - b) - - - L - - - P - - - L - - - R - - - c) - - - L - - - L - - - R - - - P - - - R - - - d) - - - L - - - Q - - - L - - - P - - - R - - -	1a. Valid 1b. Valid 1c. Valid 1d. Valid 1e. Valid 2ai. Not valid 2aai. Valid 2aiii. Not valid 2aiv. Valid 2av. Valid 2avi. Not valid 2bi. Valid 2bii. Valid 2biii. Not valid 2biv. Not valid 2bv. Valid 3a. Not valid 3b. Valid 4a. Not valid 4b. Not valid 4c. Valid 4d. Not valid
Q precedes P in the interval	5. A single interval is made: a) L holds in first state: i. L Q - P - - - R - - - ii. (LQ) P - - - R - - - iii. L - - - Q - P R - - - b) R holds in last state: i. ----- L Q P - - - R ii. ----- (QL) P - - - R iii. ----- L - - - Q - P R c) L-R hold in other states: i. ----- L - - - Q - - - P - - - R - - - ii. ----- L - - - Q - - - P - - - R - - - 6. Multiple intervals are made: a. L - Q - P - - R - - - L - - - R - - - L P R b. L - Q P - - R - - - Q - P - R - L - P - 7. Nested intervals are made: - - - L - - - Q - - - L - - - P - R - - -	5ai. Valid 5aai. Valid 5aiii. Valid 5bi. Valid 5bii. Valid 5biii. Valid 5ci. Valid 5cii. Valid 6a. Not valid 6b. Valid 7. Not Valid

Figure 1. Equivalence Partitioning and Boundary Analysis for the Precedence Between L and R Combination

- Two out of two known defects in *Response Between L and R*
- Two out of three defects in *Response After L Until R*
- Two out of two defects in *Precedence Between L and R*

- One out of two defects in *Precedence After L Until R*
- Two out of three defects in *Strict Precedence Between L and R*

White-box Testing. Through course lectures, the students were introduced to the notion of control flow graphs (CFGs) and the different types of white-box testing techniques and coverages such as *statement*, *branch*, *path*, and *def-use* coverages. The students were also asked to research tools that automatically generate CFGs for a particular implementation.

Using black-box testing techniques, student teams are asked to *discover the presence* of defects. The next phase of our approach is to require students to employ white-box testing techniques to *locate* defects within the Prospec implementation. For this purpose we have packaged two implementations of the *Response Between L and R* combination. Both implementations have representations of the two known defects within this combination. Both implementations were in Java. The reason for choosing two implementations was to make sure students do not share results with each other. The teams were asked to conduct white-box testing at the unit level, where a method is considered a unit. Teams were also asked to conduct white-box testing to ensure branch (edge) coverage.

While teams used different pattern/scope combination to conduct black-box testing, the choice to have all teams work on the same combination for white-box testing was two-folds; 1) We believe that the implementation for the *Response Between L and R* combination is the most straightforward one of all the other combinations. It is also one that we have had the most experience working with [12], 2) we feel that giving the teams the same combination allowed us to have the teams compete against one another to discover code defects, and as such, injecting some excitement into the class assignments.

The results of students' teams testing were as follows:

- Two teams located both known code defects, and provided the correct suggestions to fix the code,
- One team located both known defects and provided the correct suggestions to fix the code. In addition, this team located an extra defect within the implementation. This defect, however, was not domain-specific as it was I/O-related.
- Each of the remaining two teams located one of the two defects in the code, and correctly suggested a way to remove the defect.

V. ASSESSMENT

In this section we shed some light on the impact of using this described approach on students' experiences in learning the different testing techniques described in the paper. In doing so we assess students' abilities in using the different verification techniques, and we compare the performances of the students involved in this semester's course with those of previous semesters. We also, report on a survey conducted at the end of the semester which was meant to gauge students' feelings toward the semester-long project and the associated assignments and material.

A. Students' Performances Compared to Previous Semesters

To assess students' learning and mastery of the testing approaches discussed in this paper, we compare students' performances against students in previous editions of the course. This comparison is in the shape of final exam questions related pair-wise, black-box, and white-box testing. Students' performance on the same set of exam questions from the previous two additions of the course will be compared to those the current students. Below, we describe the expectations for each type of questions used in the comparisons.

Questions Related to Pair-wise Testing. In this question, students are given a description of a system with a large number of discrete inputs and asked to 1) identify an appropriate testing strategy for testing the system and provide a justification for this choice, and 2) provide test cases for testing the system.

Successful answer for this particular problem consists of Identifying pair-wise testing as the appropriate strategy as well as providing a correct mapping of input variables to elements of an orthogonal array (the students are allowed to use tools such as Hexawise [11] for this purpose.). Table 2 below provides the results of students in the current semester (22 students in total) compared to those in spring semester of 2013 and spring semester of 2014 (total of 21 students).

Table 2. Students' Answers to Pair-wise Testing Questions

Question Element	Percent of Students Correctly answering the question	
	Springs 13 & 14	Spring 15
Correctly identifying pair-wise testing as the testing strategy	90	95
Correctly mapping input variables into an orthogonal array	86	95

Questions Related to Black-box Testing. In this question, students are given a description of a problem and asked to 1) break the input domain into appropriate set of equivalence classes and identify boundary conditions within each equivalence class, and 2) develop appropriate test cases for each identified equivalence class and boundary condition. Table 3 below provides the results of students in the current semester compared to those in spring semester of 2013 and spring semester of 2014.

Table 3. Students' Answers to Black-box Questions

Question Element	Percent of Students Correctly answering the question	
	Springs 13 & 14	Spring 15
Identify correct set of equivalence classes and boundary conditions	71	77
Identify correct test cases for each equivalence class and boundary condition. A test case consist of input and expected output	62	68

Questions Related to White-box Testing. In this question, students are given a piece of code and are asked to 1) manually develop a control flow graph (CFG) of the code, 2)

identify test cases to ensure a) branch coverage, path coverage, and def-use coverage based on a particular variable. Table 4 below provides the results of students in the current semester compared to those in spring semester of 2013 and spring semester of 2014.

B. Students' Assessment of the Described Approach

In addition to assessing students' performance in the testing techniques discussed in this paper, we asked the students to complete an anonymous survey to gauge their feelings about the use of the described approach. The survey questions were meant to elicit students' attitude toward software testing both before and after completing the course.

Table 4. Students' Answers to White-box Questions

Question Element	Percent of Students Correctly answering the question	
	Springs 13 & 14	Spring 15
Correctly construct a CFG for the code	86	86
Identify correct set of test cases to ensure branch coverage	76	77
Identify correct set of test cases to ensure path coverage	71	69
Identify correct set of test cases to ensure def-use coverage	67	69

The students were also probed to provide their feelings towards the use of the Prospec tool material as a semester-long project in this course. Finally, the students were questioned regarding the applicability of the testing approaches in finding defects versus the ability to locate defects. In the following we provide the survey questions and Table 5 provides the summary of students' responses.

Question 1: My knowledge and awareness of the difficulties associated with software verification *before taking this* course were:

a)very high b)high c)average d)below average e)low

Question 2: My knowledge and awareness of the difficulties associated with software verification *after taking this* course are:

a)very high b)high c)average d)below average e)low

Question 3: The use of the semester project highlighted the subtle differences between the different verification techniques:

a)strongly agree b)agree c)neutral d)disagree e)strongly disagree

Question 4: Of the two major approaches, the one that is easier to use in generating test cases is:

a)white-box testing b) black-box testing

Question 5: Of the two major approaches, the one that is most effective at locating defects in software systems is:

a)white-box testing b) black-box testing

Table 5. Students' Answers to the Assessment of the Approach

	Number of Responses				
	a	b	c	d	e
Q1	0	6	8	7	1
Q2	8	9	4	1	0
Q3	5	9	5	0	2
	a			B	
Q4	13			9	
Q5	15			7	

Results show that overall the students performed slightly better than in previous semesters. However, this must be taken with a grain of salt due to small sample space and variances among the student's experiences and abilities. The general consensus among the student's responses is that using such hands-on approach yields a better appreciation for software verification.

VI. CONCLUSIONS AND FUTURE WORK

The use of this approach supports and enhances the teaching of software verification, such as black-box and white-box techniques, assisting in improving the education of software engineers. In particular, this approach requires significant domain knowledge in order for students to adequately test the system. Thus students are exposed to formal specifications domain knowledge which can serve them as they advance in their software engineering careers. This reflects a typical real-world environment in which software quality assurance personnel must gain domain expertise. One of the results of this work is that the Prospec tool is very appropriate for teaching classes in software engineering due to its complexity, large range of output formulas and need for high assurance.

A future goal of this work is to develop standalone teaching modules based on Prospec such that they can be used in courses that are not necessarily focused on testing, but can complement other software engineering topics. In addition, there is a need to conduct a more formal study to assess the applicability of this approach within other software quality assurance courses.

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Evaluation and Assessment of Effects on Exploring Mutation Testing in Programming Courses

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Abstract—Mutation analysis is a testing strategy that consists of using supporting tools to seed artificial faults in the original code of a software under test, generating faulty programs (“mutants”) that are supposed to produce incorrect outputs. Novice programmers suffer of a wide range of deficits due to defective training processes. We argue that the incorporation of experiences on mutation testing in programming courses adds valuable knowledge to the learning process. In this paper we evaluate the effects of using mutation testing to improve the learning process of students in programming courses. We present results of experiments and analysis involving undergraduate students. These experiments are the continuation of a previous work in which we raise empirical evidences that the adequate incorporation of mutation testing in programming courses contributes to form an effective environment that fosters learning. To do so, we provide a mutation testing tool to promote the practice of mutation testing by novice programmers. Through practical experiences and several analysis survey we measured the effects of using the mutation testing criterion to teach programming. In addition, we collected the opinion of senior students who already knew mutation testing concepts about their opinion on the usage of mutation concepts to teach novice programmers. Our findings reveal that the effective use of mutation analysis concepts contributes to the learning process, making students see the code as a product under development that is the result of a careful manual coding process which they need for measuring and predicting the effect of each command. The main contributions discussed in this paper are: (1) presenting results of an empirical analysis involving undergraduate students, thus giving us preliminary evidence on the effects of the novel practice; (2) exposing possible practices to explore mutation testing in programming classes, highlighting the limitations and strengths of such strategy; and (3) a mutation testing tool for educational purposes.

Keywords—mutation testing; experimental study; computer-aided instruction.

I. INTRODUCTION

Currently, in the information technology area, there is a high demand for highly skilled developers. There are several vacancies in the technology field due to the lack of well-prepared professionals. Part of this problem can be associated to “poorly” designed programming courses. Often, traditional programming teaching methods may not meet all students’ expectations [1]. Novice programmers suffer a wide range of deficits and professional limitations due to defective training processes [2]. Then, novice students have not had enough exposure to programming languages to develop strategies for

solving problems in a computer programming setting [3]. Even competent programmers make certain mistakes that can be used as experience to improve the learning processes. Among these mistakes, one is the off-by-one error, which happens, for example, when an iterative loop that was meant to iterate ‘ n ’ times iterates either ‘ $n - 1$ ’ or ‘ $n + 1$ ’ times. These errors arise when programmers use the wrong relational operator or fail to note that a sequence starts at zero rather than one.

A possible way to improve the learning process of novice programmers is by the practice of introducing software testing activities in the classroom [4]. Teaching testing techniques and criteria in the very beginning of programming courses may represent an effective practice to improve students’ skills [5]. Conceptually, Software Testing is the dynamic process of executing a software product (or a software module) aiming at checking whether it corresponds to its specifications, considering the environment in which it was designed [6]. Testers must use testing techniques and criteria to achieve more effective testing. Testing techniques and criteria provide systematic ways to find conditions to raise the probability of finding errors. Several researchers have been studying the application of testing practices in conjunction with programming fundamentals in programming courses [5, 7, 4]. Implementing this practice may lead to gains under two aspects: (1) supporting students to learn technical programming language concepts more quickly, and (2) creating the habit of applying testing techniques in their systems under development earlier.

Despite the fact of several researchers have been dedicated efforts on raise evidences on using testing concepts to support teaching programming, there are few studies on the effects of combining specific testing criteria and programming courses. In this context, in a previous study [8], we have presented a prototype of a mutation testing tool specially designed to supporting the learning process. *Pascal mutants* supports the mutation testing criterion of Pascal programs, being extremely useful to novice programmers. Mutation Testing [9] is a fault-based testing criterion that consists of introducing small syntactic changes into a *Software Under Test* (SUT), creating slightly different versions (so-called mutants) in order to obtain a test suite capable of identifying all of the seeded faults (small

errors) [9, 8]. Then, the tester has to analyze defective codes, providing test cases to produce distinct outputs for the SUT and its mutants [9]. Mutants are often similar to the faulty programs written by novice students in programming courses. However, the cost of mutation testing has traditionally been so high it cannot be applied without full automated tool support.

The main goal of this paper is to provide preliminary evidences and discussions on the effects of exploring the criterion mutation testing to teach programming foundations/fundamentals to novice programmers. To do so, we have conducted an experiment on using *Pascal mutants* and mutation testing in an undergraduate-first-year class. We have observed the students behaviors when in contact with the mutation testing criterion. Then, we have measured the effects on using mutation testing through a detailed questionnaire to assess the student's level of understanding over specific fragments of code. In addition to that, aiming to assess the opinion of senior undergraduate students enrolled in a software testing course, we have prepared a proper survey to assess their opinion about the premature contact with mutation testing by novice programmers. Empirical and survey-based studies have raised evidences the usage of mutation testing might improve the learning process under different aspects such as better general grasp levels and better understanding the abstract concepts that may result in the improvement of the professional skills. Then, the contributions associated to this paper are: (1) raise empirical evidences on the effects of exploring mutation testing criterion to teach programming; (2) highlighting the limitations and strengths of mutation criterion to teach novice programmers; and (3) a mutation testing tool for educational purposes. The main implication of our exploratory study is the indication of the importance of introducing software testing concepts to teach novice programmers.

II. RELATED WORK

Several researchers have been exploring the idea of using software testing integrated to programming courses in order to improve the learning process. Most of these approaches are associated to functional testing, which mean, they are not related to source code analysis. However, we consider these studies related to our research because they look to educational purpose of the usage of software testing. The main difference between our study and the group of studies presented below is the fact that we are interested on measure the educational effects of a single specific testing criterion.

Jones [7] revealed evidences on the benefits of presenting testing concepts in conjunction to programming classes instead of separated courses. The study states three points: (1) software testing represents a good topic to be inserted in the regular curriculum of technology courses; (2) students need the practice of testing activities to improve their educational experiences; (3) there is a basic set of recommended testing skills; and (4) regular courses should impart testing experiences.

Brito et al. [1] present an approach in which test cases (test input and test output) are rearranged and reused to improve the quality of activities performed by novice programmers in

programming courses. Empirical studies involving about 60 undergraduate students show that when students have some previous implemented test cases to evaluate their solutions, the quality of the programs produced by them increases significantly. Buffardi and Edwards [4] present an approach to quantitatively evaluate the effects on presenting software testing concepts to students. The study involves programs generated by 883 different students over five years. However, the study focuses on evaluating software testing behaviors that students exhibited in introductory computer science courses. Several (76%) of the students have designed different testing behaviors on different assignments, leading to good habits among students. Souza et al. [10, 5] believe that the integration of testing concepts and programming courses can improve the learning process in students. Then, the studies propose and validate a web-based tool that sets an environment in which students can submit their solution for a given problem, and then, their solution is "tested" against the reference program's.

III. METHODOLOGY

This section presents concepts and methodology for our investigation.

A. Mutation Testing

Mutation testing [9] is a fault-based testing criterion which relies on typical mistakes programmers make during software development. Mutation approaches seed defects into the SUT in order to examine its behavior. This criterion relies on the *Competent Programmer* and the *Coupling Effect* hypotheses. According to the former, the Competent Programmer's hypothesis states that due to the fact that programmers are competent, they write programs that are close to being correct. Therefore, it can be assumed that a program written by a competent programmer has simple faults; often, they are small syntactic changes. The Coupling Effect hypothesis states that complex faults result from the combination of small ones. As a result, fixing the small faults will probably solve the complex ones. Then, regarding the testing process, finding artificial defects allows the effective detection of real faults.

Mutation testing creates several versions of the SUT with slight faults. In practice, given an original program P , the criterion consists of creating a set of mutants, M , that are slightly modified versions of P . "Mutation Operators" define the modification that must be applied to P . Mutation operators are necessary to insert small defects into the original program, creating mutants. These defects are generated by using a set of simple syntactic rules. Then, for each mutant m , ($m \in M$), the tester runs the test suite T originally designed for P . If there is a test case t , ($t \in T$), and $m(t) \neq P(t)$, this mutant is considered dead. If not, the mutant is considered alive and the tester should improve T with a test case that reveals the difference between m and P . If m and P are equivalent, then $P(t) = m(t)$ for all test cases.

Creating mutants from an original program involves a set of rules established by mutation operators. These rules change the original program, creating mutants with syntactically valid

changes. Typical mutation operators modify expressions by replacing, modifying, inserting, or deleting either operators or variables. For instance, Figure 1 presents the original program and one of its mutants. In this particular case, a mutation operator replaces the logic operator (Line 3).

1	(**** Original *****)	1	(**** Mutant *****)
2		2	
3	if (a && b) then	3	if (a b) then
4	c := 1	4	c := 1
5	else	5	else
6	c := 0;	6	c := 0;

Fig. 1: Original and Mutant Source Code.

An undecidable issue in mutation testing comes out when the fault injection creates mutant programs that are functionally equivalent to the original program. Namely, original programs and *Equivalent Mutants* will always yield the same results. Detecting mutants that are equivalent to the original program is one of major obstacles for practical usage of mutation testing, requiring the full knowledge of tester who must perform this task manually through code analysis. However, using a mutation testing tool, once a tester has marked all possible equivalent mutants for an SUT, it is possible to compute the “mutation score”. The mutation score is a coverage metric and it is expressed as the ratio of the number of dead mutants over the number of non-equivalent mutants. Thus, when the tester reaches a 100% mutation score, all non-equivalent mutants are said to be dead.

B. Pascal Mutants

Pascal mutants implements the mutation testing criterion at the unit level of Pascal programs. *Pascal mutants* is available online as an open source tool in a Sourceforge repository, along with its supporting documentation and several example programs. The link to access the tool is <http://sourceforge.net/projects/pascalmutants/>

1) *General Structure and Wizard*: In Oliveira et al. [8] we have defined a prototype of a mutation testing tool for educational purposes. In this study, we have significantly improved that prototype composing *Pascal mutants*. Through seven specially designed mutation operators, testers (students) can generate faulty versions of an original program code. Students can select specific mutant operators, create testing projects, manage and execute testing data, check the mutation score and compare original and mutant codes. Technically, the implementation of *Pascal mutants* integrates six main modules: (1) a Pascal syntax analyzer and syntax tree generator, (2) a compiler and loader of mutants, (3) a test case manager, (4) a results evaluator (test oracle), (5) a mutant manager, and (6) a test reporter. Further technical details of *Pascal mutants* can be found in our preliminary study [8] in which *Pascal mutants* were presented as command-line based implementation.

Regarding the scope of this study, we have extended *Pascal mutants* to work under a robust wizard that supports all of the functionalities presented previously. After results of some pilot studies, we have designed this wizard towards

promoting the education purpose of mutation testing. Then, this wizard is important for novice programmers in order to explore mutation testing to understand parts of the source code. The wizard leads the programmer’s focus to important parts of the code instead of mutation testing details. It has an intuitive and user-friendly interface. Through a set of UIs (*User Interfaces*) provided by *Pascal mutants* students can perform several activities: (1) manage test cases, (2) analyze mutants and an original program, (3) mark equivalent mutants, and (4) visualize dead, alive, and equivalent mutants. Students can examine testing statistics (i.e., number of alive, dead, and equivalent mutants), including the mutation score. After defining a prototype for *Pascal mutants* in Oliveira et al. [8], we have implemented *Pascal mutants* in a way that it encourages the users to adopt an autonomous posture during the learning process.

2) *Mutation Operators*: *Pascal mutants* implements seven mutant operators that are presented in Table I. These operators are not a complete set with regard to the identification of an ideal test suite for testing purposes. However these mutation operators are sufficiently complete to produce sets of mutants useful for educational purposes. In addition, the generic structure of the tool enables testers to add new mutation operators.

C. Mutation Testing Supporting Novice Programmers

Defining inputs that differ between SUT and mutants requires testers to fully understand the programs’ data and information flow, from assignment of values to their use. Naturally, this full understanding depends on the specific program’s control structure of the programming language in which the SUT is written. The process of reading and understanding source code may be trivial for advanced programmers, however it may be challenging for novice programmers. On the other hand, reading source code to perform mutation testing may represent a valuable process of learning for novice programmers. Section IV presents empirical evaluations on using mutation testing and *Pascal mutants* in practical programming classes.

IV. EMPIRICAL EVALUATION

Aiming at verify the practical usage of mutation and *Pascal mutants* to support the learning process of novice programmers, we have conducted a two-fold independent evaluation:

(*Analysis 1*) A practical empirical evaluation of using *Pascal mutants* in an undergraduate course on “Computer Programming” for first-year students. This experiment aims to provide a direct assessment on using mutation testing in a programming course for beginners (Subsection IV-A). We have compared the process of code analysis and understanding by students using mutation testing criterion and regular compilers; and

(*Analysis 2*) A survey analysis involving senior students in an undergraduate course of “Software Testing and Inspection”. This survey aims at measuring the opinion of students who are familiar with mutation testing however had no contact with mutation concepts when they were novice programmers (Subsection IV-B).

TABLE I: *Pascal mutants* Mutation Operators.

	mutation operator	acronym	original code	mut. operator's effect
1	Change of Arithmetic Operator (for other arithmetic operator)	CAR	<code>c := a + b;</code>	<code>c := a - b;</code>
2	Change of Relational Operator	CRO	<code>if (a > b) then</code>	<code>if (a < b) then</code>
3	Change of Logical Operator	CLO	<code>if (a && b) then</code>	<code>if (a b) then</code>
4	Adding "NOT" Operator in Control Expressions (if, while, etc)	ANOiCE	<code>if (a > b) then</code>	<code>if (NOT(a > b)) then</code>
5	Removing A Command	RAC	<code>a := b; b := c ;</code>	<code>a := b; ;</code>
6	Change for a Scalar Constant for its Successor and Predecessor	CSCSP	<code>const average = 5;</code>	<code>const average = 6;</code>
7	Change the "Repeat" Command for "While" and vice versa	CRCfW	<code>repeat a := a*count; count := count+1; until (count < 7);</code>	<code>while (count < 7) do begin a := a*count; count := count+1; end;</code>

We now provide a detailed view of each analysis: research questions, the methodology we followed, and the experimental/survey strategies we have designed.

A. Analysis 1 – a practical experience on using mutation by novice programmers

This study is designed to answer the following *Research Questions* (RQ):

- RQ1: Can the mutation testing criterion facilitate the learning process of novice students in programming courses?
- RQ2: What are the trade-offs and recommendations of using mutation testing to support the learning process in programming courses?

We have followed the same protocol established in a previous pilot study detailed in Oliveira et al. [8]. Then, we were able to correct some imperfections, such as the need for a background on software testing by the students. In general terms, the idea of the experiment is to provide the very first contact of novice students in a programming course with mutation testing. To do so, we use the resources and functionalities provided by *Pascal mutants*

The subjects students involved in the experiment consisted of 28 undergraduate students enrolled in the second semester course on "Computer Programming" UNESP campus Rio Claro, São Paulo, Brazil (*Universidade Estadual Paulista*). The set of students were enrolled in a Bachelor of Computer Science's course and they had a prior knowledge of about fifty-hours course of algorithms in Pascal language. Then, one can conclude that the students were considered novice programmers with no background on software testing neither software engineering concepts.

The experiment was conducted in framework of a four-hour course. We have started our experiment presenting theoretical concepts on Software Testing, including definitions and practical examples. Besides the traditional test phases (*Unit, Integration, and System*), the main testing techniques and their particular criteria were presented. Then, we have focused on the mutation testing criterion, detailing each foundation of the criterion. Finally, we have present *Pascal mutants* to the subject students. We presented them a step-by-step on how to create a testing project and how to load test data, identify equivalent mutants, and compare original and muted code. However, during this step of the experiment, the students had no practical contact with *Pascal mutants*

After the aforementioned experimental setup, we conducted a controlled experiment in laboratory. This experiment was composed by a dynamic activity exploring a simple program and a survey to assess the student's level of understating on the program. We then started evaluating the behavior of each student in order to contribute to answering the RQ 2. First of all, we have divided the subject students in two groups. Group 1 (G1) was designed to conduct the experiment using a regular Pascal Compiler. Group 2 (G2) was designed to conduct the experiment using *Pascal mutants* and exploring the concepts of mutation testing. Then, we have set G1 to be a *control group*, and G2 to be our *treatment group*. We gave no further explanations and advises to any group to avoid potential biases.

The activity assigned to the students consisted of analyzing a blind code, trying to understand its functionality through code analysis and running it against different inputs. We did not provide any specification about the program functionality. Equally, the identifiers assigned to each variable offered no clues about their usage. The code represented a program to figure the classical sequence of numbers named *Fibonacci series*. Starting from one and one, Fibonacci series is a sequence of numbers in which each subsequent number is the sum of the previous two, for example: "1, 1, 2, 3, 5, 8, 13 ...". In our subject program, three parameters were accepted to represent, respectively, (1) the first element of the series, (2) the second element of the series, and (3) the limit of the series. During the previous classes, we did not offered prior contacts with the Fibonacci algorithm.

Aiming to provide empirical evidences to answer RQ 1, we elaborated a questionnaire that is able to measure the level of understating of the students. The questions were open about the program, possible specific changes in the source code, and they were designed to cover the students' attitudes toward: (1) general aspects about the program; (2) influence of the starting points in the algorithm; (3) influence of the stop conditions (ending points); and (4) relation among number of iterations and parameters. Table II presents all of the survey's questions.

Section V presents the results of this empirical evaluation.

B. Analysis 2 – a survey analysis with senior students

We believe, after having some experiences during an undergrad course, students are able to notice whether some activities could help them in some period of their student lifetime. Then, we designed a survey to assess the opinion

TABLE II: Analysis 1: Survey's Questions.

#	Questions
Q1	Describe what your thoughts are about the main functionality of this program?
Q2	Is there any difference if operator ' \leq ' were used instead of operator ' $<$ ' in the command ' <i>while</i> '? Regarding the variables ' <i>a</i> ', ' <i>b</i> ', and ' <i>c</i> ', in which situations may differences occur?
Q3	For the majority of inputs, would the number of interactions in the loop be different if the line 6 has the following command: ' <i>b</i> := 2 * <i>b</i> '? Justify your answer using examples.
Q4	What would happen in the case where line 6 has the following statement: ' <i>b</i> := <i>b</i> + <i>a</i> '? Justify?
Q5	Once ' <i>a</i> = 3', ' <i>b</i> = 5' and ' <i>c</i> = 40', how many terms would be printed in the program output if the operator '+' was replaced by '*' in the command ' <i>while</i> ' (line 1)? Justify?

of senior students about learning mutation testing during the very beginning of programming courses. Then, this analysis aims at identifying whether senior students, who are familiar with mutation testing, would advise novice programmers to practice mutation testing to improve their programming skills.

Unlike from the students involved in the previous experiment, the set of subject students that composed Analysis 2 consisted of 21 students enrolled in the undergraduate course on "Verification, Validation, and Software Testing" at USP (*University of Sao Paulo*). These students had prior knowledge of Software Engineering, concepts of Software Testing, and more than three programming language. Once the course is offered for a broad audience, the experiment involved undergraduate students from three different bachelor courses: (1) *Computer Science* (33%); (2) *Information Systems* (14%); and *Computer Engineering* (52%). Additionally, they had between 6 and 14 semesters of course, most of them having 8 semesters of course. During the course, the students faced several experiences on using the mutation testing criterion. In this context, one can notice the students were pretty experienced and some of them were already employed by software developing companies.

At the end of a complete course on Software Testing, we provided an eight-question survey aimed at assess what the students' feelings on using the mutation testing criterion as an activity to support the learning progress of novice programmers. The questions were focused on mutation testing practices and testing tool support for novice programmers. The complete survey, the possible answers, and the results are presented in Table III. The provided questions were objective and one can notice the possible answers and the percentage of the students' opinions about each issue through the column "Results". Section V provides further analysis and evidence collected from this questionnaire.

V. RESULTS AND ANALYSIS

In this section we present the results achieved from the aforementioned analysis. In addition, we present possible answers for the pre-defined RQs by Analysis 1. Results and conclusions provided from the survey assessment are presented. Finally, we raise some key points about the practice of using mutation testing concepts to add knowledge to the learning process in programming courses.

A. Results to Analysis 1

Regarding Analysis 1, we evaluated each response applying the following scale-point: 3 points for complete/correct response, 2 points for incomplete/partially correct responses, and 1 point for incoherent/wrong responses. Then, each student received a score based on his performance during the experiment. Regarding all of the five survey questions (Table II), the students must have a score varying from five to 15 points. To avoid bias during this process, at least two of this paper's authors checked each question's responses. In cases of disagreements about the scores, a third author was appointed to grade the response. Further, we made all these verification ignoring group distinctions, once there was no information about the groups in the survey. Then, after defining the scores, each survey was associated to a student and, consequently, the groups were identified.

Figure 2 contains two fan plots representing an analysis of each group performance. This analysis highlights the quantity of questions considered correct, partially correct, or incoherent/wrong for each treatment. This evaluation considers all of the questions answered by each group. Summarily, students using *Pascal mutants* (G2) answered 52% of questions correctly (Figure 2b), while students in G1 only 38% (Figure 2a).

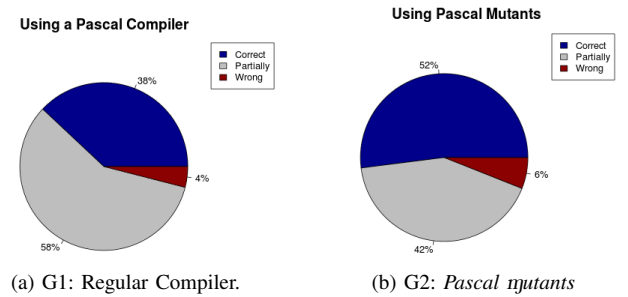


Fig. 2: Comparison between Groups' Performance.

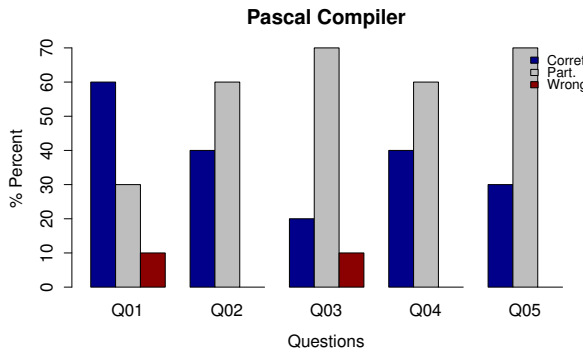
Along the same lines, regarding a broad evaluation on each question included in our experiment, Figure 3 presents a bar graph comparing the percentage of correct, partially correct and wrong answers for each question, in each group. Briefly, it is possible to notice a considerable improvement from G1 (Figure 3a) to G2 (Figure 3b), particularly in the number of correct answers. This shows that the students in G2 were better able to understand the code than those in G1.

Similarly, Table IV shows a bar graph with a comparison between the mean score for each of the five questions. For three of the five questions, the average of the students who explored the mutation tool was higher than the average of students who used a Pascal compiler. For one question (Q5), the average was exactly the same. And only for Q4 the students using a regular compiler obtained better scores.

Another quantitative analysis we made considers the time it took each student to conclude the experiment. To realize this investigation, each student had specified a starting time and an ending time for their experiment. This analysis was performed

TABLE III: Analysis 2: Survey's Question.

#	Questions	Results
SQ1	What were your previous knowledge on software testing before the course?	None 42.86% Intermediary 57.14%
SQ2	Do you encourage mutation testing concepts to be presented in conjunction to programming foundations?	Yes 38.10% Yes, superficially 52.38% No 9.52%
SQ3	What might be the effects of practicing mutation analysis by novice programmers?	Better programs 61.90% Skilled better programmers 28.57% None 9.52%
SQ4	Do you consider regular testing tools useful to teach programming foundations?	No, they need to be alleviated 9.09% Yes, using basic functionalities 54.55% Yes 36.36%
SQ5	Do you consider the mutation testing tools useful to teach programming foundations?	No, they need to be alleviated 61.09% Yes, using basic functionalities 19.55% Yes 19.4%
SQ6	Disregarding the specific course on software testing, considering your course's curriculum, software testing concepts:	were not presented 27.27% were fairly presented 13.64% were poorly presented 59.09%
SQ7	Do you think specific educational testing tools might be useful on creating good programming habits?	Yes 59.09% No 41.1%
SQ8	Do you think designing test cases through mutation testing might be useful to improve the learning capacity of novice programmers ?	Yes 72.73% No 27.27%



(a) Group 1: Regular Compiler.

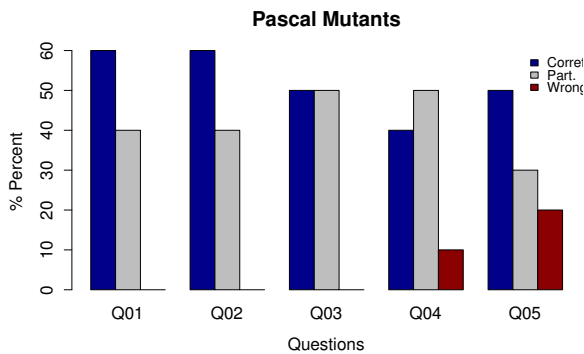
(b) Group 2: *Pascal mutants*

Fig. 3: Percentage of Hits by Question.

TABLE IV: Mean Score for Each Question by Group.

Mean Score for Each Question					
Group	Q01	Q02	Q03	Q04	Q05
G1 – Regular Comp.	2.5	2.4	2.1	2.4	2.3
G2 – <i>Pascal mutants</i>	2.6	2.6	2.5	2.3	2.3

to help answering RQ 2, involving the trade-off analysis on applying the mutation testing criterion to teach programming. RQ 2 was actually designed to complement the results from RQ 1 including the statistics from the Analysis 2. Figure 4 represents three bar plots containing the total amount of time in minutes and the final score of each student separated by the groups they belong to. Students from G1 were quicker to complete the experiment than students from G2 (Figure 4a). Altogether, students in G2 took 17 minutes more than students in G1 to finish their experiments. On the other hand, students from G2 and obtained better scores (Figure 4b). Figure 4c presents a comparative analysis of the mean time and the mean score between the two groups.

In order to provide a specific comparison involving time and scores of the groups, we established a quantitative value named *Performance Factor* (PF). This factor is figured out through the score over the time in minutes. This number represents how effective the students were in considering their time and score. Table V presents the performance factor of some student divided by groups. G1 obtained an average PF of 0.40 and G2 obtained 0.25. Which means that the control group had a high PF and G2 spent a lot of time to complete their survey.

TABLE V: Performance Factors.

G1	.17	.22	.45	.36	.44	.45	.50	.43	.40
G2	.18	.23	.30	.25	.40	.40	.22	.17	.24

Through empirical analysis, effects of using the *Pascal mutants* tool and mutations testing to tech novice programmers are positive. It is possible to notice that stats and data collected from Analysis 1 revealed *Pascal mutants* positively affects the understanding about the source code. In general, students that have used *Pascal mutants* to conduct their activities obtained a better mean score in all of the questions with the exception of Q4. We noticed students in G1 tried to solve the survey's questions through trial and errors approaches. They explored the compiler with different inputs and observing the program behavior. On the contrary, students in G2 had to think more

carefully about the algorithm to “kill” mutants, consequently they were able to formulate more accurate answers about the program. Using the mutation analysis was a valuable experience for novice programmers.

We observed that students in G2 took a long time to finish their experiments. This reveals that the practical usage of a mutation testing tool instead of regular compilers may be considered a disadvantage. This is due to the fact that students in G1 had previously obtained skills to conduct the experiment using their preferred Pascal compiler. On the other hand, students in G2 had to dedicate more effort to understand all of the resources and functionalities provided by *Pascal mutants*.

Regarding RQ1, we obtained valuable evidence that, for novice programmers, the mutation criterion can facilitate the learning process. The process of finding inputs to generate different outputs for the original program and mutants aids in the learning process. Further, the comparative analysis among similar source codes leads the student to play a tester role. In this sense, novice programmers have to perform successive evaluations and take decisions that contribute to the complete understanding of the semantic rules associated with the programming language. Then, the tool implemented and the experiences reported in this paper have helped students in understanding more deeply the concepts of the Pascal programming language. Numerically and visually, Figures 2 and 3 represent how efficient is the mutation testing to improve novice programmers’ experiences.

Regarding RQ2, which was designed to define the trade-offs of our approach, we consider the experience reported in this paper reveals important findings. Through our experiment, the main trade-off we noticed was associated with the time to finish the activity. Students using a mutation tool will take a considerable time to figure inputs able to “kill” mutants. We noticed a need for specific strategies to make the usage of mutation testing faster, intuitive and efficient. Figure 4 presents some visual evidence on how efficient and cost effective is using *Pascal mutants*. During the experiment, students from G2 designed several manual outlines of the algorithm’s behavior, contributing to the delay finishing their activity.

Still regarding the RQ2, during this research, we noticed several efforts and prerequisites that can be considered trade-offs of using a mutation criterion in the learning process of programming. Among these trade-offs we highlight three needs: (1) supporting material about mutation testing, (2) basic knowledge of software testing concepts, and (3) introductory lessons of software testing. However, we define the lack of adequate tools as the major limitation to a wide adoption of this approach. Regular tools for mutation testing are not indicated for novice programmers. In this context, to apply this testing criterion in programming courses, teachers have to adapt modules from regular mutation tools or even implement their own tools. In this context, whether Pascal is the programming language to be taught, we strongly advise teachers to use Pascal Mutants or any other adequate supporting tool.

B. Results to Analysis 2

Regarding the survey assessment, whose results are presented in Table III, it is possible to notice that the senior students appreciate the idea of exploring mutation testing to complement the learning processes of novice programmers. Besides that, we noticed that before coursing a specific class focused on software testing, 42% of the students declared they had no previous knowledge on this topic (SQ1). That is a large percentage of concern that might directly effect the quality of the software developed by that student when he/she becomes a professional. It was notable the number of students (SQ2 – 90%) that agree with the practice of including mutation testing in programming courses. Besides several benefits such as, programmer skills, programs’ quality, good programming habits, results collected from SQ3, RQ4, and SQ5 revealed that the students think it is necessary to have software testing tools specially designed to teach programming, as regular testing tools might be quite complex. 90% of the students think that practicing mutation testing contributes to better programmers (SQ3). RQ4 and RQ5 show that most of the students believe that regular testing tools are not recommended for novice programmers. This result is even worse for mutation testing tools, as 61% of the student believe the functionalities of regular mutation testing tools need to be alleviated. SQ6 and SQ7 lead us to consider the association of software testing notions to novice programmers: 87% of the students were not introduced to testing concepts and when introduced, these concepts were poorly explored (SQ6); 60% of the students see a strong relation between specific education testing tools and good programming habits. Finally, SQ8 reveals almost 73% of the students agree that the process of designing test cases to feed a mutation testing tools is a good exercise to improve the learning capacity of the student.

Further evidence can be collected through the quantitative analysis provided by Table III. In front of this evidence, we have two different conclusions: (1) mutation testing is one of the most appropriate testing criterion to help teaching programming in different languages; (2) there are no mutation testing tools specifically designed for novice programmers. In the context of the second conclusion, we can define the *Pascal mutants* states a significant contribution, being a tool specially designed to help novice programmers.

C. Discussion

The results raise some key points related to our own point of view about the usage of testing concepts in programming courses. According to our experience, the contact between novice programmers and testing activities may be profitable, establishing positive habits starting at the beginning of their professional career. For instance, regarding the questionnaire, we believe that cases in which the mutation approach resulted in minor or slight endorsements (S5 and S7) are due to the fact that regular mutation testing tools are not implemented to educational purposes. Then, some students recognize the importance of exploring mutation, however they highlight that efforts are necessary on using mutation testing tools properly.

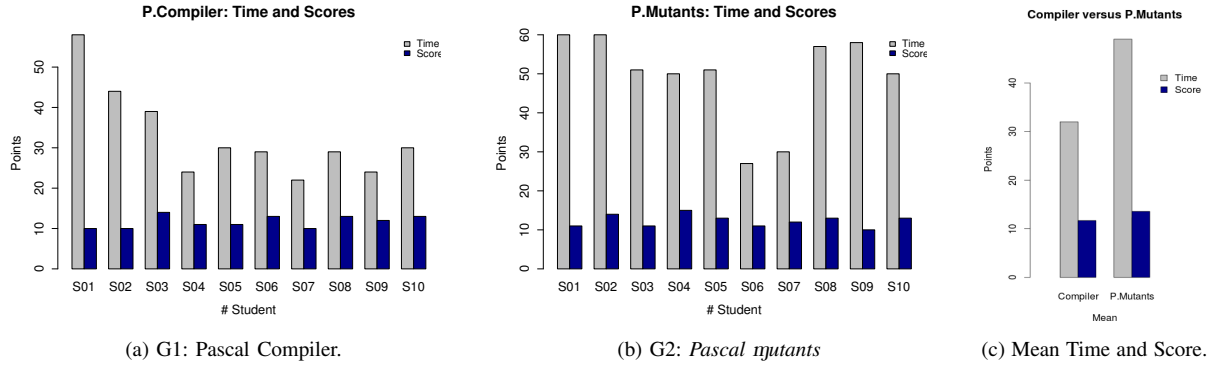


Fig. 4: Experiment: Times and Scores.

Most of the seniors believe mutation could be useful to complement their experiences when they were beginners, once testing tools specifically designed for educational purposes are explored. In addition, the students' contact with testing practices could contribute to revealing the importance of testing activities, providing the development of reliable applications.

Regarding Analysis 1, dividing the students into different groups may represent an effective environment for learning. In terms of code understanding, Table IV shows that mutation analysis leads the students to verify all of the code statements carefully, helping them to understand code issues more deeply. The score differences revealed by Table IV are small, however they are favorable to the group which has used mutation analysis to conduct the activity. The small differences are justified because the study conduct in this paper is considered small and the students were evaluated based on only 5 questions. Then, we still consider these results as significant. We believe this difference trends to be more representative with more deep studies, for example, a study comparing two different classes from different departments or universities in which only one group has previous knowledge on testing concepts. In addition, we believe the characteristics of our study (i.e., number of subjects, target systems, etc.), when contrasted with the state of the art in literature, represent a first step towards the generalization of the results achieved in this study.

In this scenario, additional ideas to explore similar environments may evolve into two scenarios: (1) simulating real teams of developers and testers, and (2) using a test case developed by one group in order to test systems developed by different groups. In this context, it is important to plan all of the activities before the beginning of the course because the mutation testing criterion will take more time than regular activities. We believe other similar activities may influence novice programmers to improve their skills and their knowledge about general program comprehension. It is important to conduct broader experiments to obtain a more in-depth validation of the ideas presented in this paper. A possible future experiment may involve the observation of two different groups of students during a semester-long course. Another

possibility is to reproduce the same experiment using different programming languages and compare the results.

D. Threats to Validity

An *internal* threat to the validity of our study concerns the better results earned by G2, once they spent more time analyzing the source code during the mutation analysis. Furthermore, an *external* validity to the study is the fact that the results observed in our analysis are provided by a small-scale study. Regarding the survey analysis presented in Table IV, we noticed a threat associated with its *conclusion* validity, since senior students may be too far from first-year students to really remember what it was like, leading them to misinterpret the survey. We consider mutation testing a powerful resource to catch students' attention and improve their learning processes, however students have to face continued experience on mutation testing to make their learning process more valuable.

VI. CONCLUSION

This paper advances a preliminary study on evaluating the mutation testing criterion as to improve the learning processes of novice students in programming courses. We present a two-fold analysis (an practical analysis and a survey assessment) on the effects of using mutation testing to improve learning processes in programming courses. As methodology, we developed and provided an open-source mutation testing tool. *Pascal mutants* is specially designed for education purposes. Results reported in this paper are enough to reveal that mutation testing criterion is profitable for programming courses. Two main contributions are associated with this study: (1) the analysis states that mutation testing can be seen as a promising testing criterion to support teaching programming foundations to novice students; (2) this study provides a more stable version of *Pascal mutants* which supports mutation testing to the educational purpose of teaching programming for novices students. We consider this second contribution as relevant, once there is a notable lack of testing tools for educational purposes. Also, we consider the usage of software testing concepts as a profitable strategy to teach novice programmers, composing the main implication of our research.

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Diversity and Anxiety: A Case Study on Collaborative Testing

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Abstract—In order to reduce students' test anxiety, collaborative testing was suggested as an evaluation strategy. However, few studies have focused on testing group construction, especially when an important factor, i.e., group diversity is taken into consideration. In this paper we conducted a case study to assess the association between group diversity and test anxiety in collaborative testing. The results observed may indicate that: 1) around 20% of students suffered from test anxiety to some extent in either an individual test or a collaborative test; 2) collaborative testing could alleviate test anxiety, whereas the effect is not statistically significant; 3) there exists a moderate positive correlation between group diversity and test anxiety in collaborative testing. The results of the study may suggest limiting group diversity in collaborative testing in order to alleviate test anxiety.

Keywords—group diversity, test anxiety, collaborative testing

I. INTRODUCTION

Test anxiety is a prevalent problem among the students of the world, and it hinders students' performance resulting in emotional or physical distress, difficulty concentrating, and emotional worry. In order to cope with the problem, the literature suggests various solutions. One solution is to evaluate students by collaborative testing where discussion and information sharing are allowed. It is a common belief that collaboration reduces test anxiety by removing the sense of competition and giving students a sense that they are not alone. A previous study showed that students rated collaborative tests as more pleasant. Students reported experiencing less anxiety and indicated they continued to learn about the material during testing [1].

When collaborative testing is used as evaluation strategy, an interesting question that arises is how to construct test groups. Group diversity has received considerable attention in enhancing group work achievement, however diversity may also introduce an additional problem from a psychological viewpoint. For instance, one problem is the free-rider or sucker effect where non-performing group members reap the benefits of the accomplishments of the remaining group members with little or no cost to themselves. [2]. This happens frequently when the group members have huge differences in functional ability. Also, other studies discovered evidence of the association between multiculturalism and uncomfortable feelings in a language class [2].

In this paper we conducted a case study to assess the associ-

ation between group diversity and test anxiety in collaborative testing. We address the following three questions.

RQ1: How prevalent and how severe is test anxiety? Previous literature has mainly focused on the prevalence and effects of test anxiety among children in compulsory education.

RQ2: Does collaborative testing alleviate test anxiety? To what extent is the effect? It is a commonly held belief that collaborative testing reduces anxiety. Therefore, it is of interest to measure the significance of the effect by using an existing scale and statistical inference.

RQ3: Does group diversity have any influence on test anxiety? In the literature, researchers have shown that diversity had significant influence on learning outcomes and several group construction models have been developed for the purpose of maximizing diversity within groups [3] [4]. Therefore, it is also of interest to investigate whether diversity affects students from a psychological viewpoint.

The rest of this paper is organized as follows. Section II describes the background knowledge of collaborative testing and group diversity. Section III provides a detailed explanation of a case study including participants, data collection and analysis. Section IV discusses conclusions and possible future research directions.

II. BACKGROUND

This section first presents the background knowledge including advantages of collaborative testing and testing anxiety, it then reviews group diversity, which is an important factor when constructing groups.

A. Testing Anxiety and Collaborative Testing

"Test anxiety is a combination of physiological over-arousal, tension and somatic symptoms, along with worry, dread, fear of failure, and catastrophizing, that occur before or during test situations" [5]. It is often caused by many factors like fear of failure, lack of preparation, poor test history. The symptoms are not only physical but also emotional and behavioral/cognitive. Symptoms include fear, disappointment, difficulty concentrating, thinking negatively and so on. It is a commonly held belief that test anxiety hinders the students testing and learning performance and has adverse effects on the students testing outcomes. According to a survey, test anxiety occurs frequently among college students especially

for the subject of math, and it is more likely to occur among women than among men and among students with inadequate high school math backgrounds [6]. Collaborative testing refers to a test environment where several people work together to come up with the solution and cooperation and discussion are involved. Individuals in the same group share resources including task-related knowledge, potentially useful information, possible solutions or ideas, so that collaborative learning leads to deeper understanding of the materials [7]. Collaboration reduces anxiety due to skills deficit since students know they will have the knowledge of other students to aid them [1]. Lusk et.al. argued that collaborative testing provided students with the opportunity to become more proficient with critical thinking and collaboration skills, and all students reported decreased test anxiety [8].

B. Group Diversity

In group organization theory, group work diversity refers to the degree of difference among group members. Although the effects of group diversity are still unclear and at times findings seem inconsistent, there is a lot of evidence in the literature showing positive effects of group diversity on group work achievement. It has been argued that people with different demographic backgrounds have qualitatively different life experiences and thus differ in their knowledge, attitudes, and opinions. This implies that demographic diversity increases the knowledge pool of the group and as a consequence has positive implications for group cognitive complexity [9]. Pelled et al. [10] studied the effects of functional diversity and their hypotheses implied that ability diversity would be positively related to group performance. Jehn et al. [11] found that informational diversity was positively related to group performance and commitment. The diversity in attitudes and values may be associated with positive outcomes (e.g., social integration) or may be unrelated to these outcomes. A number of researchers have argued that it is also important to take into account differences that may be neither readily visible nor job-related, such as differences in personality, attitudes, and values [12]. The use of interest and attendance to predict students' performance has been explored and the results verified their effectiveness. Also, it has been widely reported and commonly accepted that religion has significant effect on the personal behavior [13].

III. A CASE STUDY

We conducted a case study to explore our research questions. We first provide the information about participants, then describe the data collection procedure, then analyze the results, and finally report the threats to validity.

A. Participants

TABLE I. GROUP SIZE

Test	form	#students	#groups	average size
Test1	individual	71	—	—
Test2	collabrative	69	24	2.91

We conducted a case study in a mathematics class in the fall semester of 2014 at a university in Connecticut, USA¹. The

¹The experimental study was approved by institutional review board.

class (2 sections) consisted of 71 students. The students were enrolled in a first-year undergraduate mathematics course for non-STEM majors. Students took two monthly exams of the same complexity². It was announced that the grades of both the exams would count as parts of the final course grades. The first exam was an individual test, whereas, the second exam was a collaborative test. In order to ensure the diversity within group, the groups were constructed using a clustering-based grouping model proposed in our previous study [3].

B. Data Collection

With the purpose of quantifying the testing anxiety, we used the Westside Test Anxiety Scale, which is a brief instrument designed to identify students with anxiety impairments. The scale items cover self-assessed anxiety impairment and cognition which can impair performance [14]. We obtained this information by questionnaire shortly after the test. It is important to note that we revised some questions since the original Westside Test Anxiety Scale questionnaire is more general. For example, question 3 was originally:

“During important exams, I think that I am doing awful or that I may fail”.

whereas, we changed the object and the revised version was

“During this exam, I think that I am doing awful or that I may fail”.

Students answered questions about anxiety on a 5 point scale, from extremely or always true, to not at all or never true. The final anxiety score was computed by totaling the individual questions and interpreted from comfortably low to extremely high.

In order to formally measure the diversity within group, each student is represented as a d -dimensional real vector. In this study we employed three categories of diversity features; so-called demographic, functional, and personality diversities, following our previous study [3]. The diversity of the group is computed as the sum of distance between each pair of students in this group. For instance, for a group containing n student, the diversity is computed as:

$$diversity = \sum_{i=1}^{n-1} \sum_{j>i}^n d_{ij} \quad (1)$$

where d_{ij} is the Euclidean distance between students x_i and x_j . We obtained demographic and personality features by questionnaire. For the functional features, we simply exported the students' grades from the Grading Center in the Blackboard system³.

C. Results

We go back to address the research questions posed in Section I.

²We gave the two tests in a similar class at another university during the previous calendar year. Both of the tests were individual tests. The mean of students' grades were close, and the difference between the two projects were not significant (indicated by a hypothesis test). Therefore, we carefully claim the two test are of the same complexity.

³Blackboard is an online teaching system at this university.

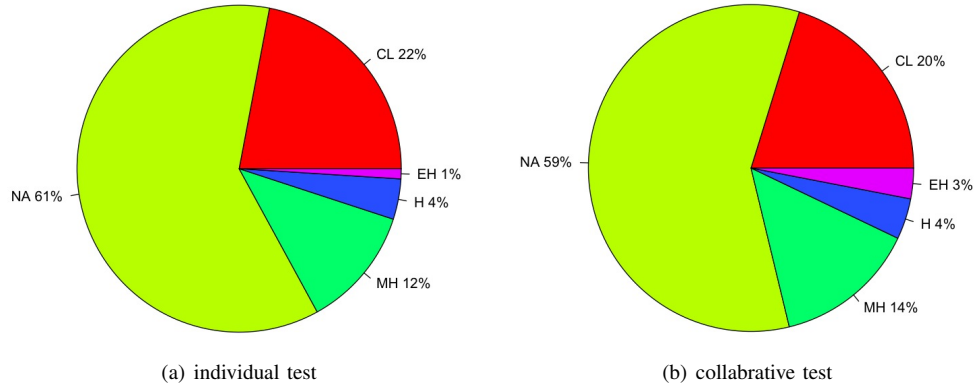


Fig. 1. The percentage of different anxiety level in individual and collaborative test. CL: comfortably low; NA: normal average; MH: moderately high; H: high; EH: extremely high

RQ1: How prevalent and how severe is test anxiety? Figure 1(a) and Figure 1(b) depict the percentage of each anxiety level for the individual test and the collaborative test respectively. The percentage of comfortably low test anxiety accounted for around 20%, and normal/average test anxiety accounted for around 60%. The percentage of three levels of high test anxiety ranged from 1% to 12% in the individual test, and ranged from 3% to 14% in the collaborative test. We also observed that the differences in percentage for the same anxiety levels between the individual test and the collaborative test were negligible. To sum up, around 20% of the students in this class suffered some extent of test anxiety in either individual test or the collaborative test, and a small percentage, 1% to 3%, of students suffered extremely high test anxiety. The results are consistent with other surveys and studies.

RQ2: How significantly does collaborative testing alleviate test anxiety? As Table II shows, the mean of anxiety score was lower in the collaborative test compared to the individual test, and the difference was around 0.2, which may indicate that collaborative testing alleviated test anxiety. Figure 2 illustrated the distribution of detailed data for both tests. In order to further compare the difference of testing anxiety between the individual test and the collaborative test, we performed a hypotheses test which is an essential method in statistical inference. We formulated the null and alternative hypotheses as follows:

- $H_0 : \mu_{individual} = \mu_{collaborative}$
- $H_1 : \mu_{individual} \neq \mu_{collaborative}$

where μ is the mean. We employed the Wilcoxon rank-sum test. The Wilcoxon test is a non-parametric alternative to two-sample t-test, which does not rely on the assumption that data are normally distributed. [15]. As Table II shows, the p -value for the test is higher than the 0.05 threshold. We conclude that there is not evidence to support the claim that mean scores for the two testing strategies are statistically significantly different.

TABLE II. THE ANXIETY SCORE IN INDIVIDUAL TEST AND COLLABORATIVE TEST

individual		collabrative		p-value
mean	stdev	mean	stdev	
2.55	0.68	2.35	0.69	0.77

TABLE III. THE CHANGE OF ANXIETY SCORE

$\uparrow\%$	$\downarrow\%$	noChange%
17.39	57.97	24.63

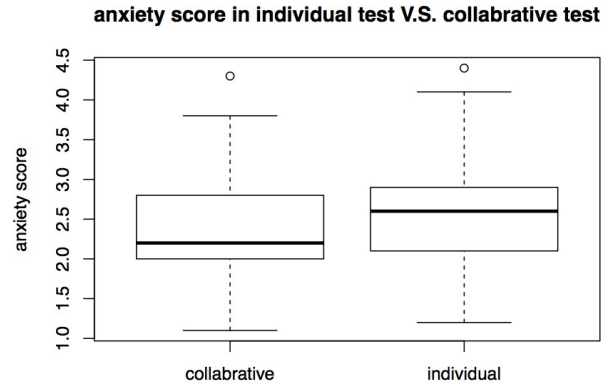


Fig. 2. Boxplots of student anxiety in the two tests

A further consideration focuses on the change of anxiety score for each student, and a new variable *anxietyChange* was derived. If a student's anxiety scores were a and b in the individual and collaborative tests respectively, the *anxietyChange* value is $b - a$, which measured the difference of his/her anxiety for the two tests. A positive value of *anxietyChange* indicated an increase of anxiety, denoted as \uparrow in the table. Similarly, a decrease was denoted as \downarrow in the table. We computed the percentage of students in each category; increase, decrease, and no change. We observed that the occurrence of a decrease in anxiety score is most frequent, 57.97%, followed by no change with 24.63%, and increase with 17.39%. For our case study, collaborative testing alleviated testing anxiety, however, these results were not statistically significant.

RQ3: Does group diversity have any influence on test anxiety? We used the Pearson correlation coefficient to measure the strength of the linear association between the explanatory variable *diversity* and the dependent variable *anxietyChange*. The value was 0.58 which indicated there was a moderate positive linear relationship. We further used the Spearman's rho coefficient, which is often used to measure the association between two variables when at least one of the variables is

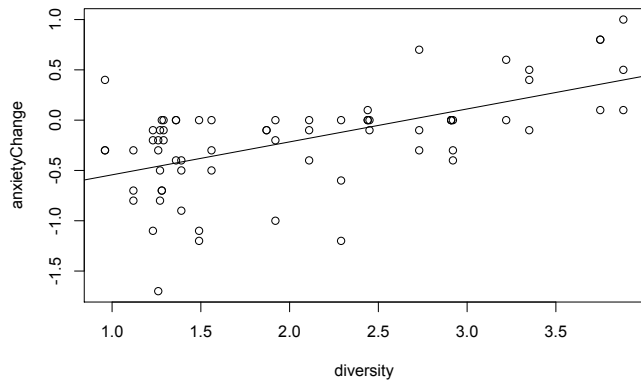


Fig. 3. scatter plots and regression

ordinal. The coefficient was 0.56, which means there was a moderate positive linear relationship. In order to have a better insight of the correlations, we performed a linear regression analysis and created a scatter plot of the two variables in Figure 3. The results demonstrated that there was a moderate positive correlation between the diversity and test anxiety.

We recorded some typical feedback from the students who had an increase in anxiety when taking the collaborative test. It is obvious that the uncomfortable feelings were caused by severe functional or personnel diversity, which verified that diversity may cause anxiety in collaborative testing.

"My partner actually can not even come up with one solution. I feel like I am doing everything, and also explain to him in that group."

"I believed my mark is destroyed in the terrible group."

"I hate group test, too much pressure when another one staring at you working all the time."

"It is good we share ideas to get to solutions, but I still prefer to working with my friends rather than a random peer."

D. Threats to Validity

We collected data from a single mathematics class. Different subjects have different characteristics. It is of interest to investigate whether the results can be applied to other subjects or not. In this case study, an individual exam was taken earlier than collaborative exam. Internal threats may be introduced by maturation, since the participants are likely to change in terms of their skills, abilities, understanding of the subject matter and proficiency of reading related materials. Further experiments are needed with a different sequence of exams. We used the features and techniques proposed in our previous study to measure the group diversity and to form the groups [3]. We defined a new quantity variable, i.e., *anxietyChange* for the purpose of measuring anxiety difference. In education academia, there are some other evaluation methodologies to assess the group diversity and anxiety level. It would be of interest to construct the assessment by other methodologies.

IV. CONCLUSIONS AND FUTURE WORK

In this paper we conducted a case study to assess the association between anxiety and group diversity for collaborative testing. We observed that around 20% students suffered some extent of test anxiety during either individual testing or the collaborative testing. We also found evidence that collaborative testing alleviates test anxiety, whereas, the effect is **not** statistically significant. Finally, we found there might be a positive correlation between group diversity and test anxiety. In order to validate the conclusion, further studies are needed, especially on other subjects and using participants from other majors. In the future we may also try to identify which diversity features have a positive influence on test anxiety, and which features have a negative influence.

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Usability challenges in digital learning solutions

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Usability is a key element in successful software. Ensuring the technical usability of a learning solution enables users to focus on their main task, learning. The purpose of this paper is to demonstrate the results of heuristic usability evaluations of digital learning solutions. Heuristic evaluations were conducted on 24 digital learning solutions from one country (Finland) and two country groups (Asian countries and Spanish speaking countries) concentrating on the usability of the user interface of each evaluated solution. The main results of this study indicate that a few heuristics cover the majority of all usability problems (UPs) observed in learning solutions, but these heuristics contain a relatively low proportion of the UPs rated as severe. The results also indicated differences in the usability problems (UPs) observed between different types of digital learning solutions and between digital learning solutions from different countries or country groups.

Keywords—usability; heuristic evaluation; digital learning solutions; usability problems

I. INTRODUCTION

Use of digital learning solutions in learning and teaching has become more popular over past decades (e.g. [12]). There is a wide variety of different digital learning solutions available, but also digital solutions that have not been originally designed for learning are utilized [7]. However, in many cases digital solutions are used in ways their designers had not imagined [9]. Digital solutions that have not been designed for educational use like social media tools [2], virtual worlds [28] and mobile devices [9] are also used in teaching and learning. The use of digital solutions that have not been designed for educational use can lead to challenges with usability [15], particularly in light of usage purpose and context [9].

Evaluating the usability of a digital solution can be approached via various techniques. Techniques include methods for user testing and usability inspections conducted by usability experts. User testing methods range from simple user testing situations [8] to usability questionnaire techniques ([3] [27]). Usability inspection techniques are used mainly to assess

the technical usability of a digital solution by means of heuristic usability evaluations [16], cognitive walkthroughs ([20][29]), time-testing [25] and error counting [4]. These methods have value for various situations, with certain outcomes in mind and can be used on various types of software.

Usability challenges have been explored on various devices, software and services including medical devices [31], software for work contexts [19], e-learning platforms [5], digital textbooks [10] and e-learning courses [30]. Common usability challenges in devices, software and services cover various topics including consistency, informing users about system status, providing feedback and more guidance to users, navigational structures and aesthetic integrity of the user interface ([5][10][30]). Although the topics covered in previous research vary, based on the set of heuristics used, a commonly shared feature seems to be that the majority of usability challenges have concentrated only on a small amount of key issues such as consistency and informing the user about system status ([5][19][30][31]).

Mayes and Fowler [13] argue that the usability of digital learning solutions cannot be measured similarly to software aimed for work contexts. They point out a paradox in digital learning solutions, in that usability is not necessarily a prerequisite for deep learning and argue that approaching learning as a conventional task can be a misguided approach, since learning is commonly a “by-product of doing something else” and that it is this “something-else” that should be supported [13]. However, Kukulska-Hulme [9] raises the issue that for the most part, mobile learning happens on devices that have not been designed with educational use in mind. All devices and software, whether they are designed for educational use or not, could benefit from ensuring a basic level of technical usability, because it enables learners to focus on their learning tasks instead of tackling problems caused by technology [22].

II. HEURISTIC EVALUATION

In this study the aim is to further explore usability challenges in digital learning solutions. The paper is based on an ongoing Finnish research project “Systemic Learning Solutions (Systech)”, which aims at developing research-based principles for the design and use of digital learning solutions (see [6]), where usability evaluation is part of the principles for the design of learning solutions. Main aim of the usability evaluation was to identify usability challenges or problems (UPs) and their severity with heuristic evaluations of digital learning solutions. The study also examined tentative differences in two background variables: firstly, between types of digital learning solutions and secondly, between countries in which the learning solutions were designed.

The following sections address these questions through breaking down and explaining the nature of heuristic evaluations, as well as outlining the empirical process of this study. The results are presented in terms of usability issue type and distribution of usability percentages. Differences between country groups are reflected in the results discussions, which subsequently inform our conclusion which focuses on existing heuristic evaluation methods while proposing improvements based on this study’s findings.

Heuristic evaluation is a systematic method to evaluate the usability of a user interface of software [16]. The heuristic evaluation of software user interfaces is conducted by a small number of evaluators, who go through the interface and judge how well its design complies with commonly accepted usability principles called ‘heuristics’ ([1][17]). Heuristic evaluation is one of the most commonly used usability inspection methods, due to its low cost in comparison with other testing methods and intuitiveness of use [30].

Heuristic evaluations have been developed from extensive design principles [26] to more manageable sets of heuristics ([16][22]) that can be used in conducting these heuristic evaluations (Table I). Heuristic evaluations are commonly conducted in a way similar to that suggested by Nielsen and Molich [16], which have been further developed by Nielsen ([17][18][20]). Furthermore, Nielsen’s [20] work on improving the effectiveness and enhancing the explanatory power of heuristic evaluations has made heuristic evaluation a popular subject of study.

TABLE I. NIELSEN’S [21] TEN USABILITY HEURISTICS FOR USER INTERFACE DESIGN

Heuristic	Description
Visibility of the system status	The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
Match between system and the real world	The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
User control and freedom	Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
Consistency and standards	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
Error prevention	Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
Recognition rather than recall	Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
Flexibility and efficiency of use	Explanation: Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
Aesthetic and minimalistic design	Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
Helping users recognize, diagnose, and recover from errors	Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
Help and documentation	Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large

One branch of heuristic evaluation study has focused on increasing the explanatory power of heuristics in analyzing the usability of digital learning solutions (e.g. [22][23][24]). Various attempts have been made to create a set of heuristics that includes both the technical [20] and pedagogical usability aspects [22]. The main aim of these heuristic sets, that combine technical and pedagogical usability has been to emphasize the need for inclusion of pedagogical features when assessing the usability of digital learning solutions ([14][22][23]). In addition, Magoulas, Chen, and Papanikolaou [11] have integrated heuristic evaluation with layered evaluation of adaptive learning environments.

III. RESEARCH DESIGN

The main aim of the study was to evaluate the amount and severity of usability problems (UPs) in digital learning solutions. In addition, the study aimed at exploring the tentative differences between country groups in which the evaluated digital learning solutions are designed and digital learning solution types.

A. Evaluation procedure

The usability evaluation of digital learning solutions were conducted via heuristic evaluation based on Nielsen's [21] ten usability heuristics (see Table I). The usability evaluations were conducted by two researchers who individually / independently evaluated each digital learning solution and reported their observations. Each of the observations was: marked with one or more heuristics to which it related to; a description of the usability problem (UP); a rating of the severity of the problem; and a suggestion on how to fix the problem. The severity of each UP was marked as either minor, moderate or major according to whether the digital learning solution could be used or if the UP prevents the use of the digital learning solution or a part of it.

The evaluators were researchers with a sizeable knowledge about usability and usability testing methods, but differed in their other expertise. One of the researchers was experienced in the fields of usability, user experience and design. The other researcher was experienced in the fields of usability, education and pedagogical use of information and communication technology.

B. Description of digital learning solutions

The heuristic evaluation was conducted for altogether 24 digital learning solutions from five countries. These digital learning solutions were selected based on suggestions from Systech research and company partners in five countries: Chile, Hong Kong, Finland, South Korea and Spain. These individual countries were later grouped based on cultural similarity to two country groups: Asian countries (Hong Kong and South Korea) and Spanish speaking countries (Chile and Spain). Finland was left as an individual country since the amount of digital learning solutions available from Finland (10) exceeded the

combined totals of learning solutions for either of the other country groups Asian countries (8) and Spanish speaking countries (6).

These digital learning solutions represent a diverse sample of technological learning solutions, with different use contexts (from classroom use to extracurricular activities), usage purposes, intended learning outcomes and user groups (from preschoolers to adult learners). They were divided into two groups, namely 1) content learning solutions (altogether 12 digital learning solutions), and 2) tools and platforms (12 digital learning solutions). Content learning solutions focused on teaching a particular preset of data or skills, with none or only minimal options for users to modify content. The selection of content learning solutions represented online learning environments for various subjects (e.g. mathematics, languages and music). They offered experiences in content enrichment, games and exercises. Tools and platforms were solutions for creating or distributing content from multiple sources or they were collections of materials. The tools and platforms were course material and other content (e.g. routes) creation software, solutions for testing knowledge, video and game platforms and platforms for applied learning, such as physics simulations or driver education.

C. Analysis

The data consisted of 24 heuristic evaluation report sheets, where one sheet combined all the observations made by two evaluators about a digital learning solution. Evaluator data was combined and observations of the same usability problem were combined to remove redundancy. There were altogether 418 observed usability issues in the 24 evaluated digital learning solutions. These observations consisted of description of the issue, severity rating, suggested solution for the issue and one more heuristics it violated. One observation could be a violation of one or more heuristics and these occurrences of heuristics were counted as usability problems (UPs). The total amount of usability problems for all 10 heuristics was 509, which is higher than the amount of observations (418), showing that there were numerous instances where individual usability issues addressed more than one heuristic.

The data was analyzed according to the amount of UPs and severity ratings for each heuristic. The UP amount and severity ratings were further analyzed according to country group the digital learning solutions belonged to and the type of digital learning solution they represented.

IV. RESULTS

A. Usability problems of digital learning solutions

1) *Amount:* The data analysis revealed large variation in the amount and severity of usability problems across the ten heuristics (Table II). It was realized that five heuristics covered altogether 73 % of the observed usability problems.

The most frequent heuristic was consistency and standards with 27 % of total UPs. The distribution of other four most frequent heuristics varied between 10-12 %. For the remaining five heuristic the distribution varied between 5-7 %.

2) *Severity*: Variation in the severity ratings within heuristics was for the most part shared by heuristics and only two showed a different variation of severity ratings. Eight heuristics had a clear pattern of having high amounts of minor usability problems (54-74 %); a modest amount of moderate UPs (12-31%) and a relatively low amount of major usability problems (3-16%). Out of these eight heuristics only one heuristic match between system and the real world had more major (16%) than moderate usability problems (12%), while others had more moderate (19-31%) than major usability problems (3-16%). The greatest difference in severity ratings could be observed in two heuristics: ‘error prevention’ and ‘helping users recognize, diagnose, and recover from errors’, which have 40-52% of major usability problems, 26% moderate UPs and 22-34% of minor UPs.

3) *Cross-analysis of amount and severity*: The five most frequent heuristics also share the feature of having more than 59% of usability problems connected to them given a severity rating of being minor usability problems. The three heuristics with the lowest to third lowest percentage of all observations show a similar trend by having more than 53% of all observed usability problems rated as minor usability problems and under 16% rated as major usability problems. The remaining two heuristics that deal with errors, ‘error prevention’ and ‘helping users recognize, diagnose, and recover from errors’ both share a feature of having more than 39% of all usability problems rated as major usability problems, which will be discussed in more detail later on in this paper.

B. Description of significant heuristics/usability problems

1) *Heuristic category - Consistency and standards*: The data analysis revealed large variation in the amount and severity of usability problems across the ten heuristics (see Table II). It was realized that five heuristics covered altogether 73 % of the observed usability problems. The most frequent heuristic was ‘consistency and standards’ with 27 % of total UPs. The distribution of other four most frequent heuristics

varied between 10-12 %. For the remaining five heuristic the distribution varied between 5-7 %.

TABLE II. UPS AND SEVERITY RATINGS

Heuristic	UPs (%)	Severity		
		Minor (%)	Moderate (%)	Major (%)
Consistency and standards	27.1	73.9	23.2	2.9
Visibility of the system status	12.2	59.7	24.2	16.1
Match between system and the real world	12.0	72.1	11.5	16.4
Aesthetic and minimalistic design	11.2	73.7	19.3	7.0
User control and freedom	10.2	67.3	23.1	9.6
Error prevention	7.5	34.2	26.3	39.5
Flexibility and efficiency of use	5.7	69.0	24.1	6.9
Help and documentation	5.1	53.8	30.8	15.4
Recognition rather than recall	4.5	69.6	21.7	8.7
Helping users recognize, diagnose, and recover from errors	4.5	21.7	26.1	52.2
Total	100.0	64.4	22.2	13.4

When looking at differences between three groups of countries (Asian countries, Finland and Spanish speaking countries) some differences in the severity ratings between country groups can be observed (Table III). The distribution of severity ratings in the heuristic ‘consistency and standards’ shows that digital learning solutions from both Asian countries and Spanish speaking countries have a high number of UPs rated as minor (82-85%). Differing distribution can be observed in the Finnish solutions where there are 60 % of minor UPs and 35% of UPS with moderate severity.

TABLE III. DIFFERENCES IN USABILITY PROBLEMS FOR THREE HEURISTICS IN FINLAND AND TWO COUNTRY GROUPS

Heuristic	All UPs (%)	Asian countries			Finland			Spanish speaking countries		
		Minor (%)	Moderate (%)	Major (%)	Minor (%)	Moderate (%)	Major (%)	Minor (%)	Moderate (%)	Major (%)
Consistency and standards	27.1	81.6	18.4	0.0	59.2	34.7	6.1	84.6	7.7	7.7
Error prevention	7.5	33.3	33.3	33.3	30.8	30.8	38.5	50.0	0.0	50.0
Helping users recognize, diagnose, and recover from errors	4.5	30.0	40.0	30.0	9.1	18.2	72.7	50.0	0.0	50.0

TABLE IV.

USABILITY PROBLEMS IN CONTENT SOLUTIONS AND TOOLS AND PLATFORMS FOR THREE HEURISTICS

	Content solutions	Severity			Tools and platforms	Severity		
<i>Heuristic</i>	<i>% of all content solution UPs</i>	<i>Minor (%)</i>	<i>Moderate (%)</i>	<i>Major (%)</i>	<i>% of all tools and platforms UPs</i>	<i>Minor (%)</i>	<i>Moderate (%)</i>	<i>Major (%)</i>
Consistency and standards	31.7	78.1	20.3	1.6	24.1	70.3	25.7	4.1
Error prevention	9.1	32.1	28.6	39.3	5.0	40.0	20.0	40.0
Helping users recognize, diagnose, and recover from errors	4.5	44.4	11.1	44.4	4.6	7.1	35.7	57.1

This difference could be further explored by looking at the distribution of usability problems within the heuristic consistency and standards between two types of digital learning solutions (Table IV). Overall trend in both content solutions and tools and platforms is similar when looking at UPs from all 24 digital learning solutions. Most of the UPs 70-78 % are rated minor, 20-26 % as moderate and 2-4 % as major.

2) *Heuristic category: Preventing and recovering from errors*: The heuristics ‘helping users recognize, diagnose, and recover from errors’ and ‘error prevention’ contain respectively 5 % and 8 % of all UPs (Table II). Even though the amount of UPs is relatively low in both heuristics the amount of UPs rated as major. ‘Helping users recognize, diagnose, and recover from errors’ and ‘error prevention’ have a distribution of 22-34% of minor, 26% moderate and 40-52% major UPs. UPs for the two heuristics consisted of issues with input formatting, password generation and recovery, nonfunctional items and error situations and messages.

The variation between Asian countries, Finland and Spanish speaking countries show some differences in the severity ratings of the heuristics ‘helping users recognize, diagnose, and recover from errors’ and ‘error prevention’ can be observed (Table III). These two heuristics have both in Asian countries and Spanish speaking countries a similar distribution within both country groups. Digital learning solutions from Finland show a clearly different distributions between these two heuristics. ‘Error prevention’ shows a pattern that is similar to the digital learning solutions from Asian countries in regards to the severity ratings, with all severity rating groups having almost one third of all UPs. However ‘helping users recognize, diagnose, and recover from errors’ shows a clear difference in distribution having 9 % minor, 18% moderate and 73 % major UPs.

When comparing digital learning solution types (content solutions and tools and platforms) in respect to the two

heuristics, ‘error prevention’ and ‘helping users recognize, diagnose, and recover from errors’ (Table IV), there are merging patterns in the distribution of severity ratings. Content solutions have a similar pattern for both heuristics with percentages of minor (32-44 %) and major (39-44 %) being similar and the amount of moderate UPs being the smallest (11-29%). Tools and platforms have similar pattern in ‘error prevention’ with 40% minor, 20% moderate and 40% major UPs, but not in ‘helping users recognize, diagnose, and recover from errors’. Tools and platforms a distribution of 7% minor, 36% moderate and 57% major UPs in helping users recognize, diagnose, and recover from errors.

V. DISCUSSION

The main results from this study verify the knowledge from earlier research ([5][19][31]) that a few heuristics cover the majority of all usability problems. Significant amount (27%) of UPs were categorized under one heuristic, namely ‘consistency and standards’, and the five heuristics with highest amount of UPs covered 73 % of all UPs. However, even though these heuristics covered the majority of all UPs more than half of the UPs in these heuristics were rated as minor. In general UPs in these heuristics were considered by the evaluators as issues that may hinder the learnability and efficiency of use and the overall user experience, but do not necessarily prevent completing tasks with the digital learning solution.

Heuristics that showed the largest proportion of major usability problems were ‘error prevention’ and ‘helping users recognize, diagnose, and recover from errors’. These two heuristics represent 12 % of all UPs, with more than half of the UPs rated as major UPs. This would suggest that UPs related to heuristics dealing with errors are mainly perceived as UPs that should be fixed most urgently. However, in this study the amount of observations under heuristics ‘helping users recognize, diagnose, and recover from errors’ and ‘error prevention’ is too low to make conclusions about the differences between country groups and digital learning solution types. The results of this study suggest that there is a

difference in the distribution of severity ratings of these two heuristics compared to the other eight heuristics that could be further explored with additional research. In previous research there has also been indications that the distribution of severity ratings might vary between heuristics ([19][30]).

The two types of digital learning solutions, tools and platforms and content learning solutions, showed a similar distribution of amount and severity ratings in almost all of the heuristics analyzed in more detail. Only one heuristic 'helping users recognize, diagnose, and recover from errors' demonstrated a shift in tools and platforms having more major UPs and moderate UPs than minor UPs. The category of tools and platforms consisted of a variation of digital learning solutions and in future research endeavors it might be relevant to divide the digital learning solutions in more precise subcategories.

There are four major limitations to this study: amount of digital learning solutions, digital learning solution types, number of evaluators and the set of heuristics used in the study. The first limitation is the sample size from each country or country group is not the same (6-10 digital learning solutions), which hinders the cross cultural analysis of the results. In future research the amount of learning solutions from each country or country group should be the same. Second limitation concerns the variation of digital learning solution types of from each country or country group and in future research each country should be represented by the same amount of each learning solution type. Furthermore the categorization of digital learning solutions might require additional research, since two large groups, content learning solutions and tools and platforms, might not be enough to explain the differences between digital learning solutions. Third limitation is the amount of evaluators, which in this study was two, while the recommended amount for heuristic evaluation is at least three evaluators [17], and in future research at least three usability experts will be used. The fourth limitation is the set of heuristics [21] used, which has been designed with the technical usability in mind and do not take pedagogical concerns into account. Pedagogical concerns in digital learning solutions will be addressed by further research of the digital learning solutions with pedagogical experts.

The suggested minimum number of evaluators for heuristic evaluation is three as was discovered by Nielsen [17] However as Nielsen's [17] results suggested, double specialists can find a significantly higher amount of UPs than regular usability specialists. Double specialists in Nielsen's [17] study consisted of usability experts who also had experience of the software type being evaluated. In this study two usability researchers, who had further experience of either learning solutions or interface design, which would classify them as double specialists in their respective fields. This would in general support the use of only two usability experts. However, additional experts could have benefitted the overall coverage of all UPs in the evaluated digital learning solutions and therefore in future research endeavors this matter should be addressed.

In general the set of ten heuristics [21] was considered by the evaluators to be useful, but for some usability problems it was difficult to find a suitable category and a broader set of heuristics might be needed. The evaluators noted that in particular problems regarding situations where errors had already occurred or features were not functioning at all, the current heuristics did not offer a category suitable to describe these types of UPs. These types of observations were categorized under the closest suitable heuristic such as error prevention, even though they do not completely fit the category.

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Applying Mindstorm in Teaching and Learning Process and Software Project Management

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Abstract—Some problems related to software process and project management improvement programs are detected during their implementation. Companies from the software projects segment have difficulty dealing with software Project management and quality models (CMMI, MPS-BR and PM-BOK) since the ways to implement the key areas of the process and the good practices inherent to Project management are interpreted with difficulty. This can be attested by the analysis of CMMI and CHAOS reports. In order to minimize the difficulties detected by the reports, the aim of this paper is to apply Mindstorms to the teaching and learning of software process and project management (key concepts used during process improvement and implementation). To validate the efficacy of the technique introduced in this paper, 8 experiments were carried out including university, high school courses and companies from the software production sector. Experimental results attest that the process of knowledge transfer in process and management using Mindstorms led to greater motivation, satisfaction and concepts consolidation.

Keywords— *Software Project management; Software Process; Teaching and Learning; Mindstorms.*

I. INTRODUCTION

Some problems related to software process and project management improvement programs are detected during implementation.

This fact can be attested through the analysis of CMMI and CHAOS reports.

In regards to process improvement, South America has 400 CMMI certified companies whereas India has 760. One of the greatest company's problems appointed by the CMMI report is to develop the necessary knowledge inherent to the creation and institutionalization of software processes.

In relation to management, 60% of 900 projects were either not concluded or had their time, cost or scope reduced. According to the CHAOS report, companies do not have efficient techniques to develop a project.

Universities are responsible for changing this scenario. To do so, they must create motivating processes to promote satisfaction and knowledge consolidation during their transference.

Within this context, the objective of this paper is to apply Mindstorms to the teaching and learning of software process and project management.

Currently, most research using Mindstorms as their teaching and learning object are found in the area of Programming (see Section 2). This paper's innovation is based on the use of Mindstorms as a resource for teaching process and process management.

Taking into consideration this context, this article tries to answer two questions:

1. Is it possible to apply Mindstorms as the object of teaching and learning process and project management?
2. Does the application of Mindstorms provide motivation during knowledge transfer in process and project management?

To validate the referred application, the authors of this paper carried out, from 2010 to 2014, 8 experiments, divided into two phases:

- A. From 2010 to 2012, the authors worked traditionally, i.e., without using Mindstorms as the object of process and software management teaching and learning. In this phase, 2 experiments were realized with 86 students from the Computer Engineering and Systems Analysis courses offered by Universidade Tecnológica Federal do Paraná (UTFPR), Campus of Cornélio Procópio.
- B. In the year 2013 and 2014, the authors carried out 6 experiments using Mindstorms as the object of software process and project management teaching and learning, with the duration of 345 minutes each. Four of them with Universidade Tecnológica Federal do Paraná (UTFPR) – Campus de Cornélio Procópio undergraduate courses; one with students (16) from the Systems Analysis Course; one with students (20) from the Computer Engineering Course and one with students (12) from the Graduate Program in Computing. One experiment was realized with 4 high school students and, finally, one in a company from the software production sector (4 collaborators). Total of students: 68.

During the experiment carried out in a traditional way - Phase A - 64.86% of the students absorbed the concepts related to software process and project management naturally. This percentage was captured by a formative evaluation¹ applied to students in subjects that deal with software process and project management concepts.

Experiments with Mindstorms - Phase B - It was possible to verify that 88.2% of the students absorbed the concepts related to software process and project management naturally, mainly under the perspective of activities planning and implementation. This percentile was captured by a formative evaluation and software project implementation, using a historical basis.

To verify whether Mindstorms promotes motivation in transferring knowledge about software process and project management, the authors of this paper mapped the level of satisfaction of the participants in the experiment - Phase B. Around 90% of them classified the level as 5 - very high level or 4 - high level (on the Likert scale).

To meet the proposed objectives, this paper was divided into 6 sections. Section 2 presents the works related to the use of Mindstorms in the academic environment. Section 3 proposes the application of Mindstorms to the teaching and learning of software process and project management. Section 4, introduces the methods and procedures used to validate the proposal. Section 5 presents the inferred results with the application of Mindstorms to the teaching and learning of software process and project management. Finally, Section 6 discusses the conclusions delineated by this work.

II. RELATED WORKS

The Mindstorms EV 3 is an evolution of the NXT version. The EV3 is a robotics kit focused on technological education and this kit contains a processor, a proprietary software and touch, light and sound sensors. More information about the Mindstorms visit the site: www.lego.com/en-us/mindstorms.

Currently, the use of Mindstorms [1] as a pedagogical tool includes the areas of Automation, Control, Robotics, Physics, Math and Computer Programming.

Brandt and Colton [2] use Mindstorms to teach Programming, mechanics and control to freshmen students from the Brigham University Mechanics Engineering Department. The objective of the work is to introduce interface and sensing. The authors conclude that Mindstorms is a versatile platform which is greatly accepted by the students. With its use, the authors have improved the learning of Mechanics, Sensors Calibration, Programming Language and the Principles of Physics.

A proposal to systematize the teaching and learning of Robotics with the use of Mindstorms was developed by Universidade Federal de Campina Grande in 2008. In this

paper, the authors [3] present a technical bias that permeates the proposal.

Tester [4] used Mindstorms to develop skills connected with innovation and communication management. The work was developed with 70 students from a Northern Arizona University Graduate Course. Results were collected by the author through direct observation of the students' behavior. The author concludes that most students gained considerable knowledge about the area of Communication Management.

Mindstorms has also been used Schumacher, Welch, Raymond [5] to teach Programming to Electrical Engineering and Computer Science freshman students from the Military Academy in the US. The authors conclude that the use of Mindstorms turned the solutions of complex problems by the students more dynamic and with a greater degree of accuracy.

Caci and D'Amico [6] used Mindstorms to develop cognitive skills in children. The authors work with cognitive principles focusing on non-verbal intelligence, visual communication, logics and robots programming. The authors worked with ten 11 -year-old students, divided in 2 groups with 5 students each. The groups worked on the physical construction of a robot and developed, in 12 meetings, a logic project using processes connected to Programming. After the development of the work, the authors conclude the cognitive skills go under significant improvement.

Calvo and Parianaze [7] propose the union of Mindstorms and PBL (Problem Based Learning) for the teaching of Programming in Electronics Engineering and Industrial Engineering Computing subjects. The authors report on experiences carried out in 2008 and 2009. The work concludes, qualitatively, that the students improved significantly their learning in questions related to Computer Programming.

Researchers from Dresden University and Málaga University developed 3 experiments at the graduate level, using Mindstorms [8]. Skills connected to the project and software development were delineated together with the students that used the referred robot. The authors proposed to the students a competition using Mindstorms. During the competition, the students had to develop software in which the robot was able to exit any maze. The authors concluded that the application of the technique improved significantly issues related to the development of structured programs and the understanding and the work with sensors and actuators.

Gandy et al. [9] used Mindstorms in the University of Sunderland Computing Department., UK in 2008 and 2009, to teach Java Programming. The work was developed with graduate students. The authors of the work used Lejos (Java Virtual Machine that works together with Mindstorms). The work was carried out with 49 students and 85% of them stated that the robot collaborated decisively with the learning of the language.

Finally, there are several other works that use Mindstorms as the object of learning [10]. They all apply the referred object to a restricted group of students to teach concepts connected with Computing and Engineering.

¹ The objective of the formative evaluation is to provide subsidies so that the students can understand their own learning process and the functioning of their underlying cognitive capacities during problem solving.

III. APPLYING WINDSTORMS IN THE TEACHING AND LEARNING OF SOFTWARE PROCESS AND PROJECT MANAGEMENT

The application of Mindstorms to the teaching and learning of software process and project management was divided into 3 phases (see Figure 1):

1. The objective of Phase 1 is to compose and introduce the theoretical background that will characterize the teaching and learning environment. In our case, this theoretical background is characterized by questions connected with software process and project management. In this phase, the teacher or tutor is responsible for composing the material and introducing it to the student. The introduction can be done during the lesson (traditional classroom) or use Distance Learning techniques.
2. In Phase 2, the teacher or tutor is responsible for the selection and composition of objects that will characterize the motivating environment for the teaching and learning. In our case, Mindstorms was the selected object. The responsibility of the professor/tutor in this phase is to define the way the student will work with the objects and map the abstract questions related to the theory, make them concrete.
3. The objective of Phase 3 is to assess the whole learning process. This assessment takes place in two steps: 1 - the student is evaluated through tests or practical works; 2- the teaching and learning process is evaluated by the students.

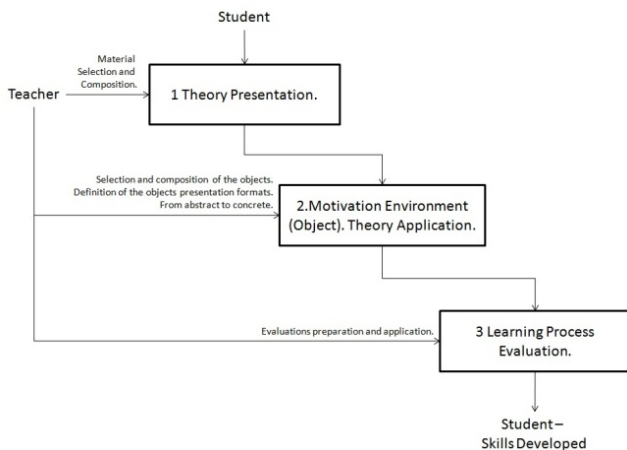


Fig. 1. Model used to compose this work

An analysis of Fig. 1 shows that it is possible to verify that the model can be used for the teaching and learning of any content. In this work, the model was applied using Mindstorms as the object of software process and project management teaching and learning. An example of the model is given in Table I.

Table I was constructed as a development plan for working in a teaching and learning environment. In this table, it is possible to find slides that compose the theory, the object (Mindstorms) and the evaluation criteria. The validation of this plan is the subject of the next section of this work.

TABLE I. MODEL FOR THE TEACHING OF PROCESS AND PROJECT MANAGEMENT USING MINDSTORMS

1. Theory Presentation	Process	Slides on software processes: https://dl.dropboxusercontent.com/u/3525445/mindstorms/softwareProcess.ppt	Worked during one traditional class (50 minutes). Available by Ian Sommerville [11]
	Project management	Slides on project management https://dl.dropboxusercontent.com/u/3525445/mindstorms/projectManagement.ppt	Worked during one traditional class (50 minutes). Available by Ian Sommerville [11]
2. Motivation Environment Composition	Classroom	Division of students into groups of 4 students.	Students developed projects, supervised by teachers, (see Fig. 2) using Mindstorms to concretize abstract concepts, tasks, activities, entry and exit artifacts, tools, skills, plans, project implementation, project control (150 minutes).
	Mindstorms	Presentation of Mindstorms to students. Presentation of the software that manipulates motors and sensors. Traditional class – 45 minutes.	
Object Selection			
Theory Application			
3. Evaluation	Students	In class evaluation, essay questions (see Table VI).	Evaluation was carried out after the students developed the projects using Mindstorms (see project scope in Fig. 2). Time (25 minutes).
	Teaching and Learning Process	After theory presentation and projects development, students evaluated the teaching and learning process (time: 25 minutes).	

IV. METHODS AND PROCEDURES USED TO VALIDATE THE APPLICATION

In order to answer the questions raised in Section I and evaluate the application of Mindstorms to the teaching and learning of software process and project management, the authors of this proposal developed, from 2010 to 2014, 8 experiments in academic (university) and business (software production sector) environments (See Table II).

Six experiments (realized from 2013 to 2014) were compared to other 2 experiments carried out from 2010 to 2012. The experiments carried out from 2010 to 2012 presented the concepts inherent to software process and project management traditionally (the authors of this paper worked the content on process and project management through lectures), i.e., without Mindstorms.

The experiments in the academic environments were carried out at the Universidade Tecnológica Federal do Paraná Computing Department, Campus of Cornélio Procopio. The Department offers 3 undergraduate courses: Software Engineering, Systems Analysis and Development Technology and Computing Engineering. In addition to these undergraduate courses the Department also offers a Graduate Program in Computing (GPC).

One of the experiments that used Mindstorms was realized with high school students. These students participate in the project Implementation of a Digital Wardrobe by High School Students from Northern Paraná as scholarship holders. The objective of this project was:

1. Recruit future professionals (female) for the Computing Engineering and Software Engineering or Technology;
2. Consolidate contents related to computer programming and software process and project management.

The project was financed by the Brazilian National Council for Scientific and Technological Development-CNPq.

TABLE II. INFORMATION ON THE EXPERIMENTS

Course	Application /Semester	Subjects	Students
Systems Analysis	6th semester (2010,2011,2012)	Software Project management (without Mindstorms)	47
Computing Engineering	7h semester (2010,2011,2012)	Software Project management (without Mindstorms)	39
High School (HS)	6th semester (2014)	Introduction to Project management	4
Software Engineering (SE)	1st semester (2014)	Introduction to Software Engineering	20
Systems Analysis	6th semester (2013)	Software Project management	16
Computing Engineering (CE)	7th semester (2013)	Software Projects Mangement	12
Graduate Program in Computing (GPC)	1st semester (2013)	Software Engineering	12
Company from the Production Sector (CPS)	IT professionals (2014)	<i>Consulting for the implementation of a software process</i>	4*

*Collaborators: Information System (2 collaborators). Systems Analysis (2 collaborators). Each group of 4 students manipulated Mindstorms.

Through the analysis of Table II it is possible to notice the presence of 6 experiments carried out in academic environments, 1 in a high school and 1 experiment realized in a company's production sector.

The company has a team of 9 people and 4 programmers from the production (programming) cell participated in the experiment. It is important to highlight that the authors of this work have not been formally authorized to disseminate the name of the company. The experiment conducted at this company was part of a software process improvement consulting developed by the authors of this work.

All experiments followed the model adopted by this work (Fig.1 and Table 1). Based on this model, the, as teachers implemented the following actions:

1. Presentation of two traditional lessons on concepts connected with software process and project s management. Duration of each lesson is 50 minutes. Support material to be used during software process [11] and project management [11] lessons can be found in the following links <https://dl.dropboxusercontent.com/u/3525445/mindstorms/softwareProcess.ppt>. and <https://dl.dropboxusercontent.com/u/3525445/mindstorms/projectManagement.ppt>.
2. Divide de students into groups of 4.

3. After having grouped the students, introduce Mindstorms to them. During the presentation, teachers work the motors, sensors and actuators. Presentation time was 45 minutes. It is important to emphasize that the teachers used the presentation this link https://www.youtube.com/watch?v=jh9u_B42ILo²
4. Definition of three projects using Mindstorms. Projects scope (a concept introduced during the Project management lessons) were based on Fig. 2.

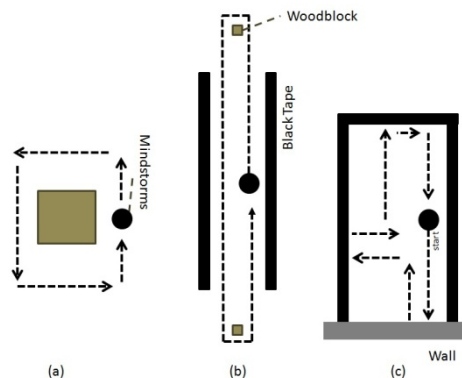


Fig. 2. Projects scope using Mindstorms

Figure 2 (a) presents the scope of project 1. In this figure, Mindstorms, represented by the circle, must go around a wood block. Figure 2 (b) represents the scope of project 2. According to this Figure, Mindstorms must go around two wood blocks and should not cross the black tape. Finally, Fig 2 (c) represents project 3, in which Mindstorms must touch one wall and return back to the initial position following the arrows – notice that by detecting the black tape, Mindstorms must change its route.

5. Definition of the development process. The process was divided into two activities: design and implementation. These activities were carried out by the students during the development of the project. The design activity has as an entry artifact the scope of the project. The exit artifact for this activity is characterized by the project specification document (see Table III). By using this artifact, the students configure (based on the scope – see Fig. 2) Mindstorms sensors and actuators parameters. Finally, it is important to highlight that the project specification document is characterized as an implementation activity entry artifact. This activity's exit artifact is the program to be embedded in Mindstorms (see Figure 3).

It is also important to emphasize that action 5 – development process definition, is based on action 1 – introduction of the concepts related to software process. Concepts such as activities, tasks, entry and exit artifacts and skills were characterized in action 1.

² YouTube Channel New Planet School. The video was translated into Portuguese and presented to the students in a traditional classroom.

6. Project development - action designed by the students with the supervisions of teachers (150 minutes). During the development of the project, the students must carry out planning and control activities. During the planning, the students create the WBS - Work Breakdown Structure (PMBOK) and estimate the necessary time and cost to execute each work package (see Figure 4). It is important to highlight that the students must develop 2 out of the 3 projects. During the development of the first project, the students do not have any information in the historical basis of the project to develop a consistent plan, which leads them to overestimate the time and cost for its execution. During the planning of the second project, however, the students have information in the historical basis, which leads them to develop more realistic estimates (see Table VII).

TABLE III SPECIFICATION PROJECT DOCUMENT

Sensor or Actuator	Parameter	Parameter Configuration
Medium Motor	On for Seconds	Second
	Power	75
	Second	4
	Port	A
Large Motor	On for Seconds	Second
	Power	75
	Second	4
	Port	D

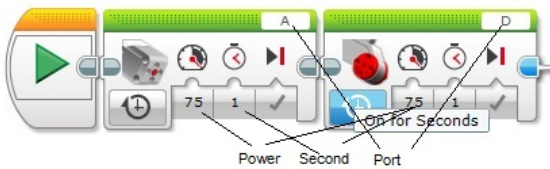


Fig. 3. Program to be embedded in Mindstorms

7. Students Evaluation. During this action, after the development of the project based on action 6, the students prepare a formative evaluation. The evaluation is composed by questions inherent to software process and project management (see questionnaire in Table IV). Action time: 25 minutes.

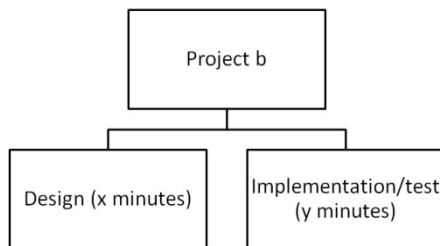


Fig. 4. Work Breakdown Structure (WBS) used in the planning activity

It is important to mention that the questions presented in Table IV were also used during the evaluation of the students who participated in the experiments from 2010 to 2012, who worked under the traditional approach.

8. Evaluation of the Teaching and Learning Process. During this action, the students, after having developed the project based on action 6, answer a questionnaire on the

application of Mindstorms to the teaching and learning of Software process and project management (see Table V). It is important to highlight that the questions focus on extremely important variables, which help the internalization of any type of knowledge, stimulus, satisfaction and consolidation [12]. Action time: 25 minutes.

TABLE IV. STUDENTS EVALUATION

As a software project manager, you must estimate the time and cost for the execution of project X. Proponent X made the project scope available. Your company has a historical basis with 3 projects developed. The scope of project X is similar to the projects stored in the basis. Based on this information, define the strategies you used to establish the time and cost for the project.
A software production company has a defined process. The activities of this process involves: 1- Requirements elicitation (tasks: mapping of key users and interviews with users). 2- Software projects (tasks: mapping of the functional model and mapping of the data model). 3 - Implementation. 4 - Test (tasks: define test cases, collect test data, test and report) . Construct a Software Project WBS that uses all activities and tasks of company X

TABLE V. EVALUATION OF THE TEACHING AND LEARNING PROCESS

Do you agree that the use of Mindstorms promoted greater stimulus to help students follow the lessons on software process and project management?
What's your level of satisfaction with Mindstorms during the learning of software process and projects development concepts?
Do you agree that the software project management concepts were consolidated during the execution of the projects using Mindstorms?
Answers to these three questions were characterized by the Likert scale (5- very high, 4- high, 3 - medium, 2- low, 1- very low)

V. RESULTS MAPPING

In the previous section, the authors presented the implementation of 8 actions to validate the application of Mindstorms to the teaching of software process and project management.

Among the actions presented, it is possible to highlight initially two of them: the evaluation of the students (7) and the evaluation of the teaching and learning process (8).

The evaluation is characterized as formative and the questions included in this evaluation are presented in Table IV. The evaluation was conducted together with the students during the experiments from 2010 to 2014 (see Table II). After the evaluation, the authors of this paper, characterized as teachers, corrected it and consolidated the results in Table VI. It is important to emphasize that Table VI presents only the results from the evaluations conducted using Mindstorms in the teaching and learning of process and project management.

Table VI shows that 68 students participated in the experiment, 88.2% answered question 1 correctly (see Table IV), i.e., the students consulted the projects historical basis as part of their planning strategy.

In regards to question 2 (Table IV), the rate of correct answers was 82.4% (see Table VI). The students constructed an WBS correctly.

Some points stand out in Table VI, where 90% of the students from the Software Engineering Course answered question 1 correctly whereas among the students from the

Graduate Program this percentile was 91.7% and among the participants from the software production sector, this value reached 100%.

In regards to question 2, it is possible to verify that the students from the Systems Analysis Course and Computer Engineering went over 90% of correct answers.

TABLE VI. STUDENTS EVALUATION MAPPED RESULTS

Course	Sem.	Q1	%Q1	Q2	%Q2	Qtde.
High School (HS)	6	3	75	3	75	4
Software Engineering (SE)	1	18	90	15	75	20
Systems Analysis (SA)	6	14	87,5	15	93,8	16
Computing Engineering (CE)	1	10	83,3	11	91,7	12
Graduate Program in Computing (GPC)	1	11	91,7	10	83,3	12
Company from the Production Sector (CPS)		4	100	2	50	4
Total		60	88,2	56	82,4	68

Sem. - Application school semester. Q1- Question 1, Q2 - Question 2. %Q1- Percentage of correct answer for Q1. %Q2 - Percentage of correct answers for Q2. Qt - Number of students who participated in the experiment.

The high levels of correct answers to questions 1 and 2 are intimately related to the implementation of action 6 – project development. This fact was detected during a meeting with the participants of the experiments.

During this action, the students under the supervision of the teachers, created the Work Breakdown Structure and estimated the necessary time and cost to implement each work package (vide Figure 4). It is important to emphasize, once again, that the students must develop 2 out of the 3 projects mapped in Figure 2. During the development of the first project, the students have no information in the historical basis to develop a consistent plan (concept required in question 1 of the test) – see Table IV), which leads the students to overestimate time and cost. However, during the planning of the second project, the students already have information in the historical basis, which helps them raise more realistic estimates. This can be attested by the information in Table VII and Figures 5 to 10.

An analysis of Table VII shows that Group 1, formed with 4 high school students (HS) estimated for Project 1 (Pro 1), 25 minutes for the execution of the project activity and 5 minutes for the implementation of the activity. Project activity execution real time was 14 minutes, a difference of 11 minutes. Activity Implementation real time was 2 minutes, a difference of 3 minutes. The last column of Table VII shows the sum of these differences: 14 minutes.

For Project 2, group 1 planned 20 minutes for the execution of the project activity which was realized in 16 minutes, a difference of 4 minutes. For the execution of the implementation activity, the difference between the planned and the realized was 2 minutes, a total of 6 minutes (see Table VII). The differences between planning times and projects execution for all groups in all courses can be visualized in the last column of Table VII and Figures 5, 6, 7, 8, 9, and 10.

An analysis of Tables VII and Figures 5, 6, 7, 8, 9, and 10 shows that:

- Four projects were accurately estimated and executed (difference between the planned and the realized was equal to zero)
- Eleven projects were estimated and executed with a difference classified by the - 1 to 5 minutes interval.
- There are 17 projects in Table VII whose estimations were made based on historical information, in 64.7% of them the difference between the planned and the realized was between - 1 to 5 minutes.
- Sixteen out of 17 project estimated based on historical information had a reduction in their overestimated time.

TABLE VII. PLANNING: PLANNED VERSUS REALIZED

Experiment/Project/Group	Project (minutes)			Implementation/test (minutes)			Pr(P-R) + I(P-R)*
	P	R	P-R	P	R	P-R	
HS – Pro 1 – Group 1	25	14	11	5	2	3	14
HS – Pro 2 – Group 1	20	16	4	3	1	2	6
SE – Pro 1 – Group 1	35	12	23	45	15	30	53
SE – Pro 1 – Group 2	30	10	20	45	10	35	55
SE – Pro 1 – Group 3	35	7	28	50	11	39	67
SE – Pro 1 – Group 4	30	20	10	60	35	25	35
SE – Pro 1 – Group 5	40	22	18	60	35	25	43
SE – Pro 2 – Group 1	14	15	1	16	15	1	0
SE – Pro 2 – Group 1	10	10	0	18	16	2	2
SE – Pro 2 – Group 1	13	12	1	13	13	0	1
SE – Pro 2 – Group 1	22	21	1	35	32	3	4
SE – Pro 2 – Group 1	24	24	0	35	34	1	1
SA – Pro 1 – Group 1	120	17	103	90	17	73	176
SA – Pro 1 – Group 2	20	15	5	65	21	44	49
SA – Pro 1 – Group 3	90	90	0	30	22	8	8
SA – Pro 1 – Group 4	30	10	20	20	18	2	22
SA – Pro 2 – Group 1	20	15	5	25	22	3	8
SA – Pro 2 – Group 2	15	15	0	23	23	0	0
SA – Pro 2 – Group 3	10	11	1	22	21	1	0
SA – Pro 2 – Group 4	21	20	1	15	15	0	1
CE – Pro 1 – Group 1	15	5	10	80	25	55	65
CE – Pro 1 – Group 2	60	10	50	140	15	125	175
CE – Pro 1 – Group 3	30	5	25	30	15	15	40
CE – Pro 2 – Group 1	15	6	9	15	5	10	19
CE – Pro 2 – Group 2	10	10	0	10	10	0	0
CE – Pro 2 – Group 3	8	8	0	13	7	6	6
GPC – Pro 1 – Group 1	20	7	13	100	26	74	87
GPC – Pro 1 – Group 2	55	9	46	40	14	26	72
GPC – Pro 1 – Group 3	35	9	26	33	14	19	45
GPC – Pro 2 – Group 1	7	6	1	26	13	-13	14
GPC – Pro 2 – Group 2	10	9	-1	14	14	0	-1
GPC – Pro 2 – Group 3	9	8	1	14	14	0	1
CPS – Pro 1 – Group 1	25	10	15	80	25	55	70
CPS – Pro 2 – Group 1	20	18	2	15	12	3	5

P: Planned R: realized P-R: Planned –Realized
Pr: Project I: Implementation/test
*Sum of the differences between Planned minus Realized for Project activities (Pr) and Implementation (I)

Therefore, based on these results, it is possible to conclude that the projects planning concept with a historical basis tends to be internalized naturally by the students. Question 1 from the formative evaluation (Table IV) corroborates directly with this finding.

During the evaluation of the teaching process, the students that participate directly in the experiment were invited to answer 3 questions (using the Likert scale) mapped in Table V. The authors of this work collected the answers given by the students in Table VIII.

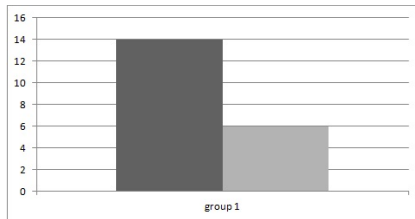


Fig. 5. High School – sum of the differences between planned and realized for Project 1 (14 minute) and Project 2 (6 minutes)

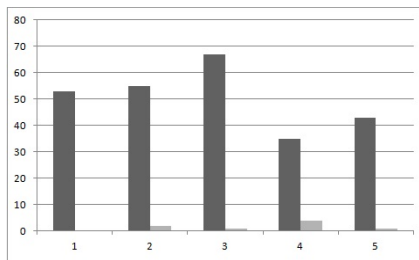


Fig. 6. Software Engineering - sum of the differences between planned and realized for Projects 1 and project 2 – the class was divided into 5 groups of 4 students.

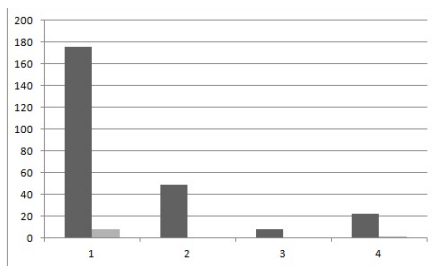


Fig. 7. Systems Analysis and development – sum of the differences between planned and realized for Project 1 and project 2 – the class was divided into 4 groups of 4 students.

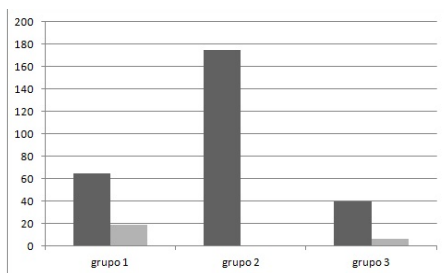


Fig. 8. Computing Engineering – sum of the differences between planned and realized for Project 1 and Project 2 – the class was divided into 3 groups of 4 students.

By adding the percentiles obtained for 4 – high and 5 very high (Table VIII), it can be verified that:

- Mindstorms promoted greater stimulus to follow the lessons on software process and project management in 92.3% of the students.

- The level of satisfaction brought by the use of Mindstorms during the learning of software process and project management concepts was 95.6%.
- The Mindstorms provided solidification about concepts project execution to 97.1% (see Figure 2).

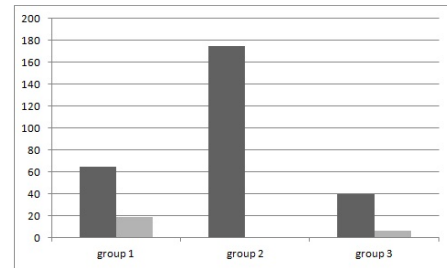


Fig. 9. Graduate Program in Computing - sum of the differences between planned and realized for Project 1 and Project 2 – the class was divided into 3 groups of 4 students.

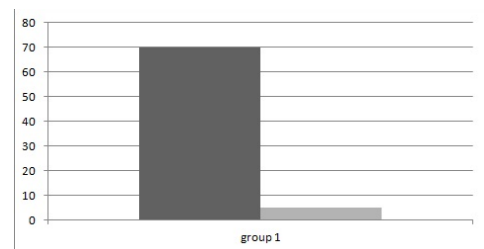


Fig. 10. Company from the Production Sector - sum of the differences between planned and realized for Project 1 (70 minutes) and Project 2 (5 minutes) .

TABLE VIII. TECHING AND LEARNING PROCESS EVALUATION MAPPED RESULTS

Questions (Table V)	Likert Scale				
	5	4	3	2	1
Stimulus generated by the use of Mindstorms	50 73,5%	13 19,1%	4 5,9%	1 1,5%	0 0%
Level of satisfaction by using Mindstorms	54 79,4%	11 16,2%	2 2,9%	1 1,5%	0 0%
Consolidation of software process and project management concepts using Mindstorms	53 77,8%	13 19,1%	1 1,5%	1 1,5%	0 0%

VI. CONCLUSIONS

Problems related to software process improvement and project management is connected to knowledge transfer. The development of an environment that promotes the internalization of abstract knowledge of process and Project management can contribute to possible solutions to these problems.

In the literature, the Mindstorms is applied in teaching and learning computer programming. This paper provides a differentiated approach; the Mindstorms is used for teaching and learning process and management of software projects. The concepts inherent in computer programming are addressed however they aren't characterized as the main focus of the paper.

In this context, the objective of this work was to apply Mindstorms as a motivating object to promote the

internalization of knowledge about software process and project management. This is not a recurring topic in the literature (see section II).

To validate the application, the authors of this work developed 8 experiments from 2010 to 2014, with the participation of 154 students (86 in Phase A, without Mindstorms, 68 in Phase B, with Mindstorms – see section 1). Five experiments were carried with graduate students, one with undergraduate students, one with high school students and one in a company from the software production sector.

With the execution of the experiments, it was possible to verify that:

1. In the two experiments carried out in the traditional way – without the use of Mindstorms as the teaching and learning object - from 2010 to 2012, the concepts connected to the software process and project management were absorbed by 64.86% of the students (see Section 1).
2. With the use of Mindstorms, 88.2% (an index superior to that pointed out by the previous item) of the students absorbed naturally the concepts related to software process and project management, mainly under the perspective of activities planning (using the historical basis of projects) and execution (see Table VI). This finding deals directly with problems inherent to project planning appointed by the CHAOS report. This fact collaborates to qualify positively question 1 (see section 1).
3. 82.4% (higher index than that appointed by item 1) of the students absorbed the concepts related to the institutionalization of a software process by using the project analytical structure as the basis (see Table VI). This finding deals directly with problems inherent to the creation and institutionalization of software processes appointed by the CMMI report. This fact collaborates to qualify question 1 positively (see section 1).
4. Stimulus, satisfaction level and consolidation of concepts promoted by the use of Mindstorms as a teaching and learning object was classified as 5 - very high level and 4-high level (Likert scale) for 95.1% of the participants (see Table VIII). This finding qualifies question 2 positively (see section 1).

Teachers who work directly with subjects related to software process and project management attested that students that participated in the experiments showed better fluidity in relation to these concepts in the following semesters.

Mindstorms was also a motivating factor for about 90% of the participants (see Table VIII). It is also emphasized that motivation in the teaching and learning process is intimately connected to stimulus, satisfaction and consolidation, variables related to the evaluation of the teaching and learning process [12].

The realization of the experiments attested that software process and project management concepts are internalized by the participants, regardless of their stage (high school,

freshman year at college, senior year at college, graduate school and company worker). These data can be found in Tables VI and VII.

After the experiment, the company from the production sector started to plan its projects using the historical basis concept, improving significantly the level of corrected cost and deadline estimates.

Finally, the authors found that the model used to develop this work presented in Fig. 1 can be applied to the teaching and learning of any content. In this work, the model was instantiated by the use Mindstorms as an object for the teaching and learning of software process and project management.

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Special Session on Design Metaphors

Rethinking the vocabulary of design education

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Abstract—Metaphors help create realities for us, especially social realities. A metaphor influences behavior; to attract and/or divide. Metaphors for education provide symbolic representations of what we intend in education; insight into the philosophy that underlines both how we educate, and what we are trying to educate. E.g., "Education as a journey" conveys a different meaning and intention than "education as a manufacturing process." Similarly, "Education is not the filling of a pail, but the lighting of a fire" encapsulates both an educational philosophy and guide for action.

This special session focuses on exploring metaphors for engineering design education, and how these metaphors divide and limit engineering design. Facilitated by the session leaders, participants will share and discuss their own metaphors, and begin a process for evaluating how metaphors limit and exclude. Participants will leave with an expanded repertoire of engineering design metaphors and reinvent the vocabulary of how metaphors inform teaching and learning of engineering design. Opportunities for future collaboration will be explored.

Keywords—Engineering Design; Design Education; Philosophy of Engineering

I. INTRODUCTION

Engineering educators, engineering practitioners, and engineering scientists have been working very closely in the last part of 20th century. Their mutual goal has and will be educating the future workforce and creating engineering problem solvers who impact the world in a meaningful way. In addition these three groups have been influencing and changing each other. Based on the findings and research in engineering design, there are different cultures that pertain to these constituents. Our education system is predominately based on the production (factory, assembly line) culture. Administrators use vocabulary that is very close to the production lines. Each group has cultural biases, they each use words, descriptions, and metaphors. While the metaphors seem to use a common language, they are enriched with ideas, biases, and cultural beliefs of the users. They are lenses used to view the term, and define meanings for their goals and objectives. The research questions are "Are they the same?" "Should they be the same?"

Among other uses, metaphor is a lens through which we see how we educate. In this context, 'design metaphors' are metaphors used for teaching how engineering design is done,

better done, and best done. These metaphors are the lenses that we use, consciously or unconsciously to communicate and teach aspects of the complex and value-laden activity we call engineering design.

II. UNDERSTANDING METAPHOR USES

Metaphor affects both linguistic and conceptual understanding. Common terms to describe the language and conceptual components are *Topic* and *Vehicle* which refer to the lexical items and to the content domains that they label. In this sense, metaphors are a vehicle relating one topic/domain to another. The actual concepts and relations activated in discourse will vary with individuals and their previous experience and knowledge. Contextual frames involve (at least) physical, social, interactional, or linguistic factors. [1,2]

A. Theories of Metaphor

Three central theories have emerged on metaphor use: Substitution Theory: metaphor as renaming of the Topic by the Vehicle, *Comparison Theory* where the metaphor is used as an implicit comparison, or restatement of similarity and *Interaction Theory* that accounts for the creation of new understandings through metaphor that cannot be paraphrased with literal equivalents. [1] Lastly are *Cognitive Theories*. These theories, support the development of repertoires.

Metaphor repertoires are developed through participation in social action and interaction. There are different levels of metaphor understanding: 'comprehension' may take place in real time without 'recognition' of the presence of metaphor happening or without further 'interpretation' of metaphor through activation of entailments of the conceptual link. [1] The fact that metaphors are used in particular ways 'in the language' does not entail that every 'individual mind' thinks metaphorically using the same conceptual metaphor. One important role is the 'cultivation of intimacy', where intimacy can be taken for granted or enhanced through the use of metaphor, especially in the development of shared discourse among participants.

B. Metaphor in Education

The challenges of metaphor in education are multifold. Fundamentally metaphor use shapes our language, thoughts and viewpoints. They effect both how learners learn, what they learn, but also how we as educators view what we teach.

Often, root-metaphors are generated from everyday experience and then extrapolated by means of analogy to some other realm of experience, such as teaching and learning. It often functions as a philosophy, metaphysics or worldview which constitutes the ultimate presuppositions or frame of reference for our educational discourse. [2] The danger is that educators unconsciously adopt a particular metaphor without conscious acknowledgement of the limitations and potential conflicts

III. METAPHORS FOR ENGINEERING DESIGN

Design metaphors in active educational use, or recommended for educational use vary significantly both in their breadth and their focus. A small sampling of this breadth is provided:

Design as Behavior: "Design is behavior. Therefore, it can best be understood by means of behavioral theory and must be taught in a way consistent with the theory of behavior modification. This simple fact appears to have been overlooked by most, if not all, engineering educators who teach design courses or write textbooks on engineering design." [3]

Design as Hypothesis Testing: "Each new patent is akin to a new hypothesis – an assertion that the thing described is novel, unobvious, and will work. If we take the framing and testing of hypotheses as the defining characteristic of science, then any new design is something to be tested by the scientific method. Proposing a bold new bridge design... lays down the hypothesis that the design will in fact work as a bridge. [4]

Design as Art: "Design is the energetic acknowledgement of our own living world through the making of things and through communication. ... New things are not born of nothingness, and they are taken from our attempts to boldly awaken our everyday existences. Design is the provocation of the senses and a way of making us discern the world afresh. " [5]

Design as Functional Composition: "Designers are focused on our interactions with objects and their functions, generally operating at a bigger, user centric scale. " [6]

Design as a Way of Thinking: Design thinking is a formal method for practical, creative resolution of problems and creation of solutions, with the intent of an improved future result. [6]

Design as Creative Synthesis: "Engineering design encompasses many activities, including the creative activity of conceiving of new devices and systems, as well as the analysis, refinement, and testing of those concepts. Synthesis is the creative step itself: the conception and postulation of possibly new solutions to solve a problem. In most engineering design, this step is performed by creative human minds." [7]

IV. SPECIAL SESSION ACTIVITIES

The activities will increase participants' background with both theories of metaphor in education and an array of specific practical uses of metaphor in engineering design. Activities will be based both on examples provided by the session organizers and design metaphors suggested by participants.

Metaphors in Education. The first part of the workshop will be a brief overview of metaphor theory and the role of

metaphors in education. This segment will provide participants with a review of established analysis of metaphors and provide a common background to inform subsequent participant discussions.

Design Metaphors by Discipline. Participants will be grouped by discipline/interest to discuss engineering design metaphors. Grouping by similar discipline/interest is intended to benefit from common frameworks and vocabularies across disciplines. This will include a brief presentation of documented metaphors to streamline discussion. Group discussion will record different metaphors used by participants, address potential applications of the metaphors focusing on questions like "what aspects of engineering design does this metaphor clarify?" Also considered will be possible misconceptions or other issues – particularly those that lead to exclusion. This discipline-focused group work will be followed by a synthesis of the metaphors discovered by the participants.

Discussion by Mixed Disciplines. In response to the synthesis work, the third set of activities will have participants grouped randomly to explore design metaphor relationships across engineering disciplines. Questions include: "Are there engineering design metaphors that span disciplines?" or "What shared values are made manifest by particular groups of metaphors?" or issue-related questions like "How do particular design metaphors limit engineers' thinking?" or "How does a particular metaphor shape how an engineer views design and therefore limits the design solution space?" These responses will then be collected, and shared followed by a discussion of the results of these cross-discipline explorations. Opportunities for future collaborations will also be explored.

The goal of these synthesis steps is to allow all participants to leave with an increased repertoire of engineering design metaphors to inform their teaching and learning processes.

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Helping Tomorrow's Engineers Ask Productive Questions

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Abstract—Most engineers and scientists would readily agree that the ability to ask and pursue productive questions can lead to a more globally competitive workforce; students with this ability can also enrich the STEM classroom learning environment. Through demonstration, active learning, and small group activities, this special session explores how we can help tomorrow's engineers ask productive questions and evaluate which questions may lead to creative solutions to research problems or innovative new products.

Keywords— *questioning, curiosity, ideation, asking questions, generating questions, enhancing questioning, critical thinking*

I. INTRODUCTION

Students can use meaningful questions to guide their exploration of the frontiers of engineering in the classroom, in the laboratory, and, ultimately, in the workplace. Physiologically, curiosity changes the brain to enhance learning [1]. Psychologically, wanting to explore a productive question also motivates students to better understand content and exercise higher level thinking skills [2]. On the job, productive questions are seen as pathways to creative solutions to research problems or innovative new products. Google CEO Eric Schmidt said, "We run this company on questions, not answers" [3].

Engineering education is often focused on students answering questions, not asking. Faculty intent on covering content may misjudge students' ability to ask productive questions as innate and therefore not explicitly cultivate this in the engineering curriculum.

Through demonstration, active learning, and small group activities this special session provides a framework for participants to help their students ask better, more productive questions. The immediate- and long-term effects of productive questions can contribute to a globally competitive supply of engineering students in the classroom and engineers in tomorrow's workplace.

II. CONTENT OF SPECIAL SESSION

Assuming the role of students, session participants become familiar with a technique for increasing fluency in the number

and types of questions they can generate. This technique is anchored in the use of models presented in class to explain past observations and make sense of new ones; it has been shown to have a statistically significant impact on engineering physics students [4] and can be adapted to diverse teaching situations [5].

Session participants are exposed to a series of prompts or triggers, such as videos, demonstrations, photos, problems, etc. The questions that participants generate serve as examples of six categories of questions: incongruous, congruous, modifying, generalizing/analogy, causal/creative, and informational. Data submitted by participants will later be used to study the questions engineering "experts" generate, in comparison to data already collected from 450 "novice" students in an introductory engineering physics class and a class of 50 graduate students.

In a small group setting, participants explore further application of this technique within specific engineering disciplines as well as how to evaluate the usefulness of the questions generated. Thus the community of participants collaboratively constructs new knowledge in this area that will help future adopters.

III. GOALS AND EXPECTED OUTCOMES

At the conclusion of this interactive, hands-on special session, participants should:

- Have a renewed interest in cultivating curiosity in their engineering students;
- Be prepared to use a process in their classrooms to improve the quality and diversity of questions their students ask;
- Have provided some data for a novice vs. expert comparison of types of questions following a prompt; and
- Have generated guidelines for other educators to help students ask productive questions and subsequently evaluate which questions may lead to creative solutions to research problems or innovative new products.

IV. SUMMARY AND CONCLUSIONS

In engineering, mathematics, and science, it is difficult to develop a compass which guides you in either solving a problem, determining a novel solution, or just finding an interesting problem to solve. The first step is to ask questions. Then, one must decide which of those questions might be productive. Linus Pauling told his student, “The best way to have good ideas is to have lots of ideas and throw away the bad ones” [6]. This special session explicitly focuses on pedagogical efforts to a) generate many questions, and b) determine which should be pursued.

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An exploration of Bloom's knowledge, skills, and affective-based goals in promoting development of freshmen engineering students' professional identities

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Abstract—Engineering educators rely on taxonomies such as Bloom's taxonomy to create learning objectives used to develop course syllabi and activities. Many times, faculty use these learning objectives to assess student attainment of engineering competencies as they relate to Engineering Accreditation Criteria (Accreditation Board of Engineering and Technology-ABET) purposes. One flaw to this approach is that it fundamentally *assumes* that student performance and completion of an engineering course will reflect the level or extent of professional development by the engineering student. Furthermore, it *assumes* that through development of a professional competency, students will more readily identify with the engineering profession. The purpose of this work is to explore the extent by which Bloom's taxonomy promotes development of freshmen engineering students' professional identities in an entry level undergraduate engineering course. A lower-level engineering course was selected as studies suggest that attrition and drop-out tends to occur between the first and second year of an engineering degree. From this work, we will begin to shed light on the needs and areas of improvement for freshmen engineering curriculum design (specifically related to selection of curriculum objectives) to promote persistent and committed professional identities in engineering students.

Keywords—Bloom's taxonomy, engineering education, student professional identity

I. INTRODUCTION

In any course, three components must be considered to accurately understand the effectiveness of a curriculum: its content, the instructional methods used to deliver course content, and the assessment approaches used to ensure course goals are being met. The latter (meeting course goals) is extremely important in technical and technologically driven disciplines such as engineering where criteria related to professional competencies through ABET must be met [1]. Through successful completion of the course goals, students are allowed to move up on the ranks of their engineering degree with a fundamental *assumption* that a certain level of expertise and growing understanding about the engineering profession has been obtained as a result of the course. One of the most widely used methods to understand if levels of expertise have been attained is through the Bloom's

Taxonomy of Educational Objectives [2]. Bloom's Taxonomy along with their revisions over the years [2,3] provides a convenient way for instructors to describe the degree of student knowledge, connection with course content (affect), and skills attained as a result of a course. Over time, Bloom's taxonomy has been criticized for not being sufficiently comprehensive [2], its over simplicity [2,4], and focus on student behavior and not transformation of behavior [4].

While Bloom's taxonomy is intended primarily as a heuristic for course design [5], it has had a stronger effect on objectives-based evaluation [6]. As such, this taxonomy along with its revisions containing affective, knowledge, and psychomotor (skills-based) goals [7] are widely used by instructors nationwide. Thus, we need to understand the extent to which Bloom's Taxonomy guides student developmental from these three domains and how these are related to professional developmental of a student.

In addition, we need to understand the intersection between student growths of these levels to foster development of a professional identity within a curriculum. This work will focus on the utility of Bloom's taxonomy in the development of students' skills as outlined in the taxonomy as well as how these guidelines motivate student identification and understanding of the engineering profession.

This work is an exploration of a freshmen engineering design course as studies suggest higher attrition rates after the first year of an engineering degree [8]. This paper explores how planning of an engineering graphics and design that includes the three Bloom's Taxonomy domains (affective, knowledge, skills) and their influence on student development of an engineering identity.

II. BACKGROUND

A. Bloom's Taxonomy

Bloom's taxonomy was created in the mid-1950s by Benjamin Bloom [9]. Primarily used to understand the hierarchical schema of the cognitive domain of learning, it has been revised over the years to include affective and psychomotor domains [7]. The domains of Bloom's taxonomy

can function to assess learning objectives and guide instruction. Bloom's taxonomy is one of the most widely used ways of organizing expertise levels in the classroom [4]. Table 1 summarizes the three learning domains present in Bloom's taxonomy.

Table 1. Summary of Revised Bloom's Taxonomy

Expertise Levels	Knowledge Based Skills	Skills Based Goals	Affective Goals
1	Remember: Recall or recognition of terms, procedures, etc	Perception: Use of sensory cues to guide action	Receiving: Demonstrates a willingness to participate in activity
2	Understand: Translate, interpret, extrapolate but not see the full implications to other scenarios	Set: Demonstrate a readiness to take action to perform the task or objective	Responding: Shows interest in the objects or activity by seeking it out or pursuing it for pleasure
3	Apply: Apply abstractions, general principles, or methods to specific concrete situations	Guided Response: Knows steps required to complete task or objective	Valuing: Internalizes an appreciation for values, the objectives, phenomena, or activity
4	Analysis: Separation of a complex idea into its constituent parts and an understanding of organization and relationship between parts	Mechanism: Performs task or objective in a somewhat confident, proficient, habitual manner	Organizing: Begins to compare different values and resolves conflicts between them to form an internally consistent system of values
5	Evaluate: Creative, mental construction of ideas and concepts from multiple sources to form complex ideas	Complex Overt Response: Performs task or objective in a confident, proficient, and habitual manner	Characterization by a Value or Value Complex: Adopts a long-term value system that is "pervasive, consistent, and predictable"
6	Create: Make judgement of ideas or methods using external evidence or informed rationalizations	Adaptation: Performs task or objectives as above, but can also modify actions to account for new or problematic situations	N/A
7	N/A	Organization: Creates new tasks or objectives incorporating learned ones	N/A

B. Chickering and Reiser Model of Student Development

According to Chickering & Reiser [10], students have personal strengths and weaknesses that influences their character development during their education. While in college, students' interactions with their surroundings (e.g., curriculum, faculty, and students) promote growth along seven

vectors. Navigation through these vectors can foster student development of a professional identity (Table 2).

Table 2. Chickering and Reiser Student Development Model [10]

Vector Level	Vector Descriptor	Brief Explanation about Student Development for each Vector
1	Developing Competence	Student's growth in intellectual and interpersonal competence
2	Managing Emotions	Student's capacity to appropriately express feelings
3	Student's Dependency on Others	Student's move from autonomy towards interdependence
4	Development of Mature Interpersonal Relationships	Student's appreciation of differences and the ability to be intimate
5	Establishing Identity	Student's sense of self within social and cultural contexts
6	Developing Purpose	Student's ability to fulfill interpersonal and family commitments
7	Developing Integrity	Student's capacity to behave in a socially responsible manner

C. Engineering Student Identity through Self-Identification with Engineering Profession

Studies in professional development of engineering students rely heavily on criteria such as the Bloom's Taxonomy and the Engineering Accreditation Board of Engineering and Technology (ABET) [1] to guide studies on teaching and assessment strategies for a range of desired competencies. These guides are *assumed* to reflect the *level or extent* that an engineering student has gained a professional identity, an area that has been pointed out by engineering educators nationwide [11-23]. However, to our understanding no connections have been established to better understand the role these metrics play in a students' self-identification with the engineering profession.

Research in engineering education has suggested that despite the academic ability of many students, the "difficult nature" of engineering has resulted higher performing students leaving engineering at rates higher than their low performing peers [8]. Existing research in engineering attrition contend that undergraduate students fail to see connections between their coursework and what their engineering profession will look like in the future [16]. This disconnect results in turmoil in students [24] that ultimately impacts their sense of belonging in engineering and their perception of their identity as engineers [18-21].

III. METHODOLOGY

A pilot study was conducted during Fall 2014 in an engineering graphics and design freshmen course at Utah State University. Students were required to learn a 3-D sketching software and apply to an open-ended service learning design activity. Three sections (totaling 88 students) were sampled.

A. Research Questions

This work is partly funded through a Utah State University Research Catalyst SEED Grant.

For this work, the research questions were:

(1) In what way does Bloom's taxonomy when used to create course objectives for an authentic engineering design activity, promotes student development?

(2) In what way does Bloom's taxonomy when used to create course objectives for an authentic engineering design activity, promotes identification with and understanding of engineering?

B. Course Objectives Design

A freshmen level Mechanical Engineering graphics and engineering design course was created based on Bloom Taxonomy objectives (Table 1). A particular focus on Bloom's affective goals was purposefully included through incorporation of a service learning engineering design project, due to its limited exploration in engineering education [25, 26] and importance in the development of 21st century skills such as communication [27]. Additionally, course objectives were cross-aligned against ABET standards pertinent to Mechanical Engineering [1].

Course activities, particularly engineering design workshops and activities, were presented according to the UTeachEngineering engineering design cycle [28]. Each workshop contained group activities that were designed to tackle the knowledge-based, affective, and skill-based domains in Bloom's taxonomy while ensuring the ABET standards were being met.

C. Engineering Design Activity and Project in Course

The engineering design project was designed in coordination with a local disability employment facility. The organization hires individuals with disabilities to assemble and package several moving parts of a mining kit to be shipped overseas. One goal of the employment facility is to hire more people with disabilities but are faced with the issue of scale-up and proper assembly/training design.

As part of the project requirement, engineering students were asked to design a process around two choices: (1) Should a process be designed that is efficient but risked eliminating the role of the 'middleman' (employees with disabilities)?; or (2) Should a process be designed to enable the assembly to occur efficiently and in turn, create more jobs?

To aid students through the project, five engineering design workshops were taught around the UTeachEngineering framework [28] using Blooms' taxonomy objectives as a guide. At the end of the semester, students were asked to complete essays around six self-reflective questions aimed at understanding if they had developed an identification with the engineering profession. The questions are summarized in Table 3.

Table 3. Essay Questions

(1) What does the term 'engineer' mean to you?
(2) At this level in your education, do you consider yourself an engineer? Why or why not?
(3) Tell us a little about your personal and/or professional goals in becoming an engineer
(4) What professional and/or personal strengths and weaknesses did you

bring to this course's team project?
(5) What challenges arose in your team project? How did you handle or overcome this challenge?
(6) From this course, what did you learn about yourself and your stakeholders (clients, customers)?

D. Analysis of Essay Questions

Responses to the essay questions, which were de-identified according to IRB protocols, were qualitatively coded using NVIVO 10. *A priori* codes based on Bloom's Taxonomy (Table 1) and student development vectors (Table 2) were used to analyze the responses to the essay questions. Matrix coding query analysis was performed to cross-tabulate coding intersections between Bloom's taxonomy levels and levels of student development.

During instances that students indicated a decision to change career paths or to remain in engineering, these cases were quantitatively recorded. Finally, all students' responses to the first question (Table 3) was quantitatively recorded and split into four categories: (1) 21st century definition of an engineer (based on the National Academy of Engineering [NAE] definition: "Process of designing the human-made world...by modifying the world to "satisfy people's needs and wants"...[engineers] develop plans, design processes, and procedures" [29]); (2) engineer as a designer (a definition based from the Industrial Revolution [30]), (3) engineer as an inventor/tinkerer (a definition based from Da Vinci's days during the Renaissance [31]), and (4) an adopter of science and math (from the Scientific Era [30, 32]).

Each approach was done to understand the linear progression and results from the course: from presentation and use of Bloom's taxonomy for design of class activities, to understanding of student's development of professional competencies in engineering, to attainment or understanding of engineering by the students, which can impact their overall sense of fit or belonging to the engineering profession in response to exposure of an authentic (real-world and relevant to their immediate community) engineering design problem.

IV. PRELIMINARY FINDINGS

A priori codes using the three domains of Bloom's taxonomy (Table 1) were used to analyze students' responses to the essay questions. These responses were also coded to levels of student development posed by Chickering & Reiser (Table 2).

A. Bloom's Taxonomy Role in Student Development Vectors

Matrix coding query analysis was carried out for each to the three domains (affective, knowledge, and skills) and levels and were compared against student development vectors. Overall, engineering students did not demonstrate a sequential growth for all areas of Bloom's taxonomy with the exception of two areas: Knowledge-Based Skill (Level 7- Organization) and Affective Goals (Level 3- Valuing) were somewhat of a linear growth was seen. Below is a summary of the intersections in Table 3. All other items (not presented or left in blank) in Table 3 represents a non-intersection.

Table 3. Matrix Coding Query Analysis of Students' Responses

Bloom's Domains/ Level	Student Development Vectors (Increasing Vectors from Left to Right)						
	1	2	3	4	5	6	7
Affective/ Level 3	43%	100%	-	100%	-	100%	-
Knowledge/ Level 1	-	-	-	-	-	-	71%
Skills/ Level 2	32%	-	-	-	100%	-	-
Skills/ Level 7	25%	29%	100%	-	-	-	-

The results suggests that despite choosing course objectives and activities around Bloom's taxonomy and required engineering competencies, students are not growing in many of the expected areas. Semi-sequential growths were found for the affective and skills levels suggesting the importance of enriching engineering education experiences with affective and psychomotor domains, both of whom traditionally takes second-place against knowledge-based skills in engineering education [25, 26].

B. Role of Student Development, Self-Identification of Engineering with their Definitions of "Engineering"

Students that indicated an identification (or lack of) with the engineering profession were quantified. Each response was sub-categorized as a response that was influenced by external factors (such as interactions with peers and learning environments) and internal factors (such as mindsets and perceptions about the 'engineering culture'). An opposite effect was found for students that identified themselves with the engineering profession and the reasons for their responses (Fig. 1). Further exploration of the responses were done with respect to essay question 1 and their definition of engineering were sub-categorized by historical era (Fig. 2). Only a quarter of the engineering students aligned their definition of engineering to the NAE 21st century definition of the field suggesting a misunderstanding by the engineering students on what does the engineering profession consists of.

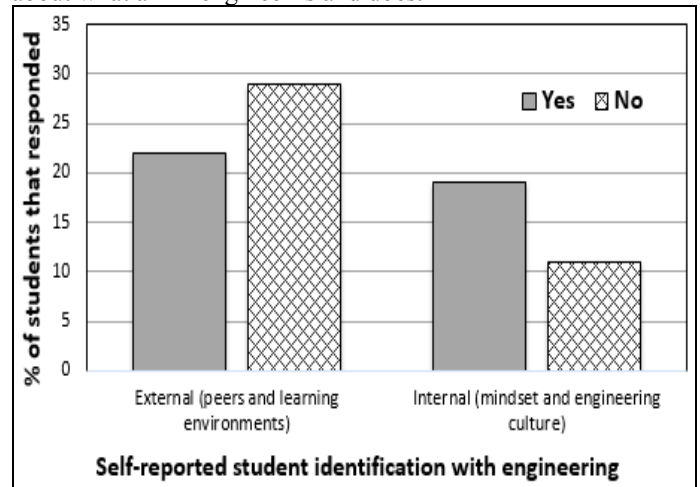
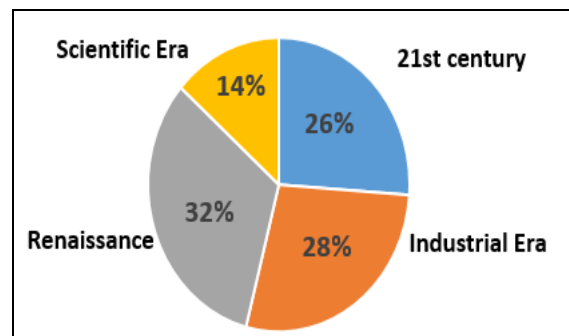
V. DISCUSSION/CONCLUSION

Preliminary findings suggest that establishment of course objectives and activities using taxonomies such as Bloom's taxonomy do not necessarily promote student development in desired domains. Furthermore, student development of these domains are heavily guided by students' perception of the field that they are studying.

In this work, only a fourth of the engineering freshmen accurately described the field. Interestingly, those that highly identified with the engineering profession attributed peer interactions, learning environments, and what they believed engineers are and do (mindsets) with their identification with the field. Those that did not identify with the field, primarily attributed this misidentification by their peer interactions and learning environments.

Overall, the data suggests that inclusion of affective and psychomotor activities promoted some growth but was

insufficient to drastically change students' perception about engineering. Interestingly, no sequential growth was identified in the knowledge-based realm suggesting that transient factors such as lack of familiarity on content may be at play [33]. These transient factors may not cement enough transferrable knowledge needed to create and establish an engineering identity. It is possible that more clarification activities to expose students to a 21st century definition of engineering may aid in further growth and development of desired competencies. An example of a clarification activity would be for an engineering educator to present students with an engineering design problem and ask them to outline the steps needed to solve the problem as if they were a professional engineer. Soon after students discuss their approaches, the engineering educator could present a video of a professional engineer describing the steps (s)he would take to solve the same engineering problem. Students can begin to self-assess the similarities and differences in their approaches and the engineering educator can premise this activity to speak about what a 21st engineer is and does.

**Figure 1.** Self-reported student identification with engineering**Figure 2.** Students' definition of "engineering"

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Building Information Modeling Laboratory Exercises in a Construction Science and Management Building Systems Course

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Abstract - This paper presents the development of Building Information Modeling laboratory exercises focused on Mechanical, Electrical and Plumbing (MEP) Systems in buildings. These laboratory exercises were developed to help construction science and management students better visualize and understand building systems and their relationship with each other as well as with other building components such as structural and architectural element. A popular BIM package was used to model the systems from an existing plan set, allowing the students to develop practical modeling skills, while providing a better understanding of MEP plan sets and system layout fundamentals. The BIM exercises were not used to replace, but rather supplement, the existing course laboratory exercises. The paper also discusses the perceived benefits as well as the challenges of using BIM as part of the teaching process. In addition to presenting the instructor experiences, a discussion of the results and observations stemming from student surveys collected at the end of the course is included. The paper ends presenting future changes to the course organization, as well as improvements to the course laboratory BIM exercises, that the author feels are required to facilitate the inclusion of BIM into the course.

Index Terms - Building Information Modeling, Computer Aided Instruction, Curriculum Design, MEP Systems.

INTRODUCTION

Starting with the 2014-2015 academic year, the curriculum of the Construction Science and Management (CSM) program at the University of Texas at San Antonio (UTSA) includes Building Information Modeling (BIM) courses as part of the degree requirements. The inclusion of BIM into the curriculum responds to current technology trends in the construction industry [1], as well as the CSM department goal of graduating well rounded students that are proficient with the software technology and tools currently being used in the construction industry, such as BIM, quantity takeoff (QTO) and estimating software, and scheduling software, among other computer programs [2].

Under the new catalog, BIM is covered primarily in three courses. The BIM software packages and fundamental concepts are first introduced in a dedicated course during the fall semester of the junior year, and then students are further exposed to specific aspects of BIM in the laboratory exercises of the program's Mechanical, Electrical and Plumbing (MEP) Systems course. Finally, students are required to use BIM as part of the program's final capstone project course during their senior year.

Reference [3] presents the computer laboratory exercises developed to introduce plan reading and quantity take off (QTO) software into various MEP systems courses taught previously by the author. The current paper presents the development of MEP focused BIM laboratory exercises used to expand and complement the current set of computer exercises used in the MEP systems course taught at the author's current institution. The MEP laboratory exercises presented here and in [3] have the objective of helping construction students develop some of the basic skillset and knowledge required and expected from them as it relates to the field of building MEP systems construction, such as plan reading, quantity take-offs (QTO), and estimating [4], [5].

In the following sections, the authors describe the MEP course, followed by the laboratory structure and topics covered, in both the new class format that incorporates BIM, and the previous class implementations prior to BIM. Then, a description of the general format used for the BIM-focused laboratory exercises is presented, as well as the instructor experiences with the development of the course together with the results and observations stemming from student surveys.

Lastly, the paper discusses future additions, changes and improvements to the course laboratory BIM exercises, as well as changes to the course organization and topics covered in order to ease the inclusion of BIM into the classroom.

MEP COURSE DESCRIPTION

The MEP course in the Construction Science Department at UTSA is structured as a 3-credit hour (2-2-3) course consisting of two hours of lecture, and a single two-hour

laboratory session per week. The MEP course goals and objectives are:

- Develop an understanding of the design principles of mechanical, electrical and plumbing systems.
- Develop an understanding of the principles, materials, and equipment used in plumbing/drainage, building electrical systems, HVAC, and fire protection and suppression systems.
- Read and interpret electrical, mechanical, plumbing and fire protection building construction plans and specifications.
- Conduct basic sizing and layout of MEP systems based on the building specifications, loads and demands.

The first two objectives are covered primarily through the lecture presentations, handout readings, and supplemental audiovisual materials, posted on the course Blackboard Learn® webpage, while the last two, more practical, objectives are covered primarily through the course laboratory exercises. Starting with the fall 2014 semester, Building Information Modeling became an essential part of the course laboratory component, as part of the department initiative to include BIM proficiency and knowledge in the program's graduate's skillset.

In the current implementation of the course, the lecture components and order of topics covered are not modified from previous incarnations, but rather the laboratory topics are arranged to follow the lecture subjects: electrical systems, followed by plumbing and fire protection, and finalizing with HVAC systems and building science fundamentals.

In the fall of 2014, the students taking the course were sophomores to seniors majoring in the Construction Science and Management (CSM) Bachelor program, and the majority of the students enrolled in the MEP course had either taken the program's first construction estimating course, or were taking it concurrently with the MEP class. Prior to the Fall 2014 semester, an introductory course to BIM was not a requirement of the program, so proficiency with BIM was not required nor expected from the students taking the MEP course at the time. However, a BIM course is now a requirement of the CSM program, and a pre-requisite for the MEP course, for any student enrolled in UTSA's CSM program under the 2014-2015 UTSA Course Catalog.

GENERAL LABORATORY DESCRIPTION

The laboratory exercises used and created during the fall 2014 semester were designed to introduce and develop practical knowledge in the following construction management areas as they apply to the most common MEP subsystems present in vertical construction:

- Plan reading and interpretation;
- Material quantity takeoffs (QTO);
- Basic system sizing;
- System modeling and layout, and;

- Fundamental principles calculations

Two software packages were used in the laboratory: On Screen TakeOff® (OST) published by OnCenter Software, Inc. [6]; and Revit 2014® (Revit) published by Autodesk, Inc. [7]. OST was used to perform the material QTO during some of the electrical and plumbing related exercises. A detailed description of the development of the OST based laboratory exercises was presented by the author in a previously in [3]. Revit was the only BIM software package used during the course, and it was required to perform the system modeling and layout exercises for the various MEP subsystems covered in the course. Finally, system sizing and fundamental calculations exercises were performed in the laboratory manually or using a spreadsheet program such as Microsoft's Excel®.

There were a total of ten laboratory exercises during the semester covering the areas described above. The order of the laboratories, as mentioned previously, closely follows the topics covered in the lecture component of the course. TABLE I lists the current laboratory topics, and the specific areas covered in each. All the laboratory instructions, handouts and supporting materials, were delivered, and the student work collected, using the Blackboard Learn® course management system. Students were required to submit a pdf file of their work, and in the case of BIM exercises, the Revit® model file (.rvt) or a pdf of a specific view of the model.

TABLE I LABORATORY WITH BIM FOCUS

Laboratory Description	Plan Reading	QTO	Sizing	BIM	Principles
Laboratory 1: Introduction to OST® and Revit®		x		x	
Laboratory 2: Electric Power and Loads					x
Laboratory 3: Power Distribution Systems	o	x		x	
Laboratory 4: Lighting Systems	o	x		x	
Laboratory 5: Electrical System Sizing			x		
Laboratory 6: Plumbing Plans and Pipe Sizing	x	x	x		x
Laboratory 7: Plumbing Layout	o			x	
Laboratory 8: Fire Suppression Layout	o			x	
Laboratory 9: HVAC Forced Air Systems Layout	o			x	
Laboratory 10: Heating and Cooling Loads			x		x

Legend: x-explicit focus; o-implicit focus.

Prior to the inclusion and use of BIM, the laboratory exercises focused on the following practical construction management areas:

- Plan reading and interpretation;
- Material quantity takeoffs (QTO);
- Basic system sizing;
- Basic material and labor estimating, and;
- Fundamental principles calculations

The main difference between this list and the one presented previously is the substitution of the estimating component of the laboratory with the system modeling and layout using Revit®. Also the number of exercises on each category was different than in the current implementation, with the five topics explicitly covered for each of the four MEP subsystems covered in the course, as presented in TABLE II.

TABLE II LABORATORY FOCUS PRIOR TO BIM

Laboratory Description	Plan Reading	QTO	Sizing	Estimating	Principles
Laboratory 1: Electrical Systems Plan Reading	x				
Laboratory 2: Electric Power and Loads					x
Laboratory 3: Conductor and Enclosure Sizing	o		x		x
Laboratory 4: Electrical QTO's and Basic Estimating	o	x		x	
Laboratory 5: Plumbing System Plan Reading and Layout	x		x		x
Laboratory 6: Plumbing QTO's and Basic Estimating	o	x		x	
Laboratory 7: Fire Protection Plan Reading and QTO's	x	x		x	
Laboratory 8: HVAC Plan Reading and QTO's	x	x			
Laboratory 9: HVAC Forced Air Systems Basic Estimating	o			x	
Laboratory 10: Heating and Cooling Loads			x		x

Legend: x-explicit focus; o-implicit focus.

BIM LABORATORY EXERCISES DESCRIPTION

A total of six BIM exercises were created for the course during the fall 2014, one introductory exercise and five exercises to cover the following MEP subsystems: electrical power, electrical lighting, plumbing, fire suppression, and forced air HVAC.

The first laboratory was intended as an introduction to the two software packages that would be used in the course: Revit® and OST®. This introductory exercise provided the students with the opportunity to explore the software packages functions, and also served as the introduction to the building model that would be used throughout the semester. The building selected for most of the laboratory exercises is a single-story, open-floor plan, retail building with two small rooms and a single bathroom known as the "West Street Video Building". It contains full plumbing, including storm drainage, rooftop HVAC with ductwork, automatic fire sprinkler system, and a full electrical power and lighting system with a single electrical distribution panel. These are the systems covered in the course, at a relatively low complexity level. A full set of digital plans for the building was provided to the students in pdf format including architectural and structural plans, at a scale of an eighth of an inch to a foot ($1/8"=1'$) in an 11x17 page size (Fig. 1). The Revit® architectural base model (Fig. 2) was developed by the instructor based on the architectural and structural plans provided to the students. The model was

then distributed to the students using Blackboard® to allow them to add the MEP systems as the course progressed throughout the semester.

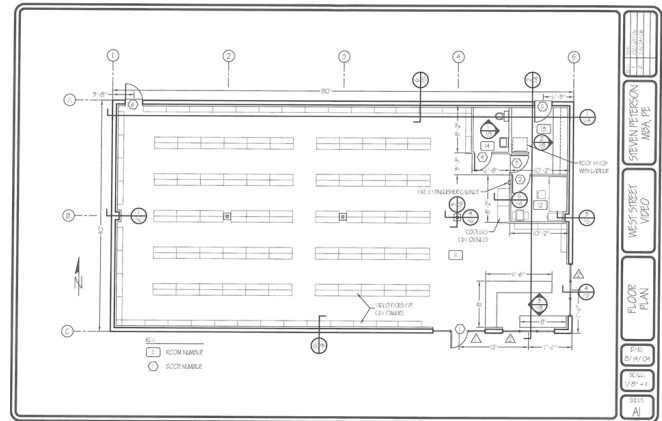


Fig. 1 Sample WEST ST. VIDEO BUILDING ARCHITECTURAL PLAN.

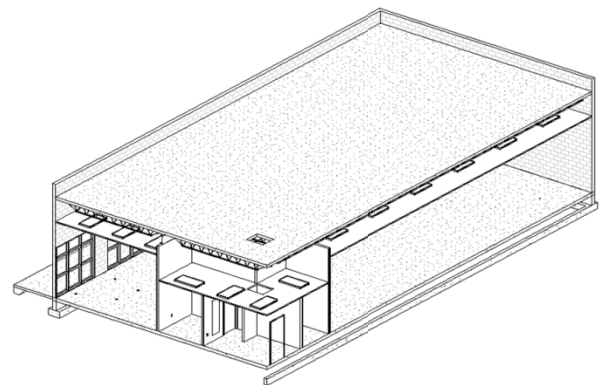


Fig. 2 West St. Video Revit Architectural 3D Model.

After the introductory laboratory, the other five problems focused on the individual systems, and were structured as step-by-step instructions that guided the student through the process of:

- setting up Revit® to define necessary floor-plans and 3D views in order to work with a particular MEP system;
- adding and defining required components to the library such as piping, fittings, ducts, equipment, fixtures, etc.;
- and placing the required system components into the provided architectural base model following the provided West St. Video Building plans.

The systems covered in these five laboratory exercises, and the order in which they were presented, followed the lecture schedule and is summarized by TABLE I presented in the previous section.

For example, Fig. 3 shows the bathroom detail available in the plumbing plans of the West St. Video Building, and Fig. 4 the resulting 3D model of the same space on Revit® that students following the "Laboratory 7: Plumbing Layout"

instructions were expected to produce using the basic architectural model provided. In order to complete the model, students had to perform, in addition to setting the appropriate model views, the following tasks

- Identify the plumbing fixture represented by the plan symbols, load the corresponding Revit family into the model file for them, and place the fixtures on the model
- Identify the required plumbing piping subsystems, such as water supply or sewer, identify the piping material and sizes, and load the required fitting families into the model in order to define the piping routing properties for the various piping systems
- Place pipes and fitting into the model at the appropriate elevations, connecting to the appropriate fixtures, and avoiding collisions (by visual inspection) with pipes already placed in the model.

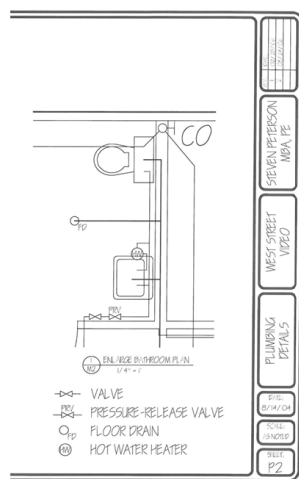


Fig. 3 West St. Video Bathroom Plumbing Detail Plan.

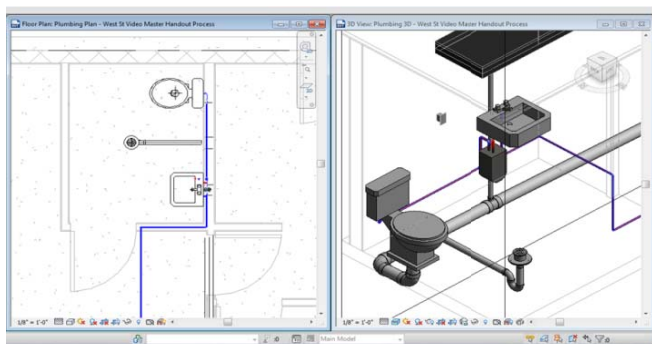


Fig. 4 Sample Revit® BIM Model of Bathroom Plumbing Detail.

Similar exercises to the plumbing systems were developed for the fire suppression and HVAC systems. These three MEP subsystems shared similar steps in the process to create the 3D Revit model, with the main difference being the Revit families that needed to be loaded into the model. For example in the case of air-forced HVAC systems, air terminals and mechanical equipment are loaded instead of the plumbing fixtures, and ducts and duct fittings are needed instead of pipes and pipe fittings.

Electrical systems followed a different approach as they focused more on generating “electrical plans” and “electrical circuiting” rather than visible 3D models of conduits and wiring layouts. Devices and lighting were placed on the architectural model in 3D, but only “electrical” connections were made between devices. Fig. 5 shows the generated electrical lighting 3D model (with HVAC and ductwork showing) with the corresponding Revit® produced lighting electrical floor plan. Notice the lack of a 3D model for the electrical circuit connections between devices as shown in the floor plan.

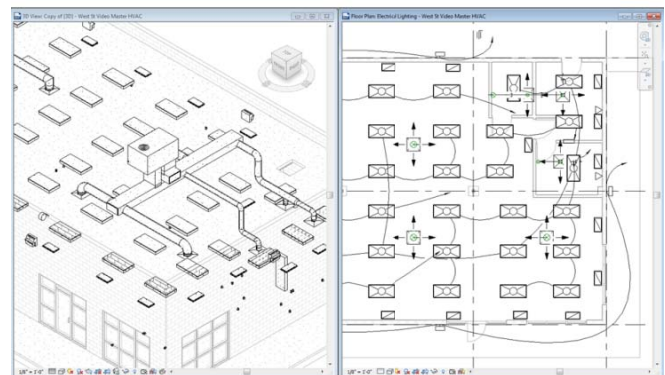


Fig. 5 Sample Revit® BIM Model of West St. Video Showing HVAC System and Reflective Ceiling Plan with Electric Lighting.

DISCUSSION

1. Instructor Perspective

From the author perspective, one of the main advantages of using BIM while teaching the MEP course is the ability to show and visualize system layout in three dimension, rather than relying only on two dimensional plans and drawings. The students are able to visualize layout issues that would otherwise not be evident, without prior experience or good intuition, from a collection of plans and riser diagrams. Among the issues that are better explained using three dimensional models are changes in elevation, overlaps, and special location of components in relation to other building components such as doors, windows, ceiling, etc. Also, subsystems can be easily classified and identified, and the relative scale of the components is clear from the BIM model.

One of the main problems encountered using the BIM software package was the learning curve associated with the software, which was accentuated by the fact that most of the students enrolled had no previous exposure to the software. Another caveat of the software relates to the working files size and the computer laboratory storage policies, which requires the use of external portable drives in order to allow students to work on the same project on different computers at various times during the semester, when the software is not installed on their personal laptops. Also, the instructor needs to plan accordingly to introduce the software package itself to the students, especially if it is the first time students are exposed to it.

Also, from the modeling perspective, Revit® requires extensive workspace setup, such as library loadings, systems definitions, and routing preferences to name a few, which requires a considerable amount of time and effort, as well as MEP systems knowledge, before the software can be used effectively. Also, the requirement of using a separate software package (i.e. Navisworks®), in order to run clash detection of systems in a building, requires additional class time, and possible resources, to take full advantage of the promises of BIM.

II. Student Perspective

The University of Texas at San Antonio follows a two-tier course evaluation procedure where students complete an online evaluation of the courses taken during the semester. This evaluation is used for administrative review purposes as well as assessment, and provides only a general measure of the course effectiveness and the instructor's teaching effectiveness without providing details on the individual course components.

In order to evaluate the perceived effectiveness of the BIM laboratory exercises, students were asked to complete an online survey on Blackboard® independently of the University's online course evaluation. The supplemental evaluation was used to ask the students questions regarding the following aspects:

- Usefulness and appropriateness of using BIM in a MEP course.
- Student proficiency with BIM software and effectiveness of laboratory problems.
- Laboratory problems organization and difficulty.
- And, appropriateness of the building models used in the exercises.

A total of 30 questions were asked, twenty-nine covering the topics above in a multiple selection scale format varying from 1 to 5, where 1 represents strong disagreement or highly negative feedback, and 5 represents strong agreement or highly positive feedback. The last question was included to allow students to provide written feedback on the laboratory exercises. Approximately 35 students were enrolled in the course, and the survey response rate was close to 50%.

The tables presented below summarize the student answers to the multiple choice questions asked in the end-of-class surveys. Each one of the tables presents the questions grouped by the categories or type of questions presented in the list above. TABLE III contains the questions regarding the usefulness and appropriateness of using BIM in the MEP course. TABLE IV contains the answer regarding the students self perceived proficiency with BIM before and after the MEP course, while TABLE V shows the students answers to the questions regarding the perceived effectiveness of the laboratory exercises in learning and understanding MEP systems.

TABLE III RESPONSES REGARDING BIM USE IN AN MEP COURSE.

Question	5	4	3	2	1
Do you think using Building Information Modeling, as part of the MEP System Course is a good idea?	27%	47%	20%	0%	7%
Does laboratory exercises, BIM or otherwise, should be part of the MEP course?	27%	60%	0%	13%	0%
Should an introductory BIM course be a requirement for the current MEP Course?	67%	27%	7%	0%	0%
How relevant were the BIM exercises to the CM profession?	13%	73%	13%	0%	0%
Does understanding BIM as it applies to MEP systems might help in your future CM career?	27%	73%	0%	0%	0%

TABLE IV STUDENT PERCEIVED BIM PROFICIENCY

Question	5	4	3	2	1
At the beginning of the class, how would rate your knowledge and proficiency of BIM software? (5=advanced)	0%	7%	7%	47%	40%
After completing the MEP class, how would rate your knowledge and proficiency of BIM software?	7%	40%	20%	27%	7%

TABLE V STUDENT PERCEIVED EFFECTIVENESS OF THE LAB EXERCISES

Question	5	4	3	2	1
Did you learn something useful from the BIM exercises?	7%	93%	0%	0%	0%
Using BIM in the laboratory, does it help understand MEP systems better?	13%	47%	27%	13%	0%
Using BIM in laboratory exercises, does it help understand how MEP systems are layout/routed?	20%	67%	13%	0%	0%
Using BIM in the laboratory exercises, does it help understand what components and pieces are needed?	13%	73%	13%	0%	0%
Using BIM helps understand electrical system better?	7%	40%	53%	0%	0%
Using BIM helps understand plumbing and fire suppression systems better?	7%	73%	20%	0%	0%
Using BIM helps understand HVAC systems better?	20%	60%	20%	0%	0%

TABLE VI and TABLE VII present the students answer to the questions regarding the laboratory organization and exercise difficulty, respectively. It is interesting to note that as part of the difficulty questions, students were also asked about how user friendly Revit® is, which resulted in almost an even split between students that feel the program is user friendly and those that feel it is not. Finally, TABLE VIII summarize the students answers to the questions relating to the appropriateness of the building used during the BIM exercises to model the various MEP systems covered in class.

TABLE VI STUDENT RESPONSES REGARDING THE LABORATORY FORMAT

Question	5	4	3	2	1
How do you feel about the number of BIM exercises done over the semester? (5=too much)	0%	20%	67%	13%	0%
Is one week to complete each exercise enough time? (5=too much)	0%	27%	67%	7%	0%

TABLE VII STUDENT PERCEIVED LABORATORY EXERCISES DIFFICULTY

Question	5	4	3	2	1
Ignoring the software learning curve, the tasks that you were asked to complete during the BIM exercises were difficult?	7%	27%	53%	13%	0%
In regards to the BIM software used in the	7%	40%	0%	40%	13%

Question	5	4	3	2	1
labs, is the software user friendly?					
Using REVIT is a distraction from understanding MEP systems?	0%	33%	13%	27%	27%
Does the content of the BIM exercises complement the lecture materials?	20%	40%	27%	13%	0%
Do the instructions provided in the lab handouts were easy to follow?	0%	53%	7%	33%	7%
Does the instructions provided in the labs were sufficient to complete the exercises?	7%	53%	27%	7%	7%

TABLE VIII STUDENTS RESPONSES REGARDING THE BUILDING MODELS USED

Question	5	4	3	2	1
Do you think the building model used (West St. Video Building) was a good choice?	27%	47%	27%	0%	0%
Was the other building model used (Kamp for Kids Basement) a good choice for electrical exercise?	13%	40%	47%	0%	0%
Should the same building be used for every exercise?	47%	27%	13%	13%	0%
Do you think that adding more detail to the building models, such as furniture, finishes, doors and windows is relevant while working with MEP systems in BIM?	0%	20%	27%	47%	7%
When working with a particular MEP system, should the model not have any other MEP systems on it?	7%	13%	40%	20%	20%
When working with a particular MEP system, should the model already have all the other MEP systems on it?	7%	13%	33%	40%	7%
If the same building model is used for all the exercises, should the MEP systems be added sequentially throughout all the exercises?	47%	53%	0%	0%	0%

Based on the feedback received and the results presented in the tables above, the majority of students feel that it was a good idea to have BIM as part of the course, and that the laboratory exercises were conducive to learning. However, students felt that the building model, as well as the laboratory handouts and problems could be improved, especially on the electrical systems part of the course. Also, the students strongly feel that a previous BIM course would be beneficial to student enrolled in the MEP course.

CONCLUSIONS AND RECOMMENDATIONS

Starting with the 2014-2015 academic year, the curriculum of the CSM program at UTSA encompasses BIM as part of the degree requirements. As part of this new requirement, the MEP Systems course was modified during the fall 2014 to incorporate BIM as part of the laboratory exercises.

The laboratory exercises developed during the fall 2014 semester are the first step in the ongoing process of

incorporating BIM into the MEP course offered in the Construction Science Department at UTSA. During this first stage, only the basic 3D MEP systems modeling capabilities of Revit® were explored. The BIM exercises were designed as step-by-step instruction that guided the students through the process of adding MEP systems into an existing architectural model, as a way to recreate an existing plan set.

The advanced capabilities and features of the BIM software package, such as automatic quantity take off, or schedule generations, to name a few, were not explored. Furthermore, clash detection of MEP systems and structural systems, which is one of the most important benefits, and drivers, for the use of BIM during design and construction of buildings, was not covered. These omissions would be the next logical additions to the laboratory exercises.

Finally, the order on which the MEP systems are covered in the course needs to be modified to reflect the prevalent (historically) coordination of MEP systems, and to facilitate the modeling of these systems in BIM: HVAC, followed by plumbing and fire suppression, and ending with power and lighting systems.

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How the Web Was Won

Keeping the Computer Networking Curriculum Current with HTTP/2

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Abstract— The Internet and the Web continue to grow in their pervasiveness and as new functionality and behavior emerge it is a challenge to keep the computer networking curriculum up to date. There are many excellent networking textbooks available but they cannot always keep pace with the rate of change. Recent developments in HTTP are a good example of this situation. Since around 2012 many of the web transactions between popular browsers and major web sites have been using a protocol called SPDY, which operates significantly differently from HTTP version 1.1 – the version covered in networking textbooks. SPDY has been largely adopted into the final standard of HTTP version 2. This paper seeks to fill the gap between current textbooks and the versions of HTTP now in use. It gives an overview of HTTP evolution from a technical perspective before suggesting materials and approaches that can be used as learning resources for the topic and how conceptual understanding can be reinforced through hands-on activities which use browsers' native network monitoring capabilities and other readily available tools.

Keywords—Computer Networking Education, HTTP Evolution

I. INTRODUCTION

As a consequence of the Internet boom around the year 2000 computer networking education has been well served in terms of textbooks. A challenge for authors of the more comprehensive networking textbooks however is keeping them up to date.

Table I: Frequency of networking textbook publication update

	Edition and Year of Publication						<i>average update interval</i>
	1	2	3	4	5	6	
T&W	1980	1988	1995	2002	2010		7 years
P & D	1996	1999	2003	2007	2011		4 years
K & R	2000	2003	2005	2007	2009	2012	2 years

If we take three major texts: Tanenbaum and Wetherall¹ (T&W) [1], Peterson and Davie (P&D) [2], Kurose and Ross (K&R) [3]; we can get a feel for the rate of change by looking at the frequency of new editions (see Table I).

¹ Andrew Tanenbaum was the sole author of editions 1 – 4; he was joined by David Wetherall as co-author for the 5th edition.

The more recently authored books show a greater frequency of revision and as revising a major textbook is a time consuming process it can be assumed that these updates are considered too important to delay for longer periods. Yet, at the same time, we do not have to look far to find an example of a widely used Internet protocol that is not covered by even the most recent textbooks – SPDY – the basis for HTTP/2.

Why is the HTTP family of protocols (HTTP 1.0, HTTP 1.1, HTTPS, SPDY, HTTP/2) an important part of the networking curriculum? Firstly, these are the application level protocols that carry the largest proportion of Internet traffic including social media, e-commerce, and streaming video. As such it is incumbent on networking education to explain the principles, operation, benefits and drawbacks of such a widely used set of protocols.

Secondly, in contrast to the traditional bottom-up networking pedagogy whereby the physical layer is covered first, then the link layer, and so on, a top-down approach starting with the application level has been introduced by books such as K&R, and widely adopted. Peterson and Davie's book is structured as bottom-up but for the 5th edition they issued an alternative pathway document on how to use their content in a top-down manner. HTTP is naturally one of the most relevant application level protocols to use in a top-down approach. Students can quickly feel a sense of achievement in designing and deploying their own web server which in turn promotes engagement with other aspects of the discipline.

Finally, through the critical study of this family of protocols students can gain insight into Internet protocol design, evolution and standardization. For example, there is educational value in covering HTTP/2 as it shows that key features of HTTP 1.1 such as pipelining, described as performance enhancement in textbooks, never actually worked in practice and were not adopted or deployed. While it is testimony to the value of layered model abstraction that few web users are aware when they are obtaining content via SPDY rather than HTTP 1.1 it is not an acceptable situation for students in computer networking classes, especially as they are still being taught about the operation of earlier forms of HTTP in major texts.

This paper proceeds by reviewing the HTTP story so far then makes suggestions for readily available resources which can

support the inclusion of HTTP/2 in an evolutionary context, within the networking curriculum.

II. THE HTTP STORY SO FAR....

The original Web was based around the hypertext transfer protocol (HTTP) and the hypertext mark-up language (HTML). There were numerous precursors in the form of distributed hypertext systems, but in true Internet tradition the simplicity and openness of the original HTTP and HTML standards allowed them to be readily implemented in forms that could be made to interoperate across the network. HTTP 0.9 was published in 1991 [4]; it was a subset of what was called “Basic HTTP” in 1992 [5] – much of which became known as HTTP 1.0 [6]. In 1993 a major boost came in the form of the Mosaic web browser [7] which was easy to use and brought multimedia web pages to life. It was not uncommon to hear the term “the Mosaic protocol” being incorrectly used to refer to the web at that time. As the use of the web snowballed, HTTP 1.0 (fully specified in 1996), attracted attention from network researchers and they discovered considerable space for improvement [2-5].

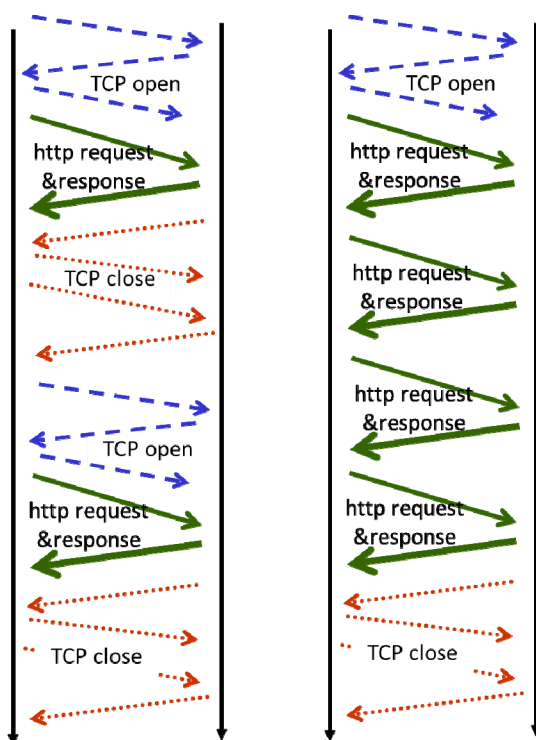


Figure 1. (a) http 1.0 (b) http 1.1

The most significant problem identified was the interplay between TCP and HTTP. Most interactions between a web client and a web server at that time were between a client and the same server. However, each HTTP response and request required its own TCP connection. As TCP uses three segments to set up a connection and up to four segments to close it down, the transport protocol overhead typically used more network resource in terms of Round Trip Time and bandwidth than the application level protocol. Figure 1a shows

HTTP 1.0 obtaining two web objects. This profligate use of TCP was seen as wasteful, and of course, congestion avoidance was also a big issue. In addition HTTP 1.0 is a “stop and wait” protocol so if a web page consisting of some text and a few images was to be built and rendered then multiple TCP connections were needed and enterprising browser designers decided to open these in parallel, reducing the overall Page Load Time (PLT), delivering a better user experience, but effectively subverting the aims of TCP’s congestion management mechanisms in the sense that one application was getting more than its “fair share” of available network resource. However, depending on the context consisting of the actual clients and servers, their platforms, the web page(s) being requested, and the network path, significant parts of the overall delay in PLT could often be traced to the browser, the server or the TCP protocol rather than the network throughput or HTTP protocol [8] [9].

A. HTTP 1.1

HTTP 1.1 [10] sought to improve over the previous version in the areas of: Caching, Bandwidth optimization, Connection management, Message transmission, Internet address conservation, Error notification, Security, Integrity & Authentication, and Content negotiation [11].

Briefly; IP address conservation was improved through the use of virtual hostnames for servers, specified in the new header “host” field; caching was better supported by the introduction of unique ETags for objects; in practice HTTPS (HTTP over SSL or TLS) was adopted rather than the proposed HTTP 1.1 mechanisms for security; message transmission encoding could be treated distinctly from content encoding.

The concern over the inefficient use of TCP was addressed by improved connection management in the form of persistent connections. This is supported by the “Keep-Alive” header field and is in widespread use. This means that a single TCP connection between a client and a web server can be kept open to support multiple HTTP request/response interactions (see Fig. 1b).

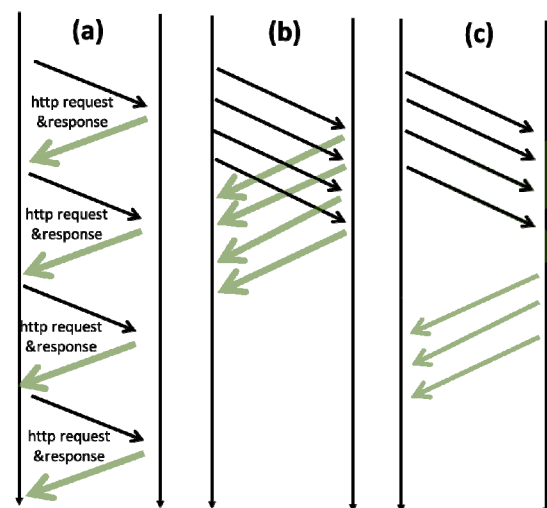


Figure 2. a) Stop & Wait; b) Pipelining; c)Head of Line Blocking.

It was hoped that the introduction of persistent TCP connections would reduce the number of parallel HTTP/TCP connections opened by a browser. In practice this did not happen.

Bandwidth optimization was addressed mainly by the introduction of pipelining, whereby a client did not need to wait for a response before sending a further request (see Fig 2a, b). In practice, pipelining was not adopted. It was partly thwarted by intermediary boxes such as proxies, but also by the “head of line blocking” situation (see Fig 2c), whereby servicing a single long-running request could hold up all subsequent ones, even though they could be answered relatively efficiently. In short, bandwidth optimization did not succeed.

Two points should be noted about HTTP 1.1. Firstly, it was designed to be backwardly compatible with HTTP 1.0, so older clients could still interact with newer servers and newer clients work with older servers. This was achieved by simply making none of the new features mandatory. Hence pipelining could be allowed to fail through lack of popular adoption. However, another new feature, the “Upgrade” header, was intended to allow for both client and server to switch entirely to an alternate protocol for content transfer. This added some future proofing to HTTP 1.1 and is now used for switching to HTTPS or SPDY.

B. HTTPS

As the global, public Internet became increasingly used for commercial and mission critical purposes it became necessary to provide security.

Application	Application
TCP	SSL
	TCP
IP Network	IP Network

Figure 3: The Secure Sockets Layer

The Secure Sockets Layer (SSL) or Transport Layer Security (TLS) does this for TCP at the transport level. SSL provides confidentiality, integrity & end-point authentication. Any networked application written using the TCP socket programming abstraction can readily improve its security by using SSL. This has led to many common networking applications being deprecated or firewalled and replaced by their SSL-based secure versions. The remote shell command `rsh` became `ssh`, `cp` became `scp`, `ftp` became `sftp` and so on. While some HTTP sites moved to HTTPS, the relative proportion of HTTPS/HTTP traffic remains small, even though there was a post-Snowden surge in May 2014:

“before the Snowden revelations encrypted traffic accounted for 2.29 percent of all peak hour traffic in North America, according to Sandvine’s report. Now, it spans 3.8 percent. But that’s a small jump compared to other parts of the world. In Europe, encrypted traffic went from 1.47 percent to 6.10 percent, and in Latin America, it increased from 1.8 percent to 10.37 percent.” [12]

While HTTPS provides a relatively high degree of security for web traffic compared with HTTP the flawed operation of the Public Key Infrastructure commercial market has partially undermined its reliability [13].

C. HTTP/2 and SPDY

HTTP/2 [14] [15] is a major enhancement to HTTP 1.1, principally motivated by the need to improve the Page Load Time (PLT) of modern, large, complex web pages. Average page sizes and their complexity in terms of the number of objects have grown from approximately 10 Kbytes in 1995 to 1600 Kbytes in 2014, and from two objects in 1995 to over one hundred objects in 2014 [16]. Not only has the number of objects grown, but they are more varied in type and come from an increasing number of different domains.

“Today’s Web bears little resemblance to the Web of a decade ago. A Web page today encapsulates tens to hundreds of resources pulled from multiple domains. Users access the Web from diverse device form factors, while browsers have improved dramatically.....A constant throughout this evolution is the underlying application layer protocol—HTTP— designed at a time of far less page complexity.....HTTP (1.1) is not optimal, with pages taking longer to load. Studies over the past five years suggest even 100 milliseconds additional delay can have a quantifiably negative effect on Web use, spurring interest in improving Web performance” [17].

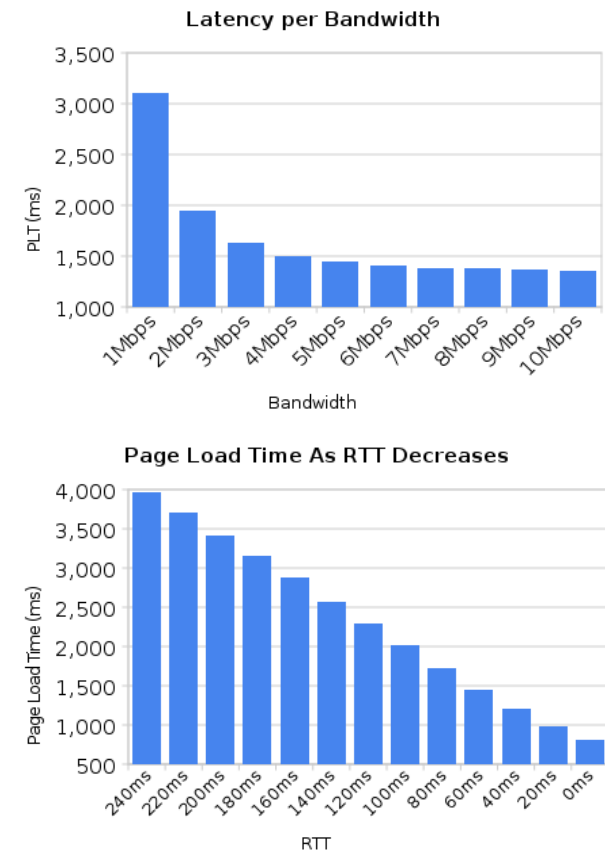


Figure 4: Impacts of Bandwidth vs RTT on Page Load Time (from [18]).

While the network and protocol components are only part of the overall delay in Page Load Time, the latency engendered by HTTP 1.1 was seen as a worthwhile target, and hence Google launched the SPDY R&D project in 2009 to provide an alternative protocol.

“SPDY adds a framing layer for multiplexing multiple, concurrent streams across a single TCP connection (or any reliable transport stream). The framing layer is optimized for HTTP-like request-response streams, such that applications which run over HTTP today can work over SPDY with little or no change on behalf of the web application writer.....SPDY attempts to preserve the existing semantics of HTTP. All features such as cookies, ETags, Vary headers, Content-Encoding negotiations, etc work as they do with HTTP; SPDY only replaces the way the data is written to the network.” [19]

Internet access bandwidths have increased while pages have grown but the basis for much of SPDY’s design was the belief that the main gains could be achieved by reducing the aggregate Round Trip Time (RTT) in a session. The comparison provided by Belshe [18] (see Fig. 4) pointed towards the relative importance of reducing RTT as opposed to increasing bandwidth beyond e.g. 3 Mb/s. In 2014 Akamai reported the global average connection bandwidth as 4.5 Mb/s [20].

HTTP/2, which started as a copy of SPDY in 2012, was almost fully accepted as an Internet standard by early 2015[14].² A very significant point is that unlike the change from HTTP 1.0 to HTTP 1.1, a SPDY implementation must support *all* the SPDY protocol features. This is achieved by using the “UPGRADE” header in HTTP i.e. if the client and server agree to switch to SPDY then all the new features must be supported. All SPDY traffic is encapsulated by SSL, and uses port 443. HTTP/2 has left open the possibility of non-SSL based sessions, but by March 2015 this option does not appear to have been implemented, and it is not clear that it will be. HTTP/2 also seeks to reduce the number of concurrent TCP connections from a browser to the same domain.

By 2014 most of the global web-based service providers including Google, Twitter and Facebook supported SPDY at the server side, and most of the popular browsers, Chrome, Firefox, Safari and IE, supported SPDY at the client side, so in effect, SPDY had already conquered a significant part of the web before being repackaged as the HTTP/2 draft standard.

The following subsections outline the key features introduced by SPDY and mostly adopted in HTTP/2 [21].

1) Frames, Streams and Multiplexing

The unit of communication in HTTP/2 is the *frame*. There are ten different frame types: DATA, HEADERS, PRIORITY, RST_STREAM, SETTINGS, PUSH_PROMISE, PING, GOAWAY, WINDOW_UPDATE, CONTINUATION.

² SPDY and HTTP/2 are used interchangeably in many papers due to the great influence of SPDY on HTTP/2.

A *stream* in HTTP/2 consists of bidirectional sequences of frames flowing between two endpoints (client and server). The server and client can send data simultaneously. Multiplexing allows for multiple streams of request and response frames (of maybe similar or different data) on a single TCP connection.

2) Prioritization, Dependency of Streams

Streams can be interleaved and prioritized. This allows an endpoint to allocate more resources to what is being prioritized when managing concurrent streams. Priority information can be used to select the appropriate streams for transmitting frames when there is limited sending capacity for any reason. A client can assign a priority number for a new stream in the HEADERS frame. Reprioritization of reserved streams can be regulated by the PRIORITY frames. This allows for more effective pipelining than HTTP 1.1 in that Head of Line blocking (see Fig 2c) can be avoided.

Streams can explicitly depend on the completion of other streams. This also affects the priority of streams. Dependency is assigned a weight between 1 and 256 inclusive. Dependent streams share the resources assigned to their parent in accordance with the weight assigned to them. Dependent streams move with their parent stream whenever the parent is reprioritized. A stream that is not dependent on any other stream is given a weight of 0 [14].

3) Binary Framing Layer

The binary framing layer in SPDY “dictates how the HTTP messages are encapsulated and transferred between the client and server”[22]. HTTP/2 has kept the same semantics, such as verbs and headers of HTTP 1.x. Changes occur in how these semantics are encoded, encapsulated and then transferred. In other words, their encoding in transit is what is different.

4) Server Push

A server can send pre-emptively (or “push”) additional objects in addition to replying to requests from clients. For example, a server can send images, icons, CSS or JavaScript code before the client explicitly requests them. A client can however request that *server push* be disabled during a connection. Khalid et al. [23] have argued that this feature can be problematic in mobile devices because it can waste battery or bandwidth and proposes mechanisms for HTTP/2 that adjust the overall performance on mobile devices.

5) Header Compression

In HTTP 1.x, headers are typically repetitive and verbose. HTTP/2 compresses headers using the HPACK algorithm [24], based on Huffman encoding.

6) Flow Control

HTTP/2 Flow Control is used for both individual streams and for the connection as a whole. It is regulated through the use of the WINDOW_UPDATE frame; only DATA frames are subject to its effect. Receivers advertise how many octets they can receive for a specific stream or for the whole connection. The sender must respect the limits advertised by the receiver.

Flow control in HTTP/2 aims to make it possible to utilize network resources better by not allowing a particular stream to starve, and by dealing with slow/fast upstream and downstream connections adequately.

7) RTT and Liveness

PING frames have the highest priority. They are used to measure round trip time and check if the connection is still functional or the peer is still alive.

III. SUPPORTING HTTP IN THE NETWORKING CURRICULUM

This section suggests resources that can be used educationally to complement the accounts of HTTP in popular texts through contextualization and hands-on exercises.

A. Contextualisation

The story of HTTP evolution from HTTP 0.9 to HTTP/2 is in itself an educational topic, illustrating the standardization process in the W3C and IETF. Popular textbooks use HTTP 1.1 as a reference, some of them including the pipelining feature which has never been widely used in practice. It is recommended that the sections on HTTP in such texts are augmented by information on SPDY and HTTP/2. An accessible, if rather uncritical, overview of SPDY can be found in [17]. A short and readable account of the key differences between HTTP 1.0 and HTTP 1.1 can be found in [11]. Critical commentaries on SPDY and HTTP/2 can be found in [25, 26]. Table II gives a summary overview of key differences between the deployed versions of HTTP between 1995 and 2015.

Internet standards are published as RFCs. The nature of RFC content has been referred to as “...very technical, turgid and nearly incomprehensible” [27]. As a light-hearted poke at RFC 2068 (HTTP 1.1), RFC 2324 uses the same language style to describe the Hyper Text Coffee Pot Control Protocol (HTCPCP) [28], which amongst other features introduces the new error code 418 “I’m a teapot”.

These types of textual materials can be used by lecturers as the basis for learning resources, or can be passed directly to students as study topics for essays. Branches can be followed if there is time in the curriculum. For example a particular criticism from [26] is that all HTTP/2 sessions are being run over TLS. Empirical studies have shown that there can be a significant cost of using SSL [29] – so when is a secure connection really (not) needed? Do public library opening hours and bus timetables need to be rendered immune from eavesdroppers?

Another criticism of HTTP/2, possibly best suited for more advanced students, is that it violates the established network design principle of *layering and abstraction* by replicating much of the functionality already provided by TCP at the underlying transport level. For example, both protocols support flow control, window size negotiation and pipelining. A further consideration is that SPDY introduces explicit state to HTTP, by way of session initiation and closedown, in a similar way that a TCP virtual connection is managed in its macro state.

Studies have compared the performance of SPDY to previous HTTP versions [30] [31]. These give mixed, sometimes contradictory, results in terms of SPDY outperforming older versions of HTTP or the opposite. SPDY has been studied on mobile devices[32] and on high latency Satellite networks [33].

Other factors such as Web page characteristics, server load and browser processing also play an important role in the overall perceived page load time of course [25].

Part of the wider context includes the topic of making the web faster. This can include Content Distribution Networks (covered in major textbooks); increasing TCP’s opening window size [34], and domain sharding, whereby a browser is forced into making parallel connections due to deliberately placing web page components in different domains [35].

Table II: Summary of major differences in HTTP versions 1.0, 1.1 and 2

HTTP 1.0	HTTP 1.1	HTTP/2
“Stop and Wait”, strictly sequential processing of requests and responses over TCP	“Stop and Wait”, strictly sequential processing of requests and responses over TCP	Full duplex streams of binary frames over TLS/TCP
PDU: HTTP Message	PDU: HTTP Message	PDU: HTTP/2 Frame (10 Types)
New TCP connection opened for each Request/Response pair Browsers seek performance gain by opening multiple parallel TCP connections, even between client and server in same domain	Persistent TCP connections specified and adopted Pipelining specified but not mandatory and not adopted Browsers continue to open multiple parallel TCP connections within same domain	Aim: One persistent TCP Connection per domain Multiple concurrent streams within the TCP connection Pipelining mandatory Stream Multiplexing and Prioritization Dynamic stream dependencies and reprioritization
Caching, Content compression option	Caching, content compression option	Caching, Content compression Header Compression Server Push Flow Control

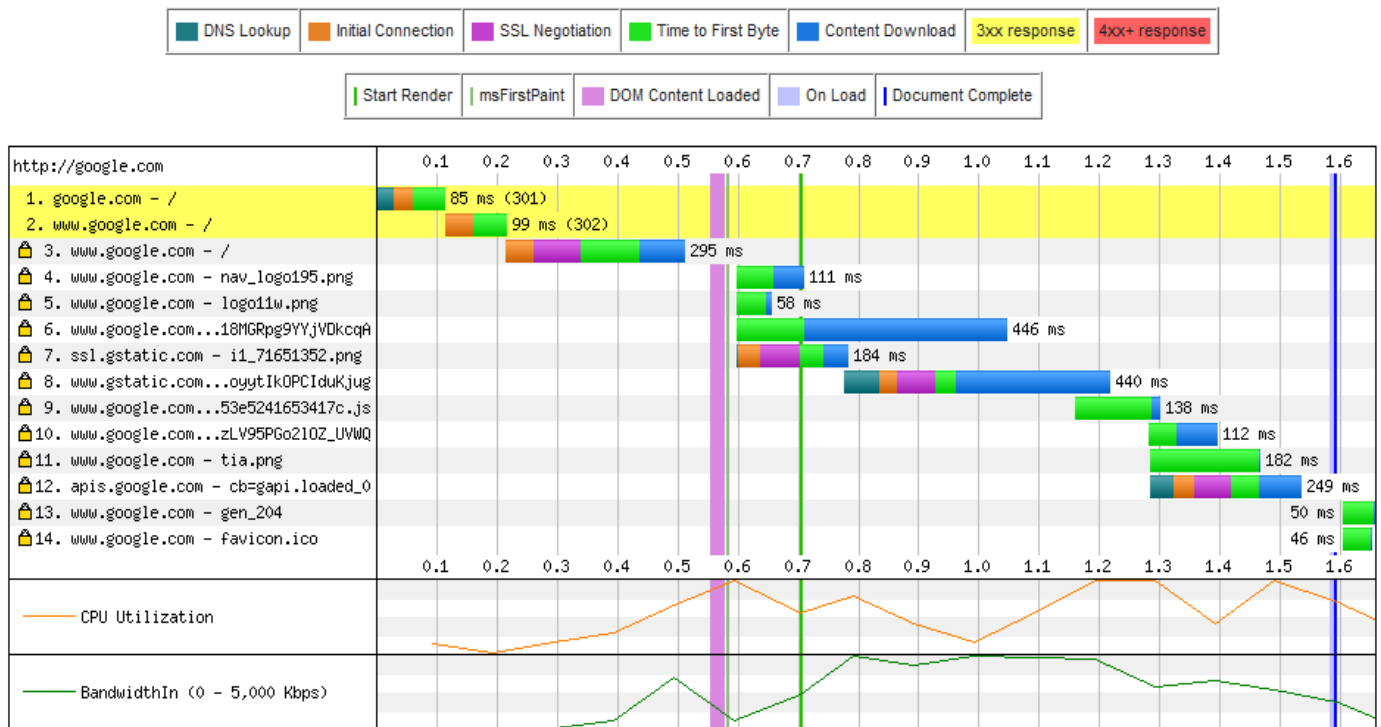


Figure 5: A waterfall view of page load time from www.webpagetest.org after accessing google.com

Web page content optimization is supported by systems such as ModPageSpeed [36], an executable Apache module that uses a complex set of rules to dynamically rewrites a page for particular connection.

David Wetherall has prepared a MOOC based on T&W 5th edition [1]; the videos can be accessed on demand, irrespective of the MOOC schedule. Video 8.8 [37] lasts for twenty minutes and addresses the future of HTTP, a topic not covered in the book. Around four minutes is spent on SPDY and HTTP/2 developments. The tentative nature of the discussion suggests the video was made around 2012. It is a useful high level introduction to the modern web.

B. Hands-on activities: observation and analyses

The use of Wireshark [38] in lab exercises has been popularized in supporting material by Kurose and Ross [3].

Recent Wireshark releases support both SPDY and HTTP/2 identification.

The *webpagetest* tool [39] is a free online service that is also useful educationally. Figure 5 shows a “Waterfall View” of the Page Load Time for google.com (from webpagetest’s point of view onto the Internet). There are also facilities built-in to Chrome and Firefox that allow students to observe the components of PLT. These can optionally be displayed in a waterfall style (Fig.6). Note that a Firefox add-on [40] signals in the address bar that SPDY or HTTP/2 is in use.

The web page at spdycheck.org tests user-specified sites for SPDY, TLS, HTTP/2 and HTTP 1.1 support. Networking students can progress from understanding to creating by writing their own code to carry out these tests.

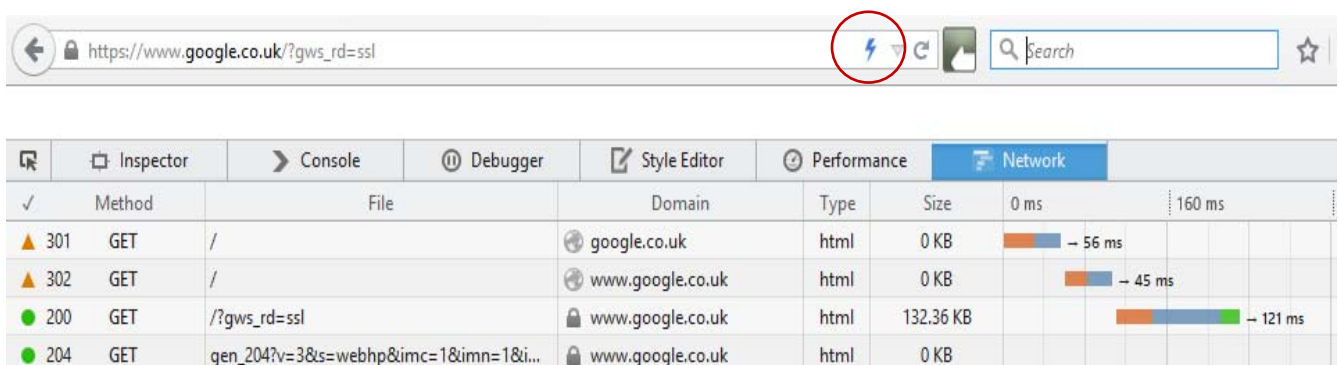


Figure 6: Screenshot of Firefox’s built-in network monitoring facility; an add-on [40] shows when SPDY or HTTP/2 is in use (circled)


```

3868: SPDY_SESSION
clients2.google.com:443 (DIRECT)
Start Time: 2015-04-27 12:01:32.782

t=88844 [st= 0] +SPDY_SESSION [dt=?]
--> host = "clients2.google.com:443"
--> proxy = "DIRECT"
t=88844 [st= 0] SPDY_SESSION_INITIALIZED
--> protocol = "h2-14"
--> source_dependency = 3865 (SOCKET)
t=88844 [st= 0] SPDY_SESSION_SEND_SETTINGS
--> settings = ["[id:3 flags:0 value:1000]", "[id:4 flags:0 value:10485760]"]
t=88844 [st= 0] SPDY_STREAM_UPDATE_RECV_WINDOW
--> delta = 10420225
--> window_size = 10485760
t=88844 [st= 0] SPDY_SESSION_SENT_WINDOW_UPDATE_FRAME
--> delta = 10420225
--> stream_id = 0
t=88845 [st= 1] SPDY_SESSION_SYN_STREAM
--> fin = false
--> :authority: clients2.google.com
--> :method: POST
--> :path: /service/update2
--> :scheme: https
--> accept-encoding: gzip, deflate
--> content-length: 1261
--> content-type: application/xml
--> user-agent: Mozilla/5.0 (Windows NT 6.3; WOW64) AppleWebKit/537.36 (KHTML,
--> spdy_priority = 3
--> stream_id = 1
--> unidirectional = false
t=88845 [st= 1] SPDY_SESSION_SEND_DATA
--> fin = true
--> size = 1261
--> stream_id = 1
t=88845 [st= 1] SPDY_SESSION_UPDATE_SEND_WINDOW
--> delta = -1261
--> window_size = 64274

```

Figure 7: A trace from Chrome's built in network monitor showing a SPDY session

It is possible to get a breakdown of a SPDY or HTTP/2 conversation in Chrome by initially using the URL: `chrome://net-internals/#spdy`. This brings up the following information:

- HTTP/2 Enabled: true
- Use Alternate Protocol: true
- Force HTTP/2 Always: false
- Force HTTP/2 Over SSL: true
- Next Protocols: http/1.1, spdy/3.1, h2-14

If a live HTTP/2 session is then selected, the working of the protocol can be observed, including streams, priorities and flow control window size (see Fig 7). It is interesting to note that in some cases e.g. Facebook, SPDY appears to act as an encapsulating layer for HTTP 1.1 whereas in an all-Google HTTP/2 conversation (Fig. 7) there is no explicit mention of HTTP 1.1 although the familiar header fields are listed.

Entering `about:config` and then searching for `spdy` in the Firefox address bar will elicit the list in Table III.

Table III: Firefox SPDY parameters

<code>network.http.spdy.allow-push</code>	true
<code>network.http.spdy.chunk-size</code>	16000
<code>network.http.spdy.coalesce-hostnames</code>	true
<code>network.http.spdy.default-concurrent</code>	100
<code>network.http.spdy.enabled</code>	true
<code>network.http.spdy.enabled.deps</code>	true
<code>network.http.spdy.enabled.http2</code>	true
<code>network.http.spdy.enabled.http2draft</code>	true
<code>network.http.spdy.enabled.v3-1</code>	true
<code>network.http.spdy.enforce-tls-profile</code>	true
<code>network.http.spdy.persistent-settings</code>	false
<code>network.http.spdy.ping-threshold</code>	58
<code>network.http.spdy.ping-timeout</code>	8
<code>network.http.spdy.push-allowance</code>	131072
<code>network.http.spdy.send-buffer-size</code>	131072
<code>network.http.spdy.timeout</code>	180

Students can be asked to research and explain the meanings of these parameters, and can also change the settings and record the effects when interacting with the same web site.

C. Hands-on activities: Simulators and Emulators

For students with adequate time the next stage beyond observation and analyses is to use a simulator to modify traffic characteristics such as bandwidth, packet loss and delay, to see how that impacts on performance. A good starting point is to give the student a pointer towards Belshe’s comparison of bandwidth vs RTT [18] with respect to impact on PLT (see Fig. 4) and ask them to see if they can reproduce these figures through simulation and measurement. Science is built on reproducible research results but in the case of Internet measurements, even simulations, reproducibility can be challenging.

There are various open source network simulation tools available, including ns3 [41] and Trickle [42]. Opnet is now called Riverbed Modeler [43] and is free for academic use.

In lab exercises the traffic shaping Linux kernel library (tc) [44] and NetEm [45] can be used to emulate delay and packet loss. Bandwidth control can be achieved using the Hierarchical Token Bucket control feature of the queuing discipline interface (qdisc) [46] in Linux. SPDY or HTTP/2 can be turned on and off in Chrome using the Chrome settings option. Sites including Facebook, YouTube and StatCounter can be used as test cases. In our experience it proved hard for any student to replicate the performance gains expected by moving to SPDY, but we should emphasize that this was an educational exercise rather than a robust piece of research.

IV. QUIC

Interestingly, when observing and analyzing live HTTP/2 connections we discovered the QUIC protocol [47] being deployed by Google.

“QUIC is an experimental protocol aimed at reducing web latency over that of TCP. On the surface, QUIC is very similar to TCP+TLS+SPDY implemented on UDP. Because TCP is implement in operating system kernels, and middlebox firmware, making significant changes to TCP is next to impossible. However, since QUIC is built on top of UDP, it suffers from no such limitations.” [47]

QUIC supports HTTP/2 functionality over UDP port 443. During a SPDY session the UPDATE header is used to switch to QUIC; this appears to be the current Google protocol of choice for short exchanges such as visits to sites which record advertising, analytics and marketing information. Entering `chrome://net-internals/#spdy` in the Chrome address bar reveals a comprehensive list of alternative QUIC based URLs for Google services.

Why QUIC? Part of the performance problem for SPDY and HTTP/2 lies in the behavior of TCP (see [48] [32]). A single TCP congestion avoidance window can put SPDY or HTTP/2 at a disadvantage compared with multiple HTTP 1.1/TCP connections each with a separate congestion window, which is often the case with HTTP 1.x.

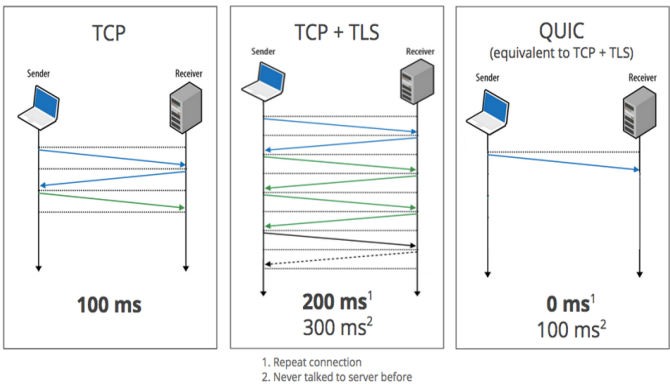


Figure 9: QUIC’s Zero Round Trip handshake

A single lost packet will impact on *all* the multiplexed streams in a single TCP connection. QUIC is UDP based so avoids this. In addition, QUIC has a *zero round trip handshake* capability, see Fig. 9, conveniently avoiding the TCP handshaking and close down exchanges (see Fig. 3) that would increase the number of round trips.

HTTP/2	HTTP/2
SSL or TLS	QUIC
TCP	UDP
IP Network	IP Network

Figure 10: HTTP/2 alternative protocol stacks

However, UDP lacks congestion control and SSL functionality so QUIC seeks to replicate these within itself: QUIC has a pluggable congestion control algorithm option which is currently TCP Cubic and supports its own TLS-like security protocol, thus seeking to recreate the semantics of HTTP/2 over TLS/TCP without the performance drawback. Figure 10 summarizes using networking layered models. Recent versions of Wireshark can identify QUIC.

V. CONCLUSION

Areas of the Internet are undergoing a rapid rate of change. A pertinent example is the HTTP 1.1 application-level protocol which has been superseded by SPDY in many of the web transactions between popular browsers and major web sites since 2012. While it is testimony to the value of protocol layering that web users are largely unaware of this major change in HTTP it is not acceptable that computer networking students remain ignorant of it. It is incumbent on educators to ensure that the curriculum reflects such significant changes in this pervasive web protocol. Most of SPDY has now been adopted as the HTTP/2 standard but even the most recent editions of established computer textbooks have not caught up with HTTP/2. This paper makes a modest contribution towards filling the current gap by giving recommendations for resources that can be used to contextualize and obtain hands-on experience of recent developments in HTTP evolution.

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Understanding the Prototyping Strategies of Experienced Designers

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Abstract—

Engineering students need to learn highly effective processes for pursuing difficult design problems that require highly innovative solutions. Few studies exist of highly successful expert design teams. The current paper presents the results from a multi-million dollar department of energy research project which reduced the racking hardware and mounting installation costs for commercial applications by more than 50%. This was an extremely challenging goal which was met. This study focuses on the prototyping processes of the team in order to determine effective approaches. Structured interviews with documentations of the prototypes were conducted. Results show the team while the team started with prototyping the complete system they often iterated at the component then integrating it into the complete system prototypes. The early tests of the prototypes tended to be less formal and the number of test increased with each prototype. The professional team also reverted to earlier versions and restarting their processes when a given design path was not successful.

Keywords—prototyping strategy; expertise; product design

I. INTRODUCTION

In order for engineering students to be very successful designers, they need to learn effective design processes and practices to complete their technical skills. Included in these skills sets are strategies for effective prototyping that maximize the knowledge and design confidence gained while minimizing cost and time. Unfortunately, few studies provide highly detailed accounts of the prototyping strategies employed by highly innovative design teams. The lead authors of this paper were provided access to a team of designers that have made significant inroads to reducing the installation costs of solar panels. Through structured follow-up interviews, details account of the prototypes and their purposes was obtained from the designers. Some intriguing outcomes and potential strategies for students were obtained.

II. BACKGROUND

A. Prototyping Strategies

Prototypes are powerful tools in the process of designing a new product. They allow for the designers to strengthen their mental models of how a design will look and behave [1], effectively share ideas with other designers [2] and

provide a medium for validating or improving design decisions [3]. Prototypes have the ability to reveal shortcomings that may not be detectable by other methods [1, 4-6]. However, there are potential problems that can occur as a result of using prototypes. Due to the money, effort, and time spent on materials and fabrication of prototypes, design fixation can occur as a part of the “Sunk Cost Effect” [6]. This theory states that the more resources expended on a certain path, the less likely a designer will be to move on to a new idea. Design fixation and other shortcomings in the use of prototypes can be mitigated through strategy in the construction of prototypes [7-9]. It has also been observed that more experienced designers are more successful in mitigating design fixation [10].

While experts are better at mitigating fixation, physical prototypes have been found to help students overcome design fixation. In the experiment performed in [11], students were given a flawed prototype and asked to construct a more effective design. The participants fixated on the flawed design at first. However, the participants were able to quickly overcome their initial fixation through testing a rebuilding the prototypes. This shows that while prototypes can cause fixation, they can also be used to overcome it. Therefore, it is important for students to learn effective prototyping strategies. In a previous study [1], Viswanathan, et al. found that professional designers would purposefully implement strategies specifically geared towards avoiding shortcomings such as the “Sunk Cost Effect”. This paper looks to build off of the work done by Viswanathan, et al. by using more qualitative research methods to look specifically at what strategies were used and why they were implemented.

B. Classifications

Several classification systems have been created by researchers as they study prototypes. These classifications often characterize both the intent of the prototype, such as performing evaluations or communicating aesthetics [12], and the physical characteristics, such as the scale or the material used to create prototype [13]. Gaining a better understanding of these characteristics improves the researchers’ ability to record, analyze, and discuss data collected during the study of prototypes [14]. The classification system defines both the intended use of the

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prototype as well as its physical characteristics. The classifications developed are shown in Table 1.

This classification system was divided up into different sections used to describe the overall prototype. An extensive literature review of past efforts in prototype taxonomy was conducted and used to determine the needed categories and categories available in each section. The first section was the overall Purpose of the prototype. The purpose of the prototype defines how the prototype was used by the designers. Ulrich and Eppinger [15] suggest that prototypes can have four major purposes: learning, communication, integration, and milestones. However, through the data collection in the previous work on this project, Viswanathan et al. [1] found that the designers on the SIMPLE BoS project had an informal taxonomy system to describe the purpose of a prototype: Design Intent, Functional, or Representation. The categories used for this classification system were based on the designers' current system as this allowed them to classify each prototype more easily during data collection. Adjustments were made based on literature to include other aspects not represented by this taxonomy and represent the clear differences between each category.

The Design Intent category describes a prototype used to communicate to other designers on a project how the product should look and/or operate. Communication is one of the major purposes behind creating a prototype as it allows all stakeholders in a project to possess the same mental model of how the product will look and/or function [1]. The Functional category describes prototype that carry out some or all of the functions intended to be performed by the final product. The Integration category describes prototypes that combine separately developed components or design ideas to investigate how they perform as a whole system [13]. Milestone prototypes are used for presentations or to benchmark a certain level of functionality [15].

The next section defines the evaluations intended to be performed on the prototype. Eggert [12] suggests that all prototypes can be grouped into one of three categories: Form, Fit, or Function. Form evaluations are used to determine if the product has an acceptable appearance. Fit evaluations determine how well the separate parts fit together properly and if the product fits well in the space it is intended for. Function evaluations test how well the product completes its desired functions. The designers were also asked to list the Function evaluations that were performed on each prototype.

The Manufacturing section defines how the prototype is created. The prototype may be made in-house by the designer or outsourced. Depending on the nature of the product being developed, the final prototype may be made at a

separate facility to test the production level on a mass quantity level. Prototypes made using the intended production method enable the evaluation of the design's compatibility with the intended manufacturing method [16]. The designers also described what materials were used to create each prototype and whether or not these materials differed from the intended production material.

The Scale section defines the size of the prototype compared to the intended production size. Otto and Wood [3] state that prototypes can be to-scale, large-scale, or small-scale. The classification system developed for this study allowed more specific options of a to-scale model or not-to-scale prototype. A rough scale model was also included as an option to classify models made nearly to scale, but no scale measurements were actually considered.

The Functionality section looks to define the level of functionality of the prototype. Otto and Wood [3] present useful ways to divide the functions of a product and discuss how each function can be improved individually. Therefore, not all prototypes are fully functional. That is, some prototypes are created only to address how one or some of the functions is address by the overall product. These prototypes are categorized as being partially functional while prototypes that address all of the intended functions are classified as fully functional prototypes. A prototype can also be non-functional, not possessing any functionality and created solely to represent the aesthetics of the final product.

Table 1 Prototype Classifications

Purpose-Why is this prototype being created?	
Design Intent	Used to convey design intent.
Functional	Used for functional tests (see below).
Integration	Integrates components of the product [13, 16].
Milestone	Used for showcasing progress [1, 13].
Evaluation-What evaluations are being performed?	
Form	Evaluates the aesthetics of the product [12, 13].
Fit	Evaluates how the components fit together [12, 13].
Function	Evaluates the functionality of the prototype [12, 13].
Manufacturing-How was this prototype made?	
Production Level	Manufactured as intended for the final product [16].
Outsourced	Manufactured by an outside source [16].
In-House	Manufacture in-house [16].
Scale-What are the proportions of this prototype? [3, 13]	
Full-Scale	Intended size of the final product.
To-Scale	Not intended for final product, but built to-scale of final.
Rough Scale	Similar to the scale of final product (within 20%).
Not-to-Scale	Built without regard to scale.
Functionality-What functions does this prototype possess?	
Fully Functional	Has all of the functions intended in the final product [3].
Partially	Has some functions intended for the final product [3].
Non-Functional	Is not functional/Appearance-only Model [3].
Components-What components does this prototype include?[16, 17]	
All	Includes all components intended in the final product.
Multiple	Includes multiple components.
Single	Is only of one component of the final product.

The final section defines how any components are included in the prototype. Moe et al. [17] discuss the benefits of prototyping separate parts of a product to reduce fixation along with other benefits. By creating a “less complete” prototype that omits component to be included in the final product, the prototype can be used to more fully evaluate the effectiveness of each individual component. This section classifies prototypes as either single component, including multiple components, or including all components intended to be included in the final product.

In previous efforts to create a prototyping taxonomy, orthogonality was considered to be a measure of success between the categories in each section [13, 16]. However, the authors of this paper found it more appropriate to allow the designer to choose all categories that applied to a prototype for the Purpose and Evaluation sections as this created a more accurate description of why the prototype was constructed.

It is important to note that this study used the presented categorization system to gather data. This allowed us to have a clear definition of why the prototype was constructed in the opinion of the designers and provided a tool with which to construct the interviews around. Future studies may be done to evaluate the strength of this classification system, but that is not the scope of the current study.

C. SIMPLE BoS

The study described in this paper is conducted on a project carried out by Georgia Tech Research Institute (GTRI) aiming to minimize the balance of system (BoS) costs associated with the production of solar energy. The BoS typically consists of mounting of solar panels and power-conditioning equipment to properly convert the generated DC to AC [16]. They may also contain batteries for operation on cloudy days [17]. Currently, BoS costs account for around 40% of the total installed cost of the solar energy systems.

The SunShot Initiative by the U.S. Department of Energy (DOE) aims to produce cost effective solar energy. This program aims to reduce the cost of solar energy production by 75% before 2020 [18]. As a part of achieving this target, the DOE provided a grant to the researchers at the Georgia Institute of Technology to develop commercially-ready, next generation solar PV BoS designs [19]. This project, titled “SIMPLE BoS” (Solar, Installation, Mounting, Production, Labor and Equipment), is led by the Georgia Tech Research Institute (GTRI). The final goal of the SIMPLE BoS project is to reduce the racking/mounting hardware and labor costs by greater than 50%.

As a part of this project, the team involved produced many prototypes at each stage. For example, Figure 1 shows an early stage mock-up of the supporting structure design during its design phase. Figure 2 shows a fully functional system on the rooftop of a commercial building. This design was a result of the team’s extensive design and prototyping process. Many times, these prototypes provide them useful insights and inspire significant changes in their ideas. As the

team consists of experienced professional designers, this project provides an ideal opportunity to learn about the benefits of prototyping for professional designers.



Figure 1: A Residential Mockup Developed during Early-Phase Design



Figure 2: Installed, fully functional system on the rooftop of Install at Ponce City Market in Atlanta, GA

D. Framework

Extensive prior by Camburn, et al., has identified a set of decisions designs must make when defining a prototyping strategy [18-20]. This serves as one of the theoretical frameworks for this research guiding the type of data that is gathered. Camburn outlines the following set of ‘strategy variables’:

- *Parallel versus serial concept prototyping*- Design team may intentionally prototype multiple completely different design concepts simultaneously. Alternatively a single design concept may be chosen and only one concept is prototyped at a time.
- *Planned iterations*- Depending on the available time, design risk, and costs of individual prototypes, team may intend to create multiple iterations of a design or may plan for only very few.
- *Scaling*- Prototypes can be a different size than the actual size. Micro or smaller scale components may be scaled up to macro size. Large objects such as buildings and airplanes are often scaled down.
- *Subsystem isolation*- Only subsystem or partial systems may be prototyped. The design may be optimized and improved at the component level.

- *Design Requirement Relaxation*- Prototypes may perform at a lower level than required by the final design. For example, they may have lower strength, less corrosion resistance, able to withstand fewer cycles.
- *Physical vs Virtual*- The virtual prototyping can model a wide range of product performance parameters. Some virtual prototyping is extremely fast and efficient while other times physical prototypes provide either more accurate data or are simply faster and cheaper to build.

The systematic, empirical study of prototyping practices is an emerging area in design research and warrants much greater study. This paper seeks to add to this growing body of literature by providing an in-depth analysis of the prototyping process for a highly innovative team of designers.

III. RESEARCH METHODOLOGY

The research question sought to be answered through the study of the expert designers is: *What strategies are used by expert designers in the construction, implementation, and evaluation of prototypes to aid in the development of a final product?* The SIMPLE BoS project is an excellent opportunity to answer this question due to the number and variety of physical prototypes used during the design process. This study lends itself to more qualitative methods as it looks specifically at why something occurs and the impacts of certain design decisions [21]. A qualitative study such as this one can provide a deeper insight into the motivations of the designers and how the project looks from their point-of-view [22]. This insight allows for a more complete understanding of the strategies implemented by the designers. The semi-structured interviews of the designers with the use of the prototype classifications developed by the authors allow for an effective way for this data to be collected.

A. Semi-structure interview

The data in this study was collected through three semi-structured interviews with a lead designer on one of the SIMPLE BoS teams who was also a student pursuing his PhD in architecture. These interviews lasted about one hour each and were conducted by the first author. For the first two meetings, the second author was present and assisted in the interview by asking follow-up questions. Both interviewers collected data via pen and paper. After the first interview, a slightly modified list of classifications was created. This classification list was a simplified version of the original list, leaving off categories originally included that remained constant throughout all of the prototypes. For example, all of the prototypes were made to-scale. Therefore, after the first interview, the scale classification was left off the list. This allowed the interviewers to focus more on the aspects that were changing between the prototypes.

The data collected from this interview was aimed to gain a more in-depth understanding of the data collected in a previous study by Viswanathan, et al. [1] by using this qualitative approach. The designer was provided with a copy of the classification list along with pictures of prototypes collected from the previous study. These prototypes were developed during various stages of the design process. The designer was asked to use the classifications provided to describe each prototype. The classification system provided structure to the interview to be based around, but open discussion about each prototype was had with emphasis on the reasoning behind the purpose of the creation of each prototype, at what point in the design process they were created, and what was learned from the evaluations. The designer was also able to list which evaluations were performed on each prototype.

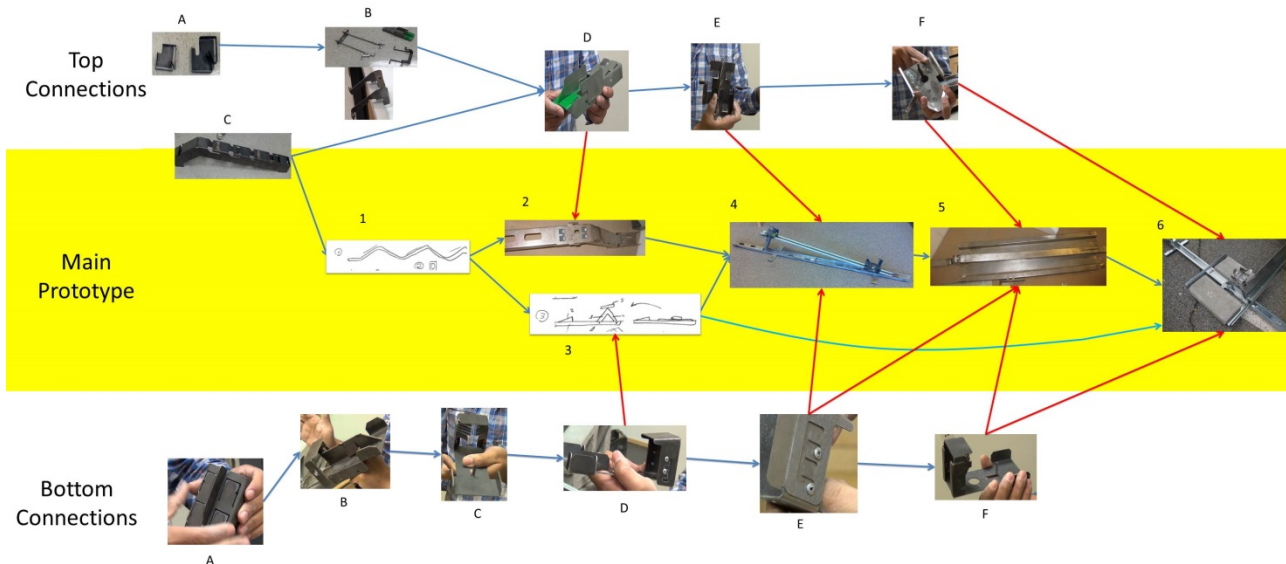


Figure 3: Overview of the prototypes. Prototypes are shown in chronological order with indicators showing influence from previous versions.

IV. FINDINGS

The results of the interviews are summarized in Table 2 and Figure 3.

Table 2: Total Number of Each Classification			
Classification	Total	Complete Prototype	Component Prototype
Purpose			
Design Intent	19	6	13
Functional	19	6	13
Integration	19	6	13
Milestone	3	3	0
Evaluation			
Form	19	6	13
Fit	19	6	13
Function	19	6	13
Manufacturing			
Final Production Level	0	0	0
Outsourced	0	0	0
In-House	19	6	13
Scale			
Intended Production	19	6	13
To-Scale	0	0	0
Rough Scale	0	0	0
Not-to-Scale	0	0	0
Functionality			
Fully Functional	13	1	12
Partially Functional	5	5	0
Non-Functional	0	0	0
Components			
All components	6	6	0
Multiple components	0	0	0
Single Component	13	0	13

Through analysis of the data collected in this study, three major findings arose answering the question, “What strategies are used by expert designers in the construction, implementation, and evaluation of prototypes to aid in the development of a final product?” The first finding was that the designers would begin each iteration of a design on the component level. The second finding was that the designers would revert back to previous version of a design if they reached a point in their design reached a local maximum. The third finding showed that the designers would continually build upon the list of evaluations they would perform on each prototype in both number and level of sophistication.

The designers on the SIMPLE BoS project were intent on being able to develop each component of the overall product separately. The team would then combine all of the components to test the entire prototype and determine how it could be improved upon. However, instead of trying to improve the entire prototype, they would focus on the separate components. This can be seen in Figure 3 as the

connection components that attached to the top of the solar panel were developed simultaneously with the connection at the bottom of the solar panel, and both connection components were continuously being improved upon as the overall design advanced.

A. Iterative Design Process on the Component Level

Through an iterative process the designers would build, test, and evaluate a single component prototype until it reached the level desired to be implemented with the other components. Once all the separate components met this desired standard, the entire prototype would then be tested with all the components. Based on those evaluations, it would be determined what design changes need to take place to the overall prototype which determined what adjustments needed to be made on the component level. The process would then begin again with a testing and evaluating each component. This process can be visualized as a flow chart as seen in Figure 4.

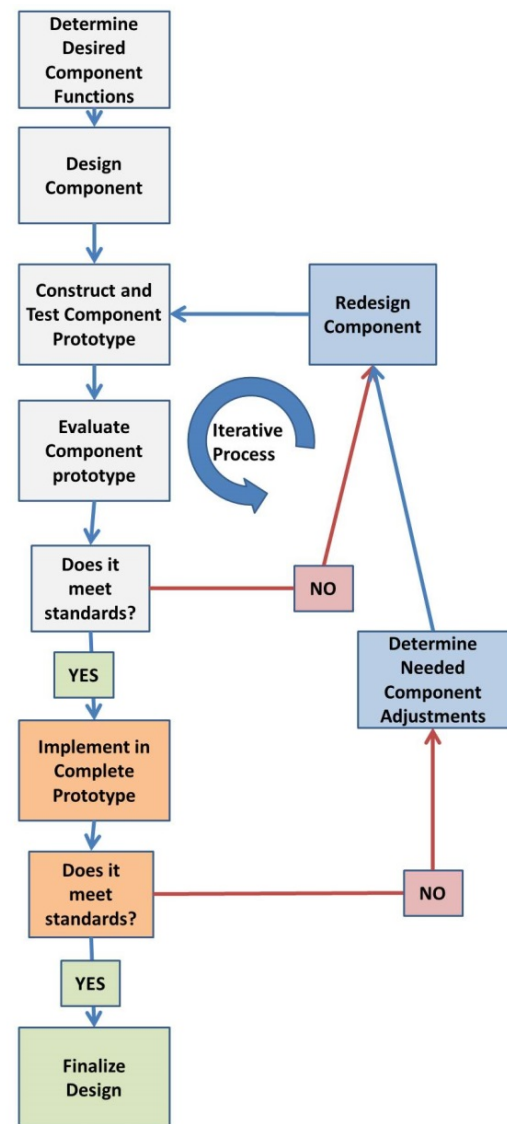


Figure 4: Iteration Design Process Implemented by the Design Team

This process was utilized to reduce the costs of prototypes as it was typically far less expensive to build and test a single component than to test an entire system. Therefore, the designers would want to ensure each component was designed properly before putting in the time and money into constructing and testing the full system.

Previous research has shown the effectiveness of iteration of prototypes in the design process [23]. It allows for an optimization of design and is effective at overcoming difficult requirements. Dividing the prototype and designing components separately as was done in this project also allows for an effective optimization and products of a higher quality [17]. *Back-tracking*

Whenever the design team found they had reached a local maximum in their design, they would often revert back to previous designs to determine what decisions were made to get them to their current state. They would then “backtrack” to a point of a major decision and then make the opposite one to see if that difference would help them to overcome that locally optimized design in search of a more globally optimized design.

The best example of this led to the final overall design of the system. A local maximum was reached near the end of the design process. The design would have been acceptable, except they were forced to change certain aspects of the structure due to a conflicting Intellectual Property. Therefore, they had to backtrack to a previous decision that lead them to the conflicting IP and find a different approach. When they reexamined a design a few iterations back, they discovered that they were able to combine aspects of their current design with aspects of that previous one and create a more optimized final design that also avoided the IP conflict (Figure 5).

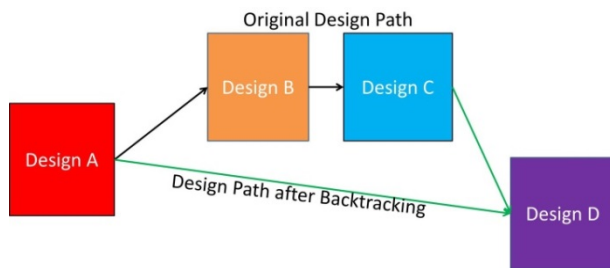


Figure 5: Backtracking Flow Chart

C. Growing Evaluation Lists

The final major finding gathered from the data was the evolution of the evaluations. During the early stages of the design process, most of the evaluations were quick and easy tests. For example, the early prototypes were statically tested by loading the panels down with sandbags so see how much weight that could hold. By the end of the end of the design process, the designers were utilizing much more formal tests such as using loading machines to evaluate the structural integrity.

Not only did the tests become more formal, as they progressed through the design process, the number of

different evaluations steadily grew. As they evaluated each prototype, more tests were added to determine how effective their design was becoming. Every time a new test was performed, that test would be performed on every prototype evaluated thereafter. A prime example of this was a test the design team referred to as the “step on” test. During one of the evaluations of the complete prototype system, one of the designers noticed a section the frame that was not designed to hold weight looked rather fragile. To simulate a worker installing the panels, he stepped on that section of the frame to hoist himself to the opposite side. The section of frame was broken as a result and the designers quickly realized the adjustments that needed to be made to account for unanticipated loads during installation. After that evaluation, every complete prototype was tested by having a worker step on it as a worker may in the installation process.

By continuing to improve their evaluation methods, the designers were able to more confidently state that the final prototype was up to the standard that was desired. The final design was put through a complete set of formal tests including static loading, electrical grounding, packing space needed, ease of assembly, and the “step on test”.

V. CONCLUSION

The study of highly successful professional design teams has great potential to provide guidance on effective strategies for the design and prototyping process. Data collection on practicing designers can be extremely challenging due to intellectual property issues, the long-time spans of projects, large amounts of data and many other issues. This paper presents a study of the prototyping process for a multi-million dollar, very successful, department of energy project. A targeted approach collects data on the prototyping practices.

This paper first presented a prototype classification approach based on an extensive literature review and then used the prototype classification to provide insights into the team’s prototyping process. Data collection was targeted at the prototyping process using structured interviews. This design team only implemented full-scale (production scale) prototypes that had the design’s final intended form, fit and function. This paper only illustrates one of the three designs that this team worked on and all designs contained a relatively high number of full-scale prototypes. This strategy choice may be significantly impacted by the type of product being designed and the team’s goals. The goals were centered on installation cost reductions, a characteristic that is difficult to predict without a physical prototype at full-scale or very detailed mental models due to extensive experience in installing solar panels. For very innovative designs it can also be very difficult to make accurate predictions based on a person’s mental models.

This team also implemented a very extensive number of component level prototypes illustrating the need for students to be very effective at recognizing system interfaces, key functions of components, the ability to optimize at the

component level, and the knowledge to easily switch between component and system level thinking. All of the prototypes in this paper were built in-house likely due to the fact that these designs contain standard machining processes and the universities extensive prototyping resources were available. This often led to design ideas that could be more quickly evaluated. This may have also biased the team towards designs that could be quickly built in-house. However, one of the main goals of the design was to create a system that could be mass-manufactured using low-cost methods. These methods include process such as stamping and roll-forming which were replicable to a large degree due to the experienced fabricators available in-house to the design team. Therefore, these in-house designs are still viable representations of their mass-manufactured versions.

The data presented in this paper is one of three designs sought by the team. Interviews of with the designers for the other two prototypes are still in progress and will provide more details on the prototyping process for the team.

Effective prototyping skills and strategies are just one of the many tools engineers need to be highly effective engineers. More work needs to be done on developing prototyping strategies and best practices in utilizing prototypes in the design process.

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All data collection, and analysis was completed by Ethan Hilton and Julie Linsey.

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STEM Literacy: Challenges implementing ‘E’ in Local Texas-STEM Academies

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Abstract— This paper focuses on the challenges apparent to implementing the engineering experience component within science, technology, engineering and mathematics (STEM) programs adopted at state designated academies in El Paso, Texas, based on a literature review, preliminary to potential research opportunities.

El Paso is ranked as one of the poorest metropolitan areas in the country, and improvements in growing STEM success can impact the region’s output of qualified professionals in those fields.

According to research studies, students enrolled in STEM schools significantly impact enrollment in college, through taking STEM subjects in high school and pursuing STEM careers through higher education. Eight local STEM academies have been established since 2006 and their educators and school leaders may need to revamp STEM efforts by addressing these engineering implementation challenges.

The literature reviewed includes national and state policies; local initiatives; integrated curriculum; national and state engineering standards; and school leadership. Some challenges schools face when pursuing STEM literacy are educator certification and training, state requirements, standardized testing, insufficient funding, engineering curriculum, among others. As a result of this literature review, future research opportunities are identified within STEM academies, which may guide education leaders towards best practices in engineering education and quality of STEM literacy.

Keywords—*T-STEM academy; engineering literacy K-12; STEM literacy, integrated STEM curriculum; STEM policies; HBS;*

I. INTRODUCTION

El Paso Texas, situated along the US-Mexican border, is ranked as one of the poorest metropolitan area in the United States. As a result, slightly less than 12% of the region’s inhabitants hold a college degree, according to the 2009 United States Bureau of Economic Analysis report on the region. The paucity of graduates is a concern for the region which is challenged by falling behind in the overall supply of qualified professionals. This literature review will include research-based claims that the more STEM-oriented metropolitan areas the better the performance in most economic indicators. Also, that more jobs in the U.S. require a strong background in STEM areas than the supply of STEM prepared individuals in our region.

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The creation of STEM schools during the last couple of decades resulted from public and private initiatives to improve and increase our student output with a STEM concentration. Students enrolled in STEM schools may have a significant effect on college enrollment, taking STEM subjects and/or following STEM careers. Only eight STEM academies at the secondary level have been established in El Paso since 2006.

As STEM literacy programs and designated schools continue to be promoted locally, there are concerns regarding the attributes and efficacy of a STEM-focused school. There are challenges to consider by school leaders. One key problem is that most teachers in these programs are trained in either science or mathematics and may not be trained in engineering or technology. Therefore, making it difficult to successfully integrate engineering in the curriculum.

II. SIGNIFICANCE OF STUDY

A. Integrating Engineering towards STEM Literacy

Overcoming the engineering implementation challenges is key to STEM literacy success for current and future schools with such programs. “Educators must confront and resolve a number of challenges if they are to advance STEM literacy” [1]. Roger Bybee explained it best: educators must stop using the term “STEM” without actively incorporating technology and engineering into their programs.

B. Local Economy Demands High Skilled Pipeline

According to Workforce Solutions, labor market data indicates the need for a high skilled talent pipeline in the community to meet the demand for the high skill high wage jobs. Local growth in economic development will face significant challenges if the required talent pipeline is not developed. El Paso area is a tri-state, bi-national area that requires a unique educational dynamic worthy of further understanding.

C. STEM Professionals: Supply & Demand Gap

The more STEM-oriented metropolitan areas the better their performance in most economic indicators [2]. About 20% of jobs in the U.S. require a strong background in STEM, and about half of those jobs may require at least a bachelor’s degree [2]. Currently, in the United States, only about 6% of all bachelor’s degrees are in science or engineering [3]. There is a gap between supply and demand of qualified individuals to fill STEM related jobs. Also, in the next decade, the

number of retiring engineers and scientists will increase without enough home-grown talent to replace them [4].

D. STEM Schools Increase STEM Focused Graduates

STEM schools may have a significant effect on students “enrolling in college, taking STEM subjects and/or follow STEM careers” [5]. Our local T-STEM designated schools must develop certain characteristics in order to develop and promote college participation in these fields.

E. Engineering Has Never Mattered More

“Engineering and engineers have never mattered more” [6]. These authors refer to the new developments in nanotechnology, biotechnology, material science, and photonics, as carrying potential for prolonging healthier lives and overall improving human living conditions.

F. Teacher Comfort & Efficacy Yield Student Success

Studies show that training teachers in an integrated STEM experience yields higher student achievement; improves teacher comfort and efficacy with these topics; and thus the attitudes and expectations of students towards STEM [7]. Increased insights and understanding of current program practices in local schools can provide us with the basis needed to support such engineering education programs.

III. STEM LITERACY POLICIES

A. National STEM Initiatives

President Obama, in his 2013 State of the Union address, signaled his strong support for STEM-focused schools as a way to motivate and prepare students to pursue STEM careers. The United States Congress has included this recommendation in approved legislation, the America COMPETES Act of 2007 [8] and re-authorization of same Act in 2010. President Obama confirmed the plan to create 1,000 new STEM focused schools by 2020 with at least 80% at the elementary and middle school levels. Furthermore, Obama authorized the recruitment and training of 100,000 high quality STEM teachers in 10 years based on recommendations from the President’s Council of Advisors on Science and Technology from 2010.

B. Texas STEM Initiatives

Texas has adopted the policy and created the Texas science, technology, engineering and mathematics (T-STEM) designation. Since 2006, about 91 schools in Texas have been designated T-STEM academies. As indicated in the Texas Education Agency’s website [9], the main purpose for these programs is to develop the capacity to design and/or replicate and sustain performance-driven school models, transform instructional practice to model real world contexts for learning to improve student achievement for all students, and to serve as demonstration sites to inform STEM teaching and learning statewide.

The literature reviewed about Texas initiatives revealed a tremendous support for the creation of these schools as well as the priority of STEM literacy. For example, “Educate Texas” has been nationally recognized for tapping into a bold and collaborative approach for creating transformational change for Texas students [10].

C. El Paso STEM Initiatives

The El Paso area has both private and public organizations supporting the prioritization of STEM literacy, such as the Workforce Solutions Upper Rio Grande, El Paso STEM Foundation, Community en Acción, and Workforce Solutions Borderplex, among others. To date, eight secondary schools within six different school districts in El Paso area prioritized a STEM program to some degree. According to Texas Education Agency, all T-STEM programs must be rigorous, STEM integrated curriculum utilizing the design process and high quality, contextually-based teaching and learning practice [9].

El Paso opened the first T-STEM academy in 2006, in Da-Vinci public charter school (6-12th) as stand-alone, the next T-STEM academy designations went to El Paso Harmony School of Science in 2008 as a stand-alone and the Transmountain Early College High School from El Paso Independent School District (ISD) as a combination. In 2009, Ysleta ISD opened a school-within-a-school T-STEM academy in Parkland High School (9th-12th). Irvin High School from El Paso ISD was granted the T-STEM designation in 2012 as a stand-alone T-STEM school for 9th and 10th. Harmony School of Science added a second stand-alone T-STEM 6th-12th in 2012. Two more academies were designated in 2014: Clint High School from Clint ISD and Montwood High School from Socorro ISD.

D. Engineering is Not Always Incorporated

STEM resides in multiple contexts today, such as educational, technological, economic, and political, according to Stephanie Marshall [11] as she provides rationale for re-designing these academies. She adds that, as educators adopt STEM policies, often times the implementation or interpretation of these initiatives does not include enhanced courses in engineering or technology, or some form of increased engineering and technology content in revised math and science courses. It is important for us to keep this in mind as we discuss STEM education advances in context.

IV. ENGINEERING IMPLEMENTATION: CHALLENGES & INSIGHTS

A. STEM Literacy Takes Time and Funding

It is suggested that STEM literacy could take about a decade to initiate, implement, sustain and evaluate as a national initiative [1]. As project administrators, we understand that time and funding are required to conduct the activities necessary to initiate, implement, evaluate, and sustain any kind of program in schools. The most important challenge facing STEM education, according to the findings from the National Survey on STEM Education [12] was inadequate and insufficient funding (64.2%). Moore & Smith

[13] also stress the importance of funding for not only professional learning experiences but also to back new research-based STEM integration innovations in K-12 curriculum. Often times, policies do not get to be fully implemented as intended due to lack of sufficient funding and time.

B. House Bill 5: Competing Endorsements?

Recently, the Texas Education Agency adopted House Bill 5 (HB5) requiring all high school students to select an 'endorsement' or subject cluster. Beginning 2014-15 high school students must complete 22 credits of 'foundation' courses and 4 credits in one of the endorsements [9]. The five endorsement areas are: Multidisciplinary Studies, Arts and Humanities, Business and Industry, Public Services, and STEM. Local high schools offer a STEM endorsement with five separate options: Computer Science/Technology Applications, Mathematics, Science, Combination, or Career and Technology education. It is within the Career and Technology or Combination options that engineering courses may appear.

Considering that high school students have five concentration areas to pick from, then another choice of five within the STEM area alone, it is unfortunately at a miniscule level that HB5 enforces the engineering literacy within the STEM tracks. However, these academies have the option of only offering the STEM endorsement to their students and none of the other clusters. The local T-STEM academies must decide if all of their students will have no choice but to complete the STEM endorsement, and if so, which one(s).

C. STEM Literacy: An Integrated Approach

STEM teaching should be a fully integrated approach. "STEM integration can provide students with one of the best opportunities to experience learning in real-world situations, rather than learning STEM subjects in silos." [14]. It is important to consider how the interconnections of STEM components work in order to integrate the disciplines meaningfully. This set of disciplines is very organically grouped: engineering requires the application of mathematics and science through the development of technologies. "In addition to a coherent and rigorous curriculum, successful STEM school initiatives design and implement integrated curriculum content." [15]. Repeatedly, within this literature review, research-based documents have strongly expressed the need and recommendation to integrate, and embed all subjects in order to build curriculum.

D. Explicitly Integrated & Explicitly Separated

As recommended by the members of the National Academies, "Integration should be made explicit" [16] when designing STEM initiatives. This recommendation calls for carefully thought out curriculum and corresponding assessments. Schools must adopt structural changes in order to allow learning each STEM discipline separately and interconnectedly as encountered in real-world situations [13]. "STEM education is an approach in which STEM subjects are integrated through an instructional method that uses design-

based, problem-solving, discovery, and exploratory learning strategies" [17].

E. Career & Technology Education as a Model

Career and Technology Education (CTE) programs provide excellent means to support an integrated STEM approach [4,18]. CTE offers hands-on experiences embedded in the curriculum. Additionally, instructors, as former practitioners, deliver curriculum thoughtfully and successfully to all types of learners, because content is directly related to real-world applications. CTE could be used as a model towards creating a successful integrated approach to STEM literacy. Academies may not have the support of a strong CTE program.

F. Engineering Teacher Certification: Not a Priority

The problem is that most STEM teachers are trained in either science or mathematics and may not be trained in engineering or technology [19]. Only the science and mathematics certifications are enforced as requirements to teach courses in any of the four fields. This can easily be justified by the sheer quantity of science and mathematics courses required and present in K-12 curriculum in comparison to the non-required engineering courses. When referring to local T-STEM academies, by definition of the designation intention, engineering should be placed in a higher priority, together with the science and mathematics.

G. State Tested Subjects Take Center Stage

In Texas, no engineering courses are tested. A few science and mathematics courses are tested as part of state accountability efforts. This priority may deter school officials from prioritizing engineering education.

H. Texas Lacks Embedded Engineering Standards

The National Research Council [20] was given the task to come up with the K-12 engineering education national standards. Instead, they advocated for embedding such standards in existing science and mathematics curriculum. After scholars from Purdue completed an engineering standards study, they concluded that there is a lack of engineering integration in STEM when they reported: "The fact that only 12 states integrate engineering into science curricula and only one into math points to a need for an emphasis on the academic nature of engineering" [21]. According to their findings, in Texas, the engineering content was explicitly found for high school career and vocational standards only [21]. In a standards-based education, the curriculum, teacher preparation, and assessments must align to those standards. Local T-STEM academies have to deliberately incorporate engineering content in their lessons and programs, even though they are missing in the mandated state standards.

I. Access to Engineering Curriculum

Schools may purchase ready-made engineering curriculum such as "Project Lead the Way" (PLTW), "Infinity Project", "Engineering is Elementary" (EiE), and "Engineer Your Life".

Local T-STEM academies may invest limited funds and adopt one of these programs, or may seek other alternatives. The Da Vinci School for Science and the Arts became the first El Paso T-STEM academy in 2006, and after reviewing options for engineering curriculum, school officials decided on customizing their own: "Curriculum for Engineering in High School" [22].

J. Educator expertise in engineering is uncommon

The National Academies listed Educator expertise as one of the implementation opportunities and challenges when integrating STEM in K-12 [16]. The second most important challenge facing STEM education, according to the findings from the National Survey on STEM Education [12] was insufficient professional development for STEM teachers (59.7%). At the University of Texas at El Paso (UTEP), has developed new courses and programs dedicated to better prepare educators teaching STEM areas, and in particular engineering. These new engineering teacher preparation pathways have been possible due to the joint collaboration of the College of Education and the College of Engineering, efforts partly funded by 'Taking the LEAP' grant from the Department of Education.

K. Innovative teaching strategies required

Engagement in project-based learning with an emphasis on design can be the key for successful engineering education programs today [6]. At the K-12 schools, teachers are very involved with the teaching and learning processes, so project-based learning should come more natural in implementation. Project-based learning promotes traits such as good communication, teamwork, and the lifelong learning needed when preparing engineers.

L. High Rate of LEP Students in El Paso Schools

Local demographics include Spanish speaking immigrants from south of the border, contributing to 79.2% of the Limited English Proficient (LEP) students [23]. Mein and Esquinca stress that our local LEP students face barriers when accessing content knowledge because of their language challenges [23]. Fortunately, UTEP offers teacher preparation programs specifically to address the challenges of dealing with LEP populations.

M. Leadership of Inclusion Towards STEM Literacy

Equal access to an exceptional STEM program must be a priority, and school leaders must encourage inclusion of underrepresented students. Leaders must foster a mentality of inclusion in which teachers can encourage girls' achievement and interest in math and science [24].

V. DISCUSSION: RESEARCH OPPORTUNITY

Although this literature review provided some answers pertaining to challenges mainly of an external nature, further research is required to investigate and report adequately on the functional workings of local academies. Only then can a complete overall picture of the challenges of engineering

implementation can be established. Such a study may provide insight and deeper understanding of how these designated schools impart engineering learning to students. This study could assist school leaders to understand STEM education and lead a culture of STEM literacy. This study may guide current and future local leaders the best practices of engineering literacy based on model school findings.

The issues surrounding the different academy configuration combinations within schools was not addressed in any of the literature, such as: combining early college high school with a STEM designation; or T-STEM with a charter school; or with other non-STEM endorsements.

Because half of the T-STEM academies in El Paso have been recently designated, there are just not enough studies published on their progress, challenges or successes. This is also true for policies at the district level regarding these academies and in particular for engineering implementation.

In an effort to emphasize engineering in STEM, inclusion of engineering in the K-12 curriculum has increased nationwide. Similarly, for the past 15 years, research on Engineering Education P-12 has increased tremendously [25]. Although at the local level, the number of T-STEM academies has increased, it is not clear how local engineering education has changed, due to lack of available literature at this time.

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Modeling: A Computer Science Concept for General Education

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Abstract— For all computer scientists the term ‘modeling’ is well known. It displays an often-used method, which is applied in each field of computer science to investigate, describe and plan problems or structures. With the help of models, large and complex structures are divided into smaller parts, which leads to a better understanding of the problem and often provides input for the solution. With the help of different types of models, different perspectives of one problem can be observed and discussed. These processes are not only part of computer science respectively computational thinking. Problem solving skills are needed in any domain and should be trained as well as possible in primary and secondary education. This could be supported by the computer science concept of modeling including processes like reduction, decomposition, abstraction, generalization etc. and appropriate techniques like UML Unified Modeling Language or the Entity-relationship model. We suppose that a consequent use of modeling beginning in different subjects during primary and secondary education can train and improve problem-solving skills. Before being able to verify this hypothesis, it is necessary to find a way to integrate modeling in schools despite of not being part of the curriculum. This is one aim of our project “Informatics – A Child’s Play”, which tries to implement different computer science concepts in different subjects of primary and secondary education. To reach this goal we firstly have to convince and train teachers. In this paper some topics of modeling are presented as they were adapted for workshops in primary and early secondary education considering the age and interests of the students as well as topics taken from their surroundings. Furthermore, we present first evaluation results concerning its acceptance and usefulness for teachers and students as well as their performance in understanding and applying modeling in different lessons.

Keywords—models, diagrams, general education, Entity-Relationship-model

I. INTRODUCTION

In today’s society, technology affects nearly everybody in different occupational fields and has therefore a deep impact in everyday life. It is obvious that more and more experts in technical areas are needed to develop, produce and service new artefacts. To reach children as early as possible the project ‘Informatics – A Child’s Play’ came to life. The main aims of it can be summarized as follows:

- Arousing interest in informatics¹, engineering and technology as early as possible.
- Improving and consolidating students’ and teachers’ knowledge about informatics (concepts, usage, career, etc.).
- Fostering general learning skills like text comprehension, problem solving, logical thinking or creativity.
- Developing and evaluating brain-friendly teaching material.
- Establishing computer science concepts in the long-term in primary education (a lot of them are already part of the Austrian curriculum for primary education, but are not recognized as such).

During the preparation phase of the project different existing workshops, which partly based on ‘Informatik erLeben’ (Experiencing Informatics) [1] or ‘Computer Science Unplugged’ [2], have been adapted or new ideas were elaborated. Additional new material had to be developed because of the idea to integrate computer science concepts in different subjects and sciences. One link to establish such a connection can be ‘computational thinking’. In [3] computational thinking is called “[...] a fundamental skill for everyone” and it is proposed to “[...] add computational thinking to every child’s analytical ability” [3]. Further [4] describes it as “[...] a problem-solving methodology that can interweave computer science with all disciplines” and points out that it focuses on “abstraction, automation and analysis” [4]. Especially abstraction and analysis of problems and their solutions can be related to different types of diagrams and models. In the following chapter modeling will be defined and a connection between modeling and general education will be shown. Chapter 3 will explain the study with the research questions, methods and some ample units. In chapter four some first results of the study will be presented.

II. MODELING IN GENERAL EDUCATION

A. What is modeling?

In computer science, models are a very important and common form of representation in different areas or levels of development, e.g. the description of processes or problems, a

¹ The terms informatics and computer science are used as synonyms in this paper.

program or an equation [5]. A model can be defined as “an abstract description of a real or planned system, including the essential attributes of this system needed for a certain objective. Modeling can be seen as the creation of such description.” [5, p. 4]. That means that the term ‘model’ refers to a simplified representation of the real world and builds the base for the present work.

The process of modeling includes different working steps and thinking processes like reduction, simplification, abstraction, generalization, hierarchization, or classification. They can be summarized in the following four steps:

- Defining the scope: in this step the borders should be found, which define the part of the system that should be described.
- Abstracting: During this step, unimportant details or special cases should be removed.
- Idealizing: the aim of this step is to ease the description by correcting non-ideal attributes.
- Describing: in this step the representation of the main attributes, like components, relations between components, interaction with surroundings, static structure or behavior of the system, are created with the help of modeling techniques [5].

The order of these steps can vary, depending on the modeling task.

B. Modeling in general education

Models are simplified representations of the real world. They can be represented in different ways (fig. 1): mental, physical or symbolic. Mental models – the first step in reducing the complex reality – describe the way people understand some domain of knowledge [6]. This happens in any domain and any subject in school. Hence, the concept of modeling is, in our opinion, definitely important for general education. The external representation of these mental models can be physical, like a scale model of a house, or symbolic in form of graphics, diagrams, or texts (verbal models).

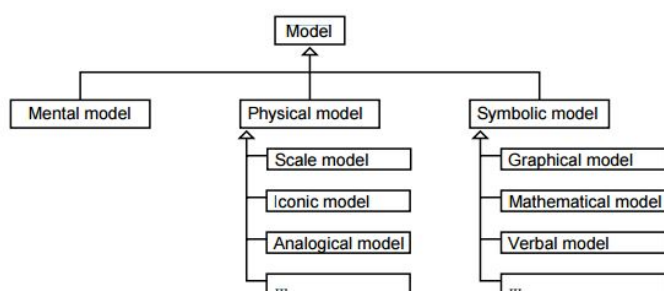


Fig. 1. Classification of models with respect to the representational form. [7]

Based on this classification, models and the process of modeling are part of any subject matter, in the curricula as well as in daily school life. Some subjects explicitly name the contents *models* or *working with models* in their curricula, e.g. mathematics, geometry, chemistry, geography or technical work. Other subjects use models or modeling without knowing

it consciously. Verbal models, that “describe a system by means of textual information” [6] are part of every subject e.g. in form of chapters in textbooks or summaries of texts in foreign languages etc.

Having a closer look to the process of modeling, its dimensions and the competencies needed like abstraction, reduction, simplification, classification, generalization etc. it becomes obvious that modeling is already an important, but mostly hidden part of general education. The primary school curriculum, for example, requires that

- teachers shall lead children to abstraction [8, p. 27]
- train the capacity of abstraction e.g. by using diagrams or symbols [8, p. 61],
- foster rational thinking processes by training basic cognitive processes like comparing, sorting, classification, abstraction, generalization etc. [8, p. 147].

C. Teaching Modeling: Techniques and Possibilities

For software development different models have to be used because each of them describes one aspect of the real system. To display the following aspects different modeling techniques can be used:

1. Structure: domain, entity-relationship, grammars
2. Attributes: domain, entity-relationship, logic
3. Relations: entity-relationship, logic
4. Behavior: finite automata, petri-nets, algebras, graphs [9]

As it can be seen the Entity-Relationship-model (ER-model) can be used to display three of these aspects. Therefore and because of its simplicity, this diagram type was perfect for our project.

This method of modeling was introduced by Peter Chen in 1976 [10] and is very useful to show objects with attributes and their relations to each other. Chen’s modified notation is easy to learn because its graphic notation includes only three basic shapes.

- An ‘entity’ is a collection of objects of the same type and is graphically displayed as a rectangle.
- A rhombus represents the ‘relation’ between entities.
- The ‘attributes’ of entities further describe these entities and are displayed as ellipses [9].
- Lines between the shapes show their connection to each other.

III. THE STUDY

A. Research Questions and Methods

The study on the use of modeling concepts and techniques in general education is part of the research project ‘Informatics – A Child’s Play?!’ that mainly aims at introducing informatics

concepts in different subjects of primary and lower secondary schools. Our main research questions concerning modeling are:

1. How and where can we introduce modeling in primary and lower secondary education?
2. Which modeling techniques are useful and practicable for teachers and students without informatics background?
3. Which dimensions of the modeling process are or shall be part of general education?
4. Is it possible to improve general learning competencies like abstraction, problem solving, text comprehension etc. by a frequent and varied use of modeling in primary and lower secondary education?

In order to answer these questions and to achieve a sustainable integration of the informatics topics, in this case “modeling”, different activities and research methods are necessary:

- *Development and implementation of teaching units and materials*
We developed new teaching units and materials based on existing curricula, topics, worksheets, activities etc. We gained data and ideas from content analyses of different curricula, interviews with teachers of different subjects as well as different worksheets and tasks that they provided us for the elaboration from the perspective of computer science. We offer different workshops for teachers and students in order to test and adapt the developed units and materials by considering findings of participatory observation, immediate feedback of the participants as well as interviews with teachers and students.
- *Usefulness and practicability of modeling techniques*
As the concept of modeling is not part of the curricula, we are firstly interested in the usefulness and practicability of modeling techniques for teachers and students without computer science background. To evaluate these aspects we use different methods, mainly immediate feedback, interviews with teachers and online-questionnaires.
- *Comprehension of modeling*
In order to assess the comprehension of modeling we analyze the answers of the participants to our questions during the workshops and we ask them to explain the concept of modeling to their colleagues. Furthermore, we evaluate their products – diagrams, posters and other materials. At the end of the school year, the students will also take a written test.
- *Assessment of general learning skills*
An eventual improvement of general learning skills like text comprehension or generalization will be evaluated by pre-post-tests. In part, we use standardized test, like some subtests of the HAWIK IV battery (matrices and finding generic terms) and the Salzburger Lese-Screening for the assessment of the reading comprehension.

B. Implementation of Modeling: Sample Units

We implemented the concept of modeling in two ways depending on the available time and/or the aim of the unit:

1. From a model to a text
2. From a text to a model

Both ways are useful and practicable (at least at a low level from the computer science perspective), but have different aims, advantages and disadvantages.

Starting from a model, e.g. the ER-diagram in figure 2 and 3, we can engage children to be creative. They can continue the diagram, tell or write a story, create similar diagrams for other topics of their choice etc. Furthermore, they can be used as example of how to represent subject specific knowledge in a structured way. In a first step, we introduce only the entities accompanied by the typical beginning of a fairy tale: “Once upon a time there was a knight and a princess. Suddenly a dragon appeared and ...”

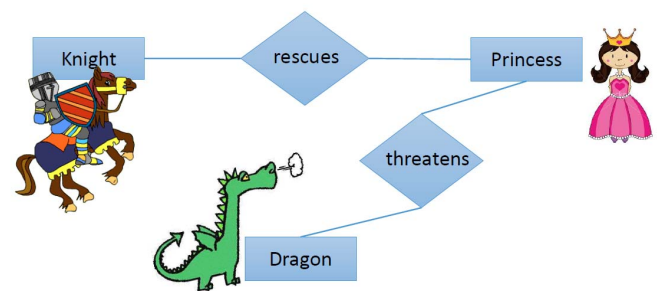


Fig. 2. 1st part of ER-diagram: Knight – Princess – Dragon

Then we show the relations (verbs) between the entities (nouns) and invite the children to continue the story together: “... and threatened the princess. But, the knight could rescue the princess.”

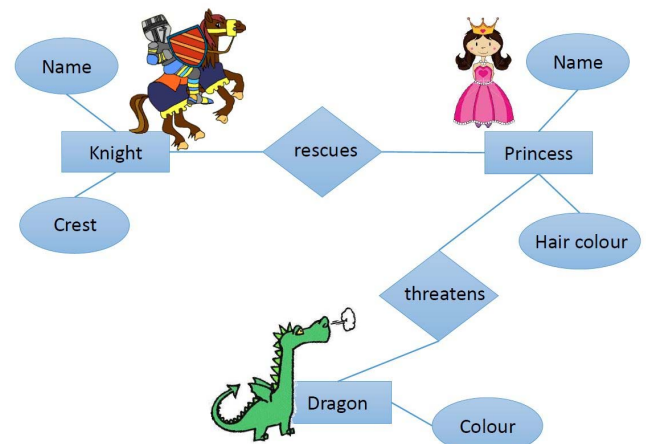


Fig. 3. Extended ER-diagram: Knight – Princess – Dragon

In the last step, we introduce the attributes or characteristics of the different entities. Besides telling the story, we introduce also the basic use of the different shapes: rectangles for entities

(nouns like persons, animals etc.), rhombs for relations respectively verbs and ellipses for attributes (characteristics).

Depending on the available time, the children can now continue the fairy tale and/or extend the ER-diagram or even invent a new story. When the children continue the story, it is reasonable that the teacher should extend the diagram with appropriate shapes (on the blackboard or by means of cards) containing correct entities, relations and attributes.

The second way of introducing models is starting from a sample text on knights, princesses and dragons, containing already the correct shapes for entities, relations and attributes (fig. 4). This task may help to train reading competencies and to extract essential information. Furthermore, comparing it with the pictures, it can be used demonstrate the difference between concrete attributes like 'green' and generic terms, in this case 'color'.

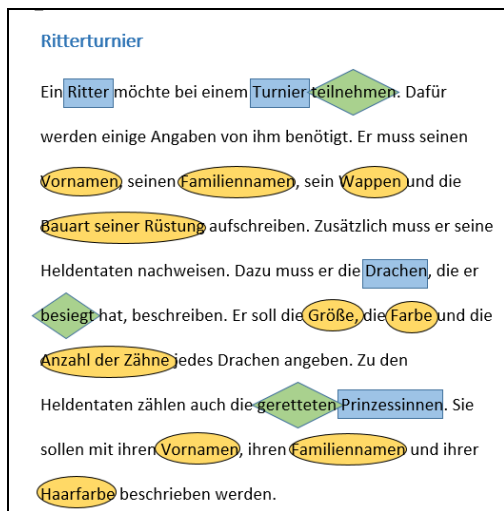


Fig. 4. Basic text for the ER-diagram 'Knight – Princess – Dragon'

IV. PRELIMINARY RESULTS

A. Practicability for teachers and students

Based on the interviews and discussions with 25 teachers in three workshops as well as the observation of students in primary and lower secondary schools we can definitely suggest modeling as a practical concept and tool for general education. All teachers said that entity-relationship diagrams are very useful for teaching and/or learning and that they would use them in one of their next lessons. However, as expected, most of them noted, that they would need more than one workshop before trying out the concepts on their own, because they were afraid of making errors. Only few teachers developed their own examples already after the first introduction into modeling, but rather as another form of mind map than as a correct diagram.

B. Comprehension of modeling

The answers and statements of the students during our workshops as well as the evaluation of their posters and diagrams showed that modeling seems easy to understand but sometimes difficult to apply. We evaluated the posters and

diagrams of students from two points of view: On the one hand, we checked the subject-specific or thematic knowledge (not informatics) as well as their capability to extract the essential information of given texts. On the other hand, we corrected the diagrams from the view of computer science in two steps. Firstly, we evaluated the correct use of the notation, i.e. the correct shapes for the different functions respectively word classes. In the second step, we focused on computer science and the correct concept of modeling including generalization. The division in two steps was necessary because of two reasons: On the one hand, when using e.g. ER-diagrams to visualize subject-specific knowledge or essential information of a text, it is often necessary to note some concrete attributes e.g. 'green' as color of the dragon in figure 3. However, using it in the ER-diagram it is not correct from the point of view of computer science, where models must contain generic terms, in the case above 'color' instead of 'green'. On the other hand, the process of generalization seems to be difficult for many participants. Hence, we decided to introduce generic terms only in a second step.

The first step was quite easy as mentioned by many participants. However, there are some striking aspects and errors from the view of computer science. Teachers and students tend to use ER-diagrams as another form of mind map. When designing an entity-relationship model most of the participants firstly concentrate only on entities (nouns) and relations (verbs), but seem to forget attributes. Furthermore, sometimes we found a verb and a noun together in one single shape, mainly when the noun is not the subject of a sentence as in the following example:



Fig. 5. Left: incorrect ER-diagram. Right: corrected ER-diagram

The second step respectively finding generic terms for the concrete names of adjectives of a text seems to be quite difficult for students as the immediate questions after the workshops, the observation of the students during the design of their own models as well as the assessment of the final posters showed.

V. CONCLUSION

Models are a basic concept for software developers and computer scientists. They are used to describe problems and can help to solve them. Competencies needed for the modeling process like abstraction, reduction, simplification, classification, generalization etc. shall be, in our opinion, part of general education. Some main aspects of modeling are even mentioned in different curricula of different subjects. Thus understanding these methods is useful for children of all ages. This paper should show different possibilities to integrate methods of modeling in primary and early secondary school. It focused on the entity-relationship-model and presented two ways to use this technique in a school unit. Following the opinions of participating teachers modeling methods are practical tools for teaching and learning. Students liked working with these concepts although they had some problems.

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DISSECT: Exploring the Relationship Between Computational Thinking and English Literature in K-12 Curricula

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Abstract—DISSECT (DIScover SciEnce through Computational Thinking) is a project aimed at introducing students to computer science principles by establishing computational thinking (CT) as a problem-solving technique within middle school and high school Science, Technology, Engineering, and Mathematics (STEM) courses. While DISSECT has shown successful integration of CT into middle school and high school STEM curricula, illustrating the pervasive nature of CT, a question remained; “can CT also be infused into humanities courses (e.g., English, Art, History) in addition to scientific courses (e.g., Chemistry, Biology, Computer Science)?” The answer is positive. The objective of this paper is to present one approach to bridge the gap between CT and humanities through the curriculum of a 12th-grade English Literature course. The course blends CT practices with composition and literature to provide students with the ability to write critical and comparative analyses of selected literature. This paper will describe multiple modules that integrate computational thinking into the course, and discuss the results and assessment tools used to measure student competency in computational thinking.

Keywords—Computer science; Computer science education; Computational thinking; English literature; K-12

I. INTRODUCTION

Despite the ubiquity of electronic devices, the majority of the students who use them don’t understand the underlying technology (i.e., how the device actually works). This may be attributed to the lack of computer science (CS) courses in K-12 education; Code.org reports [1], “the majority of schools don’t even offer computer programming classes,” and only 25 states allow CS to count toward high school graduation math or science credits. Additionally, College Board presents data [2] that shows a low participation in the Advanced Placement (AP) CS Exam. Further, there aren’t enough qualified CS teachers because the CS teacher certification is “typified by confounding processes and illogical procedures” [3].

Because CS is deeply rooted in daily life, it is essential to provide all students and teachers with the knowledge needed to succeed in a computing world. The National Center for Women & Information Technology explains that present and future innovation require students to not only be computer-literate, but to possess the design, logical reasoning, and problem solving skills inherent to CS [4]. According to the Association

for Computing Machinery [5], there are several reasons to study CS including: CS is a pervasive science that provides necessary 21st century skills, enables people to solve complex problems, offers many types of lucrative careers, and offers opportunities for creativity and innovation.

DISSECT (DIScovering SciEnce through Computational Thinking) is a project aimed at introducing students to computational thinking (CT) as a problem-solving technique within middle school and high school Science, Technology, Engineering, and Mathematics (STEM) courses. Traditionally, the underlying concepts of CT including algorithmic design, reasoning with abstraction, and problem formulation and decomposition are taught within a CS course. DISSECT operates under the premise that these concepts are also fundamental in scientific disciplines, and hypothesizes that CT can also be discovered within non-scientific disciplines. DISSECT expects that by infusing and explicitly teaching CT within the context of non-computing disciplines, students benefit from pedagogy that enhances the learning and simultaneously provides a foundation for the principles and practices of CT. In the rest of this paper, we summarize DISSECT’s program design, describe modules that have integrated CT into a 12th grade Literature course, and present the assessment tools and results of the project.

II. PROGRAM DESIGN

A. Program Organization

The organization of DISSECT can be represented by a two-pronged approach. First, as indicated above, DISSECT builds upon the idea that CT is already embedded in the curricula of many disciplines, and can be made explicit; this enables a wider use of CT within curricula and enables students to understand CT. Second, DISSECT builds on a model that pairs graduate students (fellows) from computing-related disciplines with a middle school or high school teacher; each fellow-teacher team collaboratively conduct CT activities and the discovery of CT within the curricula. The ultimate benefit of this pairing model is the cross training that occurs between the teacher and fellow. While the fellow provides the CT expertise, the teacher offers effective K-12 pedagogies. This is key, because typically fellows do not have formal teaching experience and most teachers have not been trained in CT or

have not explicitly incorporated CT into their curricula. In particular, fellows will leave DISSECT with better communication skills, increased teaching abilities, and a deeper understanding of the relationship between the teacher's subject matter and CT. The teachers will acquire knowledge and practices of CT, and have access to CT modules that can be applied to their classrooms when fellows are no longer present.

DISSECT currently staffs one full-time coordinator; ten fellows from computing-related disciplines including CS, Electrical Engineering, Horticulture, and Agricultural Biology; and nine teachers from the Las Cruces Public Schools (LCPS) district in a wide range of classrooms including CS, Science, Zoology, Chemistry, Forensic Science, Biology, and English Literature.

B. Curriculum Design

CT is the "thought process involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" [6]. In 2006, Jeanette Wing argued [7] that CT is "a fundamental skill for everyone, not just computer scientists." This statement launched a debate among educators, researchers, and computer scientists about the instruction, application, and integration of CT into other disciplines. The curricula DISSECT develops and uses to introduce CT into K-12 classrooms is composed of a series of modules that aim to portray CT within the context of the course. Building upon the characterization of CT by the Computer Science Teachers Association [8] and College Board's AP Computer Science Principles [9], DISSECT builds on and integrates the following ten concepts into their modules. An *algorithm* is a process or sequence of steps to be followed to solve a problem. A *sequence of steps* is an ordered list of instructions. *Branching* involves a choice in an algorithm that leads to a different outcome depending on the choice. *Iteration* is the repetition of instructions. *Variables* are named pieces of data used by an algorithm that are subject to change. *Clarity* is an algorithm's quality of being certain or easy to understand. *Correctness* is the measure of reliability of the result of an algorithm or sequence of steps. The algorithm is correct if it produces the correct solution to the problem being solved. *Efficiency* is a measure of the performance of an algorithm. When compared to longer algorithms, shorter algorithms that produce the same solution are more efficient. *Abstraction* is the process of removing unnecessary information in order to keep the parts that are relevant to the problem. It is used to simplify the process of achieving a desired goal. Finally, *computational thinking* is a way of solving problems that involves reasoning with abstraction and thinking algorithmically.

In general, the fellow and teacher take one of two approaches to integrate CT into their course. The most common approach is to utilize existing course units and restructure the related activities to explicitly highlight CT concepts. As an alternate approach, the fellow-teacher team may choose a CT concept to highlight and then create a module that relates to both the course discipline and the CT concept.

III. IMPLEMENTATION: ENGLISH + CT

While DISSECT has shown successful integration of CT into middle school and high school STEM curricula [10], illustrating the pervasive nature of CT, DISSECT wanted to determine whether or not CT concepts (algorithms, sequence of steps, branching, iteration, variables, clarity, correctness, efficiency, and abstraction) could be integrated into a 12th grade English Literature course (ENG12). In particular, the choice of ENG12 was to reach students who did not have pre-conceived positive attitudes toward STEM or explicit experience with CT; generally, students are intimidated by math and science, thus CT may also induce a sense of fear. On the other hand, students tend to have a positive attitude toward arts and humanities (at the very least, they aren't scared of those subjects); this allowed DISSECT to explore and teach CT in a context that is less frightening and without preconceived notions.

The following sections describe the goals of ENG12 and modules that show the seamless integration of CT into the teaching of Literature.

A. English 12

The study has been conducted during the Spring 2014 (SP14), Fall 2014 (FA14), and Spring 2015 (SP15) semesters on three ENG 12 courses taught by Timothy Staley at Onate High School (OHS) in Las Cruces, New Mexico. Staley also taught two additional sections of ENG12 in Spring 2014 which will be referred to as "Control Class 1 (CC1)" and "Control Class 2 (CC2)" throughout this paper; neither control class was taught any modules that featured or explicitly introduced the DISSECT CT concepts. As a whole, the classes utilized the collaborative tools and services provided by Google's suite of Apps for Education [11].

The OHS Curriculum Guide [12] describes ENG12 as a course that "blends composition and literature into a cohesive whole as students write critical and comparative analyses of selected literature to... develop and improve critical thinking and analytical skills." Over the course of the class, students are introduced to, and tested on, the New Mexico Content Standards with Benchmarks and Performance Standards for English Language Arts [13]. Students enrolled in ENG12 are required to take the Literature End of Course Examination (EOCE) that tasks students to: 1) answer multiple-choice questions by thinking critically and 2) write an essay that demonstrates their ability to follow directions and their knowledge of the usage of literary elements in pieces of literature. The EOCE serves as a final exam for ENG12, and student scores are reported to Staley, OHS, and Las Cruces Public Schools district for various purposes [14] including "student grades, curriculum reviews, student graduation requirements, and for the Educator Effectiveness System."

In order to meet the course objectives and to prepare students for the EOCE, Staley's ENG12 courses were comprised of four units to enhance student analyses of four main pieces of literature: Lord of the Flies [15], song lyrics, Macbeth [16], and Siddhartha [17].

B. Unit Modules + CT

The existing ENG12 unit modules were enhanced to allow students to practice CT skills. Ensuring the content of the course remained consistent was an important design constraint during the integration of CT. A summary of each ENG12 unit module and its relation to CT is provided in the following sections.

Lord of the Flies: The Lord of the Flies (LOF) is a novel about a group of boys that are stranded on an island with no adult supervision. The major theme explored is the inevitability of chaos and loss of civilization when the boys are faced with the barbaric nature of the wilderness. This theme was mainly conveyed through the author's use of symbols. Symbols are objects, characters, and figures that are used to represent an abstract idea or concept. One of the goals of ENG12 is to teach students how to identify symbols and explain in a multi-paragraph essay how the symbols developed through the entire piece of literature.

CT was integrated into this unit through the LOF Symbol Development project by having students work collaboratively on a single Google Document to find every instance of eight symbols in the novel, and then forming groups to write a one-paragraph summary of the development of a symbol. In particular, this module was designed to provide students a collaborative avenue to learn and practice abstraction, a necessary skill for success on the writing portion of the EOCE.

For example, after a group of students identified the 125+ instances of "conch", a symbol representing societal order, they used abstraction to summarize the development of the conch:

"In the beginning of the novel, Piggy finds a conch near him and Ralph in the water. The conch starts off as a way to get everybody who is on the island together, and is used as a talking stick, whoever holds it has the right to speak uninterrupted. This started out well, because all of the children followed suit. That is until Piggy held the conch; he was the one person who they'd disregard and ignore while Ralph was the only one trying to enforce the rule. After some time, the children started to ignore the call to assemble when the conch was blown. This represented the beginning of the loss of order. By the end of the novel, total chaos ensues when Roger drops a large boulder on Piggy, killing him and smashing the conch into a million pieces. All order was lost and there was no going back to civilization."

Song Lyrics: By nature, song lyrics are full of poetic devices. This unit aimed to teach students how to identify elements of poetry (e.g., rhyme, repetition, etc.) in shorter pieces of literature (i.e., song lyrics).

The CT aspect of this unit centered on the Song Lyric Analysis Site. Students worked in pairs to complete the four components of the project: lyric analysis, poetry device data analysis, song critique, and website creation. A Google Document was used to annotate the song lyrics; a Google Spreadsheet was used to chart and analyze the amount of music and figurative language elements; Internet sources were used to garner peer-reviewed song reviews; and Google Sites was used to compile their analyses into a website.

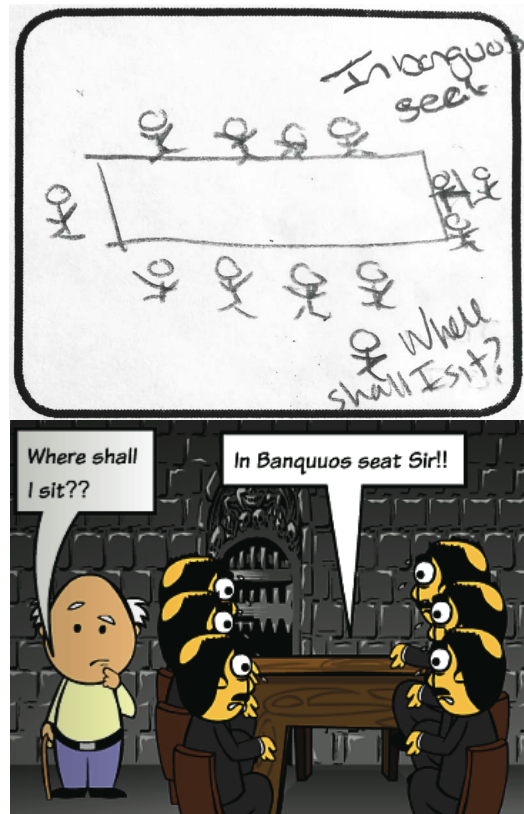


Fig. 1. Macbeth ToonDoo Project: Example panel from planning to implementation

Macbeth: Macbeth was the focus of the third unit of ENG12. The play tells the story of Macbeth, a Scottish soldier that plunges into the depths of darkness to become king regardless of the consequences. The basic premise of Macbeth is that ruthless ambition leads to its own destruction.

To have the students practice their CT abilities, the unit project required the illustration of a scene of the play using ToonDoo [18], an online drag-and-drop comic-creation tool. Before implementation, students had to sketch out a storyboard to describe each of the eight panels of their chosen scene in detail. Figure 2 shows a student-created example of the planning and implementation of one panel in their scene. Although this activity did not provide a computing problem to solve or require students to write a computer program, the goal was for students to use their algorithmic thinking abilities to create a detailed step-by-step storyboard for their scene; this mimics the process of writing pseudocode before implementing it into a programming language. In addition to illustrating a scene, students had to comment on the significance of their scene to the play as a whole; students practiced abstraction by scanning their scene and analyzing the most important passages.

Siddhartha: Siddhartha follows the journey of self-discovery and enlightenment of a man in ancient India. This particular novel was introduced to the high school seniors to provoke deeper understanding about how enlightenment relates to knowledge, how knowledge relates to them and their goals, and how Eastern philosophy correlates to the Western World.

The Siddhartha unit project involved the creation of online blogs. Each student worked individually using Google Blogger as a creative outlet to reflect on ideas, plot structure, and Eastern philosophy within the novel. The targeted CT principle was algorithms through creativity; the goal was to end the semester with a project that the students could personalize and make their own, while practicing their writing skills and their ability to follow an algorithm (set of directions). Students were given documents with all of the necessary information to successfully complete the project and were graded on how well they followed directions. One of the blog topics dealt with the source material the author may have used when writing the novel. Students were given several ancient Buddhist and Hindi texts, and asked to use reasoning with abstraction to find the correlations between the texts and Siddhartha.

C. Additional CT Modules

In addition to increasing students' ability to analyze literature, Staley's course also aimed to help students acquire necessary college-ready skills. Each activity also highlighted CT concepts.

Introduction to Algorithms: The term "algorithm" is not part of the typical high school student's vocabulary. For that reason, it was necessary to introduce the concept through an engaging activity. This module was designed to teach students the definition and step-by-step nature of an algorithm, how algorithms are used in their every day life, and how to make an algorithm better. Real world examples of the algorithms students use in their lives included: brushing their teeth, writing an essay, finding a page in a novel, and other daily routines.

In order to show students that algorithms are better when the sequence of steps that are implemented are clear and easier to understand, they were given a sheet of paper and an algorithm to build a Mighty Mite [19] paper airplane. After 20 minutes of folding, no student successfully created a Mighty Mite because the instructions were intentionally ambiguous. After the frustration, the class completed the algorithm by discussing and rewriting any unclear instructions, allowing the class to successfully build their Mighty Mites.

Internet Source Reliability: It is imperative that graduating high school students understand how to find reliable evidence to support their claim when writing an essay. This module uses the CRAAP test [20] to give students an algorithm to determine whether the information given by a source on the Internet is reliable. The CRAAP test centers around five major criteria that help determine the reliability of an Internet source:

- 1) Currency: the timeliness of the information
- 2) Relevance: the importance of the information for your needs
- 3) Authority: the source or author of the information
- 4) Accuracy: the truthfulness and correctness of the content
- 5) Purpose: the reason that the information exists

This activity served two purposes: students learned how to apply an algorithm to evaluate Internet sources and gained a new, and appropriately skeptical, perspective about the information available on the Internet.

Prompt Analysis: Analyzing a prompt and providing a relevant response is a vital skill in college. Many times, essay prompts are very long and contain extraneous information which, if not read carefully, can lead to an unrelated essay response. Hence, the class was introduced to an algorithm to help them break down and better understand the instructions in an essay prompt, effectively abstracting only the necessary information:

- 1) Read the entire prompt.
- 2) Break apart the sentences.
- 3) Highlight all important words or phrases.
- 4) Replace one highlighted word or phrase with a synonym that makes sense to you.
- 5) Repeat step 4 until there are no more highlighted words or phrases.

This algorithm also served as a useful tool to be used on the EOCE that requires students to write an essay; the students practiced prompt analysis on the following sample prompt: "Write a multi-paragraph essay and support with evidence from literature you've read this school year. Identify a symbol and explain how that symbol was developed through the entire piece of literature." Together, the class used the algorithm and converted the prompt into a less intimidating prompt: "Write an essay with 3 – 4 paragraphs and support with quotes, examples, or scenarios from a poem, short story, novel, or song you've read this school year. Identify an object that has a deeper meaning and explain how that symbol was unfolded or expanded to become more important through the entire poem, short story, novel, or song."

Summarization: Another important skill that should be learned before college is the ability to summarize a long piece of literature. Students were provided a simple three-step algorithm to do so:

- 1) Selection: Highlight or write down important sentences
- 2) Rejection: Discard the sentences that are not crucial
- 3) Substitution: Convert the highlighted sentences into your own words without altering the main ideas or introducing your own opinions and biases

Along with the step-by-step process, the class discussed some key points to remember when tasked with summarizing any piece of literature. A summary should be objective, without criticizing the author or original source; contain short, simple and self-dependent sentences without redundant phrases or repetitions; and should not reproduce sentences from the original text.

IV. EVALUATION

To recap, this study has been conducted over the course of three semesters across three DISSECT classes (SP14, FA14, and SP15) and two control classes (CC1 and CC2). In total there were 108 students in Staley's ENG12 courses within the time frame of the experiment; Figure 2 shows the number of students in each section (28, 22, 16, 25, 17, students in the SP14, FA14, SP15, CC1, and CC2 classes, respectively). The ethnicity distribution of each class mimics the cultural diversity

of the school as a whole. Figure 3 presents OHS's student ethnicities and the ethnicity distribution of each section of ENG12. According to OHS [21], the student body is 73% Hispanic, 21% Caucasian, 3% African American, and < 1% Asian, Native American, Pacific Islander, and other. All ENG12 classes were composed of 73 - 85% Hispanic, 19 - 27% Caucasian, 0 - 13% African American, 0 - 7% Asian, and 0 - 5% Native American students.

In order to accurately assess student learning of CT, DISSECT utilized a variety of assessment tools and metrics. The following sections describe the assessment approach and results.

A. CT Assessment

Of course, many of the activities and course units were designed to indirectly teach students CT through modules that were relevant to the ENG12 course. At the end of the semester, a five-question test was distributed to the five sections of ENG12: SP14, FA14, SP15, CC1, CC2. The aim was to determine how effective the modules were at integrating CT into ENG12 by measuring the students' ability to apply CT. Below, we will describe the details of each question and then summarize student performance.

Algorithms through spatial reasoning: The first multiple-choice question was designed not only to test students' spatial reasoning abilities, but also to test whether or not the students could use algorithmic thinking in an abstract way. A 2-dimensional image of six different colored faces of a flattened cube and four 3-dimensional cubes (shown in Figure 4) were included with the question: "Using the image, you need to fold the flat cut out in your mind and choose the correct cube representation of the cut out." A successful algorithmic approach to solve the problem would be to mentally fold the flat cut out into a cube one face at a time. After every fold, the four choices should be analyzed to determine if any should be eliminated from the possible solution. After the step-by-step mental completion of the cube, the correct answer should be chosen.

Abstraction through data analysis: The concept of abstracting useful information from data was introduced in the Song Analysis unit of the course. The data question on the test asked students to analyze and determine the possible distribution of fruit from a pie chart, shown in Figure 5, which graphs fruit percentages. The multiple-choice question read:

Which of the following could be the possible distribution of fruit based on the graph?

- 1) 3 apples, 2 oranges, 5 bananas
- 2) 2 apples, 5 oranges, 3 bananas
- 3) 5 apples, 3 oranges, 2 bananas
- 4) 3 apples, 5 oranges, 2 bananas

Upon careful inspection of the legend, the solution is obvious. The red slice represents the 30% (3) apples, the blue slice represents 50% (5) oranges, and the orange slice represents 20% (2) bananas.

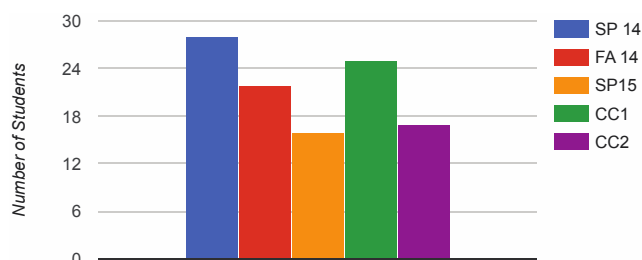


Fig. 2. ENG12 Student Distribution

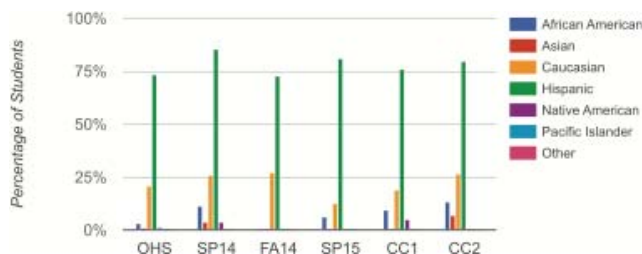


Fig. 3. OHS Ethnicity Distribution

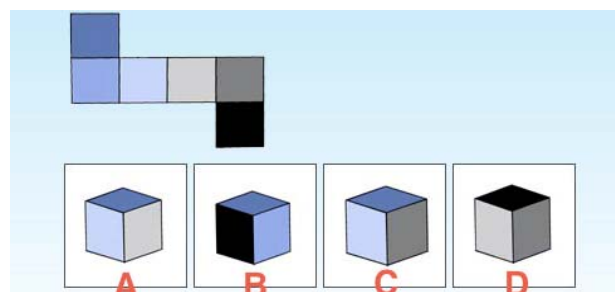


Fig. 4. CT Assessment Question: Algorithms through spatial reasoning

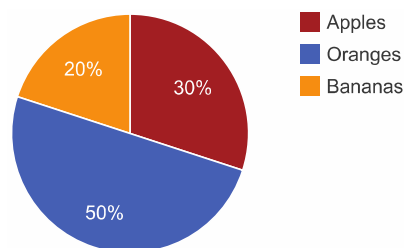


Fig. 5. CT Assessment Question: Abstraction through data analysis

Abstraction through analogy: The analogy question tested the students' ability to use their critical thinking skills to analyze the relationship between two objects. Analogies were not directly taught during the school year, so the question was relatively simple:

Milk is to cow as wool is to ____.

- 1) sweater
- 2) sheep
- 3) soft
- 4) farm

In order to solve this question correctly, abstraction should be used to determine the relationship between the two sets of terms: milk is to cow as wool is to sheep.

Abstraction through prompt summarization: Because prompt summarization was highlighted in the ENG12 curriculum, it was the focus of the fourth multiple-choice question. It instructed students to read a prompt and choose the option that best summarized the directions of the prompt.

Which sentence best summarizes the following prompt?

Works of literature often depict acts of betrayal. Friends and even family may betray their own values. Select a novel or play that includes such acts of betrayal. Then, in a well-written essay, analyze the nature of the betrayal and show how it contributes to the meaning of the work as a whole.

- 1) Write an essay that gives an example of a character in a book that may have committed an act of betrayal against a friend or family member.
- 2) Write an essay that explains how an act of betrayal was unfolded to become more important through a piece of literature.

The correct answer is 2; option 1 fails to require the analysis and development of the betrayal throughout the entire piece of literature.

Algorithms: Throughout the course, students were given many algorithms to accomplish English-related tasks (e.g., writing an essay, summarizing a prompt, analyzing Internet sources, etc.). This question was included to test their mastery at breaking down a problem into a sequence of steps. The question presented a picture of three blocks A, B, and C in an initial position (shown in Figure 6) and the goal was to move the blocks to achieve a specific position:

You have three blocks, A, B, and C that are initially in this position. Your goal is to move the blocks, one by one, in order to have A atop B and B atop C. What would be the correct sequence of steps to accomplish this?

- 1) B on C
- 2) C on B, A on C
- 3) C on floor, A on C, B on A
- 4) C on floor, B on A, C on B
- 5) C on floor, B on C, A on B
- 6) C on floor, A on B, C on A

This problem could be solved in different ways. A brute force trial of each multiple-choice answer will show that among the choices there is only one that will produce the goal position: 5. On the other hand, the problem could be solved logically by analyzing the goal position. It is known that in the end, block C should be on the floor, B on top of C, and A on top of B; these three facts lead directly to the correct solution.

Results: Overall, the students in the DISSECT classes performed better on the CT assessment than their peers in the control classes. Throughout the semester, the DISSECT-enhanced curriculum provided a heavy emphasis on

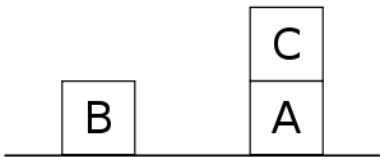


Fig. 6. CT Assessment Question: Algorithms

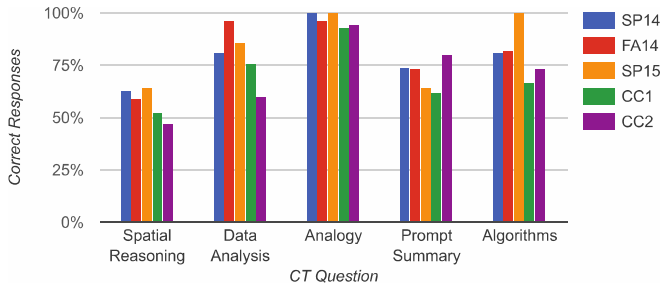


Fig. 7. CT Assessment Performance

algorithmic thinking and reasoning with abstraction. Figure 7 summarizes and compares the performance of each class on each question of the test. Below are the key results and short discussion.

All DISSECT classes, SP14, FA14, and SP15, outperformed both control classes in spatial reasoning, data analysis, analogy, and algorithms. The better performance in spatial reasoning and algorithms was expected because the Introduction to Algorithms activity had a spatial reasoning aspect to it (i.e., folding the paper airplanes) and, in general, many of the modules and activities highlighted or required algorithmic thinking. Furthermore, the Song Analysis project emphasized abstraction through data analysis, so SP14, FA14 and SP15 classes were prepared for this type of question. Regarding the analogy question, the two DISSECT courses did better, but not significantly. This could be attributed to the fact that the question may have been too simple, or that students were already familiar with these types of questions.

The results on the prompt summarization problem were not expected; considering performance, the SP14, FA14, and SP15 classes ranked second, third, and fourth, respectively. Specifically, this question featured an EOCE-like essay prompt. It is hypothesized that the DISSECT classes did not perform better than the control classes, because the control classes were also prepared for the essay-writing portion of the EOCE. Although, the fact that more than 64% of students in each DISSECT class answered the question correctly is a success.

B. EOCE Performance

LCPS requires every graduating senior to take the English Language Arts IV EOCE, which is composed of a reading and writing section. The maximum score for the reading and essay-writing portion of the EOCE is 24 and 20, respectively. Reading exams contain multiple-choice questions that utilize automated grading; the essay-writing portion is anonymously graded by English teachers. While Staley’s class aims to improve students’ critical reading skills, the CT modules

centered on augmenting students' analysis and writing abilities. Figure 8 shows the performance of the DISSECT and control classes on both sections of the EOCE, as well as the averages for both sets of courses. Regarding the reading section, the graph shows that all classes performed approximately the same on that portion of the exam; all classes received the same amount of critical reading instruction and practice. However, both DISSECT classes outperformed their peers in the control classes on the EOCE writing section; on average, the DISSECT classes scored three points, or 15%, higher than the control classes. EOCE performance data from SP15 was not available before submission.

C. CT Terms Assessment

In an effort to create a standardized form of assessment across all scientific and non-scientific DISSECT courses in the project, pre- and post-assessments are given to each student. The assessment centers around the CT terminology; students are provided with a list of concepts (CT, algorithms, sequence of steps, branching, iteration, variables, clarity, correctness, efficiency, and abstraction), and prompts them to circle, define, and give an example of each concept they are familiar with. By using this standardized document, DISSECT is able to determine how students' understanding of CT is changed throughout the school year across all classes and disciplines.

Each activity on the assessment was graded separately. The circling, or recognition, of terms was graded on a scale from 0 – 10, where each circled term was worth one point. Specifically, the document asked students to define and give an example of up to four terms, so the definition and usage categories were graded on a scale of 0 – 4, where each definition or usage was worth 0, 0.5, or 1 depending on the quality of the response. Figure 9 compares the pre- and post-performance of the ENG12 DISSECT classes on the CT terms assessment. As expected, the ENG12 classes improved in all three areas: recognition, definition, and usage of CT.

D. Post-ENG12 Feedback

A post-survey was also distributed to the ENG12 DISSECT classes to gather student feedback about the course and CT modules. One question asked students to disclose their attitudes about the class units. For each unit, they were asked whether they “hated”, “disliked”, “liked”, or “loved” the unit as a whole including the ENG12 content and related CT modules. Figure 10 charts the percentage of students who responded positively to the course units. In general, students enjoyed the Lord of the Flies, Macbeth, and song analysis units. In all classes, the Siddhartha unit was taught at the conclusion of the semester, and often felt rushed because 12th-graders are released seven school days before non-graduating students; at this point the graduating seniors showed a lower motivation for school and greater excitement for graduation and summer.

The class units, modules, activities, and access to course materials in the DISSECT courses required more technology than the standard English Literature class familiar to most high school seniors. Technologies used during the course included: the Google Drive suite (Documents, Spreadsheets, Presentations), Google Sites, Google Blogger, ToonDoo, and other online resources provided by the OHS Library. The post-survey included a question that asked students how much more

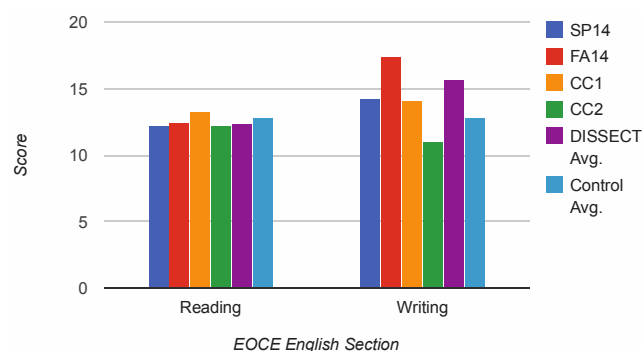


Fig. 8. EOCE Performance

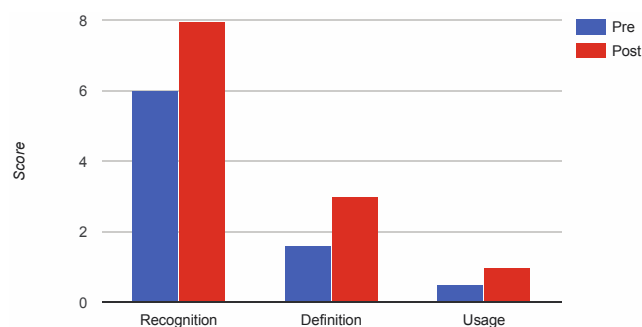


Fig. 9. ENG12 CT Terms Pre- and Post-DISSECT Performance

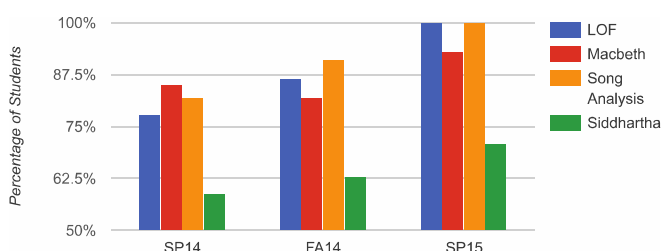


Fig. 10. ENG12 Unit Feedback

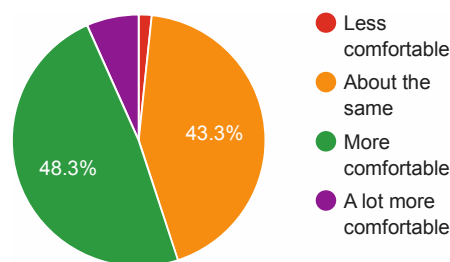


Fig. 11. Comfort Level with Technology Post-DISSECT

comfortable they were with technology as a direct result of the class and the projects they completed. Figure 11 depicts the 60 responses of the DISSECT students. Overall, 52% of students felt they were “a lot more comfortable” or “more comfortable” with technology at the conclusion of the course.

Despite the positive results of the incorporation of CT into ENG12, the impact could have been greater if each student had been fully engaged. Students were asked to identify which factors negatively impacted their engagement with the ENG12 course and CT-related modules. We found that students were very willing to admit some of the factors that distracted them.

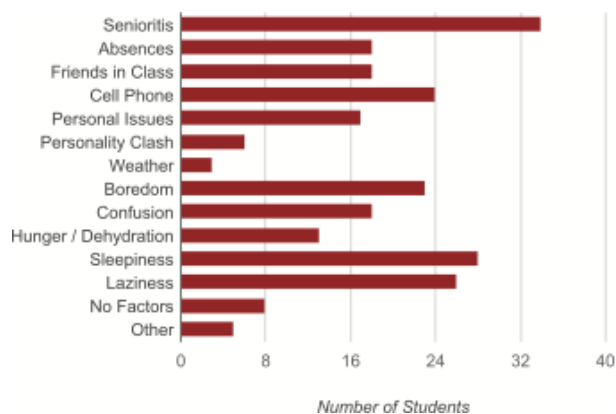


Fig. 12. Factors Impeding Full Participation in CT

Figure 12 shows the number of students across all DISSECT classes who selected a particular distraction. From the chart, it is clear that the factor that contributed to the highest level of disengagement was senioritis, an affliction of high school seniors characterized by a decline in motivation or performance. The next factors that had a significant effect on the DISSECT students were sleepiness, laziness, cell phones, and boredom. Smaller distractions included hunger and dehydration, personality clashes with the instructors, and the weather.

V. CONCLUSION AND FUTURE WORK

In this paper, we provided an overview of DISSECT, a project that aims to provide middle and high school students with essential CT skills. Adopting the perspective that CT is a tool that not only makes the learning of STEM classes more engaging, but also enhances the curricula of non-scientific courses (e.g., English) is unique to DISSECT. The modules presented show that CT can be seamlessly taught within the context of an English Literature course while remaining true to the course description, instruction requirements, and student performance expectations. On average, the students who were introduced to DISSECT modules that featured CT concepts performed 15% higher on the writing portion of the standardized EOCE. This suggests that CT should be explicitly taught as a problem-solving mechanism within the context of all courses, especially courses that are fundamental for success. For example, reading and writing are integral to learning, understanding, and communication in all disciplines, both scientific and non-scientific. Thus, if students can use CT to enhance their reading and writing abilities, they will be better equipped to pursue and succeed in the discipline of their choice.

Furthermore, assessment tools revealed that the integration of CT and English Literature was successful. The DISSECT classes demonstrated their abilities to use algorithms, algorithms through spatial reasoning and abstraction through data analysis; the classes also performed well, but not significantly better than the control classes, on abstraction through analogy and prompt summarization.

DISSECT has discovered an innate relationship between English Literature and CT. As DISSECT modules reach a level

of maturity within ENG12 and the student sample size grows, there will be room for further evaluation opportunities. If available, there could be interesting analysis of EOCE data comparing: DISSECT EOCE scores to control scores; DISSECT student performance to school-wide and district-wide performance; and student increase or decrease in performance from ENG11 to DISSECT ENG12.

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Using life course theory to frame women and girls' trajectories toward (or away) from computing

Pre high-school through college years

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Abstract— In this study life course theory was used to synthesize research on women's underrepresentation in computing into 4 stages across their academic trajectory: pre high-school, high-school, college recruitment and college retention. The Association for Computing Machinery and IEEE Explore databases, as well as select journals that publish on women in computing, were searched for relevant work. The synthesis reveals issues of use and access at early ages, many knowledge or interests interventions at the pre high-school and high-school stage, the influence of stereotypical images of computing at the recruitment stage and exclusionary behavior and women's computing self efficacy as important issues at the retention stage. Next the paper discusses similarities and differences across the stages and lastly makes recommendations for future work based on the synthesis and life course framework.

Keywords—underrepresentation, women and girls in computing, computer education, life course theory

I. INTRODUCTION

Women are under-represented in most computing fields and their representation has decreased since 2003 [1]. Women's underrepresentation in computing has sparked research into many factors that may affect a student's trajectory toward or away from computing. These studies often examine distinct time periods on students educational trajectory, from pre high-school, high-school to college and beyond. However, to date few papers have attempted to integrate findings across studies as well as across time periods examined. The few reviews that do exist are either older [2]-[3] or limited in their coverage of students' academic trajectory[4]-[5]. In this paper we report on our ongoing work that attempts to address these limitations in women and girls' underrepresentation research in computing by reviewing and integrating the newest findings across several studies. In earlier work Xie and Shauman [6] advocated for a life course perspective for analyzing women's pathways through science fields. Later Castaño and Weber [7] extended the use of life course theory to computing fields in specific. Following these researchers [6]-[7] we draw on life course theory [8] to organize the results into four stages: pre high-school, high-school, college recruitment and college retention. While inferences cannot be drawn across these stages since most studies are not longitudinal, placing studies into stages and summarizing the findings within reveal some

plausible cross-stage factors that warrant further research. Finally some national data sources from the National Science Foundation and Computer Science Teacher Association are drawn on to supplement the literature review. By organizing the literature into distinct stages across the life course, connecting across those stages and comparing with national data, we aim to develop a more comprehensive understanding of women's underrepresentation in computing and identify new areas of research.

Creating a more comprehensive understanding is important because there are many environmental influences, agents and other factors that attract or repel girls and women from computing. Using life course theory we can integrate the findings into academic trajectory and find recurring themes across students' trajectories or critical junctures that may push or pull girls or women away from computing. Greater understanding of recurring themes or critical junctures can lead to more informed interventions, change and recruitment.

Lastly, following Frieze, Quesenberry, Kemp and Velaquez, Kvasny, Trauth and Morgan and others [9]-[14] we argue that research on women's underrepresentation in computing must take into account the cultural dimension of computing as a field, the cultural practices at particular institutions and the ways the those in the field conceive of gender as research concept.

II. THEORETICAL FRAMEWORK

Life course theory, often used in sociological research, frames the study of individuals or groups as (shared) pathways that are composed of series of roles people take on [8], [15]. These roles are situated within unique contexts and have different processes or conditions operating within each context. When applied to an educational setting, life course theory is often called educational trajectories or educational pathways for individuals or some larger aggregate of people, respectively [16]. Some researchers also call individual's trajectories life histories [17]. On either trajectories or pathways people start at one role within some context or contexts, such as a middle-school student in middle-school, and then transition into a new role within a new context, such as a high-school student in high-school. Castaño and Weber [7] proposed using life course theory explicitly for research on girls and women's

Table 1

Common Research Themes for Women and Girls in Computing by Life Course Stages

Stage/Theme	Articles				Push or Pull
<u>Pre High-School</u>					
Access, Use and Skill Gaps	Willoughby, 2009	Ching, 2000	Bain, 2006	Fields, 2014	Push/Pull
	Cherney, 2006	Cotten, 2014	Sheldon, 2006		
Middle-School computing Interventions	Husley, 2014	Robison, 2014	Webb, 2011	Baytak , 2010	Pull
	Werner, 2005				
<u>High-School</u>					
High-school computing interventions	Freeman, 2014	Gannon, 2104	Guzdial, 2014	Kelly, 2013	Pull
	Dahlberg, 2011	Goode, 2011	Sands, 2010	Weisgram, 2006	
<u>College Recruitment</u>					
Effects of stereotypical images	Cheryan, 2013a	Cheryan, 2011	Cheryan, 2010	Cheryan, 2009	Push
	Cheryan, 2013b				
<u>College Retention</u>					
Exclusionary behavior	Margolis, 2002	Barker, 2009	Crenshaw, 2008	Powell, 2008	Push
	Larsen, 2005	Garvin-Doxas, 2004	Barker, 2004	Margolis, 2000	
	Varma, 2006				
Self-Efficacy/ Belonging	Appianing, 2015	Beyer, 2014	Huffman, 2013	Rosson, 2011	Push/Pull
	Beyer, 2006	Beyer, 2003	Lopez, 2008	Redmond, 2013	

trajectories through computing fields. We build in this theoretical work by using life course theory to organize extant research on women and girls in computing. While few of the studies identified for this review conducted longitudinal research, this framework provides a means for organizing research at different stages of a students'

trajectory toward or away from computing. Direct connections between results at one stage and results at another stage cannot be made, due to different samples, timing, and design, organizing the studies by stages can help identify plausible connections that warrant further research.

In this review four stages toward or away from computing fields are examined: 1) pre high-school (preschool - middle school); 2) high-school; 3) college recruitment (undeclared majors and new college students who might enter computing fields of study); 4) college retention (students who have entered a computing field of study). Each stage is covered in sequential order from pre high-school to college retention. Table 1 summarizes research themes common to each stage, as well as papers that directly report on that theme. To conserve space only the first author of each paper is listed. These were identified through our synthesis of existing research. Note that other topics have been researched at each stage, but themes in table 1 have received more attention. The final column in table 1 indicates whether that theme primarily pushed girls/women away from computing, pulled girls/women toward computing or exhibited both a push and pull effect depending on some other condition (such as levels of self-efficacy).

III. METHODS

The Association for Computing Machinery (ACM) and IEEE Explore were used as the primary databases for identifying papers on women or girls in computing. Furthermore, a subset of the journals that have a record of publishing on women and girls in computing were also searched: The Journal of Women in Science and Engineering, Sex Roles and the International Journal of Gender Science and Technology. For the ACM and IEEE Explore databases the search terms "girls," "women," and "gender" were used since both databases focus on computing topics. For the additional journals, the same search terms and "computing" or "computer" were used.

To be included in the study, papers had to meet one of two criteria tracks. First, for empirical articles the study must: report on a computing topic, report results by gender, study a U.S. or Canadian sample and fit within the life stages studied for this review. It is important to note that, while studies related to any field of computing were included, there was a preponderance of studies examining computer science. Other computing fields that were covered include: computer engineering, information systems, computer-graphics, human-computer interaction and web development. Additionally, since this review targets recent work in computing, only papers published in 2000 or later were analyzed. The second track of studies, which were fewer in number, were theoretical or conceptual in nature. These were used to frame the empirical studies. To be included theoretical or conceptual studies must: be applicable to computing topics, study men/women or boys/girls and fit within the life stages studied in this review. If theoretical/conceptual studies reported any empirical results, they were only included if they studied U.S. or Canadian populations. To gain the fullest picture of research on women and girls as it relates to computing, we also examined the citations of included studies, if these citations met the criteria above.

Table 2 displays the number of review articles from each database, specific journal or citations. Note that table 2 contains all the papers in table 1 (those specifically tied to themes) and supporting papers we discuss in this review (that did not directly tie to the major themes).

An important point needs clarification before continuing. There is a vast amount of work studying women's underrepresentation at several stages of science, technology, engineering and math (STEM) academic study or careers. However, here we only reviewed research that investigated computing fields in specific. The major rationale behind this decision is that computing fields have displayed some stark differences from most other STEM fields in regards to women's representation. First, while the percent of women pursuing bachelors in most STEM fields have remained fairly constant or increased slightly over the past 20 years, the computer sciences have dropped from 28% in 2000 to 18% in 2012 as reported by the National Science Foundation [18], [19] (and displayed in Fig. 2 later in this article). Furthermore, in industrial settings women's representation in the computing workforce has also decreased dramatically, from 36% of the computing workforce in 1991 to 25% in 2009 [20]. These trends suggest there may be something unique happening within computing leading women to pursue fewer degrees and careers in computing. In light of this, and the lack of recent comprehensive reviews of computing research related to girls and women's underrepresentation across the stages of computing, we focus specifically on computing research to better understand the dynamics operating within this field.

Our review is ongoing and in future work we aim to incorporate computing graduate students and industry professionals' stages.

A. Stage 1 – Pre High-School

A process that starts early on and can influence the likelihood of young, pre-college children entering a computing field in is the somewhat nebulously named digital divide. In earlier work and public discussion the digital divide was often defined as those who did or did not have

Table 2
Sources of Reviewed Articles or Chapters

Source	Number of papers
ACM	23
IEEE Explore	3
Journal of Women /Minorities in S&E	4
Sex Roles	7
Intl Journal of Gender Science & Tech	4
Citation of reviewed article	18
Total	59

direct access to a computer [21]. As computers have become more prolific in schools, households, libraries and other venues, researchers have elaborated on other dimensions of the digital divide [22]-[25]. While direct access remains an issue, especially for minority groups (e.g. [26] reports that African American and Hispanic households have lower rates of computer ownership than White households) these other dimensions have increased in importance, particularly as preparation for pursuing computing degrees later in life. van Dijk [23] developed a four part scheme for the digital divide: physical access (direct access, same as past research); skills, which refers to differences in computing skills across groups; motivational, which refers to differences in desire/interest to use computers; and usage which refers to frequency of use in specific ways (e.g. basic vs. more complex uses). van Dijk [23] guides our review of pre high-school studies.

Identifying studies that examined pre high-school populations proved challenging. Meelissen [27], in a discussion of studies of computer competencies by gender, notes that many of these papers focus on collegiate populations. Nonetheless, we were able to identify a small set of studies that analyzed pre high-school students by gender in relation to different aspects of the digital divide outlined by van Dijk [23]. Willoughby et al's [28] work examined the teamwork dynamics of mixed gender teams for pre-schoolers and 5th/6th graders working on age-appropriate computing tasks. Somewhat surprisingly, they found in the mixed-gender preschool girls dominated computer use whereas for older children young boys dominated computer use. Ching, Kafai and Marshall [29] similarly found that until the researchers intervened (by having teams use fixed schedules for different tasks), 5th and 6th grade boys dominated more complex computer tasks (including programming) whereas girl team members were more frequently left recording team notes or conducting basic research. If one group dominates computer use this may lead to uneven development of computing ability, particularly higher order skills (e.g. programming).

Outside of the classroom Fields, Giang and Kafai [30] developed profiles for how middle school to high school aged boys and girls used Scratch, web platform for creating and sharing animations, games, simulations and interactive art. They report that girls were overrepresented in user profiles that used the platform the least and that boys were overrepresented in the profile of users that used the platform the most. In other words, boys used the platform and participated in the informal computing community to a greater degree than girls. Finally, Bain and Rice [31] found no differences in middle school boys and girls' attitudes, perceptions and general use of computers. It may be that young boys and girls have are not strongly distinguished by perceptions and attitudes toward computers at this age.

Another study by Cherney and London [32] on girls and boys between the ages of 5-13 found that boys played significantly more computer/video games (use) than girls. Bain and Rice [31] also found that boys used computers for games more than girls. Related research by Cotton, Shank and Anderson [33] found that middle-school boys had a

statistically higher percent of game system ownership (physical access), although both girls and boys reported high ownership (81 vs. 96). Playing video/computer games has been found to improve mental rotation abilities [34]-[35] which are relevant skills for computing fields like computer graphics and game development. More generally video games are seen as a common route into computing [36]-[37] However, the way in which games can serve as an entry for developing interest in computing remains a contested point in the literature [4],[38]-[40]. These different patterns in access, use and skill development may have an impact on high-school girls' involvement with computing as well.

Several papers also present interventions researchers undertook to increase young girls' interests or knowledge of computing [36], [41]-[44]. Most of these papers target middle school populations. These studies had students use tools such as the Alice programming software or Macromedia Flash to create interactive stories [41], games [42]-[43] or interfaces [44]. However, most of the studies we identified report mixed results [41], [43], [44] or report limited results [42].

B. Stage 2- High-School

At the high-school level many studies also focus on interventions to increase girls interest or knowledge of computing [45]-[52]. These studies vary in scope of the content they cover, the size and type of participants and the duration both of individual interventions and whether or not they were repeated. One of the most ambitious projects is called Georgia Computes! which ran for 6 years across the state of Georgia [47]. The project aimed to reach underrepresented populations in computing including young women/girls, African Americans and Hispanic students (grades 4th-12th) and also had professional development for secondary and postsecondary educators. Student interventions took the form of after school/weekend programs and summer camps. Georgia Computes! was one of the more extensive interventions we identified in this review.

Generally, many interventions reported positive post-intervention gains in young women's interest in or attitude toward computing [45], [47], [50]-[51] or computing classes [49], however some also reported mixed results [47],[51], null results [46] or loss of interest/attitude [52]. For example, in the Georgia Computes! students in their summer camps were significantly higher on post statements including whether they liked computing, were good at it, and were good at computing compared to their friends. Furthermore, comparing the 2006 and 2012 Georgia Computes! cohorts there was 237% increase in the number of young women taking the computer science advanced placement exam (CS AP). However, young women who took the CS AP exam continued to lag behind their male classmates on passing the exam, 37% to 54%, respectively. Dahlberg, Barnes, Buch and Rorrer [50] and Guzdial, Erickson, Mcklin and Engleman [47] study longer term impacts of their interventions (e.g. do students enter computing in college) which are important in light of challenges women face

pursuing computing degrees, as discussed in the following sections.

Some studies of high-school students also find they are largely unaware of what is covered in computing degrees in college [48], [53]. The Computer Science Teachers Associations (CSTA) published the results from a series of bi-annual national studies from 2005-2013 showing that less than 50% of the high-schools surveyed had CS AP classes [54]. In the same study CSTA also reported on the percent of young women in high school introductory Computer Science courses, visualized in fig. 1. Fig. 1 shows that over the past 6 years there has been a sharp increase in the number of introductory CS courses with 0-20% young women, suggesting fewer high-school aged young women are taking this course. This may also contribute to students' limited familiarity with computing degrees. A few qualitative studies of young women in high-school also indicate they are aware of difficulties women face pursuing computing degrees including intimidation and exclusion [48] or experience exclusion (e.g. having their work ridiculed based on gender) in high-school computing courses [55]. Exclusionary behaviors, often from male classmates, have been studied more frequently in college students and will be discussed in the college retention section. It is difficult to say how similar high-school and college behaviors are without more studies looking at computing classroom dynamics in high-school. Nevertheless, research finds that women enter college with less computing experience on average [5], [56]. It seems plausible the dimensions of the digital divide discussed earlier and limited advanced computer exposure in high-school contributes to this unfamiliarity. Young women's awareness of or experience with exclusionary behavior in computing classes or degrees may contribute to their low numbers in introductory CS courses, as displayed in fig. 1. Interventions are a promising start to addressing women's lower rates of computing enrollment. Additionally, studies that examined the trajectory of girls to young women in relation to computer experience, skills and interests would greatly benefit our understanding of women's underrepresentation and ability to create new interventions.

C. Stage 3- College Recruitment

At the earliest stage of students undergraduate work one researcher and her colleagues have conducted numerous experiments to identify potential deterrents to entering computer science. Cheryan and her colleagues [57]-[60] consistently find that women, but not men, express lower interest in pursuing a computer science degree after being exposed to a stereotypical presentation of a computer scientist. As Cheryan, Plaut, Handron and Hudson [61] explain this stereotype projects computer scientists as technology (and not person) oriented, singularly focused on computers (to the exclusion of other interests), lacking in interpersonal skills, highly intelligent, of a certain physical appearance (pale, thin), perhaps with glasses and male/masculine. While some of these attributes are positive (e.g. intelligent) others can be exclusionary. but if these images are projected by the field or other sources like media

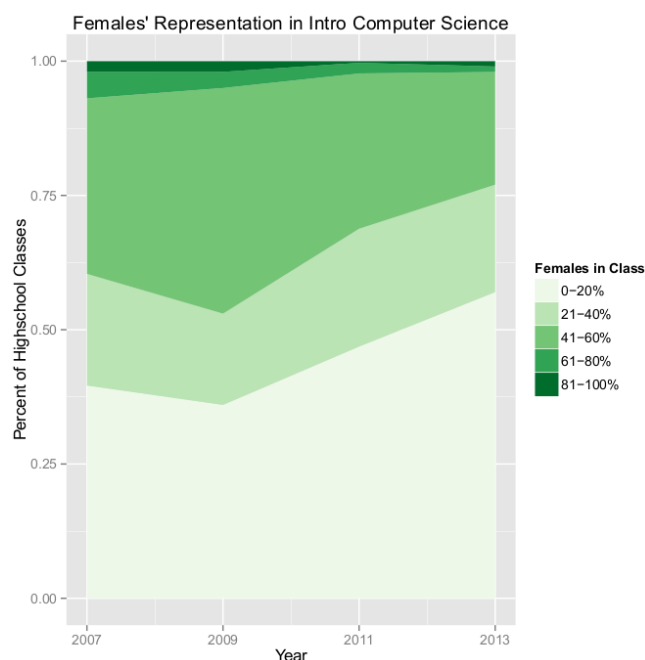


Fig 1 - Percent of Classes with Different Ranks of Female Representation

people will act on the images they receive. As discussed in the college retention section, there is some evidence that these stereotypical attributes of computer science are present in the field as well.

An example of the experiments Cheryan and colleagues have run help demonstrate how stereotypical images of computer science affect women's interest. In Cheryan, Drury and Vishayapai [57] non-computer science students were assigned to 1 of 3 conditions: interaction with a computer science major who evoked stereotypical attributes, interacting with a computer science major who did not evoke stereotypical attributes or no interaction (baseline comparison). Interest in pursuing computer science was measured pre/post. Participants in the experiment were told the session was studying how people get to know others (i.e. they were not informed of the intent of the study until debriefing afterward). In the baseline group students were told that their partner did not show up and were "randomly" asked to evaluate their interest in a given field (all slips were computer science). Results showed that women expressed statistically lower interest in pursuing computer science when exposed to the stereotypical partner than the baseline or non-stereotypical condition. Men showed no difference across conditions. Cheryan and colleagues [57]-[60] have found similar effects on women's interest in computer science when exposed to other stereotypical imagery (e.g. a virtual classroom). In these studies Cheryan and colleagues also found that sense of belonging--whether a person felt they fit in with the field--mediated the relationship between exposure to the stereotypical condition and loss in interest. Thus it seems that these images negatively influence whether female students feel like they fit within the field. Issues of fit also arise while women pursue computing degrees.

D. Stage 4 – College Retention

For women who do enter computing fields, several qualitative studies have identified aspects of the academic culture similar to attributes of the stereotypical image (e.g. masculine/aggressive) of computing [56], [62]-[68]. For example, Garvin-Doxas and Barker [65]) conducted an ethnographic analysis for 2 years at a public research intensive university. One of their major findings was that male students engaged in "strutting" behavior, whereby they exaggerated their ability on a given topic/class and understated its difficulty. This behavior held for male students even when the student performed no different or worse than the average. This behavior inflated expectations for students and was often used to cast others as unable to succeed in computing. Across this study and others that identified strutting behavior in computing fields [56], [69] women were often targeted as academically unskilled, regardless of actual ability. More generally, other qualitative studies like Barker [62], who studied undergraduate research experiences in computer science, found that it was common for male students to understate female students' ability, regardless of their actual ability. Strutting, dismissive and exclusionary behavior complicate women's trajectory through computing and may plausibly be connected to some of the other research in this section including women's self-efficacy.

Self-efficacy is the belief in one's own ability to perform some task [70]. Several studies have found that females have lower self efficacy in computing [71]-[76]. Furthermore, some studies have shown that females in computer science have lower self-efficacy than males in computer science [74]-[76]. For example, Beyer and Haller [75] found that women in computer science had statistically lower self-efficacy in their ability to teach someone a computer software package; discuss the strengths and weaknesses of software packages; and write a complex program. Disturbingly, Beyer and Haller [75] and Beyer, Rynes, Perrault, Kay and Haller [76] has found that male non-computer science majors express greater overall self-efficacy than female computer science majors. Somewhat related, Lopez, Zhang and Lopez [77] found no difference between women non-majors and women in computer science self-efficacy. Furthermore, Redmond, Evans and Sahami [78] found that non-computing and computing major women had similar levels of math confidence, a construct similar to self-efficacy. It seems that that women's self-efficacy related to computers does not increase despite their progress in computing degrees. Indeed, studies of self-efficacy in other STEM fields often show women with lower or decreasing levels of self-efficacy as they advance in their degree (e.g. [79]). While the exclusive, dismissive behaviors of some male computing students are often studied separately from women's self-efficacy in computing, there is some overlap. For instance Lopez, Zhang and Lopez [77], who examined 359 women computing majors and 333 women non-computing majors, found that women computing majors reported statistically higher levels of gender stereotyping than non-majors. It seems plausible that the exclusionary behaviors may have impact on women's self-efficacy while pursuing computing

degrees, although this is something that needs to be researched further.

Looking at another aspect of the retention stage, Cohoon [80] examined men and women's attrition from computer science majors averaged over a 5 year period (1992-1997). While this data is older it is also one of the more comprehensive examinations of attrition by gender in computer science. Across 23 institutions in Virginia most (13) had slightly higher attrition rates for women, a few (5) had much larger attrition rates for women (over 15%). There were only 2 institutions with slightly higher rates of attrition for men (the rest were even). During this time, enrollment rates in Virginia were similar to national trends [80]. Margolis, Fisher and Miller [67] also found higher attrition rates for women in Carnegie Mellon's computer science department. Again, while it's not possible to directly connect this outcome to the exclusionary behavior women experience or lower self-efficacy women express, it seems plausible that both may have an impact on attrition rates.

Finally fig. 2 shows the graduation rates for men and women with bachelors in computing science from 1994-2012 (adapted from NSF Women, Minorities and People with Disabilities' Reports). Across the four stages we have reviewed research that suggests there gaps in use, access and computing skill between boys and girls in pre high-school years, interventions that have unclear long-term impacts and a general lack of awareness of computing fields in high-school, stereotypical images of computing that keep women from entering computer science and exclusionary practices, lower levels of self-efficacy and higher rates of attrition for women in computing. These studies were conducted in isolation and cannot be directly linked to each other; however it is plausible that at each stage of a women's trajectory toward or away from computing, these forces (likely along with others) resulted in the gender skewed distribution of bachelors graduates in figure 1. Longitudinal studies could shed light onto the complex trajectories that appear to lead more women away from computing at different stages.

IV. DISCUSSION

Surveying across the four stages reviewed, two composite (cross-stage) themes emerge: access to computing and orientation to computing. Across the stages, different individuals or conditions impede (or enhance) girls access to computing. This theme changes across stages; in pre high-school boys sometimes monopolize computer time, but in high-school and college classes, young women may be marginalized in computer classes. Outside of computing but in college stereotypical images may deter women as well. What access is being affected differs across stages as well, from computing time or classes to degrees and high-level computing skills. It appears that the severity of exclusionary behavior is most pronounced within computing degrees; however, this may be an artifact of limited research at the pre high-school and high-school stage and requires further study. The second composite theme focuses on the ways women or

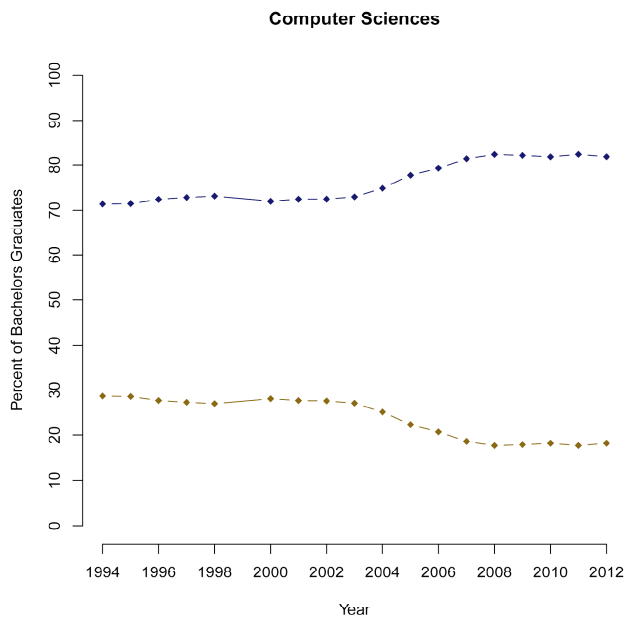


Fig. 2 - Computer Sciences Bachelors Graduates by Gender

girls orient themselves toward computing. Coverage of this theme is different across stages; in pre high-school and high-school years the prevalence of interventions indicate low interest for women, but later in college studies find women express low sense of belonging or self-efficacy with computing. These orientations are of different kinds but they may overlap. Few studies seem to have examined these 3 factors interrelations (although some such as [75] captured interest and self-efficacy). All 3 factors are likely present across the stages, however not all have received equal attention at each stage.

These composite themes suggest some areas for further study. Issues of access deserve greater attention at the pre high-school and high-school level, as well as longitudinally or comparatively across these stages. Another avenue for further research is exploring the interrelations between self-efficacy, interest and sense of belonging in regards to computing as well as how these factors do or do not change over time. As suggested in the synthesis, there may also be a relationship between exclusionary behavior in computer science and women's self-efficacy and sense of belonging. Other longitudinal studies across subsets or longer portions of the stages identified here are also needed to better understand students' life course toward or away from computing including the long-term effects of interventions.

Finally, while pre high-school and high-school interventions were emphasized here, other interventions in college recruitment or college retention (e.g.[49]) may also help address the second composite theme. Furthermore, as we argued in the beginning of the paper, researchers examining women's underrepresentation in computing need to analyze the culture of computing professions, computing in the classroom and how gender is conceived in computing research. Some research addresses computing culture or

problematicizes how gender is conceived in computing research, such as those associated with the first composite theme. More critical research is needed if we aim to create a more open and equally rigorous computing field. The exclusionary behavior discussed earlier can affect male and female success and contributes little to computing excellence.

V. CONCLUSION

In this study we drew on life course theory to frame a review of research on women's underrepresentation in computing fields. Four stages were identified: pre high-school, high-school, college recruitment and college retention. Across the four stages we reviewed research that suggests there are gaps in use, access and computing skills between boys and girls in pre high-school years, interventions that have unclear long-term impacts and a general lack of awareness of computing fields in high-school, stereotypical images of computing that keep women from entering computer science and exclusionary practices, lower levels of self-efficacy and higher rates of attrition for women in computing. As this review develops we aim to incorporate later stages for women including graduate studies and to similarly review minorities in computing. For future work on women and girls in computing this review suggests the importance of taking a life course perspective and studying students' trajectories toward or away from computing. While academic career cohort studies may not be feasible in all cases, studies that look across two or more of the stages discussed here hold promise for better understanding the places of divergence and conditions or choices that affect whether women pursue computing.

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Motivational Factors Predicting STEM and Engineering Career Intentions for High School Students

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Abstract— The objective of this research was to determine various motivational factors that influence high school students towards intended careers in engineering. This study utilized data from the High School Longitudinal Study of 2009, which surveyed over 24,000 students in 9th grade and again in 11th grade. We classified students into four categories of intentions: 1) *Not STEM Intending*, those who did not select a STEM occupation in either the 2009 or 2011 administrations; 2) *Leavers*, students who selected a STEM occupation in 2009 but not in 2011; 3) *Newcomers*, those who did not originally specify a STEM career in 2009, but who did in 2011; and 4) *Stayers*, those who chose STEM careers in both 2009 and 2011. Repeated measures analysis of variance modeled the extent to which the motivational variables, measured for both mathematics and science, were related to students' career intentions. Results show that occupational intentions change dramatically between 9th and 11th grades, and that the relationship between STEM intention and motivation is highly time-sensitive: Of the 6,788 STEM intending students in 2009 (29% of the total sample), only 3,560 remained STEM intending in 2011 (48% attrition).

Keywords—*motivation, careers; self-efficacy; persistence*

I. INTRODUCTION

For many years, the relationship between students' attitudes and their college and career intentions has been an important area of inquiry in STEM education. Betz & Hackett, for example, examined the impact that mathematics *self-efficacy* beliefs had on high schoolers' intention to select science majors in college. They surveyed upwards of 250 students and found that, not only are students' expectations for future success in mathematics significantly related to their choice of college major, but that young women and young men differed significantly in their mathematical self efficacy [1].

This seminal study is indicative of the general body of work in STEM intent and persistence. In general, research has found that students' beliefs about their abilities relative to mathematics and science subject matter help them form expectations of future success in that subject matter.

Moreover, inasmuch as students' perceive their earlier STEM experiences as indicative of future experiences in a potential occupational field, these perceptions also color their career intentions and occupational choices. Additionally, there has been reasonably consistent findings that these beliefs and perceptions differentially impact the intentions of women and under-represented populations for going into engineering and other STEM fields [2].

Sadler et al, in a huge study of US high schoolers found that males are about 3 times more likely to be interested in a STEM career than females [3]. Partial causative factors for this disparity include young women's beliefs in the *utility* of STEM for their future career goals, lack of role models, and young women having more developed communal goals, as opposed to individualistic goals, than young men [4] [5].

However, recent research indicates that change is in the works (see Marra et al.) [6]. While women represent far fewer professionals in the fields of science, technology, engineering, and mathematics both in the United States and abroad, the number of women in STEM fields is steadily increasing. Marra et al, suggest that recent reduction in gender differences can be partly attributed to more equitable preparation in mathematics and science. Ethnicity and socio-economic status are also known to influence intention for STEM careers, mediated by poorer academic success for under-represented groups [7].

One critique we can make of this body of research is that most of these studies draw upon samples of convenience, making estimation of effects difficult to project and disaggregate across pertinent subgroups. Additionally, the longitudinal nature of students' motivations and STEM intention is unclear. What happens that might influence a non-STEM intending student to choose to become an engineer? What experiences enable or constrain intentions to pursue technical and scientific occupations?

The objective of this research was to determine various motivational factors that influence high school students towards intended careers in engineering. Compared to other occupational fields, engineering-intending students compose a small minority, requiring relatively large samples to estimate population parameters. This study utilized data from the High School Longitudinal Study of 2009, a sample of 23,415 students, representative, nationally, of US 9th graders [8].

Clearly motivations and beliefs about the subject matter are influential factors. Cass et al report that interest, mathematics competence and performance, and mathematics recognition significantly predict choice of an engineering career, even after controlling for prior performance, and demographics. Thus, factors relating to *identity* within at least one domain (mathematics) are highly predictive of pursuit of STEM in general, and engineering in particular [4].

Identity is developed over time in a field, but there is evidence that consistency across the high school years is paramount for keeping students engineering intending. Adelman analyzed the transcripts of persons enrolled in the High School and Beyond longitudinal study (1982-1993) and their subsequent choices of major and occupation. He found that at age 28/29, the people who persisted in engineering displayed a consistent occupational goal, beginning in high school. Forty-one percent of engineers displayed a consistent goal through high school and through college, as compared to only 10% of engineers, who changed their career goals often [2]. Because many students move from discipline to discipline in college, the likelihood of a student with engineering intent going into university actually graduating with a degree in engineering is below 50%. This is especially true for women. Marra, et al studied nearly 200 undergraduate women to ascertain their efficacy-related beliefs and career intentions. They found that self-efficacy mediated students' career intentions, and that, at least for women, it should be a factor in deciding when to switch majors [6].

In a subsequent study, the authors found three factors impacting students intentions to leave engineering: 1) Poor teaching and Advising; 2) difficulty of the engineering curriculum; and 3) lack of belonging in engineering [7]. Likewise, Christensen et al report that the top three factors for predicting student interest in STEM were: 1) parental support; 2) a high quality/motivating teacher; and 3) self-motivation/feelings of efficacy [9]. We interpret these factors to indicate that students' STEM experiences, their self-efficacy and identity in STEM subject matter should be predictive of their intentions to stay or leave engineering or other STEM disciplines. What patterns exist across motivations and STEM intentions as students matriculate through high schools is the primary focus of the analysis reported here.

Seymour and Hewitt's seminal work supports these findings as students move on to the world of work. They identified two categories of students who leave

science/engineering programs: those who lose *interest* or become disappointed with the curriculum and those who feel they must leave because of a loss of academic self-efficacy in the competitive environment [10].

It has been shown that these motivational variables: Interest, Identity, Self-Efficacy, and Utility each impact the *effort* a student is willing to expend in academic subject matter, and that they interact to significantly predict academic performance in STEM subject matter [11]. In general, the model suggests that interest and perceived utility of the subject matter is a key driver of effort students are willing to expend, and that self efficacy and identity mediate students' goals for engaging and persisting in STEM. The purpose of the present study builds on this body of research to ascertain the *longitudinal* impact of these variables on the career intentions of high schoolers, with particular attention to engineering aspirations.

II. METHOD

A. HSLS: 09

The High School Longitudinal Study of 2009 (HSLS:09, NCES, 2011) is a long-term study of 21,000 9th graders in 944 schools administered by the National Center for Education Statistics (NCES, 2009). Data collected in the study focuses on students' decisions on what courses to take, what occupations to pursue, their aspirations for higher education and their reasons for engaging in these pursuits. STEM pursuits, in particular, including mathematics and science courses, majors and careers, are a special focus of the study.

The initial administration of the HSLS:09 began in Fall, 2009, surveying 9th graders on their past experiences in middle school, and on their current attitudes, motivation, and achievement. Students were surveyed again in the Fall of 2011, and a follow up survey was administered again in 2013 following graduation. Dropouts were also followed on this schedule. Future data collections are planned in 2016 and 2021 to learn about participants' life trajectories and markers of success. This study reports only on the first two administrations.

HSLS:09 generated a nationally representative sample of 944 high schools, including both public and private schools. This makes the data set representative of communities in the US. Following this initial sampling, approximately 25 ninth-graders were selected from each school. The resulting sample totals approximately 24,000 students, representative of all ethnic categories and socioeconomic strata. Students' parents, mathematics and science teachers, and other school personnel were then asked to complete surveys on their student's behaviors and experiences. We only analyze student data at the national level in this study.

B. Weighting

The HSLS:09 dataset provides several types of sampling weights to account for the complex survey design and produces estimates for the target population of choice. These weights

allow for multilevel analyses across a variety of factors (e.g., students within ethnicities, teachers within schools, etc.). For this study the two pertinent subpopulations described are Sex and Ethnicity. The appropriate variable weights provided by NCES were applied to provide accurate descriptive statistics for these factors. The survey items show minimal non-response bias. Some missing data, therefore, were imputed. For the present study, students' sex and ethnicity have some imputed scores.

C. Motivation Scales

Eighteen items from HSLs:09 were utilized in the construction of motivation and achievement indices in the present study. Table 1 provides a listing of items for each hypothesized scale. All items were rated on a 1-4 Likert scale ranging from 1 (Strongly Disagree) to 4 (Strongly Agree). Motivation for both mathematics and science were measured separately to account for differences in students' perceptions and experiences in the different subject matter.

D. STEM Intentions

STEM career intentions were measured using standard categories from the US Bureau of Labor Statistics: Computers/Mathematics, Architecture/Engineering, Life and Physical Sciences, and Healthcare Professionals. Any student who chose one of these four categories of occupations as "where they see themselves at age 30" was classified as STEM intending. With measures administered longitudinally at two points in time (2009 and 2011), we classified students into four categories of intentions: 1) Not STEM Intending, those who did not select a STEM occupation in either the 2009 or 2011 administrations; Leavers, students who selected a STEM occupation in 2009 but not in 2011; 3) Newcomers, those who did not originally specify a STEM career in 2009, but who did in 2011; and 4) Stayers, those who chose STEM careers in both 2009 and 2011.

III. RESULTS

A. Overall Results

Repeated measures analysis of variance modeled the extent to which each of the motivational variables was related to students' career intentions. Overall, males, students who identify more with math and science, students with parents who are engineers, Asian, Hispanic, and White students, and more affluent students have a higher probability of engineering intention in comparison to other students. However, STEM intentions changed dramatically between 9th and 11th grades. Of the nearly 6,800 STEM intending students in 2009 (29% of the total sample), only roughly 3,500 remained STEM intending in 2011. This is an overall attrition rate of 48% for the 2009 cohort.

The attrition away from STEM occupations is heavy across all occupational categories. Computer/Mathematics professions saw a drop from 350 original students to only 94 (a drop of 73%). Architecture/Engineering dropped from 1,035 to 363, an attrition of 65%. Physical and Biological Sciences saw the largest attrition, dropping from 1,055 to 208, an 80% rate. Health Professions, the category representing the

largest group of STEM intending students in 2009, dropped from 4,348 to 2,193 (50%).

But, there is hope! Students also select *into* Engineering and related fields. Computers/Mathematics jumped from 350 students in 2009 to 412 in 2011, Architecture/Engineering jumped from 1,035 to 1,169, while Health Professions jumped from 4,348 to 4,612. Only Biological and Physical Sciences showed a net drop in overall numbers of students who, as high

Table 1. HSLs:09 Items Chosen to Comprise Motivational Scales

Motivation Scale
Prompt
Item
Identity
<i>How much do you agree or disagree with the following statements?</i>
1. You see yourself as a math person
2. Others see you as a math person
Interest
<i>How much do you agree or disagree with the following statements about your Fall 2009 math course?</i>
1. You are enjoying this class very much
2. You think this class is a waste of your time (R)
3. You think this class is boring (R)
Utility
<i>How much do you agree or disagree with the following statements about the usefulness of your Fall 2009 math course? What students learn in this course...</i>
1. is useful for everyday life.
2. will be useful for college.
3. will be useful for a future career.
Self Efficacy
<i>How much do you agree or disagree with the following statements about your Fall 2009 math course?</i>
1. You are confident that you can do an excellent job on tests in this course
2. You are certain that you can understand the most difficult material presented in the textbook used in this course
3. You are certain that you can master the skills being taught in this course
4. You are confident that you can do an excellent job on assignments in this course
Effort
<i>How often do you...</i>
1. go to class without your homework done? (R)
2. go to class without pencil or paper? (R)
3. go to class without books? (R)
4. go to class late? (R)

(R) indicates reverse scored items.

Note: These scales are identical to the science motivation scales, with the exception of substituting the word "science" for "math"

school juniors, see themselves pursuing those occupations by age 30 (from 1,055 in 2009 to 938 in 2011). Overall, students selecting STEM careers as their intended occupations at age 30 increased by 5% over the two-year study. Based on the predictors from the preliminary analysis, students who are

Table 2. Percentages of students selecting STEM fields as potential occupation at age 30

		2011					Row Total 2009
		No Preference Listed	Comp/ Math	Arch/ Eng	Phys/ Bio	Health	
2009	No Pref (~STEM)	13,056 (79.0%)	244 (1.5%)	662 (4.0%)	527 (3.2%)	2,138 (12.9%)	16,627
	Computer/ Math	210 (60.0%)	94 (26.9%)	19 (5.4%)	6 (1.7%)	21 (6.0%)	350
	Architect/ Engineer	523 (50.5%)	33 (3.2%)	363 (35.1%)	25 (2.4%)	91 (8.8%)	1,035
	Physics/ Bio Sci.	618 (58.6%)	17 (1.6%)	43 (4.1%)	208 (19.7%)	169 (16.0%)	1,055
	Health Profession	1,877 (43.2%)	24 (0.6%)	82 (1.9%)	172 (4.0%)	2,193 (19.7%)	4,348
Total STEM Intending 2009							6,788
Total Switching Within STEM Fields			168 (2.4%)	507 (7.5%)	411 (6.1%)	2,474 (36.4%)	3,650
Total Leaving STEM (Leavers)							3,228
Total Switching into STEM (Newcomers)		3,571					
Total STEM Intending 2011							7,131

male, above the poverty line, expect to earn a bachelor's or master's degree, have parents who expect the student to go far in school, are engineers, or have an associate's degree or higher, or students who view math and/or science positively are more likely to be engineering-intending. Ethnically, Asians, Hispanics, and Whites seem to be more engineering inclined, although the trend did not seem as strong.

B. Leavers, Newcomers, Stayers

Table 2 provides a breakdown of students' career intentions for 2009 and 2011. Health professions represent the largest proportions of STEM intenders, closely followed by Architecture/Engineering and Physical and Biological Sciences. Computer Science and Mathematics bring up the rear with very low percentages of students intending to engage in these occupations.

We are most interested in any information we can find that might explain what the characteristics are of these three categories: Who stays in STEM, who switches out, and who switches in, and what characteristics and attitudes might influence these students' decisions. Table 3 provides a breakdown of Stayers, Leavers, Newcomers and Not-Interested students across the different STEM occupational categories surveyed. In terms of overall movement from one category to another, we see roughly equal proportions of students across all categories. 15.2 percent of students stayed STEM intending (Stayers), another 15.3 switched into STEM (Newcomers), while 13.8 elected some other STEM category as intended occupation, or could not choose. Table 3 shows

that Asians were more likely to stay or switch into STEM than other ethnic groups. While there is a slight tendency for underrepresented minorities to be not STEM intending, these differences are relatively small compared to Whites, with the exception of American Indian students.

Repeated measures ANOVA shows that, across all motivational variables, significant differences exist for Stayers, Newcomers, Leavers, and Not STEM Intending students. We see that those who switch into STEM experienced an increased identity, interest, self-efficacy, and feelings of utility for both mathematics and science, while those who switch out or remain not-interested in STEM careers showed reduced identity or no change in attitude. Those who stayed with STEM career intention maintained moderately high attitudes across these variables. Table 4 shows the magnitudes of these changes.

C. Sex differences

We found few differences overall when analyzing motivations by sex. Repeated measures ANOVA with sex as a fixed factor shows that males started out with higher motivation than females in 2009, but two years later, these differences became non-significant. It is important to note that, in accordance with the overall analyses above, *both* sexes tend to lose identity, feelings of utility, self-efficacy, and interest in both mathematics and science over time. However, for STEM intention, females are much more likely to have stayed with a vision of a STEM occupation at age 30 than males. Females, in fact, are almost twice as likely to remain STEM intending than males. They were also, however, marginally more likely to switch their intended occupation from STEM to some other occupation, or feel unable to make a choice. Table 5 shows the proportion of males versus females across categories of STEM intent. Females, typically were less likely to be uninterested in STEM careers than males, more likely to switch out of STEM, more likely to switch *into* STEM, and about twice as likely to remain STEM intending, than their male counterparts ($X^2_{(3 \text{ df})} = 846.13, p < .0001$).

Table 3. Breakdown of STEM Intent categories by ethnicity.

	STEM Intent				Total
	~STEM	Leavers	Newcomers	Stayers	
Am. Indian	101 (61%)	21 (27%)	23 (14%)	20 (12%)	165 (100%)
Asian	873 (46%)	302 (16%)	358 (19%)	377 (20%)	1910
Black	1430 (59%)	299 (12%)	378 (16%)	337 (14%)	2444
Pacific Islander	55 (50%)	20 (18%)	16 (15%)	19 (17%)	110
Hispanic	3314 (58%)	772 (14%)	819 (14%)	799 (14%)	5704
White	6598 (55%)	1814 (15%)	1656 (14%)	2008 (17%)	12076
Total	13056 (56%)	3228 (14%)	3571 (15%)	3560 (15%)	23415

Table 4. Means and Standard Deviations of Key Motivational Variables for Mathematics and Science, by STEM Intent.

Motivation Variable STEM Intent	Mathematics		Science	
	2009 Mean (S)	2011 Mean (S)	2009 Mean (S)	2011 Mean (S)
Identity				
~STEM	-1.07 (2.77)	-1.60 (3.26)	-1.14 (2.78)	-1.73 (3.24)
Leavers	0.05 (1.35)	-2.05 (3.69)	0.18 (1.39)	-2.07 (3.69)
Newcomers	-1.34 (3.25)	0.03 (1.63)	-1.38 (3.22)	0.10 (1.67)
Stayers	.30 (1.22)	.22 (1.51)	.038 (1.35)	0.43 (1.58)
Utility				
~STEM	-1.86 (3.33)	-1.63 (3.27)	-2.38 (3.49)	-1.64 (3.27)
Leavers	-0.65 (2.43)	-2.12 (3.66)	-0.96 (2.88)	-2.12 (3.66)
Newcomers	-1.98 (3.49)	-0.05 (1.67)	-2.46 (3.65)	-0.05 (1.67)
Stayers	-.51 (2.39)	0.06 (1.60)	-0.76 (2.88)	0.07 (1.67)
Self-Efficacy				
~STEM	-1.89 (3.37)	-1.67 (3.36)	-2.34 (3.54)	-1.79 (3.42)
Leavers	-0.67 (2.46)	-2.14 (3.70)	-1.06 (2.46)	-2.25 (3.76)
Newcomers	-1.99 (3.59)	-0.14 (1.93)	-2.42 (3.70)	-0.15 (1.97)
Stayers	-0.40 (2.39)	0.03 (1.73)	-0.81 (2.84)	-0.02 (1.94)
Interest				
~STEM	-2.02 (3.47)	-2.63 (3.72)	-2.50 (3.61)	-3.24 (3.79)
Leavers	-0.77 (2.67)	-2.83 (3.88)	-1.13 (3.01)	-3.27 (3.91)
Newcomers	-2.11 (3.65)	-1.07 (3.00)	-2.54 (3.74)	-1.53 (3.33)
Stayers	-0.53 (2.60)	-0.85 (2.91)	-0.93 (2.99)	-0.98 (3.10)
Effort*				
~STEM	--	-2.53 (3.67)	--	-3.14 (3.79)
Leavers	--	-2.72 (3.86)	--	-3.19 (3.91)
Newcomers	--	-0.97 (2.87)	--	-1.48 (3.24)
Stayers	--	-0.74 (2.80)	--	-0.96 (2.99)

Table 5. Crosstabulation of Sex by STEM Intent Category

	STEM Intent				Total
	~STEM	Leavers	Newcomers	Stayers	
Male	7704 64.6%	1403 11.8%	1566 13.1%	1247 10.5%	11920 100.0%
Female	5347 46.5%	1825 15.9%	2004 17.4%	2313 20.1%	11489 100.0%
Total	13051 55.8%	3228 13.8%	3570 15.3%	3560 15.2%	23409 100.0%

Table 6. Means and Standard Deviations of Motivational Variables by Sex

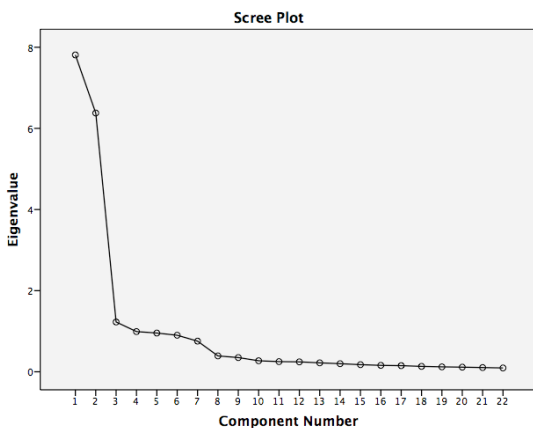
Motivation Variable	Mathematics		Science	
	2009 Mean (S)	2011 Mean (S)	2009 Mean (S)	2011 Mean (S)
Identity				
Male	-.75 (2.68)	-1.13 (3.13)	-1.76 (3.41)	-2.25 (3.68)
Female	-.74 (2.5)	-1.15 (2.95)	-1.50 (3.25)	-2.05 (3.55)
Utility				
Male	-1.57 (3.25)	-1.25 (3.14)	-2.05 (3.47)	-1.31 (3.01)
Female	-1.46 (3.10)	-1.15 (2.95)	-1.83 (3.37)	-1.17 (2.88)
Self-Efficacy				
Male	-1.49 (3.31)	-1.25 (3.26)	-1.97 (3.56)	-1.37 (3.34)
Female	-1.49 (3.12)	-1.24 (3.01)	-1.92 (3.32)	-1.30 (3.08)
Interest				
Male	-1.76 (3.41)	-2.25 (3.68)	-2.18 (3.61)	-2.76 (3.81)
Female	-1.50 (3.25)	-2.05 (3.55)	-1.96 (3.44)	-2.51 (3.70)
Effort*				
Male		-2.21 (3.57)		-2.76 (3.74)
Female		-1.87 (3.54)		-2.37 (3.71)

D. Principle Components Analysis

To test the degree to which students' ratings of motivational variables in 2009 were associated with their ratings in 2011, we performed a Principle Components Analysis (PCA) on each of the mathematics and science-related scale scores for each respondent. PCA computes orthogonal eigenvectors (Principle Components) corresponding to the major and minor axes of a hyper-ellipse—the “cloud” of data plotted in n -dimensional space, n being the number of motivational variables in 2009 and 2011 collectively. We kept the administration years separate, because we are interested in detecting any changes in motivation associated with each year. The eigenvalues for each principle component represent the amount of residual variation accounted for by each successive axis in the solution. Figure 1 illustrates a scree test of the eigenvalues to distinguish “true” principle components—those that account for significant variation in the data—from “error” components—those that account for negligible variation. Two significant factors were extracted (see Table 7 for Principle Component scores for each dimension).

The first two dimensions account for close to 65% of the total variation in the data, while the remaining 20 components account for only 35% collectively. When the scale scores of all the motivational variables in the dataset are correlated with these two “true” principle components, we see that they fall out clearly by year. We can thus label these factors *2009 motivation* (Component 2) and *2011 motivation* (Component 1). Table 7 shows this pattern; students' motivations in 2009 are closely related to each other, but these 2009 motivations are only weakly associated with the same variables in 2011.

Figure 1. Scree Plot Showing Two Significant Principle Components for Motivation Variables Across 2009 and 2011



What does this mean? Essentially, it suggests that students' motivations are highly located in the moment. Their experiences in mathematics and sciences in one year may not be related strongly to their experiences in another year, and their motivations, being tied to the experiences at hand, seem to be highly unstable in the high school years..

Indeed, when Pearson correlations are computed for these variables across years, *none* of the 2009 scale scores correlates

strongly with *any* of the 2011 scores (no correlations showed a magnitude greater than ± 0.123).

IV. DISCUSSION

Results show clearly that US high schoolers typically change their career intentions between grade 9 and 11. This two-year period is one of high volatility, with people originally STEM intending no longer remaining interested, while others not originally STEM intending beginning to see STEM as a potential future pathway. Motivationally, the interest, identity, beliefs about utility and efficacy of these Leavers and Newcomers reflect their changing views towards mathematics and science subject matter. Leavers tended to grow more disillusioned with STEM, while Newcomers tended to grow more enamoured.

Table 7. Principle Component Scores for Two Extracted Dimensions.

Component		
Variable	1	2
2009		
Math Identity	.190	.753
Math Utility	.221	.809
Math Self-efficacy	.252	.806
Math Interest	.247	.794
Science Identity	.177	.752
Science Utility	.238	.798
Science Self-efficacy	.252	.795
Science Interest	.253	.787
2011		
Math Effort	.773	-.120
Science Effort	.739	-.080
Math Identity	.877	-.220
Math Utility	.856	-.230
Math Self-efficacy	.848	-.207
Math Interest	.776	-.118
Science Identity	.864	-.218
Science Utility	.852	-.249
Science Self-efficacy	.834	-.206
Science Interest	.743	-.084

Two critical findings are of note: First, overall STEM motivations in 2009 and 2011 are not closely related to each other. This is indicative of the volatility of students' future perspectives, and how they utilize proximal information to gauge their efficacy beliefs and project their future selves [12].

In practical terms, we speculate that students' experiences in mathematics and science coursework, coupled with parental support primarily, and extracurricular activities secondarily, greatly determine their motivations in the moment. It is likely that Leavers who had initially positive STEM experiences in the elementary and middle grades may have confronted difficulties in early high school that convinced them to be less enamoured with STEM and potential STEM-related careers. Likewise, Newcomers may have encountered excellent teachers, or mentors in extracurricular activities, and changed their beliefs for the better. The fact that Leavers, Newcomers, and Stayers made up equal proportions of students in the nationally representative sample means that there was only small increase in overall STEM intending numbers between 2009 and 2011. Given the importance of consistent STEM intent for predicting actual STEM occupations after college, it is highly likely that little net increase in the STEM workforce is upcoming in the near future in the US.

Second, our findings echo those of Marra et al, in that in the 11th grade, we find non-significant differences in the proportion of females and males who are STEM intending. Additionally we find little to no differences in STEM attitudes in 2011. Given that young females in the sample came into high school with generally lower attitudes and intent, there is a net positive in finding non-significant differences two years later. However, because both females and males tend to reduce in motivation towards STEM between their freshman and senior years, we still have an overall problem of attracting students to these critical fields [6] [7].

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Targeted Blended Learning through Competency Assessment in an Undergraduate Information Systems Program

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Abstract— In this paper we report our study on the problem of competency acquisition when students progress from one course to another and more generally, from one term to the next. We observed that some students moved on to a second programming course without acquiring some of the competencies in the first programming course. This leads to problem in the second course, especially when these competencies are pre-requisites for this course. We applied blended learning, which allows a student to learn at least in part through delivery of content and instruction via online media, to overcome this problem. Our approach is unique in the sense that we first assess student competencies and then develop targeted blended learning content to address competencies that have not been acquired in a pre-requisite course. We have applied the method to students doing the first year BSc Information Systems program.

Keywords—information systems, competency, blended learning, assessment, programming

I. INTRODUCTION

Online content for blended learning in engineering education helps supporting and stimulating student learning in different contexts: during class lessons, refresher courses and reinforcement, and sharing of content with subject matter experts from the industry. In this paper we report on a study undertaken to estimate the efficacy of targeted blended learning content using videos and practice tests as an instrument to support acquisition of programming competencies. Unlike other approaches, the uniqueness of our work is that we first assess student competencies and then develop targeted blended learning content to address competencies that have not been acquired.

Students doing the Information Systems Management Program are required to do the first programming course in Term 1 (August), titled Information Systems Software Foundation (ISSF). This course introduces students to building blocks of programming concepts such as object manipulation, repetition, decisions, etc. In the subsequent semester in Term 2 (January), students' progress to the next course, titled Object Oriented Application Development (OOAD). The course progression is designed such that some of the competencies acquired in the ISSF course are pre-requisites competencies for the OOAD course. These pre-requisite competencies are

assessed through the ISSF final exam and detailed analysis of students results show that some of these pre-requisite competencies may not have been acquired by students at the end of the ISSF course. Therefore it is possible for a student to get an overall pass mark in Term 1 for the ISSF course and then move on to the next course OOAD in Term 2, without having the necessary pre-requisite competencies for that course, which is a major issue. Therefore, in January 2013, we put in place an entry-test at the beginning of the OOAD course, based on the pre-requisite competencies that were failed in ISSF, and we informed the students about this test, one week in advance, for allowing proper revision. However, we observed that many students were still unable to demonstrate some of the pre-requisite competencies and failed the "entry test" of the OOAD course, or performed poorly compared to their final exam in ISSF. In order to overcome this problem, in December 2014, we introduced targeted blended learning by developing online videos along with practice tests to enable reinforcement, and students were required to view the videos and attempt the practice tests 2 to 3 weeks before the start of Term 2. A total of 203 students took part in the study. In January 2014 we observed a substantial improvement in the performance in the "entry test" compared to January 2013. We observed that, for similar tested competencies, 85% of the students performed better at the "entry test" of OOAD compared to the final exam of ISSF. A key takeaway from our innovative practice is that a competency driven, targeted blended learning using online videos together with associated practice exercises represents an important tool to refresh and reinforce previous learning in engineering education, and furthermore, to improve the student's progression across the curriculum by ensuring that pre-requisite competencies are acquired before moving on to the next course.

The paper is structured as follows: In Section II we review other related work in the areas of competency based learning and assessment and blended learning. In Section III we present some background information related to our work on the Learning Outcomes Framework (LOF) and the Course Life-Cycle Competency Framework (CLCC) that were developed at School of Information Systems. In Section IV we describe the initial approach adopted along with the results analysis showing the problems observed. Section V presents the

improved approach using targeted blended learning; we also give a detailed description of the process adopted in our study along with the results. Section VI presents a discussion on the usefulness of the presented approach and areas for future work. Section VII summarizes the conclusions from our work.

II. RELATED WORK

We review two areas of work that are related to the current research, namely competency based learning and assessment and blended learning.

A. Competency Based Learning and Assessment

Many higher education institutions have clearly defined learning outcomes for the program, and competencies for specific courses within the program [9], [14]. Some have also gone further and developed frameworks to successfully leverage the learning outcomes and competencies in a systematic way when designing, delivering or revising a course within the program [4], [5], [6], [17].

Assessment is a crucial component of learning. Hence having defined learning outcomes and competencies, the next step is to define assessments and then to map student performance in these assessments to competencies. For example, the Course Life-Cycle Competency (CLCC) framework developed at the School of Information Systems provides a systematic approach to assess competencies and then uses the results of this assessment to give valuable feedback to both students and instructors teaching the course [17]. Tovar and Soto provide a framework, where they assess basic competencies that high school students must have, before they can embark on a Computer Engineering program [4]. Here the emphasis is on identifying whether the students have the necessary pre-requisite competencies before starting the program. Bekki et al., propose a modified-mastery based learning approach that uses a finite cycle of formative assessments and feedback to demonstrate mastery of the competencies for the course [10]. This is achieved through use of three types of assignments; “evidence assignments”, which provide evidence of the students’ attempt to learn the topics; “competency assignments”, which assess the mastery of a competency; and “enrichment assignments”, which present challenges beyond what is covered in the course material and help extend students’ understanding of the related topics.

With more and more emphasis on online learning for higher education, e-assessment is also increasingly becoming important. Sitthisak et al., present a system for automatically generating questions from a competency framework, based on question templates, criteria for effective questions, and the instructional content and ability matrix [13]. Ilhai et al., show how a competency based assessment can be extended to online learning environments using assessment grid and feedback [12].

Competencies also provide a means for assessing student progression within the various topics in a course and across different courses in the curriculum [6]. Luca De Coi et al., present the concepts of “input competencies” and “output competencies” [8]. For a given course, the students apply their prior competency in the context of the given task or problem to

demonstrate the “output competency” for that course. Thus the “input competency” may also be defined as pre-requisite competency that the student must demonstrate before starting the course. This concept is very important when looking at competency progression from one course to another course in the curriculum.

B. Blended Learning

In blended learning online learning is systematically integrated with periodic face-to-face interaction with instructor [1]. There have been number of attempts in implementing blended learning in computer science and information systems programs [2]. However, there have been mixed result in terms of effectiveness, where some have reported positive learning impact and others see neutral or not much improvement in learning experience when compared to face-to-face learning.

Hadjerrouit applied blended learning for an introductory Java programming course and observed positive impact on students’ learning, which is attributed mainly to well organized and easy, any time access of the content [15]. Perez-Martin and Pascual-Nieta have successfully used blended learning in an operating systems course to encourage students to study after class. The results of this study revealed higher levels of engagement and higher frequency of study [3]. Reza experimented with using guided discovery and blended learning with learning management system in delivering a computer application course to business students with little or no IT background [11]. Analysis of student grades over a four year period strongly supported the blended learning approach. The study conducted in [16] investigated the effect of blended learning on novices’ understandings of introductory programming. The study revealed that blended and face-to-face methods had statistically similar effects on academic achievements in terms of the grades. However, face-to-face method was more effective on permanence in terms of retaining the knowledge over a longer period of time compared to the blended method. This highlights that though blended learning has benefits, there could be challenges when teaching certain topics that require deep cognitive processes and new approaches are needed to enhance permanence of learning.

In the subsequent sections, we report our proposed method to enhance blended learning effectiveness by targeting it to specific competencies that students failed to acquire.

III. BACKGROUND

A. Learning Outcomes Framework

Several frameworks have been proposed to incorporate learning outcomes and competencies into engineering education [9] [12]. In Figure 1, we show the key components of the Learning Outcomes Framework (LOF) implemented at the School of Information Systems, Singapore Management University [7].

The LOF consists of three major components: learning outcomes, competencies and assessments. While the learning outcomes have been established at the program level, competencies and assessments are defined at the individual course level.

For each 1st level learning outcome, several 2nd level learning outcomes have been defined (not shown in the figure), and each 2nd level learning outcome has several competencies attached to it. For a complete list, please refer to [5] and [7].

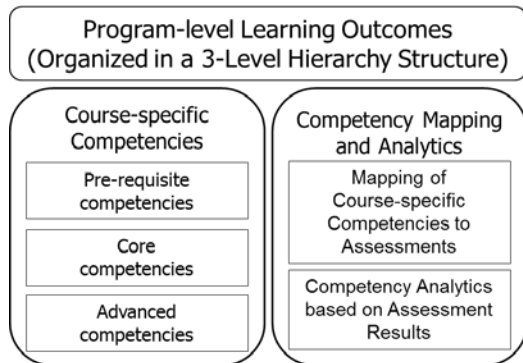


Fig. 1. Key Components of the Learning Outcomes Framework

The second important component of the LOF is competencies. Contrary to the learning outcomes which are defined at the program-level (and are, thus, common for all core as well as elective program courses), the competencies are defined at the individual course level. These competencies are defined by the teaching staff to describe “what the student is capable of doing” on completing the course. Core competencies refer to those competencies that all students are expected to acquire and demonstrate on completing the course.

For a specific course, in addition to the core competencies, two additional competencies can be defined namely, pre-requisite and advanced. Pre-requisite refers to the competencies that a student must acquire and demonstrate before starting a course; these are used as building blocks for the course in question. Advanced refers to those competencies that a subset of students doing the course may acquire and demonstrate on completing the course. Table 1 shows a sample set of core, pre-requisite and advanced competencies for the OOAD course.

When designing a curriculum it is best practice to have some higher level courses build on competencies acquired in the lower level courses. In the School of Information Systems Curriculum, course progression is designed such that the Object Oriented Applications Development (OOAD) course builds on the competencies gained in the previous course namely, Introduction to Software Foundations (ISSF). Therefore, a number of competencies in ISSF course form the pre-requisite for the OOAD course.

The third component of the LOF is assessments. The competencies are mapped to individual assessments in a course and the results of the assessments are analysed. This analysis provides insights into the extent to which the competencies have been acquired by the students. Several methods of assessments are used in the student evaluation process namely labs, quiz, project, exam, and case studies. For measuring the alignment within a course, in our framework, we use the course level competencies and assessments defined in the course.

TABLE I. SAMPLE SET OF COMPETENCIES FOR OOAD COURSE

Pre-requisite Competencies	<ul style="list-style-type: none"> • Explain the difference between classes and objects and know how to create an object using default or specific constructors. • Use effectively conditional constructs in Java to control the path of execution of statements. • Manipulate efficiently boolean, equality and relational operators used in conditional and repetition Java constructs. • Use and apply ArrayList structures for managing collections of similar classes of objects in Java • Know how to draw a memory state diagram to deduct an output trace. • ...
Core Competencies	<ul style="list-style-type: none"> • Understand and apply the basic principles of object orientation such as abstraction, encapsulation, modularity (object decomposition) and hierarchy. • Using the UML notation, create various design artifacts (such as use case model, domain model, sequence diagrams and class diagram) to fulfil a given set of functional requirements. • Read from a file and write to a file. • Know how to use and apply HashMaps structures versus ArrayLists structures in Java, for efficiently solving a problem. • ...
Advanced Competencies	<ul style="list-style-type: none"> • Understand and apply appropriately CSVReader and CSVWriter provided by the Java library. • ...

B. Course Life Cycle and Competency Framework

The Course Life Cycle and Competency framework, Figure 2, is adopted for delivering the introductory programming courses namely, ISSF and OOAD courses. In this approach, course competencies are leveraged during the five phases of a course, namely, content design, assessment design, content delivery and assessment, assessment feedback, and content review. In this paper we briefly describe the assessment feedback phase. The reader may refer to [17] for more details of this framework and the other phases.

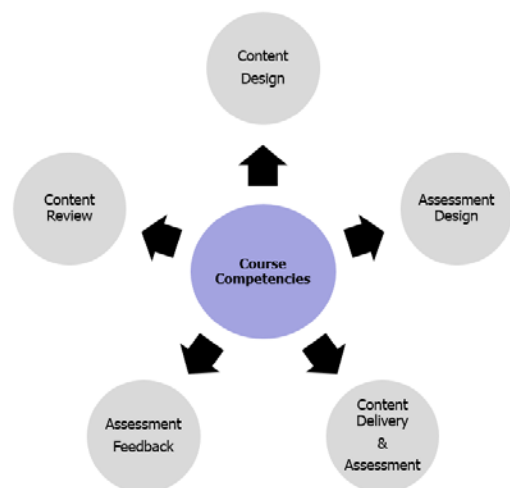


Fig. 2. Course Life Cycle and Competency Framework (CLCC)

During assessment feedback, the instructor analyses the assessment scores and present feedback to the students. This is done immediately after the assessment is marked. The standard practice of presenting the scores, averages, etc., is adopted. In addition, and more importantly, a detailed walkthrough of the cohort competency acquisition map is conducted. The map contains the different competencies assessed in the particular assessment and for each competency, whether it was acquired or not acquired. The question thresholds set during the Assessment Design Phase are used to determine which competencies are acquired or not acquired.

For the questions, where the score is below the threshold, the related competencies for those questions are considered as not acquired. In this case, a detailed walkthrough of the common mistakes is conducted through a collaborative session with the student's participation.

Though the feedback is given at the cohort level, individual students will know their own mark for specific questions, and hence indirectly can identify the competencies they have fully acquired or not acquired.

In the next two sections, we describe the process and results analysis without and with targeted blended learning respectively. Both the approaches use the LOF and the CLCC framework across the various phases of the course life-cycle.

IV. PART 1: WITHOUT BLENDED LEARNING

A. Process

Figure 3 shows the process for progression from ISSF to OOAD course, during the academic year 2012-2013. The Course Life Cycle and Competency framework is adopted for delivering the ISSF course in Term 1.

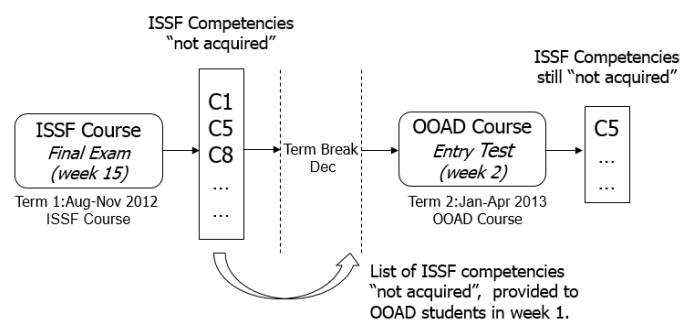


Fig. 3. Process without blended learning

At the end of each assessment, the students' results are analyzed and competencies not acquired by students are identified. Then using this result, an in-class walkthrough of common mistakes is conducted. This is done with active participation of the students, for example, by asking them to identify the mistakes done in the assessment. This approach provides an efficient way to "close the learning loop" by clarifying doubts and therefore reducing the understanding gap.

At the end of ISSF course the final exam tested the students on all the ISSF competencies (which are also pre-requisite competencies for the OOAD course). After the ISSF final exam

grading, a consolidated competency acquisition map was produced. This map revealed, for the entire cohort, those competencies that have been "acquired" and "not acquired". The focus was then shifted only to competencies that have not been acquired. However, even if some competencies are "not acquired", it is still possible for a student to get an overall pass mark in the ISSF course and then move on to do the next course namely, OOAD in Term 2. As discussed earlier, a set of the competencies in ISSF course form the pre-requisite competencies for the OOAD course. Therefore, this leads to a problem, where students do not have the necessary set of pre-requisite competencies before embarking on the OOAD course. To alleviate this problem, it was necessary to ensure that students revisit the content related to ISSF course and acquire the pre-requisite competencies required by the OOAD course. So, in the Week 2 of OOAD course, students were tested on some of the ISSF competencies, especially, those that have been deemed as "not acquired". Students were informed of the test in Week 1 of the OOAD course and given a week to prepare for the test. To help them revise, the list of the ISSF competencies "not acquired" was given to them.

B. Competency Acquisitions Results Analysis

Table II shows the results that compare the competency acquisition map across the "ISSF Final Exam" and "OOAD Entry test".

TABLE II. COMPARISON OF COMPETENCY ACQUISITION WITHOUT BLENDED LEARNING

Comp. Tested	In ISSF Final Exam Competency Acquisition (% of students)	In OOAD Entry Test Competency Acquisition (% of students)
C30 C37 C38	<p>51% "not acquired"</p>	<p>57% "not acquired"</p>
C25 C26 C9 C14	<p>26% "not acquired"</p>	<p>38% "not acquired"</p>
C13 C24 C26 C7	<p>14% "not acquired"</p>	<p>14% "not acquired"</p>

In Academic Year 2012-2013, there were 226 students who completed the ISSF course and progressed to the OOAD course. As seen from the results, there was no improvement in the competency acquisition. In fact, for the first two sets of competencies, there was a decrease of 6% and 12% respectively, and for the third set, no change. These results lead to the following conclusions:

- Neither the one week preparation time that was given to students nor did the list of competencies help them.
- Some students may have forgotten what they learnt in ISSF, due to the term break in between the ISSF and OOAD courses.
- Just by asking students to take a test to assess their competencies from the previous course does not help in improving the competency acquisition.

This led the teaching team to explore the option of targeted blended learning to help students acquire competencies that were not acquired in regular class sessions and also help retain the competencies that were acquired during regular class sessions and thus enhance the overall student performance and retention.

V. PART 2: WITH TARGETED BLENDED LEARNING

A. Process

Figure 4 shows the modified process with targeted blended learning for progression from ISSF to OOAD course, during the academic year 2013-2014. Most of the process is the same except for the introduction of the blended learning during the term break.

The teaching team prepared a set of nine videos that targeted the competencies that were deemed as “not acquired” by the student cohort after the ISSF final exam (see Table III).

TABLE III. VIDEOS FOR BLENDED LEARNING

Competencies Covered by the Videos, Exercises and Quiz	Tutorial Videos Prepared and posted on YouTube
C25 and C33	Topic 1: Meaning and various usage of the “null” Java Literal
C22	Topic 2: Constraints and implications of the “final” Java keyword
C8	Topic 3: Pre/post incrementation and decrementation
C8, C13, C16 and C17	Topic 4: Java operators, boolean expressions and loops
C13, C16 and C17	Topic 5: Looping until criteria is met, De Morgan’s Law
C27	Topic 6: Simple algorithms such as min, max, etc.
C33	Topic 7: Local and instance variables
C8	Topic 8: Java arithmetic operators
C9	Topic 9: Memory state diagram involving ArrayLists of objects.

Each video also has a set of self-work exercises which the students were expected to work on their own, immediately after

watching the video. Additionally, each video is accompanied by a self-quiz comprising of five to ten questions. Students are expected to complete this quiz, with unlimited number of trials without being penalized. Students are expected to view the videos, complete the exercises and quiz, two or three weeks before the semester starts.

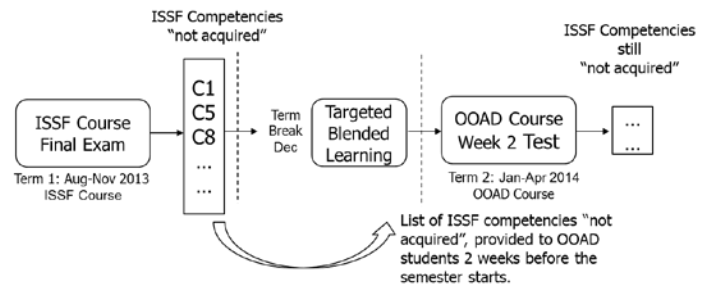
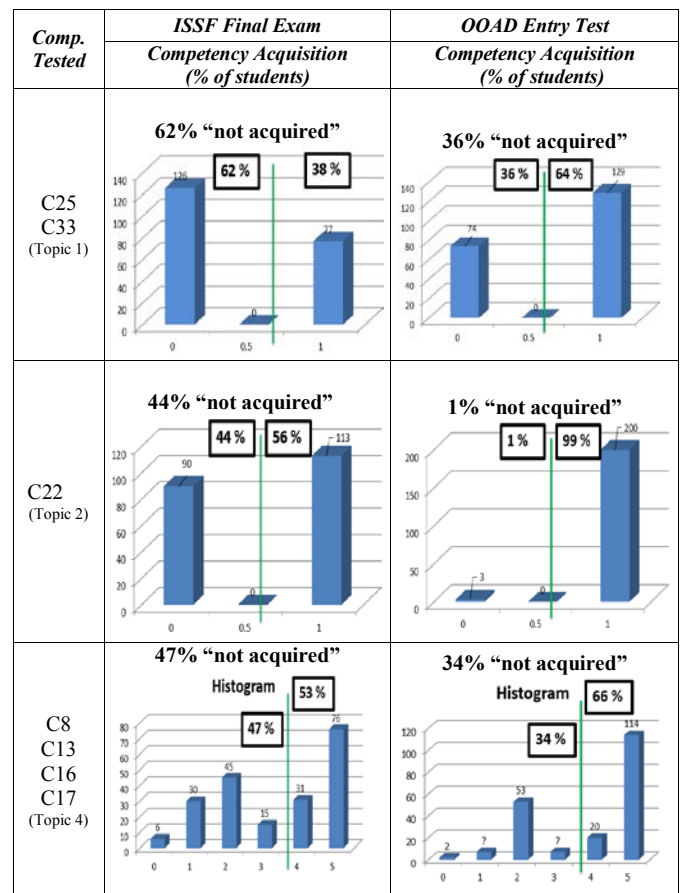


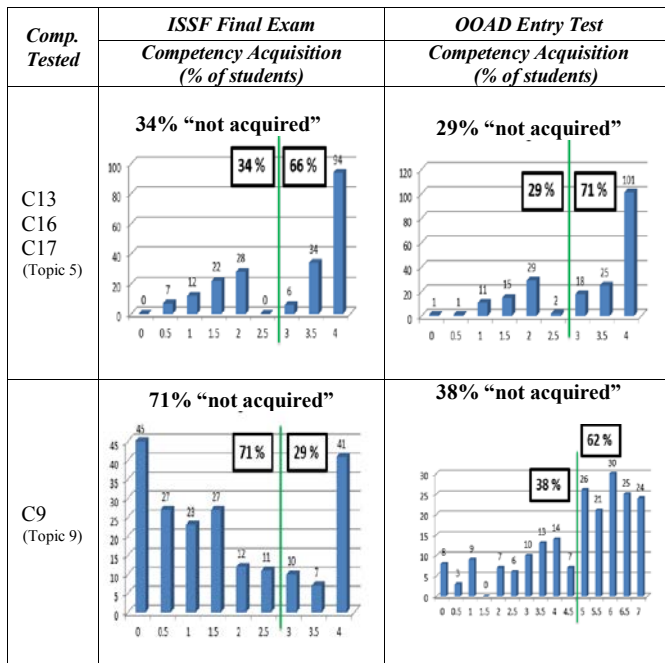
Fig. 4. Process with targeted blended learning

B. Competency Acquisitions Results Analysis

Table IV shows the results that compare the competency acquisition map across the “ISSF Final Exam” and “OOAD Entry Test” with targeted blended learning. In total in Academic Year 2013-2014, there were 203 students who completed the ISSF course and progressed to the OOAD course.

TABLE IV. COMPARISON OF COMPETENCY ACQUISITION WITHOUT BLENDED LEARNING





As seen from the results shown in Table IV, there has been a substantial improvement in the competency acquisition between the final exam in ISSF and the first test in the OOAD course. Table V shows the percentage improvement in competency acquisition between ISSF Final Exam and OOAD Entry Test for the different topics and the corresponding competencies. Across all competencies there has been an improvement in the percentage of students acquiring the competencies.

TABLE V. PERCENTAGE IMPROVMENT IN COMPETENCY ACQUISITION

Competencies Tested and Corresponding Blended Learning Modules	Increase in the number of students acquiring the competencies in OOAD entry test compared to ISSF final exam (% of students)
C25, C33 (Topic 1)	26%
C22 (Topic 2)	43%
C8, C13, C16, C17 (Topic 4)	13%
C13, C16, C17 (Topic 5)	5%
C9 (Topic 9)	33%

The results in Table V shows that the percentage of students who have acquired the competencies shown in the table is higher for OOAD entry test compared to those questions in the final exam of ISSF corresponding to the same set of competencies. This improvement was over a range from 5% higher to 43% higher.

Additionally, referring to Table III and IV, within the same cohort in academic year 2013-2014, we have seen a substantial improvement in competency acquisition.

This leads us to the conclusion that targeted blended learning help students to acquire competencies that were not acquired in regular class sessions and also help retain the competencies that were acquired during regular class sessions and thus enhance the overall student performance and retention. The experiment helps ensure that the students have then acquired the necessary pre-requisites competencies before embarking on OOAD, thus enhancing the overall student performance.

VI. DISCUSSION

The analysis of the results shows that the improvements in competency acquisition are not consistent across all the competencies. For example, referring to Table V, competencies C13, C16, C17, related to topic 5, have a moderate improvement of 5% whereas competency C22 related to topic 2 has a substantial improvement of 43%. We attribute this to the inherent difficulty of some topics and the associated competencies. With the cohort having a spread of very capable to weak students this is expected. This is in alignment with the grade distribution curve for the ISSF course.

One might argue that our results measure competency acquisition across two cohorts. We use cohort in academic year 2012-2013 for experiment without blended learning and academic year 2013-2014 for experiment with targeted blended learning. However, given the range of incoming student capability, the distribution of the capable and weak students' has remained more or less the same across these cohorts. Hence we can conclude that this does not adversely affect the results.

Informal chat with students has also revealed that using the blended learning content students were able to prepare at their own pace, time and place. The most important reason cited was that slow learners could watch the videos several times and practice the exercises multiple times. Additionally, the weaker students could also work at their own pace without the stress of having to complete the exercise within a given time limit. We also observed an improvement in the scores for individual students in these questions as shown in the results summarized in Table VI.

TABLE VI. IMPROVEMENT IN TERMS OF STUDENT NUMBERS

Number of students who performed better in OOAD entry test compared to ISSF final exam	173
Number of students who performed similarly in OOAD entry test compared to ISSF final exam	5
Number of students who did worse in OOAD entry test compared to ISSF final exam	25
Total Number of Students in the Cohort	203

Our approach of competency driven targeted blended learning has been applied for the transition from Year 1, ISSF to OOAD course. Since the results are very encouraging, future work will be aimed towards implementing and evaluating this approach to other academic years, for example, in Year 2, progressing from OOAD to Software Engineering course. Additionally, future work will also be aimed at developing a tool to alleviate the extra effort required in linking

competencies to assessment questions and in conducting a detailed analysis of students' results to derive the competency acquisition map. Currently, though the spread sheet approach works, the tool will facilitate the generalization of the process and help in its implementation across the different courses in the curriculum. This will result in an overall improvement of the teaching and learning in the undergraduate curriculum and therefore, enhance the competency level of the undergraduate students.

Another important challenge is how to motivate students to watch the blended learning videos, do the self-work exercises and self-quizzes especially 2 or 3 weeks before the semester's start. Our approach was to email the students the list of competencies that they need to master along with the URL to the video, lessons and self-work exercises and self-quizzes. Since the videos were uploaded to YouTube, we could not track if students actually viewed. However, we were able to track self-quizzes as they were posted on the School's Learning Management System. The LMS statistics showed that 90% of the students attempted self-quizzes. Hence there was not a major issue with students not doing the work at the end of the break period. Besides the email reminder, this conscientious behaviour could also be attributed to the Asian education culture.

VII. CONCLUSIONS

We studied the problem of competency acquisition when students progress from one course to another and more generally, from one term to next. We observed that some students moved on to a subsequent course (e.g. OOAD) without acquiring some of the competencies in the prior course (e.g. ISSF). This leads to problem in the subsequent course (e.g. OOAD), especially when these competencies are pre-requisites for this. We proposed a targeted blended learning approach to overcome this problem. The blended learning material comprises a set of videos along with hands-on exercises and quizzes, which address the specific set of competencies that were not acquired in the prior course (ISSF).

We evaluated our approach on the batch of students in the academic year 2013-2014 and observed that the targeted blended learning leads to substantial improvements in terms of the percentage of students whose scores went above the threshold which leads the corresponding competencies to be deemed as "mastered". We showed that these results were clearly better than those from the previous batch which did not have the targeted blended learning.

ACKNOWLEDGMENT

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Instructor and Graduate Teaching Assistant Development and Training for a Blended Linear Circuits and Electronics Course

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Abstract—This paper discusses a training program that we are developing and are using for instructors who teach a circuits and electronics course in a blended format. The course has over 450 students enrolled in nine different sections each semester and has been taught in a blended format for six semesters. A key motivation for teaching the course in this format is to improve consistency across sections, which necessitates the need for training among the instructors on how to teach blended courses.

Keywords—*blended class, flipped class, development, training*

I. INTRODUCTION

The 2012 PCAST report titled *Engage to Excel; Producing One Million Additional College Graduates With Degrees In Science, Technology, Engineering, And Mathematics* [1] called on researchers and instructors alike to create learning environments that better engage and motivate students towards building a much needed STEM workforce. Achieving this vision in large enrollment introductory engineering courses is particularly challenging on several accounts. Such multi-section courses are taught by a collection of instructors with idiosyncratic teaching styles, differing personal interests in wanting or having to teach it, and differing personal priorities for what should be covered. Compounding these challenges is the unpredictable nature of who gets assigned to these courses. It could be a totally different group term to term, and in many cases, instructors could be graduate teaching assistant with limited or no teaching experience. In a study of 200 electrical and chemical engineering faculty in the USA and their use of research-based instructional practices (RBIS), while they were aware of such practices and 82.1% reported using some, the most common reason given for non-use was the fear that these strategies would take up too much class time [2]. This typical scenario works against achieving learning consistency across sections as well as wide-scale adoption of pedagogical innovation. Essentially, students can find themselves in a poorly designed and executed classroom, a moderately well-designed and executed one or a vibrant, highly interactive and motivating one. Since faculty members in many institutions are solely in

control of their classroom with little or no oversight, rectifying this situation can seem very difficult to achieve.

II. CIRCUITS AND ELECTRONICS COURSE

To address the problem of inconsistency in material coverage, varied use of research-based instructional practices and idiosyncratic teaching approaches, we implemented a blended format using MOOCs [3] in the Georgia Tech, large-enrollment, multi-section *ECE Circuits and Electronics* course. The online content of the course is provided by two MOOCs on the Coursera platform, *Linear Circuits* and *Introduction to Electronics*. Both MOOCs contain video lectures, videos of sample worked problems, automatically graded homework problems, and a discussion forum. The weekly schedule for all sections includes the online videos that are assigned and the homework that is due. There are two common tests and a common final, given outside of the normal class hours. The course also includes six in-class labs where students do experiments on their own myDAQ digital acquisition board [3]. The content of the course includes resistor network analysis methods, RC/RL/RLC first-order circuits and series second-order circuits, AC steady-state analysis, transfer functions and frequency response, AC power, basic op amp amplifier circuits, passive and op amp filters, and the introduction to diode and transistor circuits. The coverage is very broad but not as deep as that contained in circuits courses for ECE majors.

We have found that blending classes adds more flexibility of activities to a course than is present in a traditional lecture-style course. In-class activities can include mini-lectures covering more depth in a topic or presenting interesting applications, the instructor working extra sample problems, short quizzes, in-class labs, worksheets, and small-group discussions. The best mix of these activities can vary depending on the personality of the instructor, the prior experience of the students, and the topic being covered. A longitudinal study on the evolution of this particular course over a six-semester period demonstrates how a feedback mechanism can be used to adjust the mix of online and in-class activities to improve learning and reduce student workload [4]. That paper discusses the difficulties faced by a

person new to teaching a blended course. While this expanded variety of classroom activities and what Phillips refers to as transformed classroom “participant structures” [5] can be significant in changing the classroom climate and promoting greater engagement, for instructors well practiced in a lecture style class, transitions can be problematic.

The blended class model has received a great deal of attention over the last two years [3,6,7]. A new technology or methodology that experiences this level of attention often has exaggerated hype associated with it as illustrated in the Gartner Hype Cycle [8] shown in Figure 1. The initial successes by early adopters is often followed by a “trough of disillusionment” when the next wave of adopters do not reach the same successes. A number of problems encountered by faculty teaching blended classes are summarized in [9]. Since the technology or methodology is new, best practices are not yet established or widely known. As more people try the method and become proficient at it, then a level plateau is reached. We suggest that the particular hype cycle for the blended class model can be modified by proper instructor training on the method as shown by the added dashed line in Figure 1. An example of training materials for faculty is the online course for flipping classes [10].



Figure 1: Gartner Hype Cycle from [8] applied to blended learning with a modification showing the possible effect of instructor training.

We have built a model for instructor development that is apprentice-based, where a faculty member who is experienced in blending courses serves as a lead instructor of a course that has nine different sections that are all blended, ECE 3710. This model also serves other purposes: it ensures consistency in coverage among different sections of the same course, it provides the collaborative and exploratory benefits of a blended classroom, and it provides a structured mentorship program that gives teaching experience to graduate students who are interested in faculty positions. This course is a two-credit course, for non-majors, and is fifteen-weeks long and meets weekly for 110 minutes. Over 1100 students enroll in the course each year, primarily AE, ME, and MSE students for whom this is a required course as well as some biomedical and chemical engineering students who take it as an elective. During the fall and spring terms, 450 students each term are

distributed equally across nine sections of the course taught by one of eight or nine different instructors. The lead instructor is responsible for the online content of the course and coordination of the course activity among the sections. This lead instructor also acts as a mentor to the section instructors and provides training on teaching blended classes.

The current instructor development for *ECE 3710 Circuits and Electronics* includes 1) mentoring and modeling for how lessons should be taught using a blended approach; 2) creating and scoring in-class worksheets and quizzes; 3) creating and scoring examinations using a collaborative approach; and 4) small team (instructors of three) teaching of laboratory activities using a collaborative approach. Since moving to the flipped and blended format in Summer 2013, the section instructors have been either advanced PhD students who are hired as graduate teaching assistants for the course or one of two faculty members who have also served as the lead instructor for the entire course.

Instructors are given guidelines at the beginning of the term on how to conduct a class in the blended format. There are weekly group meetings with the lead instructor to discuss what needs to be covered. For any section with a new instructor for the course, the lead instructor does part of the first lecture in order to give the students in the class the motivation for why the course is being run that way and tips on how to take a course in that format, and to demonstrate to the instructors how to run the class. The lead instructor also goes into classes with new instructors two to three times during the semester to run an activity (to give the instructors a chance to observe). The lead instructor or an educational specialist observes all of the instructors during class two to three times per term and gives feedback. The lead instructor does one focus group in each section mid-term with feedback given to the section in order for them to make corrections. The lead instructor observes four out of nine lab sessions for each experiment and gives feedback to the three instructors in the class about how they interact with the students.

The need for instructor training is demonstrated in Table 1, which shows that several important metrics became worse in Fall 2014: the student workload went up, the average test score decreased, and the average homework grade decreased. Also, the DF rate went up (though the overall DFW rate decreased). These trends are correlated with the number of new instructors to the course that term, in fact, none of the five new instructors had ever taught any course in the past. (More detailed six-semester data summary is contained in [4].)

Another indication of the impact of the instructor is given in Figure 2, showing the results of student responses from a post survey in Fall 2014 across nine sections of the course. Students were asked to rate different instructional methods, shown in the table below the figure, on a scale of 1 to 4 where 1 = “little to no help”, 2 = “moderate help”, 3 = “significant help”, 4 = “one of the most helpful methods”. A total of 310 students completed the survey, and the results were averaged by section and each section average is plotted in the figure. A large spread among the averages for a given instructional method means that method is dependent on the instructor,

while tight bounds in the averages means that method is more independent of the section instructor.

The three topics that are most instructor-dependent showed the highest variation in responses: 1 Instructor lectures in class, 4 Recitation, and 6 Students working on problems during class.

TABLE I. COMPARISON OF METRICS FOR DIFFERENT SEMESTERS.

	Spring 2014	Summer 2014	Fall 2014
DFW Rate (DF/W rates)	19.7 (7.73/11.97)	19.97 (6.9/13.07)	16.82 (8.99/7.83)
Homework Ave	84.0	86.1	81.6
Exam ave	78.8	77.3	69.3
Student workload, ave. hours/week	7.06	6.64	7.37
Number of sections with new instructors course	1 of 9	0 of 3	5 of 9

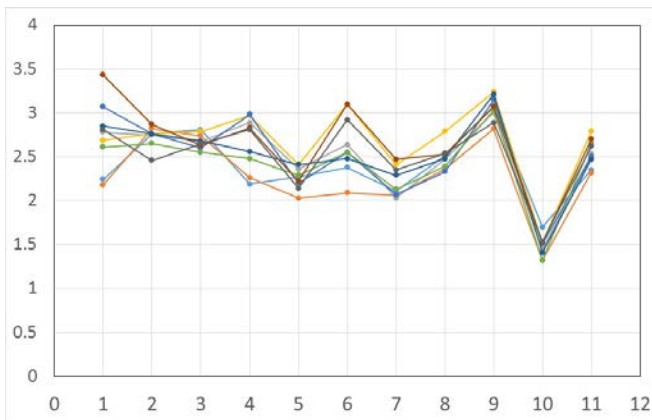


Figure 2: Post-survey results of average ratings of the importance of 11 different instructional methods (see code in table) across nine sections of ECE3710, from 1 = “little to no help” to 4 = “one of the most helpful”

Code for Horizontal Axis:

- 1 Instructor lectures in class
- 2 Online videos of lectures
- 3 Online videos of sample worked problems
- 4 Recitation (in-class Q&A)
- 5 Instructor experimental demonstrations
- 6 Students work on problems in class
- 7 Simulations
- 8 Hands-on experiments
- 9 Homework
- 10 Using textbook
- 11 Tests and quizzes

III. FUTURE PLANS

To rectify instructor and instructional disparities in this blended environment, we plan to institute a more theory-driven approach to instructor training. Our new strategy is informed the Lave and Wenger’s (1991) notion of *communities of practice*, which brings to the fore important issues regarding membership, identity and social contexts that can promote or retard individual and unit changes [9]. Our goal is to build a community of reformed teaching instructors. We also subscribe to Roger’s (2003) theory of innovation diffusion which we feel is applicable at the individual, the unit and the institutional levels where the five stages of *awareness, interest, evaluation, trial and adoption* can and do play out [10]. Building from these theories we seek to develop a supportive educational innovation learning community.

Our new instructor learning experience will comprise four elements:

1. Development of a supportive community of practice for teaching transformation
2. Use of the Reformed Teaching Observational Protocol (RTOP) instrument for observation and training
3. Ambrose’s book *How Learning Works*
4. Videos of blended classrooms for analysis
5. Micro-teaching and evaluation sessions

We will commence with a 4-hour workshop where instructors new to the blended learning environment will engage in a number of activities that activate their prior understanding of effective and ineffective learning experiences. We will also introduce them to the RTOP instrument by watching and evaluating two physics classrooms on video. This activity will be the start of the developing an understanding of each classroom dimension measured in the RTOP instrument. In this workshop, instructors will also see videos of the blended *ECE 3710 Circuits and Electronics* classroom, to get a feel for the new role and its various dimensions that the instructor needs to played in this revised version of an engineering classroom. Finally, we will introduce them to the seven research-based principles that undergird robust learning.

Instructors will have the option of participating in a blended teaching practicum, a practicum that is based on a workshop series for ECE Teaching Fellows that we piloted in the Spring 2015. The practicum meetings will give instructors the chance to do microteaching, to get immediate feedback from their peers using elements from the RTOP as the basis for evaluation. We will also encourage member of this teaching cohort to observe each others’ blended classrooms for real-time evaluation and feedback.

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A Feedback-Based Approach for Evolving a Blended Class Model for Large Enrollment, Multiple Section Circuits Courses

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Abstract—The development of a feedback-based method for evolving the blended class format for large, multiple section courses is presented with the application to two circuits courses taught at Georgia Tech: ECE 2040 is a circuits course for ECE majors and ECE 3710 is a circuits and electronics course for non-majors. These are both multi-section, high-enrollment courses, with a combined enrollment of over 600 students per term. The courses utilize two MOOCs that provide all of the online content. ECE 3710 was first offered in a flipped mode in the Summer of 2013 and has evolved over five semesters based on feedback from the student surveys, focus groups, instructor feedback, discussion forum questions, and performance on tests. ECE2040 has been offered two semesters in the blended mode using a modified version of the blended model developed for ECE3710.

Keywords—blended class, flipped class, circuits, adaptation, feedback

I. INTRODUCTION

Broadly defined, blended learning is “the use of learning activities of differing kinds and venues to synergistically achieve overarching learning objectives” [1]. A narrower definition is “a hybrid classroom and on-line learning that includes some of the conveniences of on-line courses without the complete loss of face-to-face tact” [2]. Because of the advantages offered by blended courses, many educators are implementing them and exploring their benefits. Another expression, “flipped class”, is often used interchangeably with “blended class”. In both the flipped and blended courses, all students watch the same lectures online prior to class. The two modes are differentiated in this paper by how students spend class time. In the flipped mode course, in-class time is spent answering student questions about the online lectures and doing homework collaboratively in small groups with instructor help. The blended mode course has more variation in the activities done during class, including small group activities for discussion, quizzes, worksheets, projects, and hands-on experiments. Because there are so many components in the blended class model, both online and in class, the course format can be improved by evolving the mix of activities and resources over several semesters to improve student learning with a reasonable student workload spent on the course.

Several studies have compared learning outcomes, student success, and other figures of merit in blended versus traditional courses. Educators report that students preferred blended courses over traditional lectures [2]; grades were higher in blended classes [2-5]; and blended classes were better for measuring learning effectiveness and faculty

satisfaction [6]. Furthermore, positive results were reported for blended courses implemented in both two-year and four-year programs, in undergraduate and graduate programs, and in different subjects including accounting, math, management information systems, and health, among others [1-5].

Nevertheless, adopting and implementing a blended learning course can be challenging both for the teachers and the students. These challenges were summarized into eight different categories by Ocak [11]. Some instructors find it difficult to re-design a course while maintaining their current workload. Other educators struggle with the technical issues that accompany online course delivery. Students who are more familiar with traditional courses often resist the blended course format [9-10]. Also, learners have reported a lack of community and feelings of learning in isolation while taking blended classes [11].

The evolution of a blended course can alleviate many of the challenges faced by instructors and students, with each iteration seeking to learn from and improve upon the last. For instance, faculty at Pennsylvania State University reported how they changed a blended environmental engineering course from one semester to the next. During the first semester that the course was offered in a blended format, students were noticeably more involved in class, but they raised concerns about the amount of time they had to dedicate to the course. Hence, the instructor adjusted the course the next semester by reducing online lecture time (while covering the same material) and working more homework problems in class. This revision to the class eliminated student complaints about the time commitment and students became more engaged in solving problems during class [12].

While the aforementioned study reports insight gained during two semesters, this paper discusses a feedback-based methodology and resulting evolution of a course through six consecutive semesters. The method is applied to two large enrollment, multi-section circuits courses taught within the School of Electrical and Computer Engineering (ECE) at Georgia Tech. ECE 2040 Circuits is 3-credit hour lecture-based course given to ECE majors while ECE 3710 Circuits and Electronics is a 2-credit hour lecture-based course given to non ECE majors. There are 150-180 ECE students enrolled each term (fall and spring) in ECE 2040, which is divided into four sections taught by different faculty. There are 400-450 students enrolled in ECE3710, divided into nine sections taught by one lead instructor – a faculty member who manages the course – and individual instructors who are advanced PhD students. ECE 3710 covers topics in both circuits and electronics. The course for majors, ECE 2040, goes more deeply into each topic but excludes diodes and transistors from the ECE3710 Topics.

ECE 3710 was reformatted from a traditional lecture-based course in Summer 2013 to be offered in a flipped mode and then in a blended mode. The rationale for the change from the lecture style was to introduce hands-on experience into the classroom and to improve consistency across sections. We were able to add six in-class labs to the course because of the flexibility provided due to the flipped/blended format. Prior to the change in format, the inconsistency among multiple sections of ECE 3710 was examined through a survey of the instructors who taught the course. Because of the breadth, instructors experienced difficulty covering all the topics. The survey indicated that there was a mismatch in coverage of up to 25% from the syllabus and 50% among the sections. The standard range for the class average GPA was from 2.5 to 3.7 with large variations in how the grades were curved.

II. MODELS FOR LARGE ENROLLMENT COURSES

The circuits courses at Georgia Tech, like any large enrollment course, can be offered in different formats, such as multiple individual sections of medium size (40-50 students) that are independently taught or one large common lecture section (>150 students) with smaller recitation sections. Multiple individual sections have the advantage of providing potentially more personal in-class experience for the students and the disadvantage of inconsistency. Specifically, different instructors cover the material at different rates and in different depths. Also, the instructors may have different philosophies on summative assessment, including the relative weighting on homework, quizzes, tests, projects, and labs as well as how harshly the material is graded, leading to inconsistency in assessment and the final grades. The large lecture section model suffers from a climate during the lecture period that is not generally conducive to two-way student/instructor interaction, leading to a sub-optimal in-class social climate [13].

A third way to handle large enrollment courses is a blended model, where the course is offered in multiple sections but all students watch the same lectures online. Then the in-class time is spent in more interactive activities with collaborations between students and small-group interaction with the instructor. This is the model that was developed for ECE3710, with the first instance being taught in the summer of 2013. The online content in this course is delivered in two Massive Online Open Courses (MOOC), Linear Circuits and Introduction to Electronics on the Coursera platform (coursera.org) [14]. The specific format of ECE 3710 is that all nine sections use the same online lectures, and there were common homework and tests across the sections. This model seems similar to the large lecture model discussed above, giving the advantage of consistency in the lectures and assignments, except that the students are able to watch the lecture videos at their own pace and in their own time. These videos are broken into 10-12 minute lengths to accommodate the average attention span. Handouts of the video slides are provided to students. To facilitate active note taking and to keep students focused, only partial slides are provided. The videos show the instructors writing on the slides during the lecture. The movement of the pen or cursor helps to keep students focused and encourages students to take notes

actively. Every 4-5 minutes, the video is broken into a formative assessment quiz on a basic concept just covered. Students need to click on either the answer or the “skip” button to proceed. This gives them timely feedback on their understanding of the basic concepts [13].

Many of the features built into these online videos can be duplicated in a large lecture format: clicker questions can substitute for the in-video quizzes and the PowerPoint slides can be made more active by providing partial slides and having the instructor write on the slides during the lecture. A live lecture gives students the ability to stop the professor in real time to ask for clarification or more depth. However, very few students will stop the instructor with questions in a large lecture hall; hence, this benefit of a live lecture is not realized in actual situations. The features of online videos that cannot be duplicated in any live lecture are that the 10-12 minute length of the videos are appropriate for typical attention spans; the videos can be re-watched or paused and parts can be replayed; students have the flexibility to watch the videos anytime and anywhere; and students can choose the speed of play from 0.75x normal speed up to 2x normal speed.

III. OVERVIEW OF THE FEEDBACK PROCESS FOR BLENDING

The block diagrams in Figure 1 and 2 show the feedback mechanisms used in the evolution process for ECE3710. Each semester, we assessed ECE 3710 and used these assessments as measurements in a feedback loop to readjust the way that the class was taught the following semester. The student learning process in Figure 1 represents the system to be controlled. The MOOC analytics includes the data of when and how often students watch the videos and how many times they attempt the homework. Learning was assessed by examining the performance on particular topics on tests compared to the course outcomes. Low performance on an exam question was taken as an indication that the corresponding topic may be confusing. Common mistakes in the test responses were identified for intervention via course adjustments in future semesters. Another “measurement” for feedback was taken from the Piazza discussion forum [piazza.com], which was used for students to ask questions about the course. The most common questions on the forum asked for clarifications about the lectures and homework. The posted questions were used to gauge student understanding of the various topics. If there were a number of questions about a particular lecture or about a homework problem related to a particular lecture, the instructors collectively examined the source of the confusion. The adjustment was easy if the source of the confusion was ambiguous or poorly-worded problem statements, or an error in the video lecture.

Deeper levels of confusion that surfaced from either test problems or discussion forum questions needed to be addressed by a multi-pronged approach of adjustments. We added a number of videos of sample worked problems on these difficult concepts, targeted class worksheets, in-class mini-lectures that covered common mistakes in doing certain types of problems, and targeted in-video and in-class quizzes. The most sweeping change was in changing the ways that the material was presented in the lectures, either to add more details or to show different derivations and ways of examining

the concepts. While the discussion forum questions give indications of the sources of the confusion, the student answers and the follow-up discussions on the forums give ideas on better ways to present the material so that it would be understood by students more easily. Specifically, there are “super users” each time that the course is taught; these are students who give detailed, tutorial types of explanations. The follow-up responses show if other students understand the explanation.

One of the criticisms of blended classrooms is that students spend more time on task than in traditional lecture classes [11]. We are sensitive to weekly student workload and developed another feedback loop, shown in Figure 2, concerning student workload. According to [15], each credit hour should correspond to three hours of work per week. So a 2-credit hour class should represent an average workload of 6 hours per week. The end-of-term student surveys allowed us to track the self-reported average number of hours per week spent on the course. Other survey questions and student focus groups allowed us to identify specific components of the course that took an inordinate amount of time, essentially, a low ratio of value-added over time-spent. Observations taken during in-class labs along with instructor group discussions identified parts of the labs that needed to be stream-lined or eliminated. In addition to stream-lining labs, the number and type of homework problems, quizzes, and worksheets were adjusted. It should be noted that the feedback mechanisms in Figures 1 and 2 are coupled. If a concept is confusing, then it takes more time to learn. So, improving the quality of the learning process indirectly decreased the student workload.

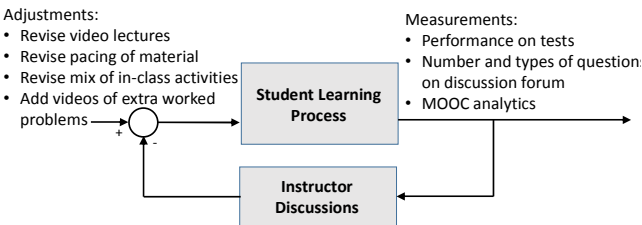


Figure 1: Feedback mechanism for improving the student learning process.

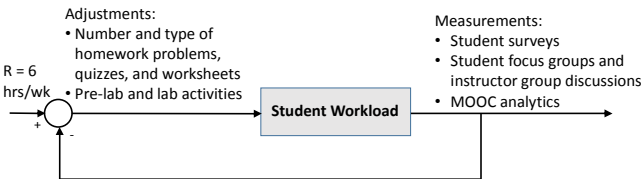


Figure 2: Feedback mechanism for regulating student workload to the targeted value of R=6 for a two-credit hour class.

A. Iterative Improvement Process

ECE 3710 requires students to view 60-70 minute worth of online lectures per week and then come to class for 2 hours per week (2 credit hour class). The Linear Circuits MOOC was used for the first 60% of the course. The rest of the material was covered by in-class lectures for the first two offerings and online later by the Introduction To Electronics MOOC (used in Spring 2014, Summer 2014, and Fall 2014, Spring 2015).

Constants across all offerings of 3710:

- The learning management system used for all online materials was Coursera
- All homework is common across sections and is completed online and graded automatically
- Common tests across all sections (except Summer 2014)
- 2-minute graded quiz at the beginning of each class on assigned videos
- 6 in-class hands-on labs
- Extra credit was given for applications (either an analysis of a real system or building a real application)

Specific course adjustments that changed because of student performance or instructor or student feedback:

- Summative online quizzes were first mandatory, then made optional, and then eliminated completely
- Supplemental in-class lectures were added and then the length and type evolved over time
- Worksheets were introduced into the classroom
- Specific online lectures were revised and extra ones added
- Automated homework problems were broken into smaller parts
- Videos of extra sample worked problems were added
- Students were given explicit instructions on how to take a course like this.

Table I gives a summary of some of the trends over the 6-term period. An explanation of what was changed each semester and the feedback is given in the subsections below.

Table 1: Summary of course metrics

	Summer 2013	Fall 2013	Spring 2014	Summer 2014	Fall 2014	Spring 2015
Ave # tries per homework problem	2.56	1.90	1.88	1.97	1.93	1.89
DFW Rate (DF/W rates)	10.16 (3.9/6.3)	19.01 (9.4/9.6)	19.7 (7.7/12.0)	19.97 (6.9/13.1)	16.82 (9.0/7.8)	13.67 (5.3/8.4)
Homework Ave	80.2	83.0	84.0	86.1	81.6	86.0
Exam ave	71.5	69.8	78.8	77.3	69.3	75.1
Student workload, ave hrs/week	7.09	7.97	7.06	6.64	7.37	6.41
# students	128	405	401	131	434	417
# of sections with new instructors	1 of 3	2 of 9	2 of 9	0 of 3	5 of 9	2 of 9

Summer 2013: The pilot offering of the course was in Summer 2013 and included three sections of 45-50 students each taught by three different instructors using a completely flipped mode, where the in-class time was spent answering student questions about the online lectures and doing homework collaboratively in small groups with instructor help. The instructors stopped to give short lectures as needed for clarification on concepts. Adjustments were made for the next offering based on the following results from student surveys, observations, and Instructor and student direct feedback in focus groups.

Overall, the students were negative about the flipped-class model:

- in-class collaborative work was difficult because of the asynchronous nature of homework; ie, different students had reached different points in the assignment
- students preferred to have some in-class lecture time where they can ask questions as the material was being taught
- students had a very low tolerance level for technical difficulties with the platform especially with the automatically graded quizzes and homework

Fall 2013: Changes based on the summer pilot offering:

- Errors in the online resources were identified and corrected.
- Homework problems were broken into steps where students get credit for correct answers along the way to the final answer
- All instructors were told to give a brief 10-15 minute summary of the online lectures during class to give students some lecture time for asking questions.

The second offering of the course had nine sections of 40-50 students each (400 students total) taught by nine different instructors: one instructor who had taught the course in a flipped mode, five who had taught it in a traditional lecture mode, and three novice instructors. The change in the automatically graded homework problems resulted in a decrease in the number of average tries per homework and the average homework grade, as seen in Table I. Frustration on the homework went down due to the problems being broken into more steps. This gives feedback to students on a more fine grain level, and allowed them to gain confidence as they made correct decisions along the way to solving a bigger problem.

There was a lot of autonomy in the way that the instructors conducted the in-class sessions; this autonomy enabled us to see what did and did not work. However, some of the more experienced instructors who had taught the course in a traditional lecture style tended to lecture, stretching the “mini-lectures” into 30-40 minutes, resulting in a decrease in students viewing online lectures for those sections. At the other end of the spectrum, some of the novice instructors gave summaries of the online lectures that lacked insight or perspective, instead consisting primarily of a listing of what was covered. Students saw little value-added in those sections, so a significant number of students in three of the sections consistently left right after the in-class quiz at the beginning of class. The other sections had a much more engaged atmosphere, both between the instructor and students and among students. Those instructors were more flexible in how they conducted the class, adjusting activities during class based on student understanding.

A circuits concept inventory given at the beginning and at the end of the course highlighted some differences between sections. These results indicate that the pre to post gain was reasonably consistent across all sections, with the ones showing the largest percent gains belonging to the sections that had the most student engagement, based on an independent observer using an RTOP protocol [7]. We used

the mix of in-class activities in the most successful sections as a guide to new instructors for the following semester.

Overall student feedback to the Fall 2013 offering was still negative with the most vocal complaint being the total amount of time per week that the course required. Focus groups were done in each classroom, with almost 100% students in attendance and very active participation during the discussion. These focus groups identified three sources for high student workload:

- Need for more experience working problems
- Insufficient note-taking or lack of taking notes
- Automatically-graded homework had no partial credit

The first item related to students who wanted to be able to ask “why” questions while an instructor worked a problem a specific way, especially when there were different ways to work the problem. These students did not feel prepared to complete the homework and felt that it took more time than it should have had they had the chance to ask questions during an example or derivation in class. In all sections, there were opportunities for students to ask questions during class period, but the asynchronicity stymied all but the most organized students who had written down their questions while viewing the online lectures.

The second problem was much more multifaceted. To shorten note-taking time, we provided handouts of the slides for all of the lectures. However, the slide handouts, by design, partially complete in order to encourage active engagement with the videos. All of the figures, schematics, most of the text, and some of the equations were preprinted on the slides. On most slides, the instructors used a WACOM device to write on the slides, doing complete derivations, solving example problems, pointing out features of figures, etc. While some students actively took notes, a significant number (more than half, based on a show of hands in class) did not print the notes for note taking for various reasons. A surprisingly large number took no notes at all, thinking that they could just re-watch lectures as needed. Discussion with these students indicated that some watched the lectures 3-5 times each, spending much longer time per week than the instructors expected. Those that took notes in a separate notebook varied in their level of expertise and completeness, much like any other course.

As a result of the non-optimal note-taking strategies employed by students in the class, the total amount of time spent taking notes or extra time spent on homework due to insufficient note-taking was higher than the instructors had anticipated. Students who had insufficient or no notes also had difficulty studying for the exams.

The automatically graded online homework problems also increased student time on task, in both a constructive way and in a destructive way. From a destructive perspective, most students did the homework on scrap paper and entered their answer online. They then had no record of their work to help them study for tests, though solutions were given. The constructive way that homework benefited students was the immediate feedback and the chance to redo the problem to improve upon their performance. Most of the problems accepted numerical answers with the answer key accepting values within a set tolerance of the exact answer. No partial

credit was given, but students had five chances to solve each problem with the highest scores being the one that counted. In comparison, typical homework that is turned in weekly, graded mostly on effort, and returned 1-2 weeks later is neither timely nor directed. Students are on to the next topic before they realize that they did not understand the material. Students in ECE3710 work the homework problems approximately two times to achieve a grade of 80%-86%, see Table I.

In addition to the student surveys and focus groups giving feedback for course improvement, student performance on homework and on tests and the discussion forum topics and types of questions and comments were used to determine which online lectures needed revision. An example of a problem that was revealed in the discussion forums and on the tests related to the mechanics of node and mesh analysis. The original lecture included both topics together with a simple example for each. The revised lectures were split into different modules with more substantial examples.

Spring 2014: Based on feedback from Fall 2013, the following adjustments were made for Spring 2014:

- Students were given explicit instructions on how to succeed in a course taught in that format
- Students were allowed to use their notes to complete most of the in-class two-minute quizzes in order to encourage them to take notes and to come to class prepared
- Specific online lectures were revised and retaped based on students' level of confusion on those topics
- Some of the sections started giving worksheets in place of students doing homework in class

In addition, the second MOOC, Introduction to Electronics, was completed and replaced 40% of the course that had been taught with traditional lectures.

Nine sections of ECE3710 were offered in Spring 2014 with 401 students total: 7 of 9 instructors were returning from teaching the course in the blended mode in the fall, one new instructor had taught the course in the traditional method, and one new instructor had never taught a course previously. The explicit instructions to students included the following (along with an explanation of why this was important based on the prior semesters' findings, as explained above): print the slide handouts and take notes on them while viewing the lectures; do all homework in a notebook before going online to submit the answer; attend every class and stay to the end; etc.

Allowing students to use their notes during the in-class quizzes encouraged better note-taking and alleviated stress in class. Also, the types of quizzes were varied during the Spring term in one of the sections: most done individually, but more challenging ones were done in pairs. A few were inverse quizzes, where the students were asked to work in pairs to come up with two questions that the instructor might have asked. Those "quizzes" were graded on the appropriateness of the questions.

In order to give students more practice doing problems in a supportive environment, several of the sections in Spring 2014 gave worksheets (ungraded) during class for students to work on together. Just-in-time lecturing helped to alleviate misconceptions that came to light during these worksheets.

Feedback from the spring offering (surveys and focus groups) was no longer negative as we moved from a flipped model to a blended model. While many students still claimed not to like the "flipped classroom", overall performance in the course had improved to the point where the tests did not need to be curved (from an average of 7.7 points added per test in the fall to no points added in the spring. The discussions with the instructors indicated that the worksheets done in class were better than doing homework since students worked synchronously on them. Specifically, students came into class at different points in their completion of the homework while they all started at the same point on the worksheets, which facilitated collaboration.

During the spring term, we continued to monitor the student performance on specific topics in the course and on the corresponding discussion of those topics on the discussion forum. The revised video lectures on mesh/node/Thevenin alleviated the confusion seen in the previous term. Based on the discussion forum questions and comments for Spring 2014, we revised several lectures on the topics of sinusoids in circuits, complex numbers, and impedances for the next course offering.

Summer 2014: Three on-campus sections of ECE3710 were taught containing a total of 132 students. All of the instructors were returning as experienced in blending this course. In addition, a purely online section of 19 students was taught and three sections were taught in study-abroad programs. All of the off-campus sections used the online resources to varying extent, from complete reliance on them for the online section to supplemental for one of those sections. Those sections are not part of this study. During the summer term,

- The online quizzes were made optional in order to reduce the overall workload for the course
- Specific online lectures were revised and re-taped based on students' level of confusion on those topics
- Increased use of worksheets

Students preferred the immediate feedback obtained after in-class quizzes and the formative on-line (in-video) quizzes, but reported the online summative quizzes to be more time-consuming but less helpful. The in-class worksheets were viewed favorably by the students. The performance on the topics covered by the revised lectures improved on the tests and the number of discussion forum questions on those topics decreased. As seen in Table I, overall performance went up while student workload decreased. Student feedback from surveys and focus groups asked for more examples of worked problems.

Fall 2014: An increased demand in the course resulted in 8% higher enrollments from the previous academic year, and a large turn over in instructors caused transients in the course for Fall 2014. Changes made to the fall offering included

- Added 99 videos of an instructor working problems
- Revised some of the Intro. to Electronics video lectures
- Modified the purpose of the brief 10-15 minute lecture during class
- Required all instructors to use worksheets in place of homework during the in-class problem working sessions.

Early in the semester, based on student comments in focus groups, we modified the lectures to cover only new worked problems rather than an explicit summary of the online lectures. The instructors still emphasized the new concepts and methodologies as they worked the new problems, but this approach (rather than a summary) was acceptable to the diligent students who came to class prepared and did not want to waste time in explicit summaries. This approach also was acceptable to students who had not watched the lectures prior to class because they still saw the systematic problem solving methods. These students then went back to watch the online lectures later.

Spring 2015: The only negative feedback at the end of the fall term was that the labs were too long, so the adjustments made to the Spring 2015 offering of the course were to streamline the labs. We had students work the pre-labs collaboratively in-class in place of worksheets in a class period prior to the lab. In many cases, the pre-labs were the analysis of a problem followed by the actual lab where the students built the circuit to compare the theory to the experiment. So, the pre-labs were well-suited to be used as worksheets. Moreover, that extra class time on the labs (pre-labs, actually) allowed students to ask more questions on the concepts prior to the labs so that they were prepared better when they actually attempted the experiments.

The comparison of various metrics in Table 1 over the six-semester time period resulted from a combination of the adjustments made each term and the turn-over and training of new instructors. The exam average listed in the table included two exams and the final, without any exam curves being included in the table. In the actual grade weighting, curves were given on some of the exams as described below the table. Since the summer terms are shorter in length with more minutes per week, the summer workload numbers were adjusted to be consistent with the normal-length terms; that is, the reported average workload for summer was multiplied by 11/15 corresponding to 11 weeks for the summer versus 15 for the fall and spring terms. The first pilot offering in Summer 2013 had initial transients resulting in lower test scores, which were curved to obtain a DF rate that was lower than the subsequent terms. All of the terms used a straight scale for determining grades: 90-100 = A, 80-89 = B, 70-79 = C, 60-69 = D. The initial offering spent most of the in-class time allowing students to do homework, resulting in a lower weekly workload, though higher student complaints.

metrics: increase in homework and test average and a decrease in DFW and student workload. The exception was for Fall 2014. The anomalies in homework and test averages and the student workload would not seem to be linked directly to these adjustments made that term. The major factor in that term, however, was the general inexperience of the instructors where 5 of the 9 sections were taught by novice instructors who had never taught any course. In addition, several of the experienced instructors struggled with the best way of using worksheets in the class. With minor adjustments in Spring 2015, the metrics in Table 1 bounced back because the instructors had more experience. The experience of the lead instructor in training the new instructors in Fall 2014 highlighted the need for a more formal training process for instructors wanting to do flipped and blended classes. The details about the current instructor training and future plans are discussed in [15].

95% CI for the Mean

Component	Mean	95% CI Lower	95% CI Upper
Ohm's law	3.82	3.80	3.84
Kirchoff's laws	3.62	3.60	3.64
Physical behavior	3.65	3.63	3.67
Physical behavior	3.28	3.25	3.31
Digital multimeter	3.22	3.19	3.25
Resistor	3.28	3.25	3.31
Superposition	3.16	3.13	3.19
Mesh analysis	3.20	3.17	3.23
Thevenin/Norton	3.50	3.45	3.55
Physical behavior of cap.	3.16	3.13	3.19
Analyzing first-order circuits	3.38	3.34	3.42
Electronic instruments	3.32	3.28	3.36
Analyzing second-order circuits	3.06	3.02	3.10
Phasors for complex circuits	3.12	3.08	3.16
Free response to impulse signals	3.23	3.19	3.27
Transfer function (s-domain)	3.41	3.36	3.46
Low-pass & high-pass filters	3.20	3.16	3.24
Common op amp	3.35	3.31	3.39
Analyzing op amp circuits	3.24	3.20	3.28
AC power	3.19	3.15	3.23
Diode behavior	3.06	3.02	3.10
Transistor	3.14	3.10	3.18
Common diode circuits	3.05	3.01	3.09
Logic gates	3.21	3.17	3.25
Transformers	2.90	2.86	2.94

Individual standard deviations are used to calculate the intervals.

Figure 3 also demonstrates very small variance bounds on the self-perceived competence in the topics in the course. Students are asked to rate their level of understanding in a post-survey on the topics in the course, which are shown in chronological order of how they appear in the course, with Ohm's Law first and transistors last. Students are given the choice of 1 = "no understanding", 2 = "minimal understanding", 3 = "moderate understanding", and 4 = "solid understanding". The scale is magnified between 2.8 and 4 because the averages for all of the topics are very similar, so the magnification helps to see the very small variance levels. The plot includes N=310 students across all sections of ECE3710 in Fall 2014.

IV EXTENSION TO CIRCUITS COURSE FOR MAJORS

In Fall 2014, the lead instructor for ECE3710 also used the same materials to teach a section of ECE2040 Circuits, a 3 credit hour course for ECE majors in a blended format. Another instructor taught a second blended course section of ECE2040, each with section sizes of approximately 50 students. Two additional sections were taught using traditional-style lectures. The difference in the content of ECE2040 versus ECE3710 is that ECE 3710 covers all the topics in ECE 2040 plus add three weeks of basic electronics; however, the coverage is not as deep in ECE3710. A summary of the other differences in the course is listed in Table II. These differences are important because of the impact they have on the way that the course is blended.

TABLE II: COMPARISON OF GEORGIA TECH CIRCUITS COURSES

Fall 2014	ECE3710	ECE2040
Credit Hours	2	3
Student Workload	7.4 hours/week	8.8 hours/week
Required?	AE, ME, MSE	EE, CmpE
Enrollment	450 students per term	180 students per term
In-Class Labs	6	9 (blended sections) & 3-4 (traditional sections)
Online Lectures Assigned per Week	50-60 min	40-50 min
Online Homework	Yes, all	A mix of online homework and textbook homework
	Lead instructor coordinates sections, common homework and tests	Sections are run independently
Discussion Forum	Linear Circuits MOOC is synchronized with ECE3710, sharing the same homework and discussion forum	Discussion forum is limited to a single section

Another difference between the two courses is motivation, one is a required out-of-major course (3710) while the other (2040) is required of ECE majors. Thus the purpose and style of blending is different in 2040. In 3710, all of the topics are covered in the online lectures, while these same lectures constituted only about 2/3 of the lecture material for 2040, with the more complex material being done in class. The instructor who was experienced in blending ECE3710 made some adjustments in ECE2040 when compared to ECE3710:

- Mini-lectures were used to build depth on the online material both in theory and in working more difficult problems. Students were exposed to more real applications, demonstrations, and simulations.
- Since the course is taught to sophomores, emphasis was placed on developing an engineering way of approaching problems in terms of worksheets and in-class examples; homework problems that were done on paper and submitted (rather than graded online) and test problems were both graded heavily on their approach.
- Reduced the number of in-class worksheets from about 2 per week to about 1 per week. In all cases, scaffolding was completed by working one or more similar problems before the worksheets.
- Labs were done weekly, every Friday was a “bring your device day” (except for short weeks and weeks with tests)

- The students were given motivation repeatedly throughout the term on why we are blending the course and doing the labs. Understanding the value of the course approach helps to improve motivation.

Student self-perceived competence in the subject matter was examined through a post-survey. Figure 4 shows the average ratings for each topic for the one blended instructor (who had the most experience) and the average among two other sections that taught the class using a traditional lecture style.

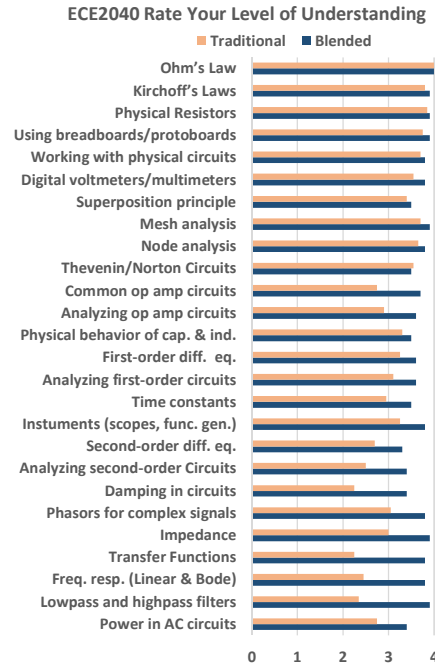


Figure 4: List of topics in order of appearance in the semester and the post-survey ratings (from 1= no understanding to 4=solid understanding) for a blended section (N=35) and two traditional lecture sections (N=30 combined).

The topics are listed in terms of their ordering in the course, starting from the beginning topics on the top to the end of the semester topics on the bottom. The dip in the traditional sections near the end of the term is reasonable in that the more complex material is often taught near the end of the term and students are usually more overwhelmed with all of their courses. The late term dip is not seen in the blended model. Students showed increased levels of confidence in the topic on phasors in all of the sections because that topic is covered in detail in another course, and that familiarity extends to the follow-on topic. Using the results in the figure, the next topics to be revised will be the second-order circuit responses, including the differential equation topics.

Figure 5 shows the post survey results from the blended version of ECE2040 where students were asked to rate the level of importance of the different instructional methods. The items marked with stars are methods that are more common to blended classes as opposed to traditional lecture-based courses. These topics all had very similar ratings from the students:

ECE2040: Importance of Instructional Methods in Helping to Learn the Material

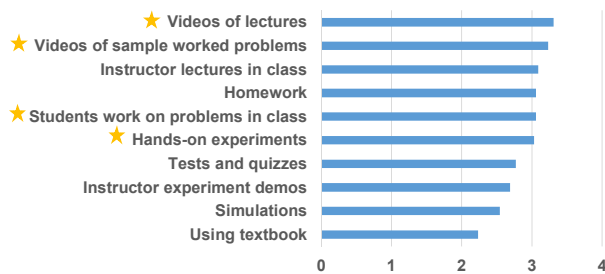


Figure 5: Post survey of the instructional methods used in the blended class: 1 = little or no help; 2 = moderate help; 3 = significant help; 4 = one of the most helpful, N = 35.

The other ECE2040 instructor taught the course in the blended way for the first time in Fall 2014, and struggled with it, in spite of having taught the course in a traditional lecture style for many years, with high teaching evaluations. Student post-survey results for this section fell between the blended section and the two traditional sections shown in Figure 4 in each category.

This other ECE2040 instructor taught the course again the following semester (just ending at the time of this writing), again using the blended method, and made several modifications.

Instead of always giving prepared mini-lectures on material complementing the online lectures, the instructor put more emphasis on working examples interactively with the students. New material was introduced sometimes indirectly as part of the examples. The assigned homework document was displayed occasionally, to show which homework problem was related to the example just worked. An undergraduate who took the course from the same instructor the previous term and did well was hired as an additional teaching assistant. Both TAs were present and answered student questions during worksheet periods, thereby reducing the student waiting time for help.

Occasionally, when extra time was needed for live lecture on new material, there was neither a quiz nor a worksheet. The class schedule indicated when worksheets were “likely.” There were fewer problems per worksheet, and the worksheet problems closely resembled the examples just worked. The instructor would do parts of the worksheet problem at the board when she sensed that more than a couple of students were confused by the same thing. The worksheets were graded based only on effort and approach, and there was no penalty if the answer was not correct. The instructor decided it was OK that the quicker students would finish early and leave, so the slower students could have adequate time and attention from the staff. These changes created a more relaxed and positive atmosphere during class.

SUMMARY

This paper outlines a feedback approach to evolving a multi-section, large enrollment course over the period of five semesters. Two circuits courses were evaluated in this study, ECE 3710 and ECE2040. ECE3710, the course for non-majors, was offered in the blended format in order to improve

consistency among 9 sections of a course and to introduce the hands-on experiences. Consequently, almost no new material was introduced during class time in ECE3710 and more reliance was placed on the online videos. Also, ECE3710 covers more topics, though in less depth than ECE2040, making ECE3710 have a faster pace. The reason for blending ECE2040 was more pedagogical in nature, again to add the hands-on activities but also to improve learning. The combination of having more motivated students in 2040 (ECE majors versus non-majors), a slower pace of new topics, the mix of covering the lower-level material online and higher-level and more depth covered in class, made the blending experience more rewarding for the ECE2040 students.

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Improving the Learning of Physics Concepts by Using Haptic Devices

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Abstract—Haptic devices are electro-mechanical tools controlled by computers that allow to recreate the sense of touch. They enhance the sense of interaction with virtual objects from purely visual to haptic and visual. One of its application areas is in training environments, where the users can interact with virtual objects to learn procedures or tasks. In this paper we describe the use of haptic devices to improve the learning process of basic physics concepts from electromagnetism and the haptic tools via simulation of magnetic forces in 3D. We have created three scenarios with different distribution of charges: point charge, line charge, and plane charge. Each scenario was properly calibrated and has different force feedback (quadratic, linear, and constant) depending on the scenario. We wanted to investigate how forces are perceived by students. A user study was carried out to assess students' perception and knowledge acquired when they were working with the system. Results suggest that students from the treatment group achieved better understanding than those from the control group. Results also indicate that 95% of the students considered that the use of haptic devices combined with appropriate virtual environments facilitated them to understand the nature and origin of electrical forces.

Keywords—Virtual Environments, Physics Simulations, Electromagnetic Forces, 3D Computer Graphics, Haptic Devices

I. INTRODUCTION AND PREVIOUS WORK

Throughout history, teachers and their use of lectures have become the most effective way to acquire new knowledge [1]. Nevertheless, as a result of the constant progress in science and technology, new alternative solutions in the area of learner-centered approaches have been developed. One of them are different types of simulations, control systems, and learning environments, some of them used via the internet, establishing the area of Technology Enhanced Learning (TEL). The new options allow students to enhance their learning by allowing them to acquire knowledge and skills via virtual environments [2].

One of the novel areas uses haptic devices that reproduce

the sense of touch for users interacting with a virtual environment. Advances in the field of electromechanical and computer technology have enabled the development and creation of various types of applications with haptic devices such as the Novint Falcon[®] or SensAble Phantom Omni[®] in Figure 1.

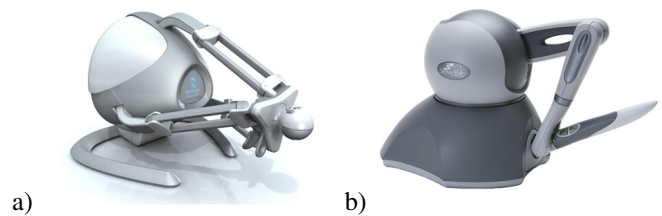


Fig. 1. a) Falcon Novint[®] and b) SensAble Phantom Omni[®] are USB-connected computer controlled haptic devices that were used in our experiments.

Haptic devices have been used in many fields such as navigation, education, e-commerce, medicine, gaming, and arts [3]. One of the most important areas where haptics have been implemented for teaching is in medicine. For example surgical operations, such as stitching and minimally invasive surgeries, have been used to train doctors [4], [5], [6]. Although haptic devices can be used in many different fields, it usually does not make a big sense to create virtual simulations of structures that can be physically fabricated in real world, such as mass-spring systems. Haptics can be effectively applied in areas where the actual force is either out-of-scale ranging from nano structures [7], [8], molecules [9] to astronomical scales [10], or for complex structures such as granular materials [11].

In traditional physics courses, students often have difficulties visualizing and perceiving basic concepts of physical phenomena. This problem worsens when abstract and non-tangible concepts are involved, i.e., electromagnetic interactions between charges [12], [13]. On one hand, real laboratories and

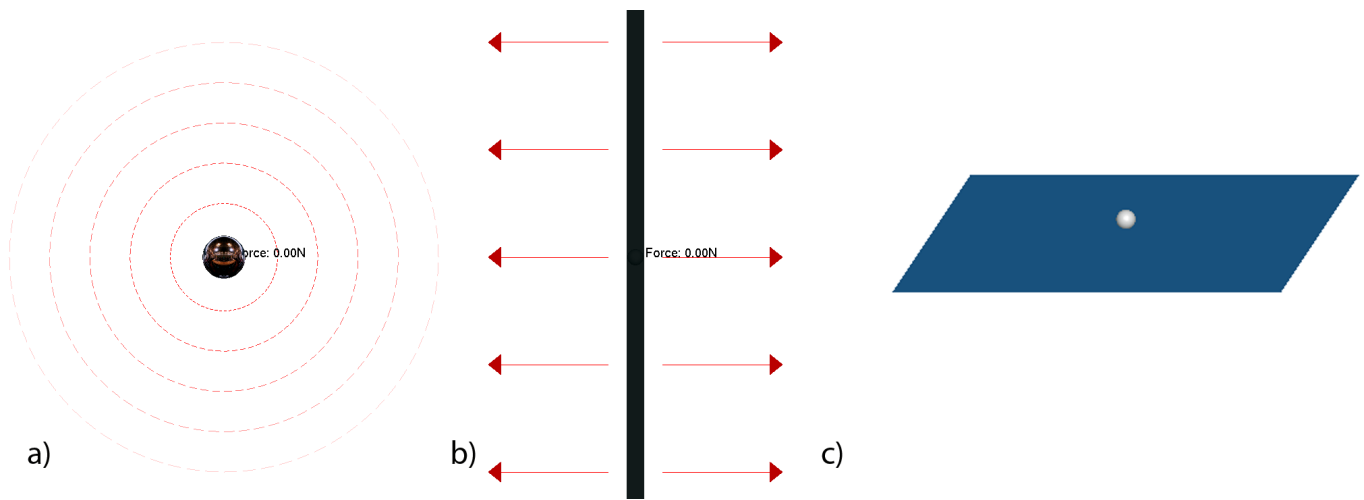


Fig. 2. Three experimental setting used in our testing point charge (a), infinite line charge (b) and infinite plane (c).

online simulators have traditionally been used to help students recreate appropriate physical scenarios [14]. Nevertheless, real laboratories are not always available in educational institutions, or they do not have all the necessary equipment to carry out suitable experiments. On the other hand, although online simulators constitute an alternative to real laboratories, most of them only address the sense of sight and in some cases the sense of hearing [15].

Electricity and magnetism concepts symbolize the basis of many current and novel technologies; however, undergraduate students often find the concepts difficult and confusing [16]. Some of the major deficiencies relate to a qualitative misunderstanding of the Maxwell's equations (expressed qualitatively); misunderstandings about the relationship between the electric fields and its sources, and the application of these concepts in problem solving [17]. Specifically, students have difficulties with electromagnetic induction and electric potential and electric energy [18].

In order to offer students a deeper perception of physical phenomena in virtual simulators, some authors have used haptic devices in online experiments. These studies had been carried in different settings, ranging from elementary school to graduate students, and they covered different physics areas, such as mechanics [19], [20], electricity and magnetism [21], [22], or heat and temperature [23]. However, although these researches helped students to better understand the nature of some physics phenomena, they are not usually applied to the field of electricity and magnetism that serve as the basis for different disciplines.

Physics educational researchers have identified the value of simulations in providing visualization of the different abstractions and complexities found in electromagnetism concepts [18]. We argue that through the implementation haptic technologies, in addition to computer simulations, can enable virtual hands-on laboratories that simulate real life scenarios or even physical abstractions. On the other hand, electromagnetism-related concepts, such as electric fields and distributed charges, are topics that have received little attention in regards to the implementation of haptic technologies. Sanchez et al. [22] investigated the efficacy of using visual

only and visuohaptic simulations for improving the learners' understanding of electromagnetic concepts. The findings of this research indicate no significant difference in the two treatment groups. Authors hypothesized that one potential reason for not identifying significant differences was attributed to students' inability to interpret touch in the context of the visualization. In order to test this hypothesis qualitative studies are needed to describe how students conceptually interpret the sense of touch. Host et al., conducted a qualitative study where they explored two different modes of using the haptic simulation in [24]. One was referred to as the force mode and the other one as force-and follow mode. The first mode allowed the learner to experience the force of the electric field and the latter one allowed the probe to be moved along the shape of the electric field. In this study authors found that before students interacted with the visuohaptics model they displayed struggles to distinguish between the concept of polarity and electric field. Host et al., hypothesized that this misunderstanding may be the source of unscientific views that all non-polar molecules are void of an electric field [24]. Authors also proposed that to remedy this problem scenario would be to directly engage electric field concepts into teaching polarity and intermolecular interactions [22]. They concluded that an integration of tactile interaction may induce an active integration of electric field knowledge with molecular charge distribution.

In this paper we explore how haptic devices can be used to effectively aid learning experience in traditionally difficult concepts from physics, namely in electromagnetism. We have developed an interactive simulator that uses three scenarios with different distribution of charges: a) point charge, b) infinite straight line of charge (hereafter, "line charge"), and c) infinite plane of charge (hereafter, "plane charge"). These scenarios can be seen in figure 2. The dependencies of the electric field strength on distance R from these charge distributions are $1/R^2$ (point charge), $1/R$ (line charge), and independent on distance (plane charge) [25]. We used haptic simulation to verify if the students are able to distinguish among the different scenarios and if they can interpret the forces correctly. The experiments were designed in 3D, and they were coupled with haptic devices.

A user study was carried to assess students' perception and knowledge acquired when they were working with the system. They were tested by engineering undergraduate students at Tecnológico de Monterrey in Mexico City and our results suggest that the use of haptic devices combined with appropriate virtual environments facilitate students to understand the nature and origin of electrical forces. Our results show that the use of haptic devices helped students to better understand electrical forces (95%), and 95% of the students stated that they would like to have haptic simulators to visualize other physics scenarios.

II. EXPERIMENT DESIGN

Electricity and magnetism provide the basis of many current and novel technologies and although undergraduate students are exposed to these concepts early in their studies they still find the topic difficult to understand. There are several reasons for this problem, among them is the complexity of mathematical concepts, and the difficulty to visualize the actual interaction of charges in the 3D space. Because of this, we have designed three experiments that provide the basic interactions, yet expose the essence of the actual interaction. The three settings were point charge, line charge, and plane charge. Each charge provides different force feedback applied to a point charge in the 3D space. The point charge experiment has quadratic attenuation with the distance. Infinite line experiment (line charge) provides linear attenuation, and an infinite plane experiment (plane charge) applies constant force independently of the location of the point charge.

A. Theoretical Framework

Embodied cognition was the theoretical framework that guided this investigation. Embodied cognition posits that bodily experiences are a key component of cognition [26]. Here, human construction of knowledge is considered closely linked to sensorimotor interactions in the world [27]. Traditional work in the cognitive sciences has primarily focused on the mind as an abstract information processor. These same views have argued that connections to the outside world (via perceptual and motor systems), were not considered relevant to understanding cognitive processes [27]. On the other hand, Artificial Intelligence has been re-thinking the nature of cognition focusing on the fact that thinking and understanding occurs in complex environments and by manipulating external props [28].

Some of the assumptions or views of embodied cognition are that it is situated, is time-pressured, is for action and body based [27]. It is also assumed that embodied cognition is used to offload cognitive work onto the environment and that the environment is part of the cognitive system [27]. In this regard, tactile sensations could stimulate learners to access and integrate embodied knowledge into their cognitive processing of abstract scientific concepts. Therefore, experiencing a coordinated visual and tactile representation of electric field concepts could have a potentially deep-seated influence on students' construction of knowledge concerning invisible and macroscopic phenomena.

B. Point charge

This experiment enables the learner to feel the electric force between two point charges that has quadratic attenuation as the

function of the distance of the charges. Charge Q_1 is fixed at the origin of the coordinate system at location $[0, 0, 0]$, and charge Q_2 is controlled by the user. It is connected to the haptic cursor, and it can be freely moved at different distances from Q_1 in the 3D environment (Figure 2 a).

The values of both charges can be chosen in the interval of $-20\mu C$ to $+20\mu C$. If learner chooses values that have different signs ($Q_1^+ Q_2^-$ or $Q_1^- Q_2^+$), he will feel the attraction force generated. On the other hand, if the learner chooses values that have equal signs ($Q_1^+ Q_2^+$ or $Q_1^- Q_2^-$), he will feel the repulsive force generated. The actual force is described by the Coulomb's law

$$\vec{F} = k_e \frac{Q_1 Q_2}{R_{QQ}^2} \hat{r}, \quad (1)$$

where $k_e = 8.987 \times 10^9 Nm^2/C^2$ is the Coulomb's constant, \hat{r} is the radial unit vector, and

$$R_{QQ} = \text{dist}[Q_1, Q_2]$$

is the Euclidean distance between the locations of charges Q_1 and Q_2 .

The purpose of this experiment is for students to realize that the force between point charges is proportional to the product of the charges magnitude and inversely proportional to the square of the distance between the charges.

C. Line charge

In the second experiment, shown in figure 2 b), the system displays a long straight-line charge fixed along the y -axis and a user-controlled mobile test point charge Q_2 .

The values for the linear charge density, λ , of the line charge can be set between the interval of $-20\mu C/m$ to $+20\mu C/m$, and the point charge can be chosen in the interval of $-20\mu C$ to $+20\mu C$. As in previous experiment in Section II-B, the x , y , and z -axes are shown and the forces that the user feels are calculated according to the sign of the values selected for the point charge and the straight-line charge. The equation for the force applied to a charge within the influence of the infinite charged line is calculated according to

$$\vec{F} = k_e \frac{2\lambda Q_2}{R_{Q\lambda}} \hat{r} \quad (2)$$

and

$$R_{Q\lambda} = \text{dist}[Q_2, \lambda]$$

is the distance between the point charge and the infinite line. Note that the attenuation is linear as the function of the distance of the charge from the line.

In this experiment the students are expected to understand that the force between a long charge line and a point charge is proportional to the product of the charges magnitude and inversely proportional to the line charge-point charge distance.

D. Plane charge

In the last experiment shown in figure 2 c), the learner senses the force generated by the interaction of a large plane of charge fixed at the yz plane and a user-controlled mobile

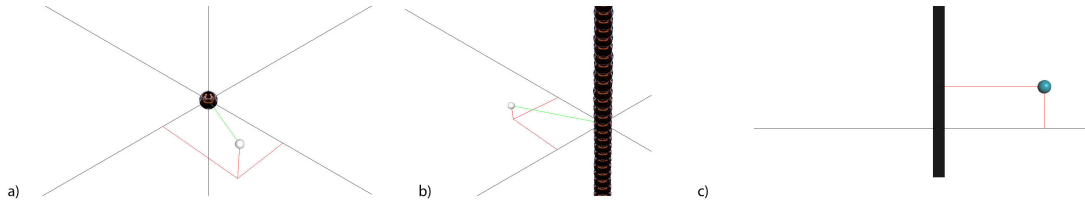


Fig. 3. Guiding lines connected to the coordinate frame were used to better orient the user in the 3D environment in point a) line b) and plane c) configurations.

test point charge Q_2 . The exerted force does not depend on the distance and is constant, because the plane is infinite.

The value for the surface charge density σ , of the plane charge can be chosen by the learner between the values of $-20\mu C/m^2$ and $+20\mu C/m^2$. The point charge value can be set between the interval of $-20\mu C$ to $+20\mu C$. As in the previous simulators, the forces that the user perceives are calculated according to the sign of the values selected for the point charge and plane charge

$$\vec{F} = 2\pi k_e \sigma Q_2 \hat{r}. \quad (3)$$

As can be seen, the actual force \vec{F} does *not* depend on the distance from the plane.

The goal of this experiment is to let students realize that the force between a large plane of charge and a point charge is proportional to the product of the charges' magnitude, and it is independent from the distance between them.

III. VIRTUAL SIMULATOR

We have developed comprehensive learning simulation systems that use haptic devices. The system was developed in C++ and uses OpenGL and GLSL for visualization. We used GLM for math processing and Chai3D [29] for haptics rendering.

Our implementation allows to use a SensAble Phantom Omni[®] or Novint Falcon[®]. All simulations were executed on a DELL T7500 Workstation equipped with Intel XEON E5620[®] processor clocked at 2.4 GHz, with 12 GB RAM, and NVIDIA GeForce 9800 GX2[®] video card, Windows 7 64 bits operating system, and on an ASUS G750JX-MBS1-H laptop, with Intel Processor i7-4700HQ[®] clocked at 2.39 GHz, with 8 GB RAM, and NVIDIA GeForce 770m[®] video Card. The user testing were performed by using the laptop and by using the Falcon Novint[®] haptic device shown in Figure 1 a).

The Point Charge and the Line Charge simulations were developed as 3D environments due to the nature of their interaction forces, as can be seen in figures 3-a and 3-b. The Point Charge, the charge Q_1 was displayed as a small sphere and its interaction forces were calculated to avoid Q_2 penetration. A line was created for the Line Charge to trace a long box. This line was placed on the y -axis and collision detection was enabled to show that Q_2 cannot enter the line. It is important to note that in both simulators the size of the moving object representing the charge Q_2 changes according to its location relative to the user because of the perspective projection to provide a better depth perception. Additionally, guiding lines connecting the haptic cursor with the projection to the axis of the Euclidean coordinate system were used to provide guidance (Figure 3).

The Plane Charge simulator is symmetrical in 3D and was developed as 2D representation showing the x and y -axes, as can be seen in figure 3-c. However, the user could navigate the scenario using the all three axis. The plane was created as a mesh to enable the simulation provide collision detection in the plane. Finally, as in the previous simulators, guidance lines were implemented to locate the user in the space.

Figure 4 shows a student interacting with the haptic device during an experimental session.



Fig. 4. A student interacting with the Plane Charge simulator. Students can freely explore the virtual scenario by using a haptic device. Depending on the position of the haptic interaction point, students can feel the interaction force in that position.

IV. EVALUATION PROCESS

During the January - May 2015 term, a focus group of 20 freshmen students of a undergraduate Electricity and Magnetism course at Tecnológico de Monterrey (Mexico City) were invited to test the three developed experiments. The testing sessions were one week long and the students were able to use the simulators coupled with haptic devices.

Each session consisted of a brief introduction and demonstration of how the system works followed by exercises for each simulator. They were asked to explore the system and solve some exercises using the haptic device in order to sense the interaction forces between the different charge distributions, as can be seen in figure 5. Each student explored the system for approximately 30 minutes. At the end of each session, students were asked to provide general comments

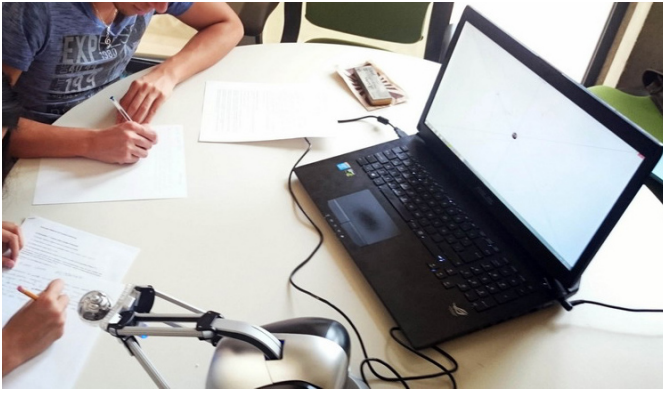


Fig. 5. Students solving exercises using the Point Charge simulator. Students followed instructions for each simulator where they can apply the knowledge they learnt in the classroom to check if the values were correct.

about the virtual systems. After that the students were also asked to answer two short multiple-choice questionnaires:

- i) A post-test, which aimed to seek whether they were able to identify the direction of the force and its dependence to the distance between the test point charge and the different charge distributions (Table I).
- ii) A perception questionnaire, which was created to assess students' overall opinion to the simulators (Table II). Likert scale was used, in this questionnaire using the values: Total Agreement (TA), Agreement (A), Indifferent (I), Disagreement (D), and Total Disagreement (TD).

By applying both questionnaires, we could measure if the student felt that this system could help them to better understand the nature and behavior of electrical forces. The post-test was also applied to 20 freshmen students of a different Electricity and Magnetism course, a control group, in order to compare the results between both groups. Even though the treatment and control groups had different professors, both groups covered the same syllabus, provided similar exercises, same lectures, and same learning resources about the concepts developed in the simulators. Therefore, students had same academic backgrounds and characteristics.

TABLE I. POST-TEST QUESTIONNAIRE APPLIED TO TREATMENT AND CONTROL GROUP.

Post-test questionnaire				
1) What kind of force is felt between charges of the same sign?				
a) Attractive	b) Repulsive	c) Depends on the magnitude of charges values		
2) What kind of force is felt between charges of opposite sign?				
a) Attractive	b) Repulsive	c) Depends on the magnitude of charges values		
3) The value of the electric force between point charges located at distance R is proportional to:				
a) R^2	b) R	c) Does not depends on R	d) $1/R$	e) $1/R^2$
4) The value of the electric force between a line charge and a point charge located at distance R is proportional to:				
a) R^2	b) R	c) Does not depends on R	d) $1/R$	e) $1/R^2$
5) The value of the electric force between a plane charge and a point charge located at distance R is proportional to:				
a) R^2	B) R	c) Does not depends on R	d) $1/R$	e) $1/R^2$

V. RESULTS AND DISCUSSION

The results of the post-test applied to the treatment and the control group are shown in figures 6 and 7. Results from the perception questionnaire (applied only to the treatment group), can be seen in figure 8.

As can be seen in figures 6 and 7, most students in both groups answered correctly the first two questions which were focused on their understanding of how the interaction force behaves (attraction or repulsive force). Nevertheless, in questions three to five, related to the dependence of the electric force to the distance between the different charge distributions, interesting differences appeared when the treatment and the control group were compared. In question number three, where the right answer is the option "e" - $(1/R^2)$, the results for this question are very similar for both groups (treatment: 60%, control: 55%). On the other hand for question four (electric force between point charge and line charge), the right answer percentage (option "d" - $1/R$), although both percentages are low, was higher in the treatment group (25%) than the one obtained in the control group (only 5%). Finally, in question five, the electric force between a point charge and a plane of charge, 75% of the members of the treatment group answered it correctly (option "c" - Does not depend). This value is higher compared to the one obtained in the control group (only a 50%). In summary, students from the treatment group achieved better results than those from the control group. This result suggest that the use of virtual learning environments coupled with haptic devices can help learners to better recognize and understand the strength of the electric forces.

TABLE II. PERCEPTION QUESTIONNAIRE APPLIED TO THE TREATMENT GROUP.

Perception Questionnaire
1) Point Charge experiment helped me to better understand the behavior of the interaction force between point charges.
2) Line Charge experiment helped me to better understand the behavior of the interaction force between a line charge and a point charge
3) Plane Charge experiment helped me to better understand the behavior of the interaction force between a plane charge and a point charge
4) Manipulating Point Charge experiment was easy and intuitive
5) Manipulating Line Charge experiment was easy and intuitive
6) Manipulating Plane Charge experiment was easy and intuitive
7) Point Charge experiments graphics are appropriate and attractive
8) Line Charge experiments graphics are appropriate and attractive
9) Plane Charge experiments graphics are appropriate and attractive
10) The three experiments, as a whole, helped me to acquire better perception of the interactions forces between the different charged distributions
11) I would recommend simulations with haptic devices to learn other concepts of Electricity and Magnetism
12) I would recommend simulations with haptic devices to learn other concepts of Physics

Results of the perception questionnaire suggest, as can be seen in figure 8, that the students of the treatment group totally agree or agree on the fact that the virtual simulator helped them to better understand the behavior of electrical forces. Moreover, they specified that the manipulation and visualization of the system was in general appropriate, and they would recommend simulations that use haptic devices to learn other concepts of the Electricity and Magnetism course, as well as for other physics topics. The average results were calculated using Total Agreement and Agreement. The highest average obtained in the questionnaire was the acceptance that simulators helped them to better understand electrical forces (92% for questions 1 - 3). There is also a high average of 87% stating that the system manipulation was easy and intuitive (questions 4 - 6). On the other hand, the lowest average of acceptance was obtained in the questions related to the visualization of the system (72% for questions 7 - 9). This can be interpreted as the need for the graphics of the simulators to be improved, in particular, in the perception of depth.

The general acceptance percentage was also rather high; 95% in question 10 suggests that students considered that the three experiments helped them to acquire and to better understand the perception of the interactions between different charge distributions. Finally, similar to the previous question, the average result for questions 11 and 12, 95% suggests that haptic simulators are recommended to visualize other physics scenarios. Results from the last part of the questionnaire (questions 10 to 12) can be further supported by the general comments that the students from the treatment group also provided.

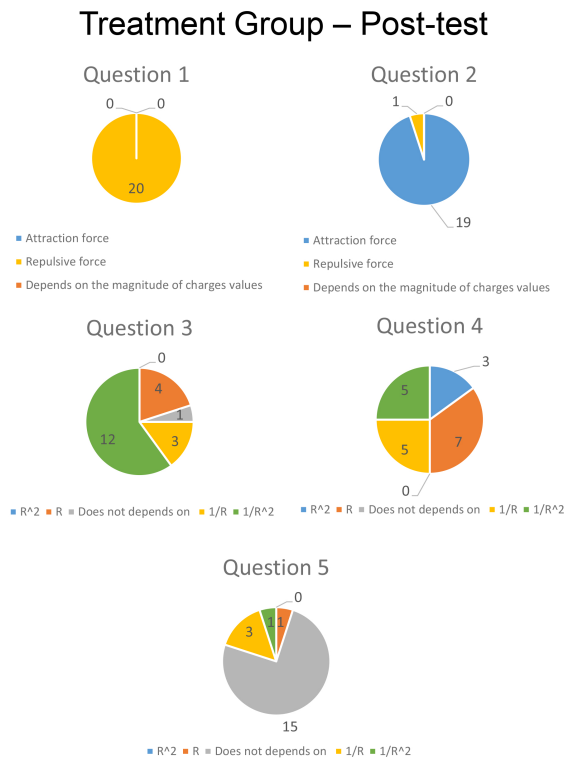


Fig. 6. Treatment group results obtained in the post-test.

Most of these comments were positive and motivating. Typical ones were: "I liked the (haptic) simulator because it shows more realistic scenarios than those seen in class", "they (haptic simulators) helped me to better understand the behavior of electric forces", "the simulations (using haptics devices) are interactive and didactic". Furthermore, there were other comments that invited the authors to improve the visualization of the experiments, the 3D perspective, and other students even encouraged the authors to create new simulators.

We believe that the high failure percentages for the treatment and control groups obtained in the question related to the line charge experiment (question four) is due to the fact that students do not recognize that the force strength increases for shorter distances, but they have troubles in disclosing between the linear and quadratic attenuation.

VI. CONCLUSIONS AND FUTURE WORK

We have shown our implementation of a 3D haptic simulations and how it was used to assess learning experienced

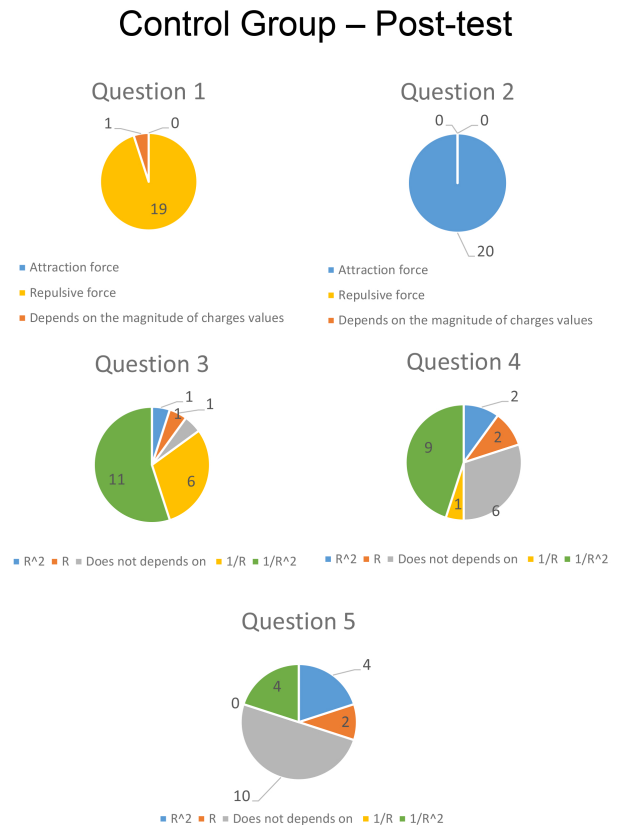


Fig. 7. Control group results obtained in the post-test.

in traditionally difficult concepts from physics - electromagnetism. Our interactive simulator uses three scenarios: point charge, line charge, and plane charge, where each scenario provides different force feedback: quadratic, linear, and constant, respectively. The third dimension was added to enrich the visualization and our system includes a three-dimensional coordinate system that shows the projections of the haptic cursor on the coordinate planes.

A user study was carried out to assess students' perception and knowledge acquired when they were working with the system. They were tested by engineering undergraduate students at Tecnológico de Monterrey in Mexico City and our results suggest that the use of haptic devices combined with appropriate virtual environments may facilitate conceptual understanding of the nature and origin of electrical forces. Results of the post-test for the three experiments were better in the treatment group than in the control group. The best result was obtained when students used the Plane Charge simulation, but positive acceptance was obtained for the Point Charge. The poorest results were found in the Line Charge simulation.

Students' perception of the virtual environments was overall positive. They stated that the experiments helped them to better understand the behavior of electric forces, the manipulation of the experiments was easy and intuitive, and that the visualization was appropriate and attractive, although it still could be improved to provide better perception of the depth. They also manifested that the three experiments helped them to acquire a better perception of the interactions forces between different charge distributions, and they would recommend the

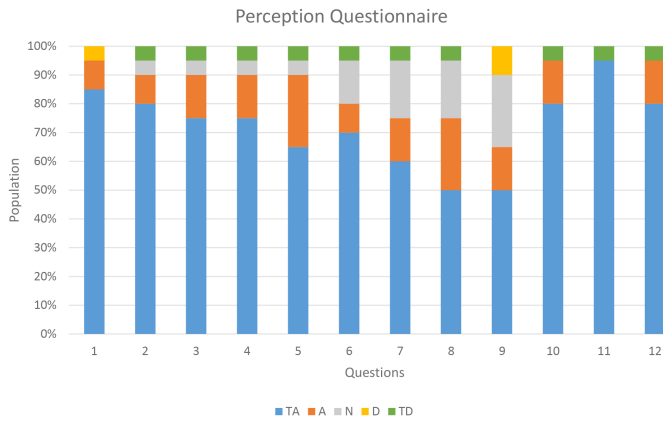


Fig. 8. Perception questionnaire results. This graph shows the acceptance and usefulness of the simulators according to the results obtained in the perception questionnaire.

use of virtual simulators coupled with haptic devices to learn other concepts of electricity and magnetism and other abstract Physics topics.

There are several possible avenues for future work. A more comprehensive study with more participants could be performed. It would be interesting to experiment with other concepts from magnetism, applying forces over wires of arbitrary shapes, among others. Several participants had difficulties in disclosing the force strength dependence on distance (linear vs. quadratic attenuation). It would be beneficial to conduct a novel study that would quantify and describe what were the reasons for these issues.

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Expression Tasks for Novice Programmers

Turning the Attention to Objectivity, Reliability and Validity

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Abstract—The understanding and transfer of mathematical expressions in a programming language is essential for studying engineering. Our experience of recent years shows that students increasingly struggle in reading, understanding and eventually transferring mathematical expressions to a programming expression so we need to provide many relevant tasks to help students overcoming this challenge. From educational psychology as well as our application-oriented research we know that the success of learning can be operationalized with objective, reliable and valid tasks only. Thus, we perceive tasks not only to be a training but also to be an empirical measuring instrument. However, tasks that are not theory driven are likely to be not suitable to measure the learning outcomes of students in an objective, reliable and valid manner. We'll present two different successful approaches that were developed individually at two different locations. Both propose a formal task description as well as a process model for task development that will facilitate the transfer of mathematical expressions to programming expressions. The tasks generated are valid and allow objective and reliable measurements of the students' learning outcomes. Our proposed tasks can also be used to iteratively improve and individualize introductory programming courses.

Keywords—Engineering Education, Computer Aided Instruction

I. INTRODUCTION – ENGINEERS NEED TO HANDLE EXPRESSIONS WELL

Mathematical expressions play an important role in engineering education. In the curriculum, understanding them is a prerequisite for subjects like statics, physics, measurement, mechanical or electrical engineering and thermodynamics. With the increased use of computers, students must become competent in translating a mathematical expression into a programming language expression (e.g. C#, FORTRAN or spreadsheets).

Unfortunately, students struggle to read, understand and eventually transfer mathematical expressions to programming expressions, and this has been worsening in recent years [1]. Students seem to no longer develop a deep mental model of expression evaluation, since the graphing calculators and computer programs they typically use give them the final result of any expression without explaining the intermediate steps. Such a mental model essentially involves understanding the tree structure of mathematical expressions. In order to set a sustainable foundation for further studies (in this course as well as in the curriculum), we must help our students develop such a

deep mental model. In this paper, we propose a set of tasks to help students learn mathematical expressions, and illustrate them with sample implementations.

II. OUTPUT ORIENTATION – TASKS AS SEEN FROM AN EMPIRICAL PERSPECTIVE

A skill or competence is a latent property that can only be operationalized (observed and measured) by a corresponding performance [2,3]. Tasks can be used to operationalize skills [3], but only if they are objective, reliable and valid [4]. This is due to the fact that tasks conform to empirical measurement, thus, requiring empirical standards. We define tasks that allow an objective, reliable and valid observation and measurement as competence-oriented tasks.

Objectivity and reliability are problematic when the task and / or the solution representation are ambiguous (i.e. not objectively assessed and therefore not reliable). Recent task reviews for novice programmers have shown that this is indeed a problem (see [4,5]). We address this problem by applying a formal task description (see [6]). The validity of a certain task in relation to a specific competence is ensured by developing a systematic procedure to create a possible (valid) task from a given competence (see [4]). In this paper, we propose to use a systematic procedure for the task of evaluating and writing expressions.

According to [4] the top down-process of creating tasks begins with the identification of a manageable number¹ of operationalizable target skills, either following a) an expert analysis, b) a curricular guideline such as [7] or c) local curricular requirements. Since not all skills needed can be operationalized in the same easy way [8] we focus on cognitive skills only. Non-cognitive skills (such as motivation) still remain important, but are out of the scope of our current work.

¹ We recommend choosing at most 3-5 top level skills because more will likely become impossible to handle during the short period of the course.

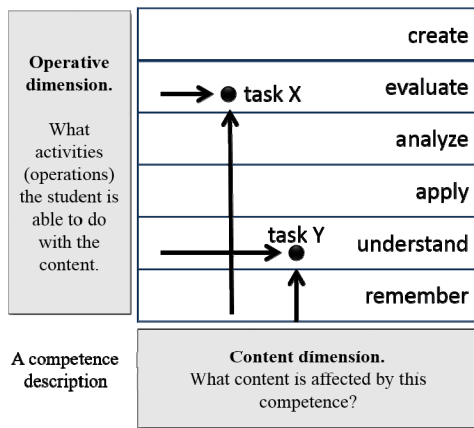


Figure 1 - Visual representation of a competence description [8].

The procedure we will follow is as follows: 1) We select a small number of necessary cognitive skills; 2) We identify the relevant learning objectives for which we have to consider the students' prior knowledge; 3) We enlist the actions (operations) we'd like the students to be able to do with the learning objectives. Those operations provide us with so called task types (4), meaning that every task type describes an individual superset of tasks with identical properties². If needed the identified task types can be ordered using an appropriate taxonomy, e.g. [9] or [10]. 5) Finally, we create atomic tasks³ following the requirements of the task type (see [4,8] for a detailed discussion of this procedure).

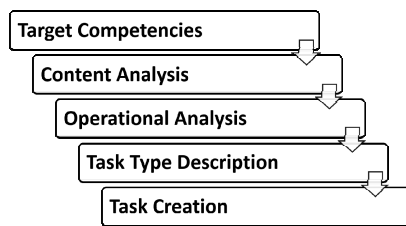


Figure 2 - Top down process of creating valid tasks [8].

The procedure above provides a number of empirically valid task. To ensure their objectivity and reliability a formal task description has to be used to avoid any kind of ambiguity⁴. The formal and procedural approach to develop tasks makes them more than just a practicing tool. They can now be used to empirically study the success of a certain didactic teaching approach. Furthermore, the existence and degree of desired expression skills can be observed and measured empirically.

² Similar to a superclass.

³ [3,11] recommend aligning the tasks (constructive alignment) to meet both the students (exam) as well as the lecturers (skill acquisition) requirements. This can be easily achieved by using the same collection of tasks for lectures, practicing sessions as well as the final exam.

⁴ For a discussion of how to describe tasks formally see [4,6].

III. COMPETENCE ANALYSIS – FROM SKILLS TO VALID TASK TYPES

The process of identifying appropriate cognitive skills⁵ is influenced by external guidelines (ACM/IEEE) and local curricular requirements. However, as experts we also have the option to identify needed skills ourselves. Since the overall goal is to teach the fundamentals of programming, understanding and transferring mathematical expressions to programming expressions can be seen as one of the top level competencies.

But what content is relevant concerning the transfer of mathematical expressions? We identify the following tasks for expressions: 1) remember expression syntax elements⁶, 2) understand an expression's semantics, 3) apply the transfer of a mathematical expression to a programming expression with a given how-to-proceed algorithm, 4) correct and 5) optimize a given expression. This provides us with 5 task levels⁷ and at least one task type per level.

TABLE I. ANDERSON'S TAXONOMY APPLIED TO OUR DOMAIN⁸ INCLUDING TASK TYPES.

Level	Anderson	Explanation
6	create	Yet undefined.
5	evaluate	Optimize expression: OPEXpr – Optimize expression with parenthesis
4	analyze	Correct expression with errors: CIMEXpr – Correct implementations of mathematical expression with errors CEXpr – Correct expression with errors
3	apply	Implement mathematical expression with given algorithms: IMEXpr – Implementation of mathematical expression RIMEXpr – Reverse implementation of mathematical expression, e.g. form mathematical expression from implementation
2	understand	Evaluate expression with given Input: EMEXpr – Evaluate mathematical expression EEXpr – Evaluate expression CEEXpr – Complete evaluate expression Problems
1	remember	Identify syntax elements (non terminals): EXprTree – Expression tree

IV. TASK ANALYSIS – FROM TASK TYPES TO VALID TASKS

In order to learn to evaluate mathematical expressions, students must understand the concepts of 1) operators and operands; 2) precedence of operators; 3) associativity of operators; 4) arity of operators; 5) that an expression is evaluated one operator at a time by the computer; and 6) the semantics of individual operators in an expression. These can be succinctly summarized by the evaluation tree of the expression. We will now develop valid tasks for the given task types and describe them formally using a unique table-based

⁵ As we'd like to discuss identified task types in detail we'll keep the explanation of this step as short as possible. For an extensive discussion see [4].

⁶ Such as literals, operators, braces etc.

⁷ Currently no task type for level 6 (create) has been developed.

⁸ Taken from [4], modified.

template. Also, we want these tasks to be usable in a computer-based learning environment, so that we can generate exercises efficiently (see [12,13]).

A. Level 1: Remember Expression Syntax Elements

1) Expression Tree (ExprTree)⁹

TABLE II. DESCRIPTION OF THE EXPRESSION TREE TASK TYPE.

Property	Details
Competency ^a	Remember (recall) syntax and semantics of expressions, statements, constructors, fields, properties, methods and operators.
Level	1 (remember)
Given ^b	Expressions ^c .
Main operator ^d	Construct the expression tree of the expressions.
Solution representation ^e	Tree
Assurance ^f	The expressions don't change the value of variables, so they do not contain ++, --, assignment, complex assignment like +=, return-method-invocation with parameter modifiers (ref or out), object creation or array creation. Variable references and literals do not lock up in the expressions in parenthesis, e.g. (5) or (a) is not allowed. LINQ-expressions or similar expressions with methods of the class Array or List are not allowed.
Assessment ^g	Subtractive ^h .
Notes ⁱ	The following types of subexpressions exists: the variable-reference, the literal, the return-method-invocation, the cast-expression, the unary-expression, the binary-expression, the tertiary-expression (?-operator)
Hint ⁱ	For this operator an algorithm exists.

^a. Target competence this task belongs to.

^b. All given information provided to the student (initial state).

^c. The number of expressions to work with, provided as a table.

^d. Main action (operation) the student has to do.

^e. Formal description of how to represent the worked out solution.

^f. Bordering the solution space by excluding unwanted scenarios.

^g. Clarifying the way of how this task is being assessed.

^h. Starting with all points. Every mistake one (or more) points less. This way of assessment has been described in [4].

ⁱ. Additional notes or hints to provide some extra information.

a) Detailed Algorithm¹⁰:

The problem-solving algorithm, which is provided to the students as well, demonstrates that we want the students to evaluate the given expression the same way a parser does. This helps them understand that not (only) algebraic but digital rules apply when evaluating expressions.

1. Identify operands: variable-references and literals.

2. Identify sub-expressions recursively. The sub-expressions are: member-access, array- and indexer-access, return-method-invocation, unary-expression (operators +, -, !, ~), cast-expression, binary-expression (operators *, /, %, +, -, <<, >>, <, >, <=, >=, is, as, ==, !=, &, ^, |, &&, ||, ??), and tertiary-expression (operator ?)

⁹ We adhere to terms of the C # programming language.

¹⁰ To solve this task students need to follow a given algorithm, which enlists every step.

Parenthesized-expressions are treated as extension of the sub expression.

Expressions (as well as sub-expressions) can be marked as fully evaluated only if there's no operator at the right hand side, which is of a higher order and which has not been evaluated yet. Because parenthesis and the "," in the argument-list are not treated as operators the search for operators of a higher priority is interrupted.

b) Remarks:

In the case of C# we can construct a lambda-expression from such an expression, if we don't have a constant expression. Constant expressions are evaluated by the compiler.

c) Example: ExprTree: Expressions 01

Nr	Expression
1	9 % 6 - 6 % 9
2	2 * y / (x + 1)
3	2 * (y / (x + 1))

Solution ▶

Nr	Expression
1	
2	
3	

B. Level 2: Understand an Expression's Semantics

1) Completely Evaluate Expression (CEExpr)¹¹

TABLE III. DESCRIPTION OF THE COMPLETELY EVALUATE EXPRESSION TASK TYPE.

Property	Details
Competency	Understanding of evaluation of expressions and return-methods.
Level	2 (understand)
Given	Variable ranges, expressions, input.
Main operator	Notice the complete evaluation of the expressions with the inputs.

¹¹ There is also a simplification of this task type, in which students need to specify only the final result without labeling the intermediate results (EExpr: Evaluate Expression), which we do not describe here.

Property	Details
Sub operators	Expression tree List of all operators for the basic-values-types, e.g. bool, int, char, double and string and the semantic of the operators
Solution representation	Tree
Assurance	See expression tree task type. The input is inside valid variable ranges.
Assessment	Subtractive.
Hint	For this operator an algorithm exists.

a) Detailed Algorithm:

Repeatedly calculate the values of sub-expressions and write down their values.

If the sub expression is a variable-name, we write down the value of the variable. If the sub expression is neither a literal nor a variable-name and doesn't contain the operators '&&', || or '?', we evaluate the value of the sub expression.

If the sub expression contains one of the operators '&&' or ||, then the value is determined as follows: If the result of the evaluation of the left operand is true for || or false for &&, we write down the value of the left sub expression and skip evaluating the right sub expression. Otherwise, we also evaluate the right sub expression, followed by the overall expression.

If the sub expression contains the operator '?', then the value is then determined as follows. If the value of the first sub expression is true, the second sub expression is evaluated and its result is returned. If the value of the first sub expression is false, the third sub expression is evaluated and its value is returned.

b) Remarks:

Mathematical Set	Corresponding Type in C# Remarks
Boolean set	bool Associative and distributive
Set of integer numbers	int only a subset of the set of integer numbers Associative and distributive in the case of unchecked Not associative and distributive in the case of checked
Set of real numbers	double Not associative and distributive

If we use return-method-invocations in the expression with possible exceptions, then the operators will no longer be commutative.

c) Example: CEEExpr: Expressions 01

Variable ranges

In: double x, y;

Out: basic-value-type

Nr	Expression
1	3 + 4 * 5
2	2 * y / (x + 1)
3	2 * (y / (x + 1))

Input

x = 2; y = 3;

Solution ►

Nr	Expression
1	
2	
3	

2) Problets

TABLE IV. DESCRIPTION OF PROBLT TASK TYPE.

Property	Details
Competency	Understanding of evaluation of expressions.
Level	2 (understand)
Given	Expressions (without variables).
Main operator	Write down the complete evaluation of the expression.
Sub operators	Expression tree Complete evaluate expressions List of all operators for the basic-values-types, e.g. bool, int, char, double and string and the semantic of the operators
Solution representation	Tree
Assurance	See expression tree task type.
Assessment	Subtractive.
Hint	For this operator an algorithm exists. The algorithms is a combination of the algorithms for expression tree and complete evaluation expressions. In the case of operators && and may be that the expression tree is not complete. In the case of the operator ? the expression tree is always not complete. Because we use literals it isn't necessary to mark the literals.

a) Remarks:

Evaluation task can be illustrated with an example from problets (problets.org), which are problem-solving software tutors designed to help students learn programming concepts by solving problems. The problets on expression evaluation (arithmetic, relational, logical, assignment and bitwise) reify the evaluation of a problem by requiring the student to identify the evaluation tree, one operator at a time, as shown in Figure 1. When using a problets on expression evaluation, students are required to use the procedure described above to evaluate the expression, again, as shown in Figure 1.

The advantages of requiring students to identify the evaluation tree en-route to evaluating the expression are: 1) the

evaluation process is emphasized just as much as the final product, i.e., the final answer; 2) in order to qualify for full credit, students must develop the correct mental model of expression evaluation and cannot simply guess the final

answer. In other words, students must use an objective, valid and reliable process to evaluate expressions.

b) Example:

Arithmetic - Practice

Edit View Options Format Help

Evaluate the following expression step by step.
Click and drag the mouse to indicate each step.
Enter intermediate result when prompted.
If you need help entering your answer, click on [Show Explanation] in the right hand panel.

9 % 6 - 6 % 9

3 ✓

6 ✓

-3 ✓

You correctly identified all 3 steps in the solution.
You correctly calculated all 3 intermediate results in the solution.
The operators in the expression are: % - %
They are evaluated in the following order, based on their precedence:
% % Highest Precedence (Evaluated Left to Right)
- Lowest Precedence

9 % 6 returns 3, the remainder when 9 is divided by 6 using ordinary division
6 % 9 returns 6, the remainder when 6 is divided by 9 using ordinary division
3 - 6 returns -3

Next Problem

Figure 1: Evaluation of an arithmetic expression with 3 operators: student answer in the left panel; correct answer in the right panel, along with explanation

Logical - Practice

Edit View Options Format Help

Evaluate the following expression step by step.
Click and drag the mouse to indicate each step.
Enter intermediate result when prompted.
If you need help entering your answer, click on [Show Explanation] in the right hand panel.

true || false && true

false ✗

✗

Short Circuit ✓

true ✓

The left-hand-side of && operator is always evaluated before its right-hand-side.
Since the left side evaluates to true, the right side of || is short circuited.
false && true is short circuited
true || false && true returns true

Next Problem

Figure 2: Evaluation of a logical expression: incorrect solution entered by the student in the left panel; correct answer and feedback shown in the right panel

3) Operator Task

In addition to learning the evaluation tree, students must also learn the semantics of individual operators, e.g., in Figure 1, they must understand that % operator returns the remainder of dividing one integer by another. The semantics of operators are reflected in the intermediate results students are expected to enter after each step of evaluation. Note that problems grade both the evaluation tree and the intermediate results entered by the student. Sometimes, intermediate results can alter the evaluation tree, as shown in Figure 2, where the right operand of a logical operator has been *short-circuited*. Both the figures 1 and 2 illustrate cases where evaluation of a programming expression differs from the evaluation of mathematical expression (% operator and short-circuit evaluation).

Controlled evaluations have shown that using problems helps students learn expressions [14]. Students have been using problems to learn expressions in C++, Java and C# since fall 2004.

C. Level 3: Applying the Transfer

1) Implementation of Mathematical Expression (IMExpr)¹²

TABLE V. DESCRIPTION OF THE IMPLEMENTATION OF MATHEMATICAL EXPRESSION TASK TYPE.

Property	Details
Competency	Implementation of mathematical expression.
Level	3 (apply)
Given	Variable ranges, mathematical expressions
Main operator	Notice the expressions
Sub operator	For every sub expression of a mathematical expression exists one sub operator.
Solution representation	Table with columns "Nr" (number of the expression), "expression"
Assessment	Subtractive for every expression.
Assurance	The mathematical expression can notice with help of the class Math and the operators. The mathematical expression does not contain symbols like sum, product, minimum, maximum, exist or for all. The variable-names have only one letter.

TABLE VI. SUB OPERATORS

Math. Expression Example	C# Expression	Contraction
Comment		
(...)	(...)	Parenth
Parenthesis are taken from the mathematical expression		
Parenthesis are every times use as pair.		ParenthPair
Parenthesis are every time round parenthesis because we do not use array-element-access		Parenth-Round
xy	x * y	ProdExpr
The multiply sign must be used at a product.		
$\frac{x+1}{x+2}$	((x + 1) / (x + 2))	QuotExpr

¹² In case the solution is exchanged with the given information a reverse task type can be described where the students need to identify a mathematical expression from a given programming expression. We call this task type RIMExpr: Reverse Implementation of Mathematical Expression.

Math. Expression Example	C# Expression	Contraction
Comment		
The nominator and the denominator of a quotient must be put into parenthesis. The quotient must be put into parenthesis if an operator of same or higher priority stands besides the quotient on the left or right.		
$1.2 \cdot 10^{23}$	1.2E23	ScientificLit
$\frac{1}{n}$	1.0 / (double)n	QuotIntExpr
If we have a quotient of int-expressions then we have to use the conversion into double-expressions. This is dangerous because we know that it isn't necessary in this strict form. The quotient must be put into parenthesis if an operator of same or higher priority stands besides the quotient on the left.		
$\ln x$	Math.Log(x)	Func
At a mathematical function the argument must be put into parenthesis.		
$ x $	Math.Abs(x)	FuncAbs
\sqrt{x}	Math.Sqrt(x)	FuncRoot
e^x	Math.Exp(x)	FuncExp
x^y	Math.Pow(x, y)	FuncPow
$-x^y$	-Math.Pow(x, y)	FuncNegPow
The negation of power is done after calculation of power.		
x^{y^z}	Math.Pow(x, Math.Pow(y, z))	FuncPowPow
The power of power is calculate by calculation of the inner power first.		
$\ln^2 x$	Math.Pow(Math.Log(x), 2)	PowFunc
The power of a mathematical function in a mathematical expression we find after the name of the function and we have to use it after the result of the function.		
$\sin xy$	Math.Sin(x * y)	FuncProd
The product with a variable or literal "extends" the use of the mathematical function.		
$\sin x \sin y$	Math.Sin(x) * Math.Sin(y)	ProdFunc
The product with a mathematical function doesn't extend the use of the mathematical function.		
$\sin x + y$	Math.Sin(x) + y	FuncSum
The sum doesn't extend the use of the mathematical function.		
$x = y$	x == y	EqualExpr
$x \neq y$	x != y	
$x \leq y$	x <= y	RelatExpr-Simple
$1 \leq y \leq 4$	1 <= y & y <= 4	RelatExpr-Complex
The behind each other execution of relational expressions of double expressions are divide into two part which are connected with the operator &. The complex relational expression must be put into parenthesis if an operator of same or higher priority stands besides the expression on the left.		
$\neg p$!p	LogNot
$p \wedge q$	p & q	LogAnd
$p \vee q$	p q	LogOr
$p \vee r = q \wedge r$	(p r) == (q & r)	LogVgl
For an equality expression of bool-expression we have to use for the left and the right side parenthesis.		
$\begin{cases} -x, x < -1 \\ x, \text{sonst}; d.h. x \geq -1 \end{cases}$		CondExpr
$x < -1? -x: x$		

Math. Expression Example	C# Expression	Contraction
Comment		
The conditional expression with the operator ? has exactly three operands, the operand 0 before ?, the operand 1 after ? and the operand 2 after.. The condition after otherwise we do not realize.		

a) Remarks:

The rules for solving this problem algorithmically were identified with the help of the software program Scientific Workplace. Unfortunately, we can't afford using this software for our classes.

The rules of evaluation are very strict and inspired from the fact that a mathematical expression is a tree. To avoid ambiguous trees we prohibit commutativity, associativity as well as distributivity because they all lead to equivalent expressions but completely different trees. This, again, demonstrates a difference between mathematics and programming where rules for term transformation doesn't apply.

b) Example: IMExpr: Expressions 00

Variable ranges

In: bool p; bool q; double x; double y;
Out: basic-value-type

Nr	Mathematical expression
1	$\frac{2y}{x+1}$
2	$2 \frac{y}{x+1}$
3	$\sin^2 x^6 y + 1$
4	$\neg p \wedge \neg y \leq x + 1 \leq 3 + y$

Solution ►

Nr	Expression
1	<code>2 * y / (x + 1)</code>
2	<code>2 * (y / (x + 1))</code>
3	<code>Math.Pow(Math.Sin(Math.Pow(x, 6) * y), 2) + 1</code>
4	<code>!p & (-y <= x + 1 & x + 1 <= 3 + y)</code>

◀

D. Level 4: Analyze the Correctness of an Implementation

1) Correction of the Implemetation of a Mathematical Expression with Errors (CIMExpr)

TABLE VII. DESCRIPTION OF THE CORRECT IMPLEMENTATIONS OF MATHEMATICAL EXPRESSIONS WITH ERRORS TASK TYPE.

Property	Details
Competency	Correction of implementations of mathematical expressions with errors ^a .
Level	4 (analyze)
Given	Variable ranges, mathematical expressions, expressions
Main operator	If in the implementation of a mathematical expression you find an error then correct the error and give the name of the sub operator which isn't correct used. If in the implementation of a mathematical expression you could not find an error then write down the expression again.
Sub operator	see IMExpr
Solution representation	Table with columns "Nr" (number of the expression), "expression" (expression without error) und "sub operator"

Property	Details
Assesment	Subtractive for every expression.
Assurance	see IMExpr The expressions only contain maximum one error

^a. Syntax- or semantic errors may occur.

a) Example: CIMExpr: Expressions 01

Variable ranges

In: bool p; bool q; double x; double y;
Out: basic-value-type

Nr	Mathematical Expression
1	$\frac{2y}{x+1}$
2	$2 \frac{y}{x+1}$
3	$\sin^2 x^6 y + 1$
4	$\neg p \wedge \neg y \leq x + 1 \leq 3 + y$

EXPRESSIONS WITH MAXIMUM ONE ERROR

Nr	Expression
1	<code>2 * y / (x + 1)</code>
2	<code>2 * y / (x + 1)</code>
3	<code>Math.Pow(Math.Sin(Math.Pow(x, 6) * y + 1), 2)</code>
4	<code>!p & (-y <= x + 1 <= 3 + y)</code>

Solution ►

Nr	Expression	Sub Operator
1	<code>2 * y / (x + 1)</code>	
2	<code>2 * (y / (x + 1))</code>	QuotExpr
3	<code>Math.Pow(Math.Sin(Math.Pow(x, 6) * y), 2) + 1</code>	FuncSum
4	<code>!p & (-y <= x + 1 & x + 1 <= 3 + y)</code>	RelatExpr-Complex

◀

E. Level 5: Evaluate (optimize) a Given Expression

1) Optimize Expressions with Parenthesis (OPEXpr)

TABLE VIII. DESCRIPTION OF THE OPTIMIZE EXPRESSIONS WITH PARENTHESIS TASK TYPE.

Property	Details
Competency	Optimize the number of parenthesis
Level	5 (evaluate)
Given	expressions
Main operator	Find an expression with a minimal number of parenthesis which has the same expression tree as the given expression.
Sub operator	ExprTree
Solution representation	Table with columns "Nr" (Number of the expression), "Expression" (Expression with the same expression tree)
Assesment	Subtractive for every expression.
Assurance	The Expressions are correct.
Notes	There are expressions, where it is impossible to delete parentheses.

a) Example: OExpr: Expressions 02

Nr	Expression
1	<code>((2 * y) / (x + 1))</code>
2	<code>(2 * (y / (x + 1)))</code>

Solution ►

EXPRESSIONS WITH NUMBERED PARENTHESIS

Nr	Expression
1	12 2 3 31 ((2 * y) / (x + 1))
2	1 2 3 321 (2 * (y / (x + 1)))

SOLUTION

Nr	Expression
1	2 * y / (x + 1)
2	2 * (y / (x + 1))

◀

V. SUMMURY AND FUTURE WORK

Mastering expressions in such a way that they can be transferred from their mathematical representation to a programming representation is an important prerequisite engineers need when learning programming. Firstly, we showed that a competence can only be operationalized (observed and measured) with the use of competence-oriented tasks (objective and reliable understood and assessed, valid concerning their corresponding competence). In terms of expressions the procedure of creating such tasks has been demonstrated focusing on the explanation of the resulting task types, which include at least on example. It has been found that problets are an excellent tool to address at least two competence levels. However, the amount of research in the field of operationalizing programming skills deeply is still too limited.

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The Issues of Adopting Simulation Games in Software Engineering Classes

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Abstract – Previous researches have pointed out that simulation games can be an effective tool for enhancing the students' motivation to learn and understand complex subjects. Although the decision to use a simulation game is made mainly by the instructor, the students' perceptions are also important in order to support its usage. The increasing interest in educational simulation games motivates us to investigate relevant factors that influence the adoption of simulation games in Software Engineering courses. Based on a theoretical adoption model and on the evaluation of a specific simulation game, we identified crucial aspects beyond the ones usually considered, such as incorporating more industrial settings phenomena and pedagogical elements. These aspects are not always considered in Software Engineering simulation games, as we identified after an evaluation. Therefore, we concluded that this class of simulation games does not address suitably the adoption attributes that we found relevant.

Keywords—simulation games; software engineering; adoption

I. INTRODUCTION

When we analyze the Software Engineering educational field, nearly every approach to teaching this subject is based on lectures and work group projects. However, judging from the dissatisfaction of industrial organizations [1], [2], it seems that these approaches are not sufficient for preparing future software engineers. In this field, simulation games represent an opportunity to present relevant concepts to the students.

Interest in using simulation games for educational purposes has steadily increased in the past years [3]. Researchers have pointed out that attracting and sustaining students' engagement and improving pedagogical outcomes are key rationale for using these games [4], [5]. The benefits of using a simulation game approach to education include, among others, practicing skills, improving critical thinking, and developing social abilities [6], [7], [8].

In the Software Engineering field, simulation games are commonly used for enhancing and reinforcing the learning and understanding of complex themes such as software processes [9], [10]. This complexity is represented by intrinsic software development characteristics such as

multiple feedback loops and the cause-effect delays [11], [12].

Simulation games in a Software Engineering curriculum suitably fits as a complementary component to lectures, projects, and readings [6], [13]. Our previous experience has demonstrated that it is important to use simulation games complementary to other educational techniques, which should be accompanied by an adequate amount of direction and guidance given to the student [7], [13].

Despite the learning potential of simulation games and the increasing interest on them, their adoption in a formal educational context remains limited [14]. This study investigates the potential factors that influence on the simulation games adoption in the academic environment.

Using a theoretical adoption model, we identified the determinants for the game adoption considering different perspectives. In order to verify the model applicability, we analyzed a specific simulation game, SPIAL [15], collecting information related to each adoption attribute and comparing them with findings in other simulation games. SPIAL is a graphical and interactive simulation game that we developed with the aim to improve Software Engineering education in dealing with the complexity of what happens in a software development organization. We evaluated SPIAL using three methodologies supported by a specific framework [13]: (1) Semiotic Inspection Method; (2) Experiment; and (3) User Test. The results have shown that crucial aspects were missing in the games' design, such as incorporating more industrial settings phenomena and pedagogical elements. This point was in agreement with a previous experiment involving students' answers and empirical observation [15]. This confirms the need to address more suitably the adoption attributes in the development of games.

The remainder of this paper is structured as follows. Section 2 outlines a discussion about the main aspects presented in this article. Section 3 describes the methodology used to evaluate the simulation games. Section 4 presents the results and Section 5 presents a discussion of them. Section 6 concludes the paper with the final considerations and future work.

II. BACKGROUND

In this section we present: (A) a discussion of adoption models from Information Technology domain and from the simulation games domain; (B) some results related to a literature review of Software Engineering simulation games; (C) the simulation game, SPIAL, used to collect detailed evidence of the discussed adoption model; and (D) a specific evaluation method used with SPIAL.

A. Technology Adoption in the Classroom

According to De Grove and others [14], the adoption of simulation games can be suitably framed in the broader context of Information Technology adoption. In this context, the studies of Venkatesh and others [16] and Sabherwal and others [17] have examined the individual's adoption and continuance usage intentions. According to them, there is a consensus that adoption is impacted by the attributes of innovation, the individual characteristics, and other contextual factors.

When considering the range of adoption studies, it is clear that a multitude of determinants has been proposed to explain the user adoption behavior [14]. Integrating all these determinants in one model would be problematic since they address too broad requirements. However, considering the crucial role of different stakeholders in deciding to adopt a new technology, different perspectives should be taken into account, such as instructors and the school context [18].

In this work we employed three attributes [19] during our evaluations: *perceived usefulness*, *perceived ease of use* and *work compatibility*. *Perceived usefulness* refers to the perceived benefits of technology adoption. *Perceived ease of use* refers to how easily a technology is adopted. *Work compatibility* describes the fit between the technology adoption and the work environment. The first two attributes came from the most basic Technology Acceptance Model (TAM) [20]. This model has been widely employed in the field of technology and education [21]. It is a robust model that can be extended with additional factors. Since we are also interested in evaluating the academic context where the game will be incorporated, we also included the *work compatibility* attribute. According to Sun and Jeyaraj [19], *work compatibility* is a critical innovation attribute and contributes significantly to the intention to adopt.

B. Simulation Games Review

Through a Systematic Literature Review, we surveyed computer-based simulation games used for teaching Software Engineering subjects [13], [22]. The selected Software Engineering simulation games are depicted in Table I, with a description of methodologies used in their evaluations.

Table I shows that basically, we can divide the simulation games in two groups: those whose final goal is to develop a software project within a certain set of constraints, and their rules are based on the Software Engineering lessons, such as SESAM, SimSE, SimJavaSP, MO-SEProcess; and those whose final goal and rules are specific to each simulation game context (e.g. to manage a

project), such as, The Incredible Manager, SimVBSE, qGame and TREG. In most of the games, the evaluations have been preliminary and informal in nature. Exceptions include SimSE, SESAM and RCAG. These evaluations results helped us to collect evidence from the adoption attributes.

TABLE I. COMPUTER-BASED SIMULATION GAMES [13].

Game	Area/Role	Evaluation
SimSE [6]	Software Engineering concepts / Project Manager	In-class use / experiment with post-questionnaire / pre-post test experiment/ observational study
SESAM [23]	Software Engineering concepts / Project Manager	In-class use / pre-post test experiment and controlled experiment
The Incredible Manager [24]	Project Management / Project Manager	Experiment with post-questionnaire
SimJavaSP [25]	Software Engineering concepts / Project Manager	Experiment with post-questionnaire
MO-SEProcess [26]	Software Engineering concepts / Team member	In-class use
SimVBSE [27]	Value-Based Software Engineering / Project Manager	Not described ⁽¹⁾
qGame [28]	Requirements Engineering / Project Manager	Not described ⁽¹⁾
TREG [29]	Requirements Engineering / Workshop facilitator	Not described ⁽¹⁾
iThink [30]	Requirement elicitation / Requirement Engineer	In-class use
SimSys [31]	Software Engineering concepts / Software Engineering Student	Not described ⁽¹⁾
SDM [32]	Software Engineering concepts / People and Project Manager	Experiment with post-questionnaire
Ameise [33]	Software Project Management / Project Manager	In-class use
Venture [34]	Social factors, cultural and linguistic differences in GSD / Software Engineer	Interview with users
eRiskGame [35]	Risk Management / Project Manager	Not described ⁽¹⁾
RCAG [36]	Requirements Collection and Analysis / Several roles	Pre-post test controlled experiment

(1) The evaluation was not described in the research paper.

C. SPI Simulation Game

SPIAL [15] (*Software Process Improvement Animated Learning Environment*) is a graphical, interactive, and adaptable simulation game (Figure 1). The game goal is to improve the Software Engineering learning, using simulation. Several Software Engineering topics are explored within the context of a Software Process Improvement project. These aspects were based on CMMI-DEV version 1.3 [37]. CMMI was chosen because it is the most widely known SPI reference model. CMMI defines 22 process areas. Each process area consists of a set of goals and these must be implemented by a set of related practices in order to satisfy the process area. Levels in CMMI describe an evolutionary path recommended for an organization to improve the processes it uses. CMMI supports two paths (or defines two forms of representation) using levels. One path, Continuous, enables a selection of process areas customized to the organization goals. The other path, Staged, enables the improvement of a set of related processes by incrementally addressing successive sets of process areas [37]. Continuous representation is defined using capability levels while Staged representation

is defined using maturity levels. In SPIAL, the simulation model can be tailored to simulate continuous or staged improvements.

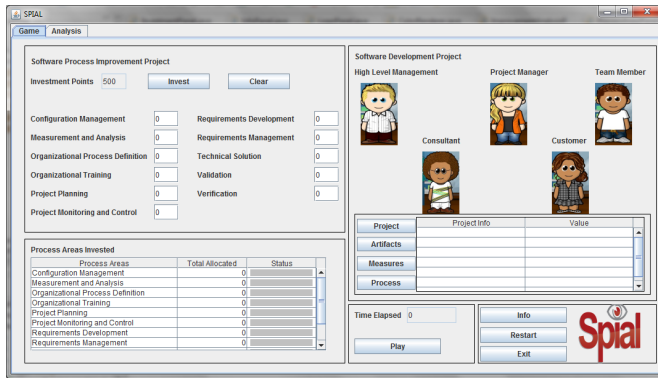


Fig. 1. SPIAL Graphical User Interface.

SPIAL was developed with the goal to provide students with a more realistic experience in software development processes within the academic environment. SPIAL allows students to practice SPI techniques and the best practices of Software Engineering. SPIAL is a single-player game in which the player takes on the role of a manager of an SPI group in a software development organization. SPIAL's scope covers both a development project and an improvement project. The player is given a process improvement task and he or she can interact with other stakeholders (high level management, project manager, team member, consultant, or customer) represented as non-player characters, i.e. a character controlled by the computer (see Figure 1). The type of improvement that is required is stated at the beginning of the game and it can include, for example, cost and defect reduction and productivity improvement. In order to complete the task, the player can make investments for improving specific process areas of a software development project. A good investment strategy will result in improvement of process areas and a bigger budget for further investments. The player can visualize project estimations, indications of process areas capability level and decide in which process areas to invest. During the development project, the player can visualize the effects of his/her selections on the outcomes (productivity, defect, cost, and time-to-market measures) and, if needed, change his/her investments. The final outcome is a score that represents how close the results are to the initial proposed target. During the game, the non-player characters communicate the effects of the player's actions through bubbles over their heads.

D. Semiotic Inspection Method

The Semiotic Inspection Method [38], [39] has been proposed within the Semiotic Engineering theoretical framework. Semiotic Engineering perceives HCI (*Human-Computer Interaction*) as a designer to user metacommunication. That is, a twofold communicative process, because the designer to user communication is achieved through user-system communication.

The system's interface is a complete and complex message sent from designers to users. This message is formed by signs. According to Peirce [40], signs are anything that stand for something (else) in someone's perspective. The message conveys to users the designers' understanding of whom the users are, what problems they want or need to solve and how to interact with the system in order to achieve their goals. This designer-to-user communication is indirect, since users understand the intended message as they interact with the interface. When users do not understand aspects of this message, a communication breakdown takes place [38].

Semiotic Engineering theory classifies the signs in an interactive system into three classes of signs: metalinguistic, static and dynamic [39]. Metalinguistic signs are signs that refer to other interface signs. They are instructions, tips, online help, error and informative messages, warnings and system documentation. Static signs express and mean the system's state; they are motionless and persistent when no interaction is taking place. Dynamic signs express and mean the system behavior. Their representations unfold and transform themselves in response to an interactive turn.

The Semiotic Inspection Method (SIM) [39] examines the designer's metacommunication that users are exposed to as they interact. The goal is to identify communication breakdowns that may take place during the user-system interaction and to reconstruct the designers' metamessage being conveyed by the system. To do so, the evaluator analyzes the message being transmitted by signs at each level.

This method is carried out in five distinct steps [39]: (1) an inspection of metalinguistic signs; (2) an inspection of static interface signs; (3) an inspection of dynamic interaction signs; (4) a contrastive comparison of designer-to-user metacommunications identified in steps (1), (2), (3); and finally (5) a conclusive appreciation of the quality of the overall designer-to-user metacommunication. At the end of steps (1), (2) and (3), the evaluator reconstructs the metamessage being conveyed by signs at that level, filling out the template of the designer to user communication. The evaluator also identifies potential communicability problems that may take place at that level. In step (4) the evaluator contrasts the metamessage generated in the previous steps and checks for inconsistencies or ambiguities among them. It is not expected that the messages generated by each sign level to be identical, but they should be consistent. Finally, in step (5), the inspector reconstructs a unified metacommunication message, judging the costs and benefits of communicative strategies identified in previous steps, and generates the evaluation report.

III. METHODOLOGY

For our work, we contrasted and compared the development and application of SPIAL with evidence collected from other simulation games. Our aim is to identify aspects that influence on the game adoption in a Software Engineering course.

Drawing an analogy with the software development processes, the game development can be structured in the following stages: problem conception, development and validation. We collected data related to these three stages in order to achieve our aim.

1) **Problem conception:** We collected additional information concerning concepts related to industrial practices and pedagogical elements [8] (discovery, practice, competition, critical thinking, goal formation and completion) employed in the game definition. These factors represent aspects that instructors may use during their lectures. In addition, we searched for information that would identify who participated in the game conceptual definition. The innovation aspects were also considered as they are important for the verification of the work compatibility attribute.

2) **Development:** Since our goal is to evaluate factors that ease the simulation game adoption, we focused more on interaction aspects than on implementation issues. In this stage, we collected information regarding the graphical user interface, focusing on elements that motivate and promote students' engagement and learning. In addition, we identified the proposed integration possibilities of the simulation game with the lectures, for instance, whether it is given an introductory explanation about the game, or whether there is an analysis of the achieved results together with the students. They are important for the verification of the work compatibility and perceived ease of use attributes.

3) **Validation:** Specific validation techniques, such as experiments are valuable tools for all practitioners who are involved in evaluating and choosing between different methods, techniques, languages and tools [41]. We identified which stakeholders were involved in the validation step, the methodologies used to validate, and whether the expected results were achieved. This information is important to define the work compatibility and perceived usefulness. Table II lists the mapping between the information collected and the innovation attributes.

For our data analysis, we extracted text containing information, presented in Table II, from SPIAL and other simulation games studies. The evidence developed in this research rests mainly on the identification and analysis of this information. Reliability and validity are dependent on the careful analysis of the research papers.

TABLE II. MAPPING ATTRIBUTES.

Innovation attribute	Information collected
Work compatibility	Concepts, pedagogical element, integration with the class, stakeholders involved in the problem definition and in validation.
Perceived usefulness	Benefits and stakeholders involved in validation.
Perceived ease of use	Integration with the class, and graphical user interface.

IV. RESULTS

In this section we describe our empirical findings. We detailed in each section the findings related to SPIAL comparing with findings related to other simulation games, which were presented in Table I.

A. Problem conception

During SPIAL development we were concerned about representing situations close to the reality of the industrial environment. Therefore, we investigate the domain of our simulation game. Through a literature review, we gained an up-to-date view of the SPI area, allowing us to identify and characterize the actual results of SPI initiatives. In addition, we collected 57 Software Engineering rules from textbooks and other Software Engineering simulation games. Both rules and industrial practices were used to represent the game behavior, to teach the best practices and to calibrate the simulation model.

Comparing SPIAL with other games, we observed that in some of them, such as SESAM, SimSE and MOSEProcess, the rules are also based on Software Engineering lessons. However, we did not find a detailed investigation about the industrial practices as in SPIAL. Other observation is that the game designers, in most cases, were involved with the Software Engineering course, such as in Deliver!, SimSE, and SESAM and there were no deep investigation whether the game meets the needs of other educational environments. The designers locally tried to propose a solution to their lectures, which were mainly based on their feelings and experience.

Analyzing the pedagogical elements we observed that these games have a considerable number of common aspects. The designers supposed users using a "trial and error" strategy, since the signs presented at the interface are limited in their message communication. The players discover the knowledge as they play the game, critically thinking about their decisions. In addition the goal is clearly stated at the game beginning. The competition is not well explored; one counter-example is qGame that presents a ranking of the best players. Only few games, such as The Incredible Manager and SimVBSE, do not use score as an evaluation tool.

B. Development

The games' interfaces were, in general, quite simple, employing basically static elements, such as in SPIAL. Exceptions include the Second Life games, such as MOSE-Process and TREG. In the set of the analyzed games, we found essential features that enhance motivation and, in consequence, the effectiveness of learning which are: not too easy nor too difficult life-like challenges (e.g. constraints on budget, defects, and time); interaction; a mechanism that provides feedback from the other team members (e.g. dialogues); graphical representation; and some indication of performance (e.g. score). Not all games presented random events, but this is also an important feature to enhance challenge and in consequence motivation. Few games provide some adaptation features

(e.g. SimSE, SPIAL, and The Incredible Manager), this is due to the complexity of design and interaction of the learning environment. qGame is an example of game which allows different levels of difficulty.

When considering the initial training, SimSE differs from other simulation games. SimSE designers provided supporting materials, including video tutorials and manuals to different stakeholders. Unfortunately, none of the assessed simulation games provided any guidance for carrying out the revisiting session which is generally referred to as debriefing sessions [42]. When executing a debriefing session, it is possible to evaluate how close the players' performance is to the target and what is needed to bridge this gap.

C. Evaluation

As presented in Table I, the evaluations mostly have been preliminary and informal in nature – SimSE, SESAM and RCAG are exceptions. However, even with these informal evaluations, there is some indication of their learning effectiveness. In SPIAL, we used the student appraisal, like in the other games, but we also brought other evaluation techniques. Part of our approach was inspired by SimSE, since it is an example of simulation game that more extensively evaluated the learning process it promotes.

We evaluated SPIAL using three methodologies supported by a specific framework [13]: (1) Semiotic Inspection Method; (2) Experiment; and (3) User Test.

C.1 Semiotic Inspection Method

An inspector conducted the first evaluation of SPIAL, carrying out the technical application of SIM. In this case, the inspector scenario is a student playing SPIAL.

After conducting all SIM steps, a unified analysis was produced, highlighting the main communication breakdowns. The analysis of SPIAL showed that getting the whole message is the result of "trial and error" interaction. A number of feedback information was presented during the whole game, such as measurement charts and improvement analyses. However, important aspects to understand the core behavior were missing, such as the reason why sometimes investments do not produce any improvement. In addition, some interface improvements should be done to allow a better interaction, moving elements from the analysis tab to the main tab. We produced a new game version, with some modifications, in order to provide more guidance to players. A more elaborated interface design was left as a future work; we only made changes related to feedback with the aim to release, as soon as possible, a new game version for the experimental activities.

C.2 Experiment

We carried out two experiments with undergraduate students of a Software Engineering course. The Software Engineering course at the Department of Computer Science at Federal University of Minas Gerais, Brazil, is taught in one semester (60 hour class).

In the first experiment our aim was to gain a better understanding of SPIAL effectiveness as an educational tool. We also determined the strengths and weaknesses of SPIAL through the feedback of the students who played it. We recruited 12 undergraduate Computer Science students to participate in this pilot experiment (one student gave up, leaving us with 11 students). In both experiments, students had a previous training about CMMI and basic Software Engineering concepts in the undergraduate course. Since this experiment was conducted during the beginning of the semester, we decided to give a brief training session in order to reinforce these concepts. This training session took 30 minutes. Then each student answered a background and a pre-test questionnaire, before playing SPIAL, and a post-test, after playing it.

On average, students found the game quite enjoyable and they had fun during the game play. They also felt that the game duration is appropriate and it is relatively easy to play. They agreed about adopting this game in a Software Engineering course as a complementary approach. They moderately learned new concepts; however, they felt this game is more successful in reinforcing concepts taught in Software Engineering course than teaching new concepts.

This pilot experiment showed that SPIAL does indeed seem to have potential to be a useful tool in teaching Software Engineering. The students' opinion gave us a valuable guidance about the ways that SPIAL needed to be enhanced.

In the second experiment, we applied UGALCO framework [13] in order to evaluate the game experience, adaptivity, learning experience and usability dimensions. We structured the experiment in the same way as the first one. In total, 16 students participated in this experiment and 15 completed. The students' answers were mapped to a value range $R = [0,1]$, where a "strong negative" is encoded as "0", a "weak negative" as "0.25", undecided as "0.5", "positive" as "0.75", and a "strong positive" as "1". The Communicability was evaluated through the SIM application. The learning experience was also evaluated through specific questions about SPI knowledge. These questions were organized according to the Bloom's Taxonomy [43]. This set of questions was presented to the students in a pre and post test format. One example of SPI question presented in both tests is: *List three metrics that can be used to monitor a Software Process Improvement initiative (Bloom's category: Knowledge on the remembering level)*. Table IV presents the average results.

The highest scored attribute was the learnability, i. e. the students understood how the game play works. The least scored was the learning goals, in which students were able to reinforce concepts presented in the lectures. Thus, they felt that they did not gain a great amount of new knowledge.

When we evaluated the number of correct SPI answers in the pre and post test, there is no statistical difference, i. e. we were not able to track the real learning effect considering this kind of evaluation.

TABLE IV. AVERAGE RESULTS FOR UGALCO'S ATTRIBUTES [13].

Dimension	Attribute	Avg.
Game Experience	Challenge	0,5
	Competence	0,7
	Immersion	0,7
	Positive affect	0,7
Adaptivity	Cognitive and motivational aspects	0,6
Learning Experience	Learning goals	0,5
	Content appropriateness	0,6
Usability	Operability	0,5
	Understandability	0,6
	Learnability	0,8
	Attractiveness	0,5
	Satisfaction	0,6

A. User Test

Although the first two evaluations provided us important data, the insight gained into an individual student's play process was limited to questionnaires. Therefore, we conducted a simple user test, where two students were observed and then interviewed about their experience.

The user test occurred in a one-to-one setting – one subject and one evaluator. As corroborating with the previous experiments, both students reported that they reinforced SPI concepts playing SPIAL, but they were not sure about what new concepts were presented to them. They failed in achieving the game goals in their first attempt. After the completion of one failed game, they hurriedly and eagerly started a new one with the aim to succeed. At the end, we observed that they came with similar new knowledge about the game strategy.

One student reported that he was not anymore challenged and interested in playing the game after discovering its fixed rules and behavior. Both students indicated that some functionalities, providing quite important feedback, were not easy to find, and they suggested interface redesign. They agreed that they learned using the strategy of “trial and error”. They were engaged when playing SPIAL. This was evident in their body language and their comments during the game play. Both students agreed about adopting SPIAL in a Software Engineering course as a complementary approach.

V. DISCUSSION

We had collected some indications that can help verifying the issues of adopting the Software Engineering simulation games. This analysis is based on the results presented in the previous sections and it is focused on the adoption issues. We structure our results in the findings described below: (F1) restricted number of represented industrial settings phenomena; (F2) lack of academic context analysis; (F3) insufficient evaluation; (F4) restricted interface elements; (F5) insufficient representation of pedagogical elements; and (F6) lack of supporting material.

F1: The main goal of simulation games is to bring to the classroom the use of highly-realistic simulators to illustrate to students, using real world data, the phenomena of Software Engineering working practices. As we pointed out, there was no comprehensive investigation of industrial phenomena with the aim to incorporate the latter in these

games. In SPIAL, we identified the core virtual world processes from the analysis of SPI initiatives reported by organizations in research papers. In most of the research studies, it was not defined the improvement context. This brought some difficulties during the reuse of information and restricted the number of phenomena represented into the simulation game. We observed this problem when we conducted the validations. Students were undecided regarding some aspects of SPI initiatives presented in SPIAL, in some cases they felt that they learned only basic new concepts (i.e. not advanced concepts) of SPI, and some students reported that they only learned the basics about the industrial settings of SPI initiatives. When analyzing the causes of this limitation, we were hindered by the difficulty to find Software Engineering data in the literature or with appropriate quality level. Even when available, industrial data are often noisy.

F2: Prior to any simulation game development it would be interesting to analyze the academic context where they would be incorporated. This includes the analysis of the instructors', universities' and students' needs. As we observed, this analysis was quite superficial or non-existent in the Software Engineering simulation games. In SPIAL development, for example, we have studied the common mistakes of students in the team-based projects and the instructor impressions of the students' main difficulties. In general, more investments are needed in order to define the game context, which facilitates the analysis of the game play benefits.

F3: There are different perspectives involved in the game design and development that should be suitably addressed during the evaluation. In our previous discussion, we identified: (i) different stakeholders (instructors, designers and students) needs and expectations; (ii) generalization of the game usage, i.e. evaluation in other contexts (e.g., universities, classes); (iii) improvement of the game evaluation *per se*, e.g. carrying out formal experiments; and (iv) performing the evaluation after the game play, using, for instance, the debriefing sessions. These additional experiments and evaluations are important to verify the potential of the simulation games as educational tools.

F4: It is common for the simulation games to have graphical user interfaces in which the simulated physical surroundings are displayed, creating a fun, game-like atmosphere. Most of the games employed static and simple elements in their design. In SPIAL's evaluations, a better interface design was pointed out as an improvement opportunity. Additional enjoyment, motivation and engagement can be achieved using more sophisticated game features and dynamics. This will ease the learning about a particular Software Engineering process, making it more memorable, and hence, more effective.

F5: An analysis of the pedagogical elements should be considered an important step during the game development. In SPIAL, we did not address this task in a suitable way, reflecting in some negative feedback during the experiments. This is also true for the other simulation games. Valuable areas of research include the improvement

of the learning evaluation mechanisms, and evaluation of the effects of competition and communication among players.

F6: Developing a new simulation game involves not only the creation of the software but also development of supporting material. As we discussed above, it is not usual among the analyzed Software Engineering simulation games to have this type of documents, including tutorials, manuals, and supporting web pages. This impacts directly on the adoption of the game in wider and diverse contexts.

In general, these games did not address suitably the adoption attributes that we found relevant, highlighting that there are still important aspects to be researched and enhanced in the field of Software Engineering education and simulation game development.

VI. CONCLUSION

This work presented a study of the challenges and opportunities for adopting simulation games in Software Engineering classes. We analyzed a specific simulation game, SPIAL, collecting information related to adoption attributes in different development stages. The adoption model covers three attributes: perceived usefulness, perceived ease of use, and work compatibility. Finally, we compared the findings with evidence collected from other Software Engineering simulation games.

Our experience with this study has highlighted some important aspects that can be used to enhance the field of Software Engineering education and simulation game development. The most concrete result is the set of issues that emerged during our analysis. These issues can guide new developers and instructors in the design and selection of educational simulation games. It was identified: (i) the restricted number of represented industrial settings phenomena; (ii) the lack of academic context analysis involving instructors', universities' and students' needs; (iii) insufficient evaluations of (iii.1) different stakeholders perspectives, (iii.2) of the game itself and (iii.3) after the game play; (iv) restricted elements used in the interface design; (v) insufficient representation of pedagogical elements; and (vi) lack of supporting material.

As a future work, we plan to address some of these issues in the SPIAL environment, mainly incorporating other phenomena that happen in the industry and improving the supporting material and interface design. We will also propose a game development process that will incorporate the issues that we found relevant.

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Digital Lockdown: A 3D Adventure Game for Engineering Education

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Abstract— Gaming in education has gained a great deal of interest for its potential positive impact on student learning. Video games can be a powerful learning tool, with the potential of reaching a wide range of people with diverse learning styles. Students in today's college classroom are known as 'digital natives'; those who grew up with technology all around them (cell phones, laptops, and tablets). These students often know more about technology than their parents and teachers. Games have a positive impact on how young people learn complex things. Content, skills, creativeness, and system thinking are just a few things that can be learned from games. This paper focuses on the design and implementation of a 3D educational game for deployment on the PC and Mac. Currently, no truly 3D games are available that focus on teaching core concepts in Digital Logic Design or Electrical and Computer Engineering concepts in general. This work presents an overall design and implementation of an educational 3D adventure game to address Number Systems, Boolean algebra, and Combinational and Logic Design in the scope of the Electrical and Computer Engineering curricula. Digital Lockdown is a game, developed in Unity 3D, that takes place in an outer space engineering research facility. The research facility has been placed on digital lockdown due to an experiment gone wrong and the player must use his/her knowledge of digital logic to override the lockdown protocols. The player is faced with tasks that help assess basic knowledge of digital logic. The game also contains learning zones where the player can go in order to learn the information needed to complete the tasks.

Keywords—*Engineering education; serious games; digital design; games in education*

I. INTRODUCTION

In the education arena, 'gaming in education' has gained a great deal of interest for its promising positive impact that it can have on students. The natural behavior of the way students learn has changed with the rapid advancement of new technologies over the last few years. In most cases, if not all, students learn the best when they are motivated and have an interest in the subject matter. It is rare that a student will like every subject that s/he is taught, however, by introducing the subject matter in the form of a game, a motivation to learn can be created.

The teaching methods often used in the higher education system include lectures and lab classes. The method that is used most often is lectures [2]. Jeremy Schneider, author of the book "Chalkboard: What's Wrong with School and how to Fix It", stated that it is "now possible to teach students effectively and respectfully. Advances in technology allow for personalized instruction, fascinating content, direct immersion in learning, immediate feedback, and the opportunity for mastery. Yet modern education ignores this potential, leaving classrooms essentially unchanged for more than a century." [1]

In a typical lecture, a teacher will stand in front of the class teaching while the students sit and take notes. One problem with this method is one teacher cannot meet the needs of all students for various reasons beyond the teacher's control. Students in the same class may not have the same learning style as others. This can cause some students to learn at a slower pace while others to learn at a faster one. To compensate for this, instructors sometimes try teaching at a medium pace. However, when this is done the students who learn at a slower pace start to fall behind and the students who learn faster become bored and lose focus [1]. This makes it hard for "lectures to meet the optimal learning pace of all students because one teacher cannot deliver dozens of customized lessons simultaneously [1]."

Bill Gates, the chairman of Microsoft, made an interesting statement at the 2005 National Education Summit address on high schools. He stated [3], "Training the workforce of tomorrow with the high schools of today is like trying to teach kids about today's computers on a 50-year-old mainframe. It's the wrong tool for the time." The way students learn has evolved to a point where traditional teaching methods of sitting in a lecture room for hours at a time listening to a professor talk and taking down notes are no longer ideal. Students are failing to retain the information presented to them in the classroom and sometimes divert their attention to more entertaining things such as their mobile devices.

During a summit on Educational Games, held by the Federation of American Scientists, the Entertainment Software Association, and the National Science Foundation, approximately 100 experts were called to discuss games in education [4]. It was proposed that "people acquire new knowledge and complex skills from game play [4]." These

discussions among others have presented a need for the development of games for education. These games need to be both educational and entertaining at the same time. Edutainment is a term that has been coined to describe content that is designed to educate and entertain at the same time. Digital Lockdown is a game designed to be just that, an edutainment experience for engineering students.

II. BACKGROUND

Many different types of games exist, however, they all fall into two main categories, 'Games' and 'Serious Games'. A game can be defined as "A system in which players engage in an artificial conflict, defined by rules that result in a quantifiable outcome [5]." Some characteristics that make up a game are achievable goals and rewards.

In digital games, which is the focus of this work, there are goals that the player or players are trying to reach. "The act of achieving goals is rewarding and reinforces actions that allow individuals to continue completing goals [6]." Achieving goals can be anything such as completing a game or unlocking new content in a game. This cycle of completing goals and being rewarded can keep a player engaged for hours on end [6].

According to Digital Marketing Ramblings [7], each month, approximately 263 million people play Angry Birds. This is just one of many games played daily worldwide. Games can be fun, engaging and sometimes addictive and have the ability to reach a lot of people. Some research has been conducted to assess the use of games in education. More needs to be done. Presented below are data and sample research findings that help present the case for the need for games in higher education, especially in engineering education.

A. The Status of Games in Education

In 2014, the Entertainment Software Association (ESA) conducted an industry survey where 59% of Americans were found to regularly play video games, 32% of which are between ages 18 and 35 [8]. Another significant statistic is that 53% of Americans who own a device to play games on, do so using a smartphone, and 41% play games using a wireless device [8]. Game sales have also been on the rise. In 2013, consumers spent more than \$20 billion on digital games. This number is expected to grow even more in the upcoming years [9].

Using games in education has been traditionally employed in the K-12 arena [10], [11], [12]. Higher education has been lagging behind despite the fact that digital natives have been in college classrooms for years. A Study by the National Association of Advisors for Computers in Education (NAACE) was conducted involving 800 students at Long Field Academy to see the effect of mobile devices used in education. Apps from the Apple App Store that pertained to the subject matter of a class were used on the iPad by students as an aid to help understand basic concepts of the subject matter. These apps included graphing apps for math, GarageBand for music, Brushes finger painting app for art, and many more. Students were able to communicate directly with the teacher from the iPad through email [13]. The results showed that 69% of the

students felt more motivated to learn and the average grade for students had improved.

Some work has been conducted in the higher education area [15] [16] where professors have seen the positive effect video games can have on education. In a report from McGraw-Hill Education, "Gaming has been one of the most popular trends in education in recent years. While all students have their own unique and preferred style, learning by actively engaging with a subject is a learning method shown to appeal to a large number of today's students [16]." McGraw education released a game called "Government in Action". This game has proven very useful in the classroom and is gradually being accepted by students with more than 750,000 students playing each year. One professor, Jason Seitz, who uses the game in his classroom, says "Government in Action helps my students tie all of the concepts in my course together to develop a deeper understanding and knowledge of the subject [16]."

III. METHODOLOGY

Digital Lockdown is currently developed for the PC with implementation for mobile devices under development.

A. Game Design

Digital Lockdown is a 3D educational adventure game that takes place in an outer space engineering research facility. The research facility has been placed on digital lock down due an AI drone project gone wrong and the AI drones have taken over the space station. To make matters worse, the research facility is going to self-destruct and now the player must use his/her knowledge of digital logic to override the lock down protocols and escape. The game is designed to allow the player to practice solving problems dealing with number systems, Boolean algebra, and combinational logic design. There are learning areas throughout the game that the player will go to in order to learn the information needed to complete each task.

B. Game Characters

Digital Lockdown has various characters that the player will come across throughout the game. Some of the characters will be friendly and help guide the player along the journey. The characters involved in this game are as follows:

- Player (main) – the player is an Electronics Engineer conducting research at the Creative Gaming and Simulation (CGS) space station. The player is controlled by the user throughout the length of the game.
- CGS Drone, Patrol Bot, and Mine Bot (foe) – are artificial intelligence (AI) enemies that are trying to take over the space station.
- Commander Simmons (friend) – the commander of the CGS space station. His role in the game is to guide the player to the shuttle hangar.

C. Level Design

In Digital Lockdown the player goes through 2 levels: Level 1 "The Escape" and Level 2 "The Hangar." Throughout

level 1, there are a combination of experiences including learning, assessment, and gameplay that correspond to the overall story of the game.

Fig. 1 Digital lockdown level design

Level 1	Level 2
<ul style="list-style-type: none"> Number Systems Boolean Algebra Combinational Logic Circuit Design 	<ul style="list-style-type: none"> K-Map minimization Combinational Logic Circuit Design

Level 1 starts with the player in the living quarters of the Creative Gaming and Simulation space station. When the level starts, a prompt appears giving the player background information about what is going on and what s/he needs to do. Once the player enters a name and selects ‘start’, the level will begin.

The first object the player can interact with in the game is the learning table for number systems (Figure 2). At this table the player can learn/refresh basic knowledge of digital logic concepts. Each table that the player interacts with informs him/her about a different concept pertaining to digital logic. Topics covered are: Number Systems, Boolean algebra, KMap minimization, and Combinational Logic Circuit Design. When the player feels comfortable enough with number systems, for example, s/he can attempt to complete the various tasks throughout the game to escape from the space station. Once the player has completed all the tasks in level one and reaches the elevator to go to the hanger, level 1 will end and the player will be brought to a summary screen which provides gameplay feedback (Figure 2). After reviewing the summary, the player will be taken to level 2 (“The Hanger”) after selecting the “Next Mission” button.

The hanger level (Figure 3) is the last level in the game in which the player must complete the damaged circuit in the hanger control room in order to disable the self-destruct protocol within 10 minutes. To do this, the player must minimize the given Boolean expression using KMaps. After completing the assessment, the player will then have to fight his/her way to the hanger bay entrance to escape off the space station.

Fig. 2 Digital lockdown level design



Fig. 3 Level 2: The hanger (showing enemies)



IV. GAME PLAY

A. Assessments

Digital Lockdown is developed to include assessments as well as fun gameplay. While the player is going through the game and achieving goals/completing tasks, s/he has to fight back against the CGS enemies. These enemies (Figure 4) attack randomly which affects the player’s health score (Figure 5).

Fig. 4 CGS enemies



Fig. 5 Game screen showing score, menu, and messages



Figure 6 shows one of the assessments in the game – Binary Conversions. Every door the player has to go through includes this assessment. If the player does not provide the correct conversion, the door will not open and the player can try again. Conversion is entered by clicking the red and green lights above the door to create the binary combination in question.

Fig. 6 Binary conversion assessment



The binary conversion assessment is randomly generated however the truth tables and Boolean expressions used are randomly selected from a predefined list of questions.

B. 3D Content Interaction

The game provides a combination of 2D and 3D interaction in order to enter the responses to the digital design problems. Figure 6 shows the 3D interaction of clicking on the lights to enter a binary combination. Figure 7 shows the 3D KMap problem the player has to solve in order to escape off the ship. In order to enter a value in a cell, the player clicks on the cell and it rotates between blank, 0, and 1 values. The player then groups the cells (shown in Figure 7 by cell text turning green) and enters the minimized expression. Once the minimized expression is generated, the player can then build the circuit (Figure 8)

Fig. 7 Truth table information HUD for KMap problem

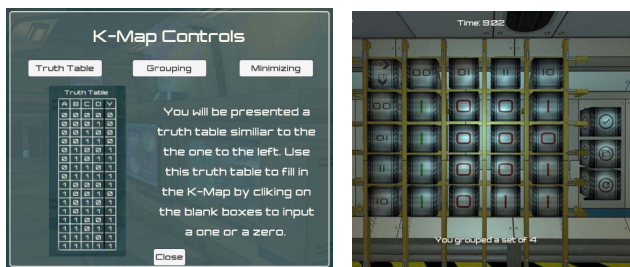
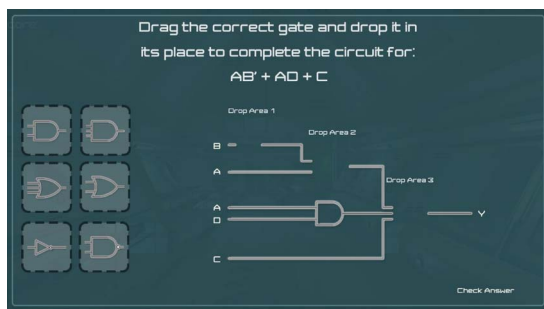


Fig. 8 Circuit design



V. CONCLUSION

A 3D adventure game comprised of two levels was developed using Unity 3D for use as a resource for Digital Logic Design. The game contains learning content, adventure gameplay, and assessment of learned content. Content and assessments are designed in both 2D and 3D interfaces. The game is designed to be fun while still incorporating education. Content includes decimal to binary conversions, Boolean minimization, KMap minimization, and combinational circuit design. Future work includes creation of gameplay using sequential logic and evaluating the game using the developed evaluation process. The game is expected to be formally evaluated in fall 2015 and spring 2016. Future work also includes converting the question generation for the remainder of the assessment to random generation of problems. This will involve a change in the script-based assessment to allow just-in-time assessment of textual input from the player's response.

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Evaluation of SiGMa, an empiric study with Math teachers

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Abstract—Gamification has achieved many positive outcomes in many fields, ranging from economics to education. This method consists in applying game concepts, mechanics and aesthetics in non-gaming applications, aiming to improve a person or group's engagement and commitment to perform a task. These concepts can range from extrinsic motivators as points, levels, leaderboards and achievements, to intrinsic ones as competition, cooperation, sense of achievement and decision making. It also have been proved that these concepts also aids in the construction and improvement of cognitive, social and emotional behaviour of a person or group. Based on the previous work of developing an online learning environment to aid in Math Lessons on basic education, this paper presents the evaluation of a Gamified Online System (SiGMa) focused on Math problems solving. The application contains a module that randomizes the values of the users' selected problems, which are divided in three areas (Arithmetic, Combinatorics and Geometry) in order to make them memorize the logic rather than answers when solving Math based questions. The system was also implemented with Gamification concepts to improve the engagement of students. The tests were applied with a group of 30 Math teachers that were exposed to the system for 3 consecutive months. Those professionals evaluated the usability and pedagogical properties of the Gamification concepts implemented within the application as: problem solving, correct classification, difficulty, context, engagement, reflection, support, interaction, visual interface, information, error recovery, message exchange. The tests also evaluated the relevance of each one of the implemented gamification concepts as: goals, rewards, points, levels, progress, time pressure, achievements, leaderboards, chances, renewal and relevant statistical information. The tests achieved positive results, above the average stipulated by the authors in the evaluation. The paper also present the preliminary tests that were made with a group of selected students, in order to test the systems' efficiency.

I. INTRODUCTION

The advent in IT area allowed the emergence of technologies to aid in the learning process. This emergence can be represented in the form of new Learning Objects [1] as Virtual Learning Environments and Game based learning methods [2].

The second one can be described as the use of digital games and its core concepts to aid in the learning process. Those concepts can be divided in groups, depending on the author, to describe the Ludification of Culture as stated by [3]: Use of games, game elements and playful interactions.

Among the Use of Games concepts is inserted the Gam-

ification concept. This consists in using gaming elements in non-game contexts [4]. This process is often used when the application, or method, focus at training or conducting an specific user behavior [5].

This concept is also useful when implemented within application since it provides statistical data [6]. This data can be used to enhance the gamification process, consequently improving the learning process. Even though, there is not a formalization of evaluation process in order to measure its efficiency [7].

Based on the above, this work aims to present the short term evaluation of the Gamified Math System, of [8], after a 3 months of use. This evaluation focus at verify the pedagogical properties of the system in order to prepare it to use within a classroom.

This work is divided as follows: Section II aims to explain some concepts related to game-based learning and games in education. Section III presents the gamification concepts. Section IV presents the implemented system and the method of evaluation of the study while section V presents the outcomes. Finally, section VI presents a brief discussion followed by the conclusions and future works.

II. GAME-BASED LEARNING

The influence of computers in education can be seen on the emergence of new Learning Objects (LO), which can be defined as an entity focused on knowledge construction [1].

According to [9], the young generation is more immerse within the new technological advances, acquiring its knowledge through the interaction within it. According to [10], one of the modalities that are gaining adepts are digital games and simulations.

The author [10] also defends that those environments can be explored through a constructivist thinking, since these are focused on problem solution. Therefore classifying it as Interactive Learning Environments. This occurs, according to [2] because the player is in a constant learning process within the game, due the continuous feedback given by the system to evaluate the players actions.

Thus, studies about the integration between digital games and education have emerged in the last decade. These studies

aims to identify the properties and characteristics within these systems and how it influences the educational process of students and teachers, positively [11] [12].

Those aided in the emergence of what some researchers call Game based learning, which according to [4] can be divided in 3 main groups: Serious Games, Gamification and Gameful Design. Those concepts derives from digital games.

According to [13], Gameful Design is the game logic applied to the user experience. It manifests through the aesthetic elements and the usability of the system, rather the game elements itself. As for Serious games, this concept can be defined as the game itself aimed to train a group or individual [14]. The main differences can be seen on Table I:

TABLE I. GROUPS DIVISION ACCORDING TO [4]

	Game logic	Game elements	Game	Fun
Gameful Design	X			
Gamification	X	X		
Serious Games	X	X	X	
Digital Game	X	X	X	X

Table I demonstrates the groups division, where each one have its own properties in a way these properties does not interfere with another one. Figure 1 demonstrates a graph with a summary of the primary objectives of each group.

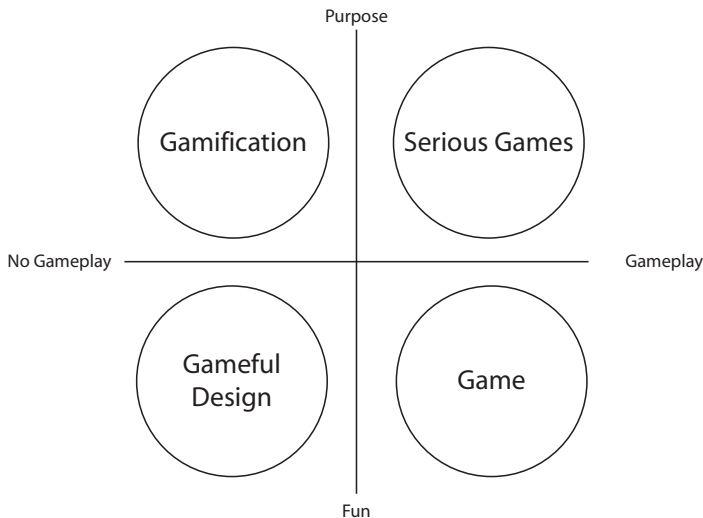


Fig. 1. Summary of primary objectives according to Deterding [15]

As can be seen on Figure 1 depending of the direction, the concepts has more of each one of the attributes. It also demonstrates the summary of the concepts, gamification focusing on game elements with a purpose not involving gameplay. Gamification, for instance, involves the use of game logic and elements (Table I) with an intent (Figure 1).

This purpose can mean the improving of a person, or group, engagement and motivation, training, or behavioural adaptance. This however, does not involve a directly gameplay as a serious game or digital game, meaning that the users' interaction are limited to the extense of the gamified application or method.

III. GAMIFICATION

Gamification can be defined as the use of game mechanics, concepts and aesthetics outside its main scope, aiming to motivate, engage, training, education or modify a behavior through intrinsic and extrinsic motivators [16], [6], [5], [4].

This occurs due the game's property to maintain the player engaged for a long time period. This property was the motivation of studies that focus on understanding te engagement effect [17]. It works on through the extraction of the game elements. However, firstly it is necessary to understand some digital game concepts.

A. Concepts and Mechanics

Reseachers in the past few years tried to conceptualize digital game concepts in order study and identify its properties. The author [18] proposed a framework (Game frame) to use game concepts within ludic application, extracting 19 game concepts that can be observed on Table II.

TABLE II. GAMIFICATION CONCEPTS EXTRACTED BY DIGNAN [18]

Objectives	Competition	Opportunities	Time pressure
Scarcity	Puzzles	Novelty	Levels
Social pressure	Cooperation	Currency	Renovation
Decision	Information	Progress	Points
Sensation	Rewards	Classification	

Table II presents the concepts extracted by [18]. He explains that each one has its own advantages and disadvantages. However it is not necessary the use of every concept in an application in order to achieve the desired outcome.

This concept is also explored by [6]. The authors discuss the implementation of gamification, where they explain that is needed a study about what is intended to gamify. This occurs due many thoughts that gamification is an universal panacea [6] however to achieve the desirable results, a deep research on the field is needed.

IV. SiGMA

A. System and Method description

The Gamified Math System (SiGMA) is an application aiming at student's training of math concept. It is implemented with gamification concepts to engage and motivate the students in problem solving activities. This work aims to continue the work made by [8] by focusing on the evaluation of the system.

The system is composed in 2 main modules: User (students) and Administrator. The User module contains the problem solving functionality, where the user is able to select a Theme, followed by a subtheme and its level. The theme and levels representation are based on the ones defined by the committee of Brazilian Math Olympics of Public Schools (OBMEP): Arithmetics, Combinatorics and Geometry, levels 1 to 3.

The subthemes were divided by a process, created by the authors, to insert the questions. This process assured that each question would have its variables values randomized, in order that the user is able to solve the same question many times without memorizing the answer but rather the logic. The

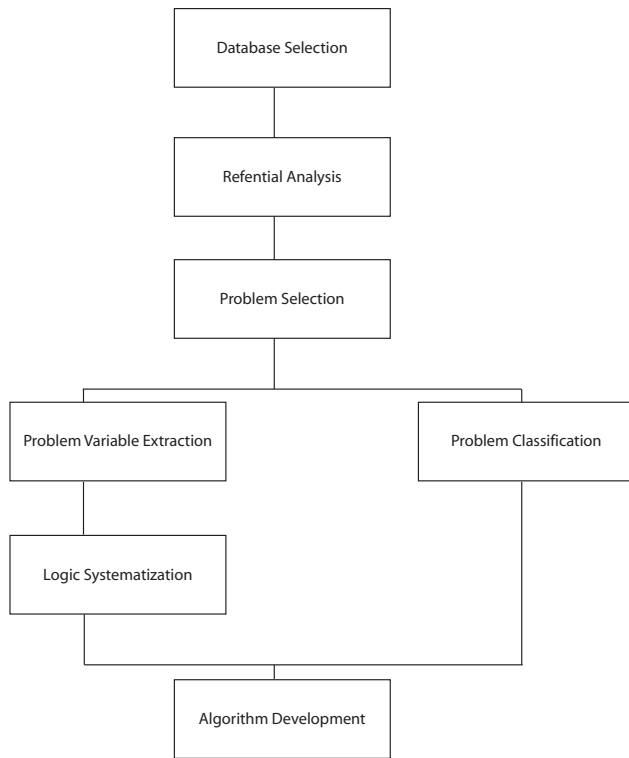


Fig. 2. Process flux

process began by selecting the databases, as can be seen on Figure 2.

As can be seen on Figure 2 Followed by the Database selection, we choose which questions are going to be codified, in order to do so we divide the Selection Phase in two fluxs, one to identify its subtheme and the other to identify the logic of the answer. By identifying those two properties, but mainly the problem logic, we can turn the question in an algorithm that will be codified to be inserted within the system.

The subthemes were based on the National Math Curriculum, and extracted with the aid of Math teachers. Initially, as the system focused on Arithmetics theme, we were able to identify 10 subthemes in 93 questions that were analysed by the process. Each question is able to belong to one or more groups. This division can be seen as:

- Basic Operations
- Logical Problems
- Greatest Common Divisor
- Least Common Multiple
- Fractions
- Factorization
- Euclidean Division
- Divisibility Criteria
- Periodic Phenomena
- Multiple and Dividers

To exemplify this method, we selected the following question from OBMEP 2010 database: Question 8 - Maria's Car. This questions was inserted in the Basic Operations subgroup and its variables are bolded within the text.

8. Maria's Car - The **alcohol liter costs \$0.75**. Maria's car is able to **travel 25km with 3 liters of alcohol**. How many dollars Maria will spend to **travel 600km**?

This problem contains the following variables: liter cost (0.75), liter consumed (3), mileage distance (25), and travelled distance (600). To solve this problem it is firstly necessary to find the mileage per liter (seen on Equation 1) to find the answer seen on Equation 2.

$$mileageperliter = \frac{mileagedistance}{literconsumed} \quad (1)$$

$$answer = \frac{travelleddistance \times litercost}{mileageperliter} \quad (2)$$

By analysing the equations generated to solve the problem, it is possible to create the algorithm to generate the random values of each variable. Through this process, we generate the algorithm 1 that describes the logic of the problem.

Algorithm 1 Maria's Car

```

liter cost ← random(0,10..3,00)
mileage distance ← random(20..50)
travelled distance ← random(100..1000)
liter consumed ← random(2..5)
mileage per liter ← mileage distance / liter consumed
answer←(travelled distance×liter cost)/mileage per liter

```

Algorithm 1 follows the same logic used to solve the questions. The values can be randomly generated which makes the system more dynamic and force the students to think about the logic rather the answer of each question. This algorithm is converted to a PHP code that will be inserted within the system.

B. System Gamification

In order to implement the gamification of the system, the authors selected the game concepts based on the division made by Dignan [18]: Points, levels, progress, classification, rewards, time pressure, opportunities, renovation, novelty, information and objective.

Points are given to the users when those scores a question. By accumulating those points, the user is able to achieve a new level which can also represent the progress within the system. The classification can be observed in the division of two main modules (User and Administrator), as for the Rewards are represented by the achievements implemented within the system.

Those achievements are directly influenced by the user points, levels and time pressure (represented in the system through a counter). The opportunities can be seen through the access to each question, equal to all users. Renovation

and novelty can be represented through the insertion of new questions and the logic of the system, that generates new values to the same question.

The data is represented in the form of statistics that can be seen on the player profile. Finally, the system objective is focusing at training the students in math concepts and problem solving.

C. The study

To evaluate the system, the authors initially began by evaluating the functionalities and pedagogical properties of the system through a questionnaire, based on Whitton's research [19]. The authors created this method to evaluate and validate educational and training applications with game-based learning concepts.

This evaluation consists in verifying two criteria: Development and Interface. The first one aims to analyse the functionalities of the system, and some pedagogical properties. The second focus on the visual features within the application (Table III).

TABLE III. CRITERIA ESTABLISHED BY WHITTON [19]

Development	Interface
Active learning	Flexible interaction
Engagement	Social Support
Adequation	Easy navigation
Reflection	User control
Equal opportunities	Error recovery
Continuous support	Visual interface

Table III demonstrates the criteria and its attributes to be evaluated. The evaluation of the system began with a group of math teachers that lasted 3 months. The interviewed group of math teachers, evaluated those properties in order for the authors prepare the system to be applied with students.

This second evaluation also aims to evaluate each one of the gamification concepts implemented within the system, in order to analyse its effectiveness and acceptability by the math teachers.

V. RESULTS

The evaluation initially began with a group of 30 math teachers that would be interacting with the system for 3 months [8]. This initial evaluation did not analysed or questioned the teachers about the acceptance of each of the game elements, since not all of them were implemented. However, this questionnaire intended to evaluate the current state of the gamification concepts that were inserted.

During the evaluation period, the extrinsic concepts were inserted in the system to be measured. These can be represented through Points, Levels, Achievements, Progress, Leaderboards, User History and Profile, which contains the user statistics.

The evaluation was performed through a questionnaire using a Lickert scale, from 1 to 5, where 1 is defined as [Strongly disagree] and 5 as [Strongly agree]. The first evaluation achieved positive results in many topics, even though all of the topics did not accomplished an average score (Table IV).

TABLE IV. RESULTS FROM THE FIRST QUESTIONNAIRE

Implementation	Average
Active learning	3.9
Engagement	3.7
Adequation	3.4
Reflection	3.8
Equal opportunities	2.9
Continuous support	2.1
Gamification proposal	4.2
Interface	Average
Flexible interaction	3.2
Social support	2.4
Easy navigation	3.5
User control	4.2
Error recovery	2.6
Visual interface	3.7
Gamification concepts	4.1

Table IV demonstrates the results of the first evaluation, without all of the gamification concepts. Most of the results were above the average, however two of them scored below the average: Continuous and Social support.

Those two attributes are represented in the system as the feedback and the interactions with other users. In the initial phase, the system did not have a properly feedback page for this functionality, which made the user return to the initial page in order to solve new problems. As for the interactions, the system had no explicit feature that could represent this concept in the beginning of the tests.

After the initial feedback from the math teachers, some improvements were made in the system in order to attend the feedback given by the interviewed group. After 3 months passed, and improvements were made, the same group would evaluate the system through a questionnaire using the same Lickert scale and evaluating the same concepts, however in this phase, they also evaluated each one of the gamification concepts that were implemented. The results can be seen on Table V.

TABLE V. RESULTS FROM THE FIRST QUESTIONNAIRE

Implementation	Average
Active learning	4.2
Engagement	4.0
Adequation	4.2
Reflection	4.0
Equal opportunities	4.1
Continuous support	3.8
Interface	Average
Flexible interaction	4.6
Social support	3.9
Easy navigation	4.5
User control	4.1
Error recovery	3.9
Visual interface	4.6

Table V refers to the outcomes in the final evaluation after 3 months using the system. All of the topics achieved more than 50% of acceptability. By comparing those two evaluations it is possible to observe that the system achieved a positive state to be used with the students (Table VI).

As can be seen on Table VI, the topics had an overall increasing. This occurs due the implementations and continuous feedback that were given by the math teachers, as they used the system for the first time. The evaluation of the gamification concepts was also positive, which means above the average in the scale, as we can see on Table VII.

TABLE VI. COMPARISON BETWEEN BOTH RESULTS

Implementation	1st Q.	2nd Q.
Active Learning	3,9	4,2
Adequation	3,4	4,2
Engagement	3,7	4,0
Reflection	3,8	4,0
Equal opportunities	2,9	4,1
Continuous support	2,1	3,8
Interface		
Easy Navigation	3,5	4,5
Visual Interface	3,7	4,6
User Control	4,2	4,5
Flexible Interaction	3,2	4,6
Error recovery	2,6	3,9
Social Support	2,4	3,9

TABLE VII. EVALUATION OF THE GAMIFICATION CONCEPTS

Gamification concepts	Average
Objective	4.3
Points	4.3
Level and Progress	4.3
Time pressure	4.2
Achievements	4.2
Leaderboards	4.4
Opportunities	4.5
Renovation	4.1
Data	4.5

Table VII demonstrates the evaluation of the gamification concepts by the math teachers. These concepts were based on the ones extracted by [18] and achieved a positive score above the average.

VI. DISCUSSION, CONCLUSIONS AND FUTURE WORK

The results of this work demonstrated that the system is ready to be applied within a classroom, being used by the students to train math concepts. The feedback given by the math teachers were very important in order to complete it. They also said that the system will be very useful to be applied within their learning methods and exercises.

Teachers also commended the gamification concepts, claiming that those concepts would be the best thing to caught their students attention, since this kind of process is a part of their routine. They also praised the achievements, which made some references to pop culture icons that are also a part of their students routine.

Even though, the work still has some limitations as: (i) study with a group of students (ii) measuring the OBMEP efficiency of the students within the group (iii) a module to provide administrator functions to the teachers (iv) expansion to the other areas covered by OBMEP.

Based on the comments and feedback given by this group, this work achieved the objectives it had proposed and the system is ready to be applied with a group of students that will evaluate their overall performance in classroom and math competitions.

Based on the same feedback, some future works include the creation of a Teacher's module, where they will be able to create, maintain or manage a classroom outside their classroom. Another future improvement consists in improving the Gamification process within the system, by modifying some concepts and insert new ones, as a collaborative problem solving.

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Badges and XP: An Observational Study About Learning

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Abstract — In the last decades, education has been supported by technology in order to reach more people and produce significant benefits to teaching and learning. Part of the success of technology and education is due to the capacity technology can adapt teaching and learning to different contexts. More recently, we noticed an increase in the use of game elements (gamification) in educational environments, which intends to promote students' engagement and, consequently, improve their learning experience. However, we do not know if the use of these elements brings the promised results. In this paper, we conducted an observational analysis focusing in XP (experience points) and Badges, checking their correlation with the students learning, in order to investigate the influence of these gamification elements.

Keywords— *game elements; gamification; environment learning.*

I. INTRODUCTION

It is known that learning is a determining factor for the autonomy of any individual and to the development of the society. According to [1] learning is a product of interaction. Depending on the chosen learning design, students can interact with instructors and tutors, with content and / or others [2]. However the type of interaction and the environment in which this mediation occurs can be impaired by personal or interaction factors. Based on that, there is an excessive concern with the learning process. To improve individual learning, some researches take into account the effects of technology applied on learning.

Technology is a great tool to support the current demand for knowledge, which is evidenced by the increasing amount of online courses [3]. This new educational paradigm intends to provide education to anybody, from anywhere and at anytime [4]. Among the existing technological approaches to education, Intelligent Tutoring Systems (ITS's) are gaining more prominence in the educational setting.

In [5] Intelligent tutoring systems (ITSs) are defined as computer-assisted learning environments, which are highly adaptive, interactive and based on computational models developed according theories from the learning sciences, cognitive sciences, mathematics, computational linguistics, artificial intelligence, and other relevant fields [6] [7]. According to [8], these systems are based on cognitive learning theory, which is interested in how the information is organized in human memory.

There are ITSs for algebra, basic mathematics, statistics, assessment and learning in knowledge spaces, physics and computer science [5]. Basically, there are four elements inherent to ITSs [9]: (1) the “knowledge domain”, which includes the knowledge that teachers want students to learn. (2) The “teacher module”, which is responsible for selecting and presenting instructions and teaching styles, as well as learning scenarios. (3) The “student module”, which represents student's personal data, their predicted capability for a particular course and her/his current state in specific knowledge domains. (4) The “user interface module”, which is used to facilitate the interactions of both teachers and students with the system.

The four modules are present in all ITSs' architecture, but some of these systems use other techniques in order to increase commitment, motivation and the students' focus on particular tasks. Gamification is a technique for these needs. It consists in the application of game mechanics in environments that are not normally game environments [10]. There are some ways to classify the elements that compose a game or a gamified activity. One of these classifications can be found in [11], which categorizes them in: mechanic elements, story elements, aesthetics elements, and technological elements.

Literature shows some examples of gamification use in ITSs, for example: Ribbon Hero 2 is an Office add-on that allows users to learn and train some skills. Another example, Khan Academy introduced badges and points through individual tutoring for students [12]. Other studies like [13]

present a game-based tutoring environment that teaches mathematical concepts such as Cartesian coordinates, symmetry and iteration to middle school and high school students. In this study, authors found that the integration of game elements fostered higher engagement in learning, and facilitated students' use of the system beyond class time.

In [14], a common way to bring game elements to an ITS is by adding badges (or trophies) and XP (experience points). In Duolingo platform, for example, XP are used to track users' progress in learning a language. In Khan Academy, badges are awarded to users who complete certain (series of) activities/tasks. Gamification use in education motivates different point of views. On one hand, some researchers state, "The current hype of gamification will unavoidably discourages the most creative elite user" [16]. On the other hand, some studies present studies positive impacts of gamification on the educational context [17]. According to [18], the same pedagogical results were obtained using a learning outcomes between a narrative-centered game-based ITS and a non-game tutor.

In this study, we did an observational analysis on the use of gamification elements in an Intelligent Tutoring System. The main objective was to evaluate whether, or not, gamification, improves student's learning. This analysis intends to investigate the correlation between gamification elements and learning in an online learning environment called MeuTutor®. We will check if badges, XP and BKT indices have any degree of correlation. For that purpose, we used the Pearson Correlation Coefficient, to measure the degree of correlation and its linear correlation signal between the variables [23]. Moreover, we used the R¹ statistical language to conduct the analysis.

This paper is structured as follows: Section II presents the some background knowledge used in this study. Section III presents the methodology used. Section IV presents the observational study, including its business and technical problems. Section V presents the statistical analysis applied on MeuTutor's data. Section VI presents and discusses the results. Section VII presents our conclusions and future works. Finally, Section VIII presents the acknowledgements.

II. BACKGROUND

According to [17], gamification uses game elements like point, badges, leader boards, stories and other elements, to enhance skills and engagement, maximize learning, promote behavior changes and socialization. Some of these elements are partially dependent [19], for example challenges, achievement and badges are related within the gamification process: challenges may, or may not be offered; once offered these can be performed by users; when completed the users receive the gains (achievements), that may be represented by a badge.

There are various elements also associated with the gamification process, including badges and XP as mentioned before. Badges are awarded to users when they perform defined (series of) tasks or activities. Experience points (XP) are the most common pointing system in gamified environments. They serve the purpose of watching, ranking and guiding the user, and also indicates how engaged a user is [19]. In MeuTutor, badges are awarded if the students successfully complete some complex activities a certain number of times (make 10 new friends, evaluate 5 videos of a specific domain, complete a part of the cognitive path, etc.). XP are awarded when students do some simple tasks, which makes them progress (level up) in the environment (correctly solve problems, evaluate a video, answer a quiz, etc.) [20].

MeuTutor is an intelligent online learning environment [20], which monitors students' learning in a personalized way, focusing on the quality of teaching and students' performance. Its objective is to prepare students for the ENEM² ("Exame Nacional do Ensino Médio"). It offers school subjects such as: Mathematics, Portuguese, Physics, Portuguese Literature, Chemistry, Biology, Geography, History, Spanish and English. However, only Mathematics is available for free. The other subjects are unlocked in the paid version.

The learning environment provides a huge variability of questions for students to test and practice what they have learned. In addition, the environment provides some gamification elements, including 28 badges distributed in 4 categories: social, collaborative, gamification and knowledge (Figure 1 and Table I).



Figure 1 - Trophies, Level and XP elements

There are 2 badges in the social category, which intends to stimulate interactions among users in the learning environment. There are 2 badges in the collaborative category, and these badges are provided to students, to stimulate cooperation in the learning environment. There are 3 badges in the gamification category, to stimulate engagement between the users and the learning environment.

A total of 21 badges compose the knowledge category, which are related to knowledge acquisition in the school subjects available, such as: correctly solve a problem, answer tests, watch videos, etc. Each discipline has at least one badge

¹ R is a fully integrated suite of routines for manipulating data, calculation and graphics [24].

² A Brazilian exam that grants students access to some public universities

related to it. In this study, we considered only badges related to the mathematics (free) domain, 12 badges (1 exclusively associated to mathematics domain, and 11 general-purpose badges). A detailed description about these purposes is described in Table I.

TABLE I.

Badge's Classification				
<i>Id</i>	<i>Trophy name</i>	<i>Condition</i>	<i>Category</i>	<i>Purpose</i>
1	Darting	Complete 50% of the topics offered by the environment.	Knowledge	General
2	Evolving	Advance one level	Knowledge	General
3	Testing the knowledge	Make the first mock test	Knowledge	General
4	Always learning	Complete the first subject	Knowledge	General
5	Gauss	Reach level 11 in math	Knowledge	General
6	Skull	Correctly answer 10 problems in a row	Knowledge	General
7	Teacher	Complete 100% of the topics offered by the environment.	Knowledge	General
8	Tireless	Learn a subject without stopping in the middle	Knowledge	General
9	Scholar	Complete 3 subjects in the same week	Knowledge	General
10	Perspicacious student	Correctly answer 5 problems in a row	Knowledge	General
11	Improving the knowledge	Complete 5 subjects	Knowledge	General
12	Simulation Perfect	Correctly answer a mock test	Knowledge	General

Source: created by authors.

In the learning point of view, MeuTutor® calculates the student's performance and gathers information related to each curriculum (topics) the students interacted with. Currently, they evaluate these interactions, at curriculum level, using a technique called BKT (Bayesian Knowledge Tracing), an efficient model to evaluate the learning process.

The BKT is a common way to determine students' knowledge in adaptive skills, in educational systems and cognitive tutors. The BKT, in essence, is supported by the Hidden Markov Model (HMM) for modeling the student's knowledge based on five parameters: (1) the probability that the student has any initial knowledge on a particular topic (curriculum); (2) the successful acquisition of new knowledge

by the student; (3) forgetfulness; (4) guessing; (5) and making a slip [22]. It tracks and monitors changes in the state of the student's knowledge during practice [22]. For each student's response to a question, the model adjusts its prediction whether the student knows the ability, or not. Within MeuTutor® the estimated rate for measuring learning is 95%, i.e., if a student achieves this percentage in the activities associated with a particular curriculum, the system considers that he/she learned that content. Based on that, it is worth consider that BKT was only used to define which curriculum would be included in the analysis.

III. METHODOLOGY

In this section, we describe the planning and execution of the proposed analysis.

Our first step was to schedule some brainstorming sessions with MeuTutor® team. We used these sessions to better understand the learning environment and the way the game elements were applied. We presented our intentions and objectives, and discussed with the development team, which data should we analyze in order to reach what we proposed.

After that, we spent some time accessing and exploring the environment. During this step, we detected the need to categorize the badges available, once they had different purposes. We later checked with MeuTutor® team if the categories were aligned with their original ideas about the badges. We also collected information about the experience points (XP) and the learning index (BKT).

Our next step was to search books and articles containing studies about the process of learning with and without the aid of technology, more specifically the use of gamification.

After understanding the aspects of the interaction between the learning environment and the user, we requested the necessary data for the analysis. We required data on the users' interactions with the game elements, and data on their learning experience (performance and knowledge state). We received the data into two XLS files. One containing the registries of 4000 students retrieved according to their number of accesses, the other registries of 100 students retrieved according to their gamification level in the environment. Given our purpose, we chose the second file.

Examining the file, we noticed the necessity to treat and enrich the data. Initially, we filtered the data available in order to keep only those pieces that were relevant to our analysis. This way, we removed everything but data about the users' achievement (XP and badges, only) and data on the students' performance (number of problems solved, and number of problems solved correctly) and their learning experience (curriculum they learned). We also removed data on the badges that were not related to the Mathematics domain.

In order to measure learning, we calculated a coefficient we named Knowledge Coefficient, which was created using the data on the students' performance and learning experience. It is composed of the number of problems solved correctly, divided

by the total number of problems solved, multiplied by the sum of the curriculum the students' learned (BKT score $\geq 95\%$), as show in Figure 4.

However, different curriculum have different demands and difficulty. In order to deal with this issue, we divided the MeuTutor® cognitive tree (curricular structure for a certain domain, in this case Mathematics) into eight large blocks (Figure 2) according to their distribution.

Assuming that the 21 curriculum available represent 100% of the knowledge students need to acquire in order to “master” the Mathematics domain, each of the eight large blocks in the proposed division, contributes with 12.5% of this amount of knowledge. If a certain block has more than one curriculum associated with it, the total value for the block (12.5%) will be divided by the amount of curriculum associated. Knowing that the content offered by MeuTutor® was created to be similar to that taught in schools (Brazilian), we can see that the knowledge acquired by the students is the sum of each curriculum in this established hierarchical sequence.

Matemática Básica		12.5%
Razões e Proporções	1.5625%	Conjuntos e Funções
	0.78125%	Sequências
	0.78125%	Matrizes, Determinantes e Sistemas
	0.78125%	Polinômios e Equações Algébricas
BLOQUEADO		1.5625%
Estatística e Probabilidade		1.5625%
Lógica		12.5%
BLOQUEADO		12.5%
Polígonos	2.08%	Geometria da posição
Sólidos geométricos	1.38%	Circunferência
	1.38%	Triângulos
Áreas	2.08%	Trigonometria
Medidas em sólidos geométricos		12.5%
Troncos e semelhança de sólidos	6.25%	Geometria analítica
Números complexos		12.5%

Figure 2. Curriculum's Weight.

Finally, we did a correlation analysis using this data we pre-processed (filtered and enriched). For this parte, we used R to analyze the correlation between the gamification elements, Badges and XP, and students' learning in an online learning environment.

IV. OBSERVATIONAL STUDY

In this section, we present our problem (business and technical), our research questions, goals and metrics.

We needed to define the variables, the situation and the context to be analyzed. In the same way, we defined what problem would be “attacked” and what hypotheses would be examined, considering the scope of study. In Figure 3, we illustrate our GQM.

A. Business Problems

1. **Problem:** Do the games elements Badges and XP influence in students' learning in the MeuTutor® environment?
2. **Research questions:**
 - a. Is there a correlation between the amount of badges students have and their learning?
 - b. Is there a correlation between the amount of XP students have and their learning?

Metrics for validation:

- a. The number of badges and XP per student.
- b. The number of problems solved.
- c. The number of problems solved correctly.
- d. The number of curriculum effectively learned (BKT $\geq 95\%$).

B. Technical Problems

1. **Problem:** Does the achievement of games elements, Badge and XP, positively influence or negatively in the learning process in MeuTutor® environment?
2. **Research questions:**
 - a. Do badges influence learning?
 - b. Do XP influence learning?

C. Goals, Question and Metrics

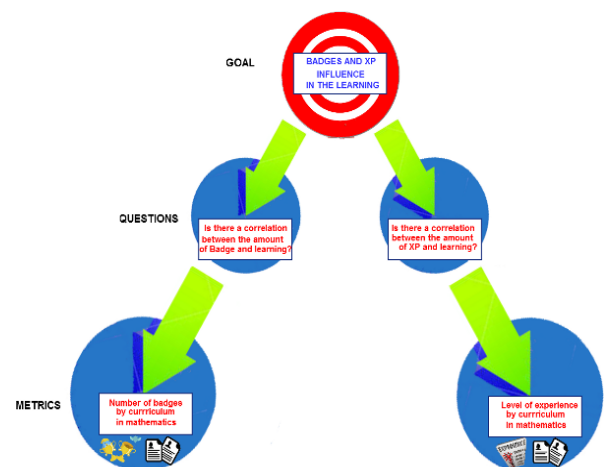


Figure 3. Illustration of GQM process.

TABLE II.

Table Column Head	
<i>Hypothesis</i>	<i>Null Hypothesis</i>
Badges do not influence learning.	Badges influence learning.
XP do not influence learning.	XP influence on learning.

Source: created by authors.

V. ANALYSIS

The analysis process described in this chapter is composed of five steps, as follows: data retrieval, data treatment, correlation analysis, results and discussion.

A. Data Retrieval

Analysis have one or more data sources, in this study, data came from a gamified online learning environment called MeuTutor®, as described in section III, after the decisions made in some brainstorming sessions, and actual use of the environment. We were able to better understand environment's dynamics and mechanics, which was vital to guide requirements for data to be used in the analysis. As mentioned, we requested data about the students' interactions and learning experience in general.

B. Data Treatment

However it was necessary to treat and enrich the dataset, in order to keep only those data related to badges, XP, BKT score (for the curriculum in the Mathematics domain), as well as data on problems solved (the total amount of problems solves and the amount of problems solved correctly) A dataset was After receiving data, it is noticed which some data founded in the dataset is not relevant for the analysis, thereby, was necessary a treatment of data. This treatment consists of choose a dataset to analysis, filter the features, definition of weights and creation of table for analysis.

a. Choosing a Dataset

We received 2 datasets. The first, consisted of 4000 students selected by their number of accesses. The second, consisted of 100 students selected due to their level in the environment. Both datasets contained the same set of features.

We opted for the second dataset, where students were selected by their levels. In it we found 100 students distributed among levels 1 to 6.

b. Filtering Features

Based on variability of the received data in the dataset, it was necessary to filter the features to be used in the analysis, keeping the features: XP, Badges, BKT score for the Curriculum, number of problems solved and number of problems solved correctly. Other features were not considered in this analysis.

The curriculum which has less than 95% of BKT score were not considered in the analysis, once according to the BKT, these curricula were not learned.

c. Weights' Definition

In order to define the level of learning of a student, this analysis considered the learned curriculum only. We also applied weights to each curriculum (Table III), according their interdependence and the importance of each curriculum to complete the cognitive tree.

d. Knowledge Coefficient

We used the information gathered of created above in order to generate an equation to measure the students' knowledge coefficient. It uses the number of problems solved correctly, divided by the total number of problems solved, multiplied by the sum of weights of the learned curriculum (Figure 4).

$$\text{Knowledge Coefficient} = \frac{\text{Number Questions Answered Correctly}}{\text{Number Questions Answered}} * \sum_{i=1}^n \text{Weight}_i$$

Figure 4. Knowledge coefficient equation

TABLE III.

Weight of Curriculum	
<i>Title</i>	<i>Weight</i>
Curriculum_Mathematics_PolinomsEquationsAlgebra	0.78125
Curriculum_Mathematics_Triangles	1.38
Curriculum_Mathematics_RatioProportions	6.25
Curriculum_Mathematics_GeometricSolids	12.5
Curriculum_Mathematics_Sequences	0.78125
Curriculum_Mathematics_ComplexNumbers	12.5
Curriculum_Mathematics_CombinationAnalysis	0.78125
Curriculum_Mathematics_StatisticsProbability	1.5625
Curriculum_Mathematics_MatricesDeterminantsSistemas	0.78125
Curriculum_Mathematics_BasicNotionsGeometry	12.5
Curriculum_Mathematics_Areas	2.08
Curriculum_Mathematics_GeometricSolidsMeasures	1.38
Curriculum_Mathematics_AnalyticGeometry	6.25
Curriculum_Mathematics_BasicMathematics	12.5
Curriculum_Mathematics_Trigonometry	2.08
Curriculum_Mathematics_Circles	1.38

Weight of Curriculum	
<i>Title</i>	<i>Weight</i>
Curriculum_Mathematics_Polygons	2.08
Curriculum_Mathematics_Logic	12.5
Curriculum_Mathematics_GeometricPositions	2.08
Curriculum_Mathematics_SolidsSimilarities	6.25
Curriculum_Mathematics_SetsFunctions	1.5625

Source: created by authors.

C. Correlation Analysis

For the analysis we considered students in levels 1 to 4. Each group contained 14 students randomly chosen. Levels 5 and 6 were not considered, because there were not enough students with these levels (less than 14 students).

The correlation among Badges, XP and the knowledge coefficient (KC) is described in the tables IV, V, VI and VII, for students in levels 1 to 4, respectively.

TABLE IV

Correlations in level 1			
	<i>XP</i>	<i>Badges</i>	<i>KC</i>
<i>XP</i>	1.0000000	0.4045567	0.2059882
<i>Badges</i>	0.4045567	1.0000000	0.5175910
<i>KC</i>	0.2059882	0.5175910	1.0000000

Source: created by authors.

TABLE V

Correlation in level 2			
	<i>XP</i>	<i>Badges</i>	<i>KC</i>
<i>XP</i>	1.0000000	NA	NA
<i>Badges</i>	NA	1.0000000	0.3822851
<i>KC</i>	NA	0.3822851	1.0000000

Source: created by authors.

TABLE VI

Correlation in level 3			
	<i>XP</i>	<i>Badges</i>	<i>KC</i>
<i>XP</i>	1.0000000	NA	NA
<i>Badges</i>	NA	1.0000000	0.485396
<i>KC</i>	NA	0.485396	1.0000000

Source: created by authors.

TABLE VII

Correlation in level 4			
	<i>XP</i>	<i>Badges</i>	<i>KC</i>
<i>XP</i>	1.0000000	NA	NA

Correlation in level 4			
	<i>XP</i>	<i>Badges</i>	<i>KC</i>
<i>Badges</i>	NA	1.0000000	-0.2669913
<i>KC</i>	NA	-0.2669913	1.0000000

Source: created by authors.

VI. RESULTS AND DISCUSSION

The results show a weak correlation between XP and learning for students in level 1, but a higher correlation between badges and learning.

For level 2, the analysis shows no correlation between XP and learning, and a lower correlation between badges and learning, compared to level 1.

For level 3, the analysis shows no correlation between XP and learning, and an increase in the correlation between badges and learning, compared to level 2, however still lower than level 1.

For level 4, the analysis, once again, shows no correlation between XP and learning, and a negative correlation between badges and learning.

These results (summarized in Figure 5) may indicate that the gamification elements studied, are gradually losing their relevance to the learning process, in MeuTutor®, which can indicate a problem in the design of these elements (their purpose). According to the pedagogical and development teams at MeuTutor®, the effort to achieve a badge increases, as a geometric progression, throughout the levels. In others words, is more difficult to earn badges as the student level up.

However, this behavior is not characterized in tables IV to VII, despite the decrease in the correlation (tables IV and V), the correlation in level 3 is practically the same of level 1. However, in level 4 the correlation has a negative value, which may indicate that the effort to achieve a badge from level 4, may be deviating students from learning.

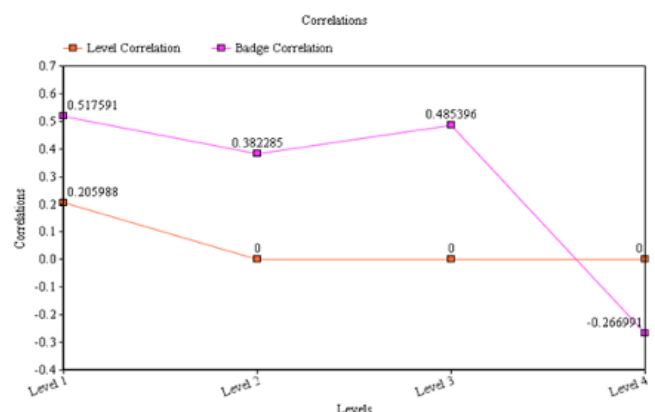


Figure 5. Correlations through the levels

The analysis revealed a low to insignificant correlation between XP and learning. Indicating low or no influence among the variables analyzed. That is, the users experience points are not crucial to effective learning, at least for levels 2, 3 and 4.

The results presented in the analysis, also suggest that there is a gap in the transition from level 1 to level 2 that can be corrected if the parameters to award each badge is changed.

We believe that the most advanced students behave differently, once they are familiar with the dynamics of achievements, not being too much influenced by achieving badges and XP. Nevertheless, we have evidences of the influence of badges in the students' learning process, while XP has almost no influence in this process.

Based on the badge correlation behavior, two hypotheses arise: (1) the badges were not well distributed or designed along the levels; (2) the badges are important/interesting, only, in the beginning of the course.

Our suggestion is the redistribution of the effort to achieve the badges, which may provide more significant results. In level 4, we saw a negative correlation (-0.2669913) indicating that a change is also needed in the distribution of the badges for the considered levels.

VII. CONCLUSION AND FUTURE WORKS

In this study we intended to analyze if there is any kind of correlation between some gamification elements and students performance. More specifically, we wanted to detect the influence of Experience Points and Badges on the students learning. Our target environment, is a gamified online learning environment called MeuTutor®.

We gathered data from the interactions of 100 students, and filtered them in order to keep only data related to their achievement of the game elements of interest (Experience Points and Badges) and data related to their learning experience (curriculum they learned, the amount of problems solved and the amount of problems solved correctly). The sample size and the data quality was appropriate for the correlation analysis.

The results showed that there is correlation between the variables investigated and learning. Badges were considerably correlated to learning, while Experience Points were just lightly correlated.

We concluded that, in order to keep XP and Badges significant to learning, it is necessary to correctly design them considering the demands and differences of the different levels (of a gamified environment), carefully plan and distribute the effort to achieve them, and make them meaningful.

As future work we intend to further investigate other methods and scenarios to verify the correlation between gamification elements and learning. We also intend to perform new analyzes for different game elements and check other types of influences (for example, do the interactions change in periods close to important tests and evaluations.

VIII. ACKNOWLEDGEMENTS

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Systematic review of literature: educational games about electric energy consumption

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Abstract— This paper presents the process and the result of a systematic literature review about educational games in which the main theme is electricity consumption, executed from January to March 2014. The systematic review is characterized by the use of a method that aims to answer the questions of the researcher with rigor in the search, making trends and biases of the researcher interfere as little as possible on the results. The research questions raised were: 1) Are there educational games about electric power consumption? 2) How were these games used? The theme choice was made as a result of the environmental issues assigned to it and the consequences that consumption can generate. The result of the work, obtained from a survey in the ACM Digital Library, Elsevier (Science Direct) and Springer scientific research bases, revealed the existence of seven papers, which responded the questions made. The results indicate a lack of papers in which use approaches of the games are reported - highlighting the need for further investigation and share. It is believed that this work contributes to the academic community by presenting a list of games and their uses, and the knowledge from this type of research serves as an incentive for new games and different approaches to be designed and created.

Keywords—systematic review; educational games; energy consumption; energy education; use of educational games.

I. INTRODUCTION

Energy is part of practically all society's sectors and it is used in many everyday activities, being responsible to ensure welfare and services to humanity [1].

Throughout history energy consumption has increased dramatically and according to estimates it will continue to increase in the next years, if consumers present the current consumption rates [2], [3].

Increase in energy consumption means not only increasing the provision of good services which enables well-being, but can also mean an increase in social and environmental problems, such as increased greenhouse effect, soil, air and water contamination.

Based on these issues, it is important to think in ways to facilitate the discussion and study about energy issues. In this paper, the use of educational games is suggested, as they have the potential to stimulate learning, critical thinking and creativity [4].

The game within the educational practice, however, requires care from its users, because its misuse can not help to

promote learning by not contributing to the teacher's objectives. Therefore, the knowledge of games and their use approaches can be considered important because from this perspective they are a source of examples for those who want to use this type of material. In order to investigate if there were academic papers about energy issues and their use approaches, we tried to make use of a method known as systematic review of the literature, as it seeks to be rigorous and eliminate, as much as possible, partiality in the search of papers.

II. ELETRIC ENERGY CONSUMPTION

Energy is one of the most important elements of modern society. It is present in our everyday lives as power, health, leisure and in all of our routine activities as well as in practically all sectors of society, such as the environment, the economy, politics, and others. It is responsible for the creation of riches based on natural resources and the consequent provision of services, from which humanity has been benefited throughout history [1].

Since the Primitive Man to the Technological Man, energy consumption has grown considerably. This grow was possible due to, above all, the scientific discoveries made over time. Examples are the use of coal as a source of heat and the extraction of mechanical energy from winds and waterfalls. Later, the Industrial Revolution and the invention of steam engines, internal combustion engines and the electricity, as well as the use of nuclear energy also favored the availability and stimulated the need for energy [2].

About electricity, specifically, there are estimates that if the global consumption do not decrease, the world will need around 2.400 GW in 2030 to satisfy different kinds of needs and in order to do so, it will be necessary to construct new sources of energy power [3], [5].

The sources of energy generation are classified, in simplified form, in renewable and non-renewable. The renewable source is the one that is returned to the natural conditions in a short period of time, as example of this type we have wind and hydropower potential. On the other hand, the non-renewable source is the one that is not replaced quickly by nature, such as oil and coal [2].

Although these sources guarantee much of what is currently being enjoyed, allowing a better quality of life for the population, it is necessary to think that the implementation and

the use of these sources affect directly the health of the planet and consequently the welfare of all living beings [1].

These different sources of energy, whether renewable or not, affect the planet in some way. The effects of these sources on the planet can be classified in three categories - local, regional and global impacts and dimensions [2]:

Local impacts and dimensions: in this category it is included air, superficial water bodies and soil pollution. The air is contaminated mainly by the burning of fossil fuels and solid waste, evaporation and volatilization of solvents and fuels, and emissions from industrial processes that emit toxic and carcinogenic substances, as well as particulate matter and gases such as nitrogen oxides (NO_x), sulfur dioxide (SO_2) and carbon monoxide (CO). Water and soil, on the other hand, can be contaminated by the use of pesticides and fertilizers, oil and fuel leaks and leachate from landfills.

Regional impacts and dimensions: acid rain and sea pollution. The reaction of NO_2 and SO_2 with water results in formation of nitric acid (HNO_3) and sulfuric acid (H_2SO_4), creating acid rain, that affects all types of ecosystems. Sea pollution happens, in general, by the leakage in international or interstate waters or, groundwater contamination by the infiltration of toxic substances.

Global impacts and dimensions: The increase of the greenhouse effect, bio-cumulative pollutants, radioactive waste, biodiversity loss and desertification of the oceans. The greenhouse effect is intensified by the emission of gases such as carbon dioxide (CO_2) and methane (CH_4) which are released mainly from deforestation and fossil fuel burning. The bio-cumulative pollutants are represented mainly by heavy metals and radioactive materials, originating mainly from emissions of coal power plants, leakages and nuclear tests.

Due to all these impacts which have social consequences, such as diseases that can be acquired through consumption of contaminated water, and polluted air inhalation, among others, it is important to think about efforts to save energy. Energy saving is usually focused on two aspects: technical, related to the efficiency of technologies for greater use of energy; and changes in lifestyle, which is related to the way in which energy is used [1].

About energy saving, some authors [6] say that the choice of energy sources, as well as their use, are not and should not only be determined by politicians and professionals with expertise in this area, but by everyone who is perceived as agent of these changes. Among the characteristics that these agents must have, the authors say that in addition to the scientific knowledge of energy, it is important that these people are aware of the impacts and consequences of its energy generation, as well as knowledge of the consequences that individual consumption has on the global community.

Preparing people with knowledge, values and self-consciousness is not an easy task. For this reason, efforts and investment programs in different levels, resources and people who can help to accomplish it are important.

One way to facilitate this kind of formation is using educational practices. This paper suggests the ones which use games.

III. EDUCATIONAL GAMES

Educational games allow to create scenarios in which it is possible to reproduce in a simplified and didactic way environmental problems, which are considered complex and enable ecological, social, financial and technical issues and solutions to these issues from a perspective that goes beyond the disciplinary vision [7].

According to [8], records of the use of games in educational activities have already been found since antiquity. Aristotle, for example, encouraged its use as a contribution to prepare children for adult life. Later, with the rise of Christianity, games had no place in the educational context because they were considered a form of crime, remaining "forgotten" until the Renaissance.

It was exactly during the Renaissance period that the games regained their significance in education, being multiplied and applied in various areas of knowledge, such as geography, mathematics and philosophy.

In the eighteenth century, with the emergence of the encyclopedia, games became popular, favoring the exchange of ideas and therefore the creation of new types. The nineteenth century, in turn, presented the expansion of historical games, running even as a political marketing, and the growth of games was used to stimulate science and mechanical content. This situation lasted until the World War I when the military games began to gain prominence.

With the end of the war, the sports games became more valued and in the 1960s, they began to reoccupy a role in educational processes and have since fluctuated considerably.

Although games have made important contributions to the educational field for a long time, as noted, it is important to acknowledge that the use of this type of material requires care, from both parts, from those who develop and from those who apply them.

Regarding the use of games as elements of educational practice, [4] the advantages and disadvantages of this type of material can be listed as follows:

1) *Advantages*

- Fixing concepts already learned in a motivating way to the learner;
- Introduction and development of difficult concepts to improve understanding;
- Learning to make decisions and evaluate them;
- Significance of apparently incomprehensible concepts;
- Provision of the relation between different disciplines (interdisciplinary);
- The game requires active participation of the learner in the construction of his own knowledge;
- The game promotes socialization and the awareness of teamwork;

- The use of games is a motivating factor for who is learning;
- Among other things, the game favors the development of creativity, critical sense, "health" competition, the various forms of the use of language and pleasure in learning redemption;
- Activities with games can be used to enhance or restore skills that the students need;
- Activities with games allow teachers to identify, diagnose some learning errors, attitudes and difficulties of learners.

2) Disadvantages

- When the games are misused, there is the danger of giving the game a purely random character, becoming an "appendix" in the proposed activity. Learners play and feel motivated only by the game, without knowing why they are playing;
- The time spent on gambling activities is larger and if the mediator is not prepared, there may be a sacrifice of other content for time;
- The misconceptions that all concepts should be taught through games. So, classes generally turn into real casinos, without any sense to the student;
- The loss of "playfulness" of the game by the constant interference of the mediator, destroying the essence of the game;
- Coercion from the mediator, requiring the learner to play, even if he does not want to, destroying the willingness that is inherent to the game;
- The difficulty of access and availability of materials and resources about the use of games in education that can support the work of those who apply games.

Despite the advantages of using games, it is important that the teacher is perceived as an intermediary and moderator of this tool, and is responsible for searching and selecting the games, as much as the methodologies to be used, aiming at facilitating the learning objectives [9].

Based on the advantages as well the disadvantages, it is important to know the games and use approaches. This study made use of a systematic review in order to distinguish whether there was work on games that dealt with energy consumption issues and also the reports of its use approaches.

IV. SYSTEMATIC REVIEW

The review of literature is commonly one of the initial steps of a survey for allowing the researcher to understand and analyze materials that present findings, techniques, operating modes and relevant information about their questions. In addition, it contributes to the minimization of errors and avoids unnecessary work, such as duplication, for example [10].

The studies that contribute to the literature review are called primary studies. They are the "regular" studies, which were made from test to check hypothesis, so the review is considered a secondary study, it depends on the primary studies, constituting an attempt to build knowledge from papers and articles already performed [11].

One way to execute a review of literature and therefore get primary education is through systematic review, also known as synthesis of systematic research, integrated search review and integrative review [10].

The systematic review is characterized by the use of a method that aims to answer the investigator's questions with rigorous search, making the researcher's trends and biases interfere as little as possible on the results. Trends and biases can be understood, for example, as the tendency to employ certain terms used in the search without taking into account other possibilities. This type of review can be performed by using a process consisting of three phases, namely: planning, conduct and review report, which will be explained based on the work of [12].

A) Planning of the Review

The planning is based on the protocol elaboration, which specifies the methods to be used to do the review, such as: the questions to be solved, the sources for the search, inclusion and exclusion criteria of the papers found. It is recommended to review the protocol in pairs of people.

B) Conduct

In this step, the database to be used is defined. The selections of studies and evaluations based on inclusion and exclusion criteria, defined in the revision protocol, are done. After the assessments, data are extracted, recorded and submitted. The presentation can be in tables and/or in graphs.

C) Review Report

The review report concerning the publication of data, can be done in technical reports, sections or chapters of academic papers, such as dissertations, theses and articles on events and publications.

Although the different steps have been sequentially presented, it is important to know that they can occur in an iterative way, allowing each step to be improved throughout the process [10].

From the analysis of the descriptions of the steps suggested by [12] one can notice that to perform a systematic review does not mean only to review from a protocol, but, to conduct a literature review, in which collected data will be analyzed to meet certain objectives. The literature review in this process can be seen as a means and not as an end.

The systematic review performed in this paper was done in January 2014, in order to verify the existence of studies about the use of games that dealt with electricity consumption.

The systematic review followed the steps suggested by [13]: planning, conduct and report (Figure 1)



Fig.1.Steps of the systematic review in this paper.

V. SYSTEMATIC REVIEW ABOUT ELETRIC ENERGY COMSUPTION

As previously mentioned, the systematic review aims to answer the questions of the researcher, in this sense, the questions to be answered by this review were:

Q1. Are there educational games about energy consumption?

Q2. How were these games used?

The reason for asking the first question (Q1) was to identify the existence of games that only dealt with the electricity consumption theme (excluding therefore those games that have the consumption of electricity as one of its many themes or sub-themes). The second question (Q2) intended to provide subsidies to recognize and analyze later pedagogical approaches in which these games were used in teaching, serving as referral sources for teachers, who wish to plan their activities with the use of games.

1) Sources, research selection criteria and construction of search strings

To perform the systematic review the bases which the search should be performed was defined. The bases of these studies were selected by their popularity, ACM Digital Library, Elsevier (Science Direct) and Springer. It was also decided that as the papers were being read and they referred to other games, Google Scholar would be used in an attempt to find papers about them. For this investigation the authors have chosen to do the research on academic bases because they wanted to know how the theme “electric energy consumption” had been explored in the academic area.

The search for papers was done by selecting key terms (called search strings), which aimed to answer the questions of the systematic review (Q1 and Q2) and the combination of these terms with logical operators (also known as Boolean operators) which purpose was to indicate to the search engine how the combinations of strings must be done – for this work the logical operators AND and OR were used [14], [15].

The strings have passed through tests. They were built in the English language and were adapted according to each base specificity.

Tests and adaptations were done with the strings. The tests involved different combinations of strings in different bases and all of them were randomly chosen publications, returned by the search engine. In the publications, the presence of terms used in the strings were manually verified in order to be validated.

Tests were also done with the terms relating to the title, abstract and text, as predecessors of the strings. It was done because the use of different predecessors can return different results.

Additionally, tests were conducted to understand the operation of each research base: how the words had to be inserted, how the terms of title and abstracts had to be considered, how to use special characters, like spaces and symbols.

Searches were conducted at the beginning of January 2014, as described below:

A) ACM Digital Library

By limiting the search engine, it was observed, at this stage, the restriction of searches was done by paper abstracts. For this reason, the term Title came prior to the first string.

The following strings were inserted into the search field at the bottom of the page. The quotation marks indicate that both terms contained in them should be searched and parentheses, on the other hand, were used to indicate which set of operations should be performed first.

Title
(Game OR play OR advergence OR serious gaming)
AND
(Education OR training OR breeding OR accomplishment OR teach OR learn OR instruction OR guideline OR pedagogical)
AND
("Save Energy" OR "consumption energy" OR "energy engagement" OR "domestic energy" OR "power energy" OR "energy efficiency" OR "save electricity" OR "electricity environment" OR "electricity savings" OR "household energy" OR "energy reduction" OR "energy conservation" OR "energy awareness")

These strings returned 75 papers.

B) Elsevier (Science Direct)

The same strings used in the previous bases were applied to the Elsevier (Science Direct) base, which were inserted in the search field, observing a title of work search in the first string. 52 papers were returned on this base.

C) Springer

During the tests, it was noted that this base had a different search engine when compared with others. It was necessary to insert one string after another. In total 138 papers were found.

D) Google Scholar

Google Scholar was used after the analysis of the publications found by search strings in order to locate specific studies, which were mentioned throughout the text. Searches consisted in the use of games names that were mentioned in the publications located by search strings. Although possible, the strings were not used in this search system, since it combines the results of different studies bases.

2) Selection Criteria: inclusion and exclusion

After the papers survey was done through the systematic review, with a total of 265 papers, the selection of studies that answered the research questions started (Q1. Are there

educational games about power consumption? And Q2. How were these games used?).

The selection was done based on inclusion and exclusion criteria:

A) Inclusion criteria

- If different studies discuss the same game, both should be analyzed
- If the papers that were found were about pilot studies or preliminary tests on the games use, they should be analyzed;
- If during the search at Google Scholar, papers about games that were not found before, were found by the search strings, they should be considered for analysis;
- Studies with any publication date;
- Studies about any kind of games: electronic, board games, etc.;
- Studies about games declared as educational;
- Studies about games for any level of education;
- Studies about games for players of all ages.

B) Exclusion criteria

- Duplicated studies;
- Studies that are not written in English¹
- Studies that do not deal specifically with games about electricity consumption;
- Studies that did not report the experience on games usage;
- Studies about games that were not declared as educational;
- Studies about gamification.

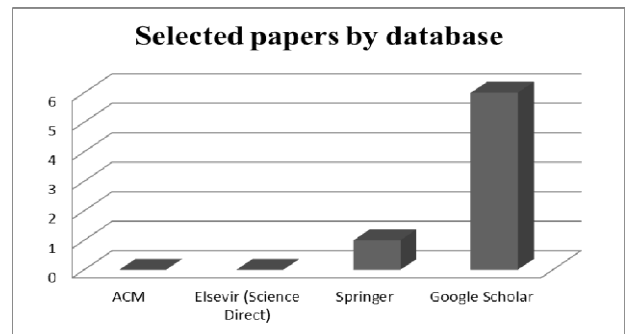
3) Data Extraction

After the papers selection process based on the exclusion and inclusion criteria, the abstract, introduction and conclusion were read and, when needed, other parts of the studies were read.

VI. RESULTS

Among the papers that were found by the systematic review, the preliminary results showed 59 papers that could answer the research questions. However, after the analysis based on the inclusion and exclusion criteria, the number of studies dropped to 7.

The number of papers found on the databases that answered the research questions Q1 and Q2 is shown in the graph 1.



Graph 1: Selected papers by database that answered Q1 and Q2.

The complete list of the papers with titles, publication year and database where they were found can be seen in the following chart:

TABLE1. PAPER TITLE, YEAR, GAME AND BASE

Paper Title	Year	Game	Base
A digital game-based learning system for energy education: an energy conservation pet	2012	Ecopet	Google
EnerCities, a Serious Game to Stimulate Sustainability and Energy Conservation: Preliminary Results	2011	EnerCities	Google
Enercities: educational game about energy	2010	EnerCities	Google
Exploring the use of a game to stimulate energy saving in households	2012	Energy battle	Google
Makahiki: an open source game engine for energy education and conservation	2012	Makahiki	Google
Serious gaming change adolescent's attitudes towards saving energy; preliminary results from the Enercities case	2011	Enercities	Google
The contract: an educational computer game analyzing and optimizing renewable efficiency in schools	2009	Contract	Springer

The presence of these publications can answer the first question of this systematic review, about the existence of educational games related to energy consumption.

Games usage

The second research question, as presented previously, was about the games usage: *How were these games used?*

Before introducing the uses, however, it is important to know that the uses were extracted from the interpretative reading of the works found by the systematic review and that the authors of this article did not have any kind of contact with the paper's authors and or people who have used these games.

¹The English language was selected because it is the most used language in academic papers.

A) Contract (Kontrakten) [17]

That is a computer simulation of a school and its energy consumption and heating, in which students were divided into groups that represented fictional companies, that would compete with each other to get a contract to implement energy saving systems to be used in the school.

In the simulation, the groups used to have a fixed amount of money, that should be managed taking in consideration the improvements desired, which would add points to the group. The group with the highest score would be considered the champion.

The game was applied in three schools in Denmark, with students from the 7th to 10th grades and ages between 12 and 16. To have access to the game, the teachers should download it from the internet, as well as the instruction manuals, introductory presentation, a brochure and a poster of the game.

The points, which the groups were competing for, were divided into the following categories: green points (related to environmental aspects), points related to energy saving and points for heating saving. In order to receive these points, firstly, the groups would be familiarized with and explore data from their school related to energy consumption and the construction of a fictional building. The data about energy consumption were added by the teachers, based on real data from the school. This was used to make the students think in improvements that could be made in their own schools, taking into consideration the costs of applying it. After that, the group could choose one of the topics listed below to be specialized in:

- Lighting/ equipment;
- Heating insulation;
- Heating sources;
- Venting;
- Interior design / Planning;
- Solar energy
- Wind energy;
- Human factor.

After that, the groups received texts related to the chosen themes and solved small problems that were presented, including the creation of devices that could improve the energy efficiency of the school. The solutions were then analyzed by the teachers and they directed the students to the next phase, where they could obtain the points. It is important to acknowledge that all the groups could analyze what was being done by the others, and then in turn they would learn with their classmates. This also improved their competitive spirit.

B) Ecopet [18]

The system simulated and monitored the environmental variables of the places where a virtual animal lived (avatar). The target of the game was to ensure that the avatar, specifically a dog, could live comfortably, but saving energy. So, the gamer would control the electronic devices of the place

and try to achieve the highest energy saving possible, while keeping the animal comfortable.

The choice of the animal theme was made taking into consideration the positive effects of the human-animal interaction.

The game was built so the players could use strategies to promote self consciousness about energy savings, allowing them to feel motivated and so the learning could happen.

23 volunteers were then selected; they were postgraduate students aged 23 to 31 years old from a university in Taiwan. They had to answer to questionnaires before and after the game, their interactions and reactions were also filmed and analyzed. The questionnaire referred to their day-to-day energy consumption habits and also their knowledge and motivation for saving energy .

C) Enercities

In this game, the player had to balance people (social approach), planet (environmental approach) and profit (economic approach) taking into consideration the demand in energy of a city. The player had to implement power saving measures, aiming to lower the CO₂ emissions and also the fossil fuels usage in electricity generation for the city. The decisions influenced the players score on people, planet and profit categories. When good actions were taken, the player received more space to expand his city and to use extra bonus for the game. Furthermore, the gamers could post their scores on the social network [19].

The game was played by high school students in five European countries, monitored by their teachers. In the first moment, quantitative tests were done, where 800 students answered online questionnaires about the game. After that, a qualitative study was done only with 76 students from different schools. Questionnaires were answered by the students after playing the game. There was also a control group that did not play the game. The aim of these questionnaires was to evaluate if there was learning due to the use of the game [20].

The game was used in regular classes or in projects that specifically dealt with the energy theme [20].

D) Energy Battle [21]

This game was performed in three phases. The first one was two weeks before the beginning of the completion. In this phase meters were installed in the players' houses, so some measurements could be made. At this point, the players did not have access to their consumption information. In the second phase, the gamers received instructions about how to use the meters and how to register on a website to receive information and tips about energy savings. On this website they could also receive feedback about their energy consumption and the classification of all the teams. The third phase was the moment where the energy measurements were taken after the end of the game, which lasted 8 months in some houses.

Some questionnaires were answered and interviews were made with some people, one month and eight months after the end of the competition. The main target was to evaluate if the habits executed during the game were incorporated to the people routine.

According to the interviews, extreme habits, which were those where people lost their comfort inside their houses, were abandoned once it stopped being an strategy to win the game. One example was to share only one computer. Despite this, people said that the new habits were incorporated to their daily routine (changing the lighting, and adding less water to the boiler).

E) Makahiki [22]

This game was part of a competition called Kukui Cup, where students from the Hawaii University formed groups, determined by the floor where their dormitories were located. From that, the players had access to tasks that should be performed through one digital screen, called Smart Grid. Such tasks were divided into activities, appointments, events and tours. The player received points for each task completed; these points could come from individual or collective tasks.

The main component of this game was the Smart Grid, where the players should check which tasks they should fulfill. To receive the points related to their activities, the players should send the answers to the administrators through the system. The answers could be texts or illustrations. The administrators should approve or reject the student activities. If accepted, the player would receive the points. If rejected, he received a feedback explaining the reasons for the rejection. After the feedback, the student could fix his activity and send it again.

The appointments were actions considered sustainable that the players should fulfill or make for a five days period. Example: reduce time during the shower, shut down the lights when leaving a room. The events and tours were related to activities done inside and outside the campus (the reading of the article did not give more details about the tasks).

The students had daily targets for energy savings and could access the webpage of the system where the information about consumption was available. The points were converted into tickets which the players could bet in a raffle for any prize they would be interested in. In an effort to get more participants, the game considered two types of bonus: social and references. In the first type, the player received a point if he could fulfill a task with another person (watch an event, for example). In the second, the player should indicate a new participant. Once this new person accepted, both were rewarded with points.

The best players -those who had more points - had access to a change of game design, which is called the visual canopy, where there was a forest background with trees, shrubs and grasses. The canopy members had a set view from the canopy (treetop) and could communicate with each other and with management, receiving special missions that were not in the smart grid. They also had access to advanced energy consumption views of other players.

After the use of the game, some evaluation in the form of questionnaires and interviews were made to know if the students felt motivated and also their impression on the game.

VII. DISCUSSION AND CONCLUSION

The results presented by the systematic review indicate a lack of publications where the use approaches of games on electricity consumption are reported - highlighting the need for further investigation and sharing. It is also important to note that information about what happened in the players' real life after playing the game was not detailed and it could be a very interesting contribution of these studies.

The results also showed that different kinds of games like electronics, competitive, in group or for one player, for any age have the potential to make people think about energy consumption. It can be done in a variety of scenarios such as, in the construction of a city, in the management of it, to help a virtual animal survive or in a competition in real life. However, if we think that energy problem is complex and draw together different areas such as technology, social and environment, it is interesting that the games try to explore all of them or if they do not do it, at least, they let the student know that maybe it is important for him to try to discover more about it by himself.

The existence of the papers that relate and share the experience of using games that are pertinent to this theme can be considered a tool to help planning activities that include the use of games.

Publications related to these issues are important because the electricity consumption issues related to property is used in various sectors of society, and its growing consumption has generated a number of impacts in different orders, namely, social and environmental impacts. This subject, which can be addressed with the use of games requires care, because although it has lots of potential for use in educational activities, it requires thought and planning. An additional study about this planning, the possible effects of the teacher being present or not and the reflections of the students is a recommendation of this paper.

It is believed that this paper contributes to the academic community by presenting a list of games and their uses. The awareness of this type of research can serve as an incentive for new games and different approaches can be designed and created.

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Engaging Students inside the Classroom to Increase Learning

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Abstract—From overhead transparencies to interactive documents, teaching and learning engineering has changed dramatically over the years. A flipped or hybrid course is a pedagogical model that reverses typical lecture and homework elements of a course. Class time is used for discussions and group activities with lecture materials being introduced in an on-line format. As research has shown, this model allows students to typically demonstrate higher levels of learning.

This paper will detail the associated learning by students through the author's transition from a typical lecture-based sophomore-level engineering class to a hybrid model. The author will address how learning can be increased through the use of active engagement tools, such as iClickers.

To address this question and gauge the overall impact on student learning, a post-course survey was used to measure the perceived value for students. In addition, evidence for improved student engagement was gathered qualitatively to compare with previous experiences. Results show that active engagement tools helped students become active learners, increased interaction with peers and instructor, and helped them evaluate whether material was understood to motivate further learning. Moreover, students benefitted from the instructor being able to pinpoint misconceptions earlier due to instant feedback from students in the class.

Keywords—iClickers, clickers, active learning, classroom engagement tool, audience response system, flipped, hybrid, inverted

I. INTRODUCTION

New technologies have rapidly changed the scene of the typical classroom. From overhead transparencies and chalk to interactive documents and on-line applications, teaching and learning engineering have evolved from the classroom elements of even ten years ago. In a traditional classroom, faculty formally introduce material in lecture, and students learn the material through reading the textbook and completing homework and demonstrate attainment of knowledge through work on exams. While the opportunity is there for students to obtain feedback through class questions and office hours for the faculty, few students take advantage of this resource [1]-[2]. In addition, faculty members typically deliver information in a one-way format, which leaves little room for student engagement and critical thinking. This type

of setting is contrasted with the inclusion of online or secondary instruction beyond the main classroom setting, which prepares the student to enter the classroom with exposure to the material and an understanding based on these resources. The additional instruction offers methods of presenting lecture or additional course material outside of the classroom, which in turn enables the professor to utilize a portion of class time for working examples and holding higher-level discussions on the material. Common monikers for this type of classroom structure include hybrid, flipped, or even inverted classes [3]. While the literature distinguishes between the three types, the terms are used interchangeably in this work to describe students constructing an understanding individually prior to entering the classroom through the use of pre-readings and videos with the instructor then facilitating a higher-level discussion to encourage engagement and critical thinking skills.

The use of audience response systems, such as iClickers, allows students to respond to polling questions during the classroom setting. Students have a physical remote that is linked in the class to record responses. While there are a variety of tools that can be used with smart devices, the use of an iClicker remote ensured access to the polling system since having a smart device was not a requirement. Tools, such as iClickers, in the classroom allows an instructor to quickly and effectively gauge the understanding of students in class and a student to anonymously determine understanding of a concept relative to others in the class. Multiple studies have found that student use of iClickers has shown to be effective in the achievement of concept retention [4]-[7].

Therefore, this study addresses how learning can be impacted and student interactions increased through the use of active engagement tools, in this case an iClicker. Examples are provided, and results obtained included. In addition, the introduction of class preparation materials is also evaluated.

II. BACKGROUND

Learning theorists conclude human learning takes place in two phases: transmission and assimilation [8]-[12]. Learners in the transmission phase acquire information in their conscious minds. Examples of learning by transmission include listening to lectures and reading a course textbook. Assimilation, on the other hand, describes learners taking information acquired during transmission and utilizing the information beyond simple recall. It involves learning by more hands-on endeavors, typically completed by homework,

lab work, and cooperative learning activities. Figure 1 illustrates the relation of these two types of learning phases to Bloom's Taxonomy [13].

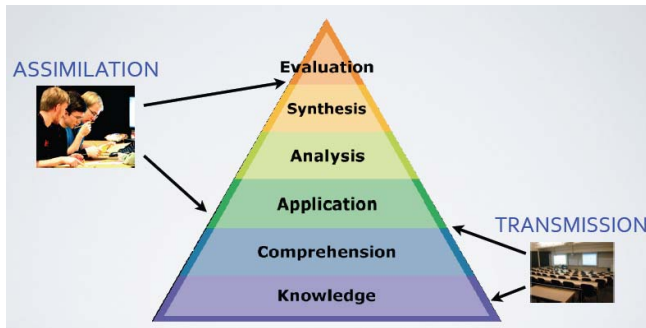


Figure 1. Relation of assimilation and transmission to Bloom's Taxonomy [8].

The traditional model of teaching devotes class time to the transmission phase of learning and leaves the higher order complex task of assimilation for students to complete outside of the classroom [12]. In Bloom's Taxonomy, the cognitive load increases as a student progresses higher up the pyramid from bottom to top. The traditional class provides the greatest accessibility of assistance at the bottom of the Taxonomy. Anderson and Krathwohl revised Bloom's Taxonomy into two dimensions developing a continuum between knowledge domain and cognitive domain [14]-[15]. This theoretical framework also shows the cognitive load increasing as a student moves from a lower form of cognition, such as remembering, to a higher level with creating. A difference in this framework, however, is the second dimension along a knowledge continuum. As shown in Figure 2, the traditional class provides assistance to students in the top left area of the taxonomy table through learning in the transmission phase while outside activities cover the other portions. A flipped or inverted classroom allows for transmission to occur outside of class while assimilation transpires in class. This format allows students to benefit from hands-on instruction from the professor during the higher order tasks and leaves the less complex tasks for students to handle individually prior to arriving in class.

Knowledge Dimension	Cognitive Process Dimension									
	Remember	Understand	Apply	Analyze	Evaluate	Create				
Factual	Transmission		Assimilation							
Conceptual										
Procedural										
Metacognitive										

Figure 2. Relation of assimilation and transmission to Anderson and Krathwohl's Taxonomy Table [14].

Some faculty may have concerns about incorporating this type of format in the class. For example, questions may arise on what to use the classroom time for in this type of setting and how to engage students in the face-to-face portion. As discussed by Dr. Talbert in his presentation on flipped

classrooms [8], he addresses these areas in the perceived challenges of flipping a course.

"Students will not come to class, how to create engaging in-class activities, students will not read, students will become overwhelmed, how to produce quality videos and make them interactive, updating materials, time necessary to create, edit and revise material, technology will not work, student buy-in, available resources, accountability, and value added."

He also discusses how benefits provided in this type of format quickly outweigh the challenges presented.

"Students will retain more, students can develop questions, modeling, lectures available for review, access true mastery, accountability, individual learning, instructor growth, class time is more productive, and reusable learning objectives."

A flipped or inverted class allows a student to actively inquire about lecture content, test skills in applying the knowledge, and obtain peer instruction during discussions on the material [16]. During the class time, professors serve as advisors and facilitators to allow the opportunity for students to delve deeper into the subject matter. This provides a stark contrast to a traditional lecture where students many times do not have time to reflect upon the material as it is being taught. By having resources available outside of the classroom, students may utilize the resources, such as readings, videos, and learning activities as many times as needed. The use of active engagement tools inside the classroom enhances the process of changing the typical lecture style format. While developing or assimilating these resources can be time consuming at the beginning, the benefits of engaging students both inside and outside the classroom are shown to outweigh the time involved.

While the notion of an audience response system, such as an iClicker, has been prevalent in some form of approach since the early 1960s, technology enhancements over the years have definitely increased their usability in the classroom, especially incorporating active learning methods. Instructors are able to pose questions through prepared slides or impulsively during class discussions. The iClicker allows students to enter answers presented in a multiple-choice or numeric input format. Numerous studies have used iClickers in classes, but many narrowly assess their impact. Czekanski and Roux [4] focused on how short-term concept retention was affected due to the anonymity provided by the devices. Their study showed such tools were valuable in aiding short term concept evaluation. In the work by Mayer et al, [5] the main prediction was that using clickers would lead to a greater student-teacher interaction. The belief was greater interaction would lead to deeper cognitive processing and increased learning. Evaluating exam scores did show a small, but significant, grade improvement for the section incorporating clickers. Research by Schmidt, Garcia, and Webber [6], specifically used clickers to evaluate the level of information

gained by means of a self-directed education using development of a podcast. Clickers were used to provide information related to material learned by the students. The researchers assessed comfort and participation using the tool. They found students were content using the clickers, but the tool did not affect their participation level in the course. A study by Head [7] addressed the classroom experience and real-time assessment using clickers. The author found the tool helped explanations by teachers through the real-time feedback from student responses. Hogan and Cernusca [17] focused on the perception by millennials on the enjoyment and engagement in the classroom environment. In the longitudinal study, the researchers evaluated perception by incorporating the tool not only at the course level but also at the university level. They found students on average required two semesters to significantly shift their perception and view clickers as supporting class activities. Not addressed in the previous works are how the tool can be used in an inverted class and how expanding feedback related to enjoyment and engagement areas allows for the potential of significant changes to be observed after one semester. In addition, specific methods for faculty to incorporate the tool in an active learning environment beyond simply asking questions anonymously were not fully described.

III. METHODS

To implement the active learning tools, the author identified a core, required, first semester sophomore-level engineering statics course taught during the Fall 2012 semester in the Aerospace Engineering Department at Texas A&M University (TAMU). The course consisted of two credit hours and was a common course type to many engineering majors at TAMU. Only one section of the course was taught in the department each semester, and the author had taught this course each semester for the last three semesters.

During the semester, students were assigned pre-work for class, which included textbook readings, on-line resources, videos, etc. This provided a context for students coming prepared for a dynamic classroom experience full of discussion, team work, and problem-solving. During the class, an active engagement tool, iClicker, was used to poll the audience on multiple-choice and numeric questions and facilitated working with peers. In addition, relevant instruction was provided by the faculty in areas where lack of knowledge could easily be identified.

The techniques utilized to analyze the implementation of active engagement tool in the course were qualitative. An on-line end of course survey with specific questions related to the use of active engagement tools was administered and provided qualitative results. Students anonymously completed the survey outside of class. A confirmation page showing completion of the survey was submitted as part of a final homework assignment by the students. There was 97% participation in the final survey with 73 students completing the survey. In addition, twenty percent of the students were randomly selected to orally discuss their final exam to detail

where they made mistakes and their thought process in achieving the results obtained. The researcher also compared the final exam scores from the section that used the tools with two previous semesters of the course offering by the same instructor where the active engagement tools had not been used.

A. Survey Instrument

The post-course survey contained a total of 64 questions inquiring about general course details, such as preparation for the course and future plans with 29 of the questions specifically covering the active engagement tool utilized in the course, which was iClicker. Factor Analysis was employed to identify the number of factors that explain most of the variance observed within a larger set of variables. The questions related to the tools evaluated through this work related to three factors, which were identified as: a) enjoyment of using clickers in the course, b) engagement of students in the classroom, and c) engagement of students outside of the classroom. The three factors and several of the questions were similar to those posed by Hogan and Cernusca [17] in related work. This survey instrument differed, however, from the previous work by expanding each of these areas and including questions on resources for the inverted class. Students evaluated each question in the survey using a five-point Likert Scale with 5-Strongly Agree, 4-Agree, 3-Neutral, 2-Disagree, and 1-Strongly Disagree. The researcher used a one-sample t-test on each of the questions to determine if the mean of the sample was greater than the comparison value of three, which would indicate the students being neutral on that particular question.

B. Final Exam

Each semester, the instructor typically keeps the questions on the final exam relatively similar with minor modifications/clarifications. This allowed an end of semester comparison between the group utilizing the active engagement tools and two prior semesters where no such tools were employed. The researcher used an ANOVA test to see if the means of the final exam scores from separate semesters were different from each other. In addition, students were randomly selected to meet with the instructor and detail their thought process on the final exam to assess their learning. Although not directly compared, the students in the three semesters were similar in nature.

IV. RESULTS

Administering the post-course on-line survey provided results in three areas previously discussed including enjoyment, engagement inside the classroom, and engagement outside of the classroom. The instructor used iClickers in the class, so a large number of questions asked in the survey related to this tool. In addition, final exam scores allowed a direct comparison of scores received by students who had used the active engagement tools versus two semesters where no such tools were employed. An alpha level of .05 was used for all statistical tests.

A. Survey – Enjoyment of Using iClickers in the Course

Results related to enjoyment of using iClickers in the course are reported in Table 1. Eight questions were asked in this category related to the iClicker in the areas of: ease of use, enjoyment, satisfaction, and recommendation in other courses.

All eight questions related to enjoyment of using iClickers showed there was a statistically significant mean difference, at the .05 level, in response rates. The highest values for mean related to ease of use, satisfaction, and helpfulness of instant feedback with the tool. Overall, using iClickers in the course provided enjoyment for students.

Table 1
Enjoyment of Using iClickers in the Course (N = 73)

Question	<i>M</i>	<i>SD</i>	95% CI for Mean Difference	<i>p</i>
Q5: I found iClickers easy to use.	4.73	0.45	1.62, 1.83	0.000*
Q6: I enjoyed using iClickers in class.	4.26	0.80	1.07, 1.45	0.000*
Q20: I am satisfied with the use of iClickers in this class.	4.30	0.70	1.14, 1.46	0.000*
Q26: I found discussion associated with iClicker questions made the course more enjoyable overall.	4.12	0.73	0.95, 1.29	0.000*
Q29: I would recommend using iClickers in other courses.	3.96	0.84	0.76, 1.16	0.000*
Q19: I felt more engaged in class material because iClickers were used.	4.22	0.73	1.05, 1.39	0.000*
Q23: I found it helpful to get instant feedback of my learning through the use of iClickers.	4.30	0.64	1.15, 1.45	0.000*
Q24: I found it helpful to have my answers to iClicker questions displayed anonymously during discussions.	4.29	0.68	1.13, 1.45	0.000*

Note: The comparison value for each of the questions was three. * $p < .05$

B. Survey – Engagement of Students in the Classroom

Results related to engagement of the student in the classroom are reported in Table 2. Eight questions were asked in this category related to the iClicker in the areas of: become a more active learner during lecture, increase interaction with peers, increase student to teacher interactions, affect attention displayed during class, understand course materials, affect class discussion, make material more interesting, engage in class material; use feedback, enhance learning, and prefer classroom delivery of material.

All eight questions related to engagement of the students in the classroom showed there was a statistically significant mean difference, at the .05 level, in response rates. The highest values for mean related to the tool helping the students become a more active learner during the class and helping gauge their knowledge level of the material being taught.

Overall, students felt the active learning tools provided engagement in the classroom.

Table 2
Engagement of Students in the Classroom (N = 73)

Question	<i>M</i>	<i>SD</i>	95% CI for Mean Difference	<i>p</i>
Q8: The iClicker questions helped me become a more active learner during lecture.	4.33	0.67	1.17, 1.48	0.000*
Q9: I found iClicker questions useful in increasing my interaction with other students.	4.22	0.65	1.07, 1.37	0.000*
Q10: I found iClicker questions useful in increasing my interaction with the professor.	4.12	0.76	0.95, 1.30	0.000*
Q11: Using iClickers helped me pay attention during class.	4.29	0.74	1.12, 1.46	0.000*
Q12: Using iClickers helped me gauge whether I am following the course materials during class.	4.32	0.67	1.16, 1.48	0.000*
Q13: Using iClickers helped me to assess if I understood material being covered.	4.24	0.74	1.06, 1.41	0.000*
Q14: Using iClickers helped me to remember the material covered in lecture.	3.94	0.79	0.76, 1.13	0.000*
Q25: I found discussion associated with iClicker questions enhanced my learning in the course.	4.14	0.61	1.00, 1.28	0.000*

Note: The comparison value for each of the questions was three. * $p < .05$

C. Survey – Engagement of Students outside the Classroom

Results related to engagement of the students outside of the classroom are reported in Table 3. Ten questions were asked in this category related to the iClicker or class set-up in general in the areas of: completion of pre-work, assessment of understanding of material, remembering of material being taught, motivation for class preparation, modification of learning, mental effort in the course, and preparation for exams.

Nine of the ten questions related to engagement of the student outside classroom showed there was a statistically significant mean difference, at the .05 level, in response rates. As a whole, this group of questions received lower scores for the values of mean than the other two previous sets. The highest values for mean related to the use of using pre-readings to prepare for class and their effect on preparing for class and using the iClicker tool to grasp material covered in class. Overall, students felt the active learning tools provided engagement outside of the classroom.

Table 3

Engagement of Students outside the Classroom (N = 73)

Question	M	SD	95% CI for Mean Difference	p
Q2: I completed the pre-readings (book material or additional reference material) for the course.	4.03	0.69	0.87, 1.19	0.000*
Q3: I felt the pre-readings helped me be prepared when I came to class.	4.06	0.57	0.92, 1.20	0.000*
Q15: Using iClickers in the class motivated me to come to class prepared.	3.84	0.88	0.63, 1.04	0.000*
Q16: I modified my learning of material after class based on results from iClicker questions.	3.27	0.92	0.06, 0.49	0.013
Q17: Having discussion in class increased my interest in class material.	3.89	0.78	0.71, 1.07	0.000*
Q18: Using iClickers made material we covered in class more interesting.	3.82	1.00	0.59, 1.06	0.000*
Q21: The iClickers caused me to put a lot of mental effort into class.	3.48	0.90	0.27, 0.69	0.000*
Q22: iClickers assisted my ability to grasp the material covered in class.	4.03	0.65	0.88, 1.18	0.000*
Q27: The iClicker questions helped me prepare for exams.	3.63	0.97	0.40, 0.85	0.000*
Q28: I would prefer to have a straight lecture provided each day in class instead of discussions.	1.97	0.90	-1.24, -0.82	0.000*

Note: The comparison value for each of the questions was three. *p < .05

D. Final Exam

The final exam scores for three different semesters were compared using an ANOVA test. All three semesters had similar final exam questions, and the same instructor taught the course each of the three semesters. There was not a significant difference in the final exam scores received between the semesters using different instruction tools.

The researcher also interviewed students about their work on the final exam to determine the level that students could describe their mistakes. The instructor has conducted similar sessions with students in previous semesters and has not seen the level of understanding received after using the active engagement tools. Students who had incorporated the active engagement tools could more readily discuss their mistakes and see how the work they had completed was flawed. The researcher found that the process of learning is not necessarily noted on the number of correct answers the participants received. Rather the learning came when the participants were asked to note what they did wrong and if they were able to fix their error.

E. Instructor Feedback

The instructor found feedback received from using iClickers was exceptional. The iClickers provided a quick snapshot of the understanding by the students on a particular topic. Responses received helped guide the discussion. With the results anonymously displayed on the screen, students felt comfortable in sharing an answer using iClickers while they might have held back if oral answers were shared that identified who provided the answer. In addition, the instructor found instant feedback on the level of understanding by the students very beneficial. Multiple choice questions typically started the class discussion. The following figures showcase two prevalent scenarios witnessed by the instructor in using iClickers in the classroom. As shown in Figure 3, the bar chart on the left represents the range of answers received after a multiple choice question was posed for the students to answer individually. The instructor also projected this image of the results received for the entire class to see. Without focusing on specific values for each of the answers of A-E, it was clear students had a wide range of understanding regarding the question posed. The instructor then asked the same question again but allowed student peer interaction discussion to occur before the answer was provided a second time. Basically, students were encouraged to discuss the question with students seated close by. As shown from the bar chart on the right hand side, students overwhelmingly answered the question correctly with only a few students selecting an incorrect answer. The instructor then discussed the incorrect solutions and corresponding reason for being incorrect. Of course if the bar chart on the right in Figure 3 was received at the initial probing, the instructor discussed the inaccuracies of the incorrect answers briefly and did not utilize peer interaction.

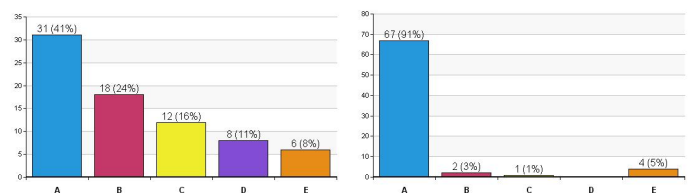


Figure 3. Visual display of multiple choice answers received from students using iClickers with initial answers displayed on the left and results after peer interaction enabled on the right.

The bar charts in Figure 4 display a similar scenario as in Figure 3. In this interaction, however, students were almost evenly split between two possible answer selections after peer interaction occurred. Therefore, the instructor provided additional instruction on the topic, discussed possible misconceptions, and allowed a second peer interaction discussion to occur, which allowed students to work through an understanding of the problem posed. Results would then normally be similar to those received on the right side in Figure 3. Otherwise, further class discussion followed.

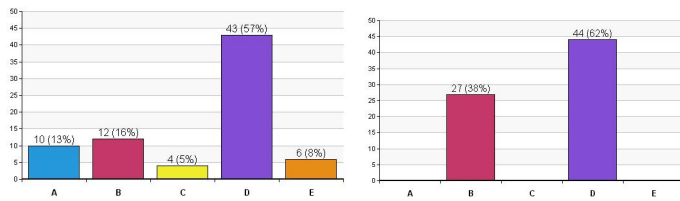


Figure 4. Visual display of multiple choice answers received from students using iClickers with initial answers displayed on the left and results after peer interaction enabled on the right.

Input answers using iClickers are not limited to multiple choice questions. Frequently the instructor would ask more in-depth calculation-based questions after initial discussions using multiple choice questions had occurred. Using iClickers to input numerical answers allowed the instructor to spontaneously gauge the understanding of students as work progressed on a problem without having to have previous multiple choice questions generated. If a wide variety of answers ensued, more discussion and teaching would occur. In addition, problems could be completed in between class meetings, and the class period could commence with students providing numerical responses to problems completed for the class.

Common questions and concerns from students related to grades received for work through iClickers. Upfront, the instructor discussed grading policies related to iClickers. Most feedback students provided was handled as a participation grade. However, the instructor did note some questions related to expected learning. These were denoted prior to querying and were graded accordingly.

Students generally provided complimentary feedback related to the use of active engagement tools. Two free-response questions on the post-course survey related to iClickers and the course in general provided insightful comments. A few examples are provided.

"[iClickers] were very enjoyable to use and kept me focused. Overall, it was a much more pleasant experience than just sitting in class and listening to an hour-long monologue."

"I enjoyed the iClicker questions sometimes. It was also very hard to prepare for lectures at times. If I ever failed to prepare for lecture then my learning ability for that class was hindered."

"Even though I hate having to take iClicker quizzes, they are very helpful and would definitely like to see more use of them in the AERO courses."

"Honestly, the iClicker discussions were probably more helpful than anything."

"The iClickers were actually exceptionally helpful. (I say actually after having an unpleasant experience with iClickers in CHEM 107.) They helped gauge my performance in AERO 209 and helped me stay on top of the material."

A couple of comments from students provided suggestions for using the tool in the classroom. For example, the following comment shows the importance of the discussion that follows the introduction of the iClicker question and not simply the use of the tool itself.

"Sometimes the questions go by really fast; not enough time to think about it, versus on paper where a person can see every problem."

The vast majority of the questions on the survey asked for input on the active engagement tool. As a whole the comments were overwhelming positive related to the three areas of enjoyment, engagement inside the classroom, and engagement outside the classroom. Only a few of the questions addressed details on the materials used in the inverted class format. However, these materials contributed to further discussions in the classroom setting where the active engagement tool was utilized.

V. CONCLUSIONS

The main focus of this work was on using an active engagement tool, iClicker, in the classroom. As part of the study, however, the author also inverted the classroom experience whereby students entered the classroom prepared for a more in-depth learning experience. The tool alone did not provide the engaging experience, however. For example, some faculty have used the polling tool simply as a means to check attendance. It was through the use of peer interactions and classroom discussions that the tool positively affected the learning experience for students in the class as shown by the feedback of students.

The instructor also determined that to be successful with an inverted course, high quality resources and a structure for utilizing the resources were vital for students outside of class. Tools utilized outside the classroom, such as pre-learning videos and document resources, were available to students through an on-line course management system. In addition, having interesting and challenging problems for students inside of class was also vital to keep students engaged. In the in-class discussions and problem solving sessions, iClickers provided individual accountability, instant feedback, and documented grading.

Overall, the experience provided a beneficial experience for the instructor and students. While results showed encouragement for refining the use of active engagement tools in subsequent semesters, the results on examinations of students will need further review. The tools provided students a variety of ways to learn the material. The researcher found learning came when the participants were asked to note what they did wrong and if they were able to fix it rather than what might have been attributed to a numerical grade in the course. Additional evaluation and fine-tuning will need to occur. The study provided evidence of learning being impacted and student interactions increased through the use of active engagement tools.

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Can Student Engagement be Measured?

and, if so, Does it Matter?

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Abstract— Students in an introductory science course offered both face-to-face and on-line at the University of Michigan used a web application that allowed them to respond to questions, pose questions and take notes. The data from their participation were recorded, quantified and compared with their resulting grades on exams to ascertain to what degree measures of student participation were related to student learning. These measures of student participation were augmented by data from the university's student information system, which provided background information. Data was also collected from a number of surveys administered over the semester. Analyses of the data revealed some strong relationships between grades and the degree and quality of student participation. Moreover the behavior of students varied significantly when stratified by their incoming GPA. The empirical relationships reported here provide evidence-based affirmation that student participation is related to learning and suggests that the strength of GPA as a predictor of grades may be due more to a lack the study skills and/or motivation rather than cognitive ability.

Keywords—student engagement, learning analytics, student outcomes, LectureTools

I. INTRODUCTION

Student engagement is widely thought to be a key predictor of student achievement. We all have a sense of what an engaged student looks like [1-3]: they participate by asking questions, challenging assertions and completing assignments. As we are able to digitally measure more and more of how a student participates, to what degree will it be possible to identify a suite of measures that can quantify engagement so we can identify underperforming students earlier in the semester?

Active participation is known to improve learning [4, 5] but typically instructors dominate the class with presentation [6, 7] and offer few opportunities for students to actively participate. Verbal questions from students tend to be limited to a small percent of class participants [8] in these environments. While it is widely accepted that the ideal learning situation tends toward lower student to instructor ratios the economics of post-secondary education are such that it is unlikely that large introductory courses are going to go away in at least the near future. So how can we use learning analytics to improve the pedagogical value of the large lecture hall?

Here we consider a broader suite of measures than previously available for a large introductory science course. The course, Extreme Weather, was offered at the University of Michigan in the winter 2014 semester with 168 students. Data collected in this class was divided between those extrinsic and those intrinsic to the course:

- Extrinsic Measures
 - Incoming Grade Point Average
 - Interest in course content
- Intrinsic Measures
 - Attendance in class
 - Participation in class activities
 - Correctness in class activities
 - Taking notes
 - Posting questions
 - Indicating confusion

Each of these intrinsic measures of participation requires the student to engage with the material being presented during class. While there are many other ways for students to engage with the class content these methods are often the most common.

The intrinsic measures are made possible through use of LectureTools, which allows students to respond to a wide range of questions as a web-based replacement for clickers, view the instructor's slides, take notes synchronized with the

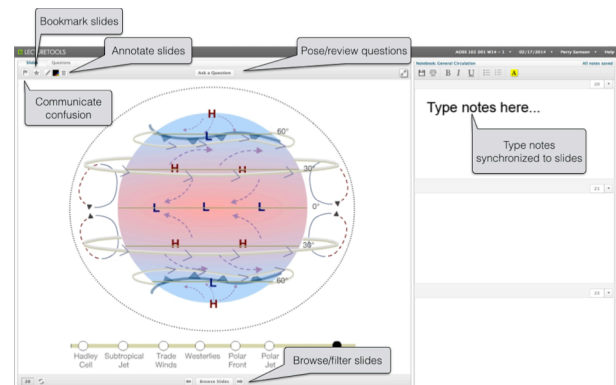


Fig. 1. Student view of LectureTools identifying their ability to take notes, annotate slides, bookmark slides, note confusion, answer questions from the instructor and pose questions to the instructor.

slides and pose questions to the instructor. While use of the tool was not mandatory more than 90% of the students voluntarily elected to use LectureTools. All the student actions are recorded to a database and made available to the instructor.

The data collected by LectureTools allows not only an examination of how student participation is related to outcome but by combining these data with data from the university's student information system (SIS) it is possible to also identify how students with differing incoming Grade Point Average (GPA) behave differently in class. Others have illustrated that student outcomes can often be predicted using current GPA's of students [9]. But for instructors this understanding is less valuable than what can be done in their own class to promote student success. In other words can we identify what it is that successful students do in class that is different from less successful students?

II. METHODS

A. Course Structure

The course studied, *AOSS 102, Extreme Weather*, is offered every semester at the University of Michigan and is offered for students as one of many "science distribution" courses to fulfill a science requirement. In the winter semester, 2014, the course was offered as a hybrid course streamed in real time with the option that students could participate in person or remotely. Students used LectureTools, which allows students to participate synchronously from wherever they are to answer questions, pose questions, annotate slides, take notes and indicate confusion.

B. Data Collection

1) Collecting Intrinsic Data

The course was both streamed live and recorded every class day using Echo360 (<http://echo360.com/capture-options>) so students could have the choice of physically coming to class or

viewing lecture remotely and synchronously. In either situation students could use LectureTools (see Figure 1), which allowed the students to:

- Type notes synchronized with the lecture slides
- Answer questions posed by the instructor
- Indicate confusion
- Pose questions to the instructor and view responses
- Print lecture slides and notes for off-line review.

LectureTools provides the instructor with tools to ask a wide range of question types including multiple choice, reorder list, free response, numerical and image-based questions, excellent for testing students understanding of graphs, images and maps.

All data for LectureTools is stored in the cloud and is available to the course instructor via a web portal that summarizes student participation on class-by-class basis. For this study the data collected during the semester was separated into three periods representing student participation between the beginning of the semester and the first exam, between the first exam and second exam, and between the second exam and third.

2) Collecting Extrinsic Data

It is reasonable to expect that there are influences on student performance that are unrelated to the conduct of the course. These could be the incoming knowledge base and confidence level of the student, their level of emotional or physical wellness and/or their level of interest in the content of the course. As others have demonstrated that student outcomes are often well correlated with the incoming GPA of students additional data was obtained from the University of Michigan student.

C. Analyses

All the data were extracted and then linked to students' hourly exam grades. Processing was accomplished using Microsoft Excel for categorical frequency analyses and Weka [10] for statistical clustering, categorization and linear regression.

III. RESULTS

A. Prior Success

As others (McKay et al., 2012) have reported, exam grades are often related to the GPA of students prior to joining a course. The data from this class do show a relationship between incoming GPA and exam grades (Figure 2) though this also illustrates a fair amount of variability in the grades regardless of GPA.

The incoming GPA of the students explains between 23 to 31% of the variance in exam grades. While this information may be of interest to an instructor as a potential harbinger of difficulty a student's GPA, by itself, does not provide guidance about what strategies to recommend to students with lower GPA's. Moreover it can be argued that instructors might not be comfortable knowing a student's record of prior success as it could influence their attitude toward the student.

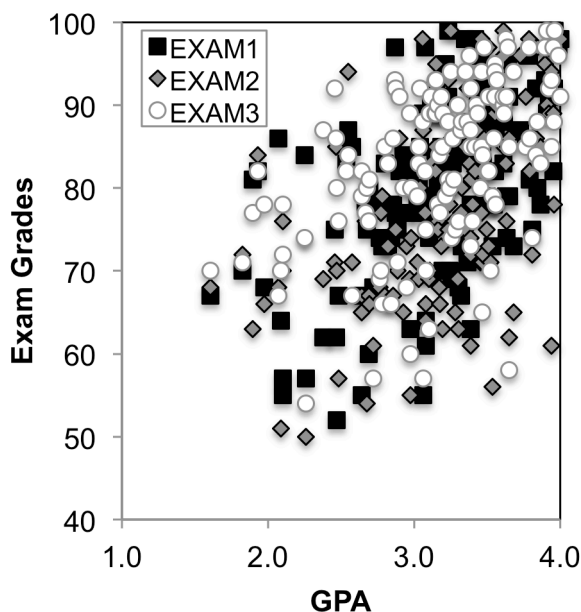


Fig. 2. Scatter plot of exam grades versus incoming grade point average (GPA) for each student.

B. Attendance in Class

When students attend class they are exposed to presentation and/or discussion, which provides an opportunity to listen to and interact with someone knowledgeable in the topic. If they don't come to class, perhaps more importantly, they are declaring that other things are more important than this course on this day.

In the class studied, and probably because of the incentivization described above for participation plus the availability of the streaming lecture feed, student "attendance" is quite high. About 150 of the 160 students in the course used LectureTools and of those about 130 attended every day of class either in person or remotely.

Table 1 shows the average grades received on each exam as function of the number of days with no participation in the period prior to each exam. These results show little relationship between missed classes and grades, but the numbers of students missing class four or more times was relatively low for each exam (11, 13, 16, respectively). This would suggest that on the whole attendance was a poor indicator of student outcomes for this course.

TABLE I. THE AVERAGE GRADES ON EACH OF THREE HOURLY EXAMS AS A FUNCTION OF THE NUMBER OF TIMES STUDENTS DID NOT PARTICIPATE.

Days of Non-Participation	Exam 1	Exam 2	Exam 3
0	80.1	76.6	83.7
1-3	80.0	75.9	82.3
4-6	83.3	69.8	78.0
>6	86.0	76.7	82.1

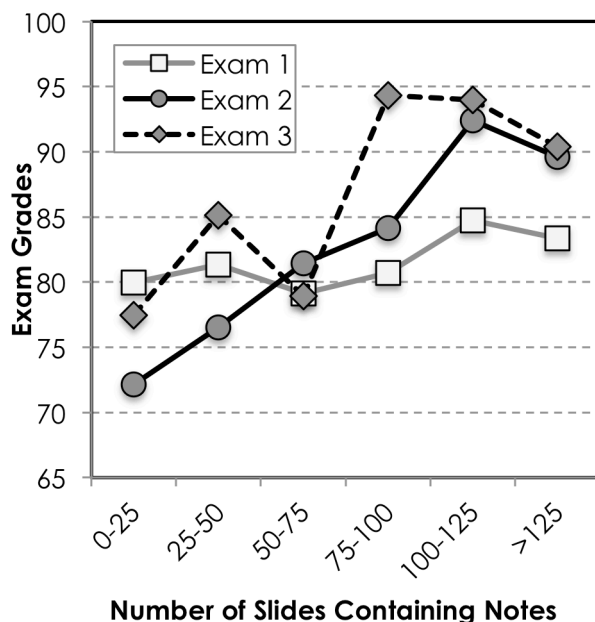


Fig. 3. Average exam scores versus the number of slides containing notes in the period prior to the exams.

C. Taking Notes

A student taking notes is obviously participating in class though note taking by itself may or may not lead to learning. The corollary is that not taking notes presumably limits the learning possible.

In this study the number of slides for which each student took notes was calculated. Again, the class was segmented into the three periods preceding each exam and the number of slides each student typed notes on were calculated and compared with the resulting exam scores. Figure 3 shows that the average grades associated with various bins of notated slides generally increase with the more slides containing notes.

D. Participation in Class Activities

Another measure of participation is how many of the instructor-posed questions do students attempt to answer. The hypothesis is that if students "attend" class but are not answering questions they are likely disengaged.

Figure 4 compares the fraction of total questions posed by the instructors that were answered by students prior to each exam to the average grade on that exam. There is a positive relationship between number of questions answered and resulting grades with an explained variance (r^2) of 0.20, 0.23 and 0.33 for Exam 1, Exam 2 and Exam 3, respectively. This may seem in conflict with the results found for attendance in Table 1 but suggests that simply "attending" class is less predictive than participating. This is an important distinction as many instructors use attendance as a measure of participation and even grading.

It is unclear whether the students did not answer questions because of disengagement or because they didn't understand the material. Nonetheless this result suggests that instructors should be cognizant of which students are not answering

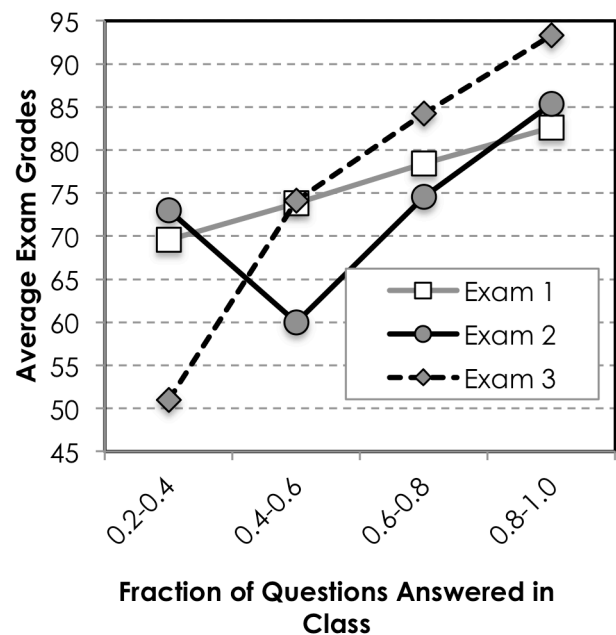


Fig. 4. The average of the three hourly exams versus the fraction of questions answered prior to each exam.

questions during class as one indicator of poorer understanding.

IV. DISCUSSION

The capacity to accurately predict student outcomes based on measurable quantities remains a significant goal for higher education. This work presents a data collection system that records student participation in multiple ways and compares those measures to student outcomes. Additionally it adds extrinsic data that represents other factors important to a student's success in class.

The fact that about 90% of students voluntarily brought technology to class is probably in part because the students saw value in having their notes available instantly on all their devices but is also partly due to the design of the class grading. The students received 15% of their grade for "participation", which was measured daily as the fraction of questions presented during class that the students answered. As the activities were central to the learning experience of the course it is important to put explicit value on their participation.

Anecdotally, it is worth addressing the concern that students with technology will be distracted. The attitude in this class was that students need to learn time management sooner or later so why not in college. That said, LectureTools offered sufficient opportunities for students to participate via questions posed, note-taking and asking questions that the course "felt" far more interactive than in previous years when interaction was verbal.

Another important outcome of the use of LectureTools is the ability for students to ask questions digitally led to dramatic increase in questions submitted. In previous years with verbal questions it was not uncommon to get questions from only a few students (and usually male students). With digital questions the number of questions rose to over 400 during the semester with female students asking more questions per capita than male students. This by itself is a strong argument for use of such technology in a large class.

V. CONCLUSIONS

This study was limited to one class and one semester and hence is not intended to represent multiple courses at multiple institutions. Nonetheless it provides a unique suite of measurements that include more parameters than have been previously reported in one set.

The results indicate that:

- Student outcomes were positively related to extrinsic influences including their incoming grade point average, their interest in the content and their physical and emotional state.

- Student outcomes were not related to measures of class attendance alone.
- Student outcomes were not related to the number of times students participated remotely.
- Student outcomes were positively related to the level of participation in in-class questions.
- Student outcomes were positively related to how many questions students got right in class.
- Student outcomes were positively related to the number of slides for which students created notes.

Next steps will be to 1) replicate all or parts of these analyses in other classes using LectureTools or similar technologies that can measure multiple aspects of student participation and 2) design an "engagement measure" for use in the studied course that identifies students with participation patterns (and possibly past performance measures) that are similar to those with low outcomes from this research. The engagement measure would be used to identify students early in the semester who could be invited to help design interventions to improve their performance.

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Engineering Students' Motivational Beliefs

Development of a Scale Utilizing an Expectancy, Value, and Cost Framework

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Abstract— In the current study, researchers developed a 12-item instrument (Engineering Student Motivational Beliefs Scale; ESMBS) to assess engineering students' perceived expectancies, values, and costs of being an engineering major and pursuing an engineering career. The purpose of the paper is to present the ESMBS development process, including *preliminary* psychometric information. Researchers used Benson's model of construct validation, encompassing three phases, to guide the development and preliminary validation of ESMBS. The substantive phase included a thorough review of the literature to theoretically and empirically define the expectancy, value, and cost constructs within the context of undergraduate engineering. The structural phase consisted of psychometric investigations of the scale to examine internal consistencies. Finally, during the external phase, the relationship between the ESMBS constructs and student engagement was examined. The results from this preliminary instrument development study were mixed, showing the need for further examination of the measure.

Keywords—*motivation, expectancy, value, cost, student engagement, expectancy-value theory, construct validation.*

I. INTRODUCTION

Research suggests that a person's motivational beliefs impact her or his choice to engage in a domain or task [1]. Students' motivational beliefs have been of particular interest to educational research in many different areas, including STEM fields. Motivational beliefs have been used, for example, to predict student achievement and intention to leave a given field [2][3]. Expectancy-Value Theory (EVT) provides a framework for understanding motivation. According to EVT, individuals' expectancies and perceptions of the value of a certain domain influence their level of involvement in that particular domain [4][5]. Translated into the context of engineering education, students' level of confidence in their learning capacities, and perspectives about the value of engineering most likely will influence the students' future academic and professional choices.

Recent development in the motivation literature enriches the interpretation of student motivation by focusing on a component largely ignored in previous studies: the perception

of the costs or drawbacks of a domain or task. Among the different attempts to operationalize and measure the cost component, the Expectancy-Value-Cost (EVC) model emerges as a sound framework for accounting for this component [4]. According to the EVC model, students' perception of the costs involved in a specific task is a salient construct for explaining students' behavior and should be differentiated from the other components of the expectancy-value model [6]. A number of recent instruments in the STEM education literature have attempted to capture the cost component while providing valuable insight into the discussion of STEM students' achievement and academic behavior [3][7][8]. However, these instruments follow the traditional EVT framework, ignoring the latest conceptual and psychometric contributions on the matter. We believe that there is a need for developing an engineering motivation instrument based on the EVC model in order to better account for students' experience in engineering. Thus, in the current study, a 12-item instrument (The Engineering Student Motivational Beliefs Scale; ESMBS), based on the EVC model, was developed to assess engineering students' expectancies, and perceived values and costs of the engineering major and career (in what follows: expectancy, values, and costs, respectively).

II. FRAMEWORK OF THE CURRENT STUDY

The ESMBS scale was developed using Benson's model of construct validation [9]. This model incorporates three different construct validation phases: the substantive, the structural, and the external phase. In the initial *substantive phase*, a thorough review of the literature was conducted to theoretically and empirically define the expectancy, value, and cost constructs within the context of undergraduate engineering. After defining the constructs, items were created and reviewed by content experts. These items were also presented to engineering students during two think-alouds conducted to evaluate sources of response error. The items were then edited based on the feedback from both the content experts and students. The *structural phase* consisted of psychometric investigations of the scale—including inter-correlations among the ESMBS items, and between each item and its corresponding subscale—to examine the internal consistency of the measure. Finally, during the *external phase*, the relationship between the ESMBS constructs and student engagement was examined to determine whether the constructs were related as predicted.

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III. THE SUBSTANTIVE PHASE

The purpose of this initial phase was to gain deeper understanding of the theoretical and empirical definitions of the expectancy, value, and cost constructs and to develop a measure based on the findings. First, a literature review of seminal motivational beliefs theories and existing measures developed in STEM education was conducted. Based on the investigation, operational definitions of the constructs of expectancy, value, and cost within the context of engineering education were developed. We then generated items to measure engineering students' perceived expectancies, values, and costs. Feedback from a team of content experts and research methodologists, as well as information gained during two think-aloud procedures with engineering students were used to modify the instrument.

A. Literature Review

1) Theoretical Framework

The Expectancy-Value-Cost (EVC) model is based on the Expectancy-Value Theory of motivation developed by Atkinson and extended into education by Jacquelyn Eccles [4]. Within EVT, motivation has been described as being governed by a person's expectancy of acquiring a specific goal and the value that the individual feels that the goal has [10]. EVT has been used to research many different academic domains, including the work pioneered by Eccles on gender differences in mathematic achievement [11]. This and other studies suggest that the EVT framework is useful for understanding students' academic behavior, from the standpoint of their motivations.

The two main components of EVT are expectancies and values. The first portion of this theory refers to having an expectancy of being successful in a task. The second portion of EVT is defined as having a value for engaging in a specific task [4]. The value component of EVT is broken down into four subcomponents that include interest, attainment, utility, and cost [12]. Having *interest value* is defined as having significance for the experience from engaging in a task, or having interest in engaging in that task. *Attainment value* is the importance of doing well on a task as defined by one's personal values. *Utility value* is the perceived usefulness of engaging in a task. Finally, *cost*, is defined as the perceived amount of effort or drawbacks that will be incurred from engaging in an activity. Eccles and colleagues [5] further partitioned the cost construct into perceived effort, loss of valued alternatives, and psychological cost. *Perceived effort* was defined as how much effort is needed to be successful at a task. *Loss of valued alternatives* was defined as not being able to engage in other valued activities due to engaging in one activity. *Psychological cost* was defined as the anxiety associated with potential failure related to the task.

A recent effort in the motivation literature has been focused on investigating the so called *forgotten* component of the expectancy-value equation: cost [6]. Work in that area illustrates the need for a consensus on the operational definitions and measurement of cost [6]. In Eccles and colleagues' initial work, for example, cost was considered a

mediator of value [5], whereas in their later work it was considered as a *type* of value [12]. More importantly, as mentioned by Flake and colleagues, although Eccles and colleagues provide a strong theoretical rationale for cost they have not developed a comprehensive measurement tool [6]. In that context, the EVC model emerges as an attempt to provide a clear framework for understanding the experience of cost in motivation. After a thorough literature review of the role of cost in the expectancy value models, Barron and Hulleman [4] found that there is no conceptual or empirical support for identifying cost as a subcomponent of value. Throughout the literature, cost has been found to depict motivational dynamics that supplement the components of expectancy and value. On these grounds, the EVC model proposes that cost should be separated and examined as an independent component, which interacts with both expectancy and value to determine when someone is motivated [4]. During their own qualitative and quantitative research program, the EVC team also found new dimensions of cost: the effort required by the task itself (i.e., effort-related cost) and the effort required by other tasks (i.e., effort-unrelated cost) [13]. Finally, through a mixed-methods study, researchers found that sometimes effort-related cost was associated with *both* motivating and demotivating tasks, but in each case it was valued differently. In other words, the effort put into *motivating* tasks was perceived positively whereas the effort put into *demotivating* tasks was perceived negatively [13]. As Barron and Hulleman [4] explain, this became a key finding for measuring cost, as depending on how the effort-cost item is worded it could be perceived as something valuable (e.g., "this class is challenging") or as a burden (e.g., "this class is *too* challenging") [4]. Thus, in order to truly capture the negative connotation of cost, the EVC researchers recommended to phrase the item in a way that represents that the effort needed has surpassed a critical threshold and is perceived as overwhelming" [4].

2) EVT and EVC Related Literature in STEM Fields

Given that our interest rests in developing an instrument based on the EVC model that directly targets the engineering student population, we mainly focused our research of motivational beliefs measures within undergraduate engineering and STEM fields. These instruments are presented briefly in this section. The Engineering Motivation Survey was created using the Expectancy Value framework and several motivation instruments from engineering education [8]. The survey consists of 35 questions: 5 interest value items, 7 attainment value items, 7 utility value items, 7 self-efficacy or expectation for success items, and 9 cost items. To test the validity and reliability of the survey, a study was conducted with more than 200 freshmen engineering students at a large public university. The results showed acceptable to good internal reliability, with all Cronbach's alphas for the items being higher than .70. Factor analysis suggests that this instrument measures five constructs from the expectancy value theory, including utility value, attainment value, interest value, cost, and self-efficacy or expectancy for success. The factor analysis revealed that the cost items loaded on two different factors, suggesting that these items may be measuring different types of cost. However, the researchers

did not differentiate conceptually between types of costs and interpreted all the cost items as measuring the same construct. Some of the interest and attainment value items were shown to load on the same factors, meaning that these items may be measuring the same construct. The researchers decided to keep these two sets of items separate arguing that interest and attainment have similar definitions.

Perez and colleagues [3], following EVT, created an instrument to assess STEM students' competence beliefs, values, and costs. For this scale, the original construct of expectancies was changed to competence beliefs, in order to incorporate both expectations for success and ability beliefs. The instrument consists of 5 competence beliefs items, and 7 value items evaluating attainment, intrinsic, and utility values, all adapted from Eccles and Wigfield [12]. In addition, 20 cost items for college STEM majors, measuring effort cost, opportunity cost, and psychological cost, were adapted from Battle and Wigfield [14]. The results of this study showed that competence beliefs, values, and perceptions of cost were related to achievement in chemistry and intent to leave STEM [3].

Jones and colleagues [2] also created an instrument based on EVT, which assesses expectancies and values in engineering students. Jones and colleagues' instrument contains 2 expectancies for success in engineering items, 2 engineering intrinsic interest value items, 3 engineering attainment value items, and 2 engineering extrinsic interest value items. All items in this measure were taken directly from Eccles and Wigfield [12], and modified to assess perceptions of expectancies and values for engineering instead of mathematics. After administering this instrument, it was found that not only do students' expectancies and values for the engineering major decrease within the first year, but that value for the major is positively associated with future career plans in engineering [2].

Panchal and colleagues [15] applied the EVT framework to an undergraduate Engineering Design course in order to create a universal model for teaching design classes. At the end of the semester, students were given a thirty-question survey created by Panchal and colleagues [15] designed to measure both expectancy beliefs and values pertaining to the design project assigned in the class. The survey consisted of 9 expectancy belief questions and 9 value questions, based on the attainment, intrinsic, utility and cost constructs. The researchers found that motivation for completing the project was positively correlated with both expectancy beliefs for the use of mathematics skills and values for the project [15]. Expectancies and values were also positively correlated with learning outcomes and performance on the project. Results related to the cost items are not clearly stated but findings suggest that cost might have been *positively* correlated with proficiency in mathematics and motivation.

Flake and colleagues [6] created a non-discipline specific cost scale to study the dimensions of the cost component of the EVC model. Their investigation supported the previous dimensions of cost described by Eccles and colleagues [5] and identified a new dimension, outside effort [6]. Outside effort cost is defined as the time or effort allotted to tasks other than

the one of interest. The scale developed by Flake and colleagues consists of 5 task effort cost items, 4 outside effort cost items, 4 loss of valued alternative items, and 6 emotional cost items. None of the items on this measure pertained to a particular domain, and all of them were designed for use in a variety of classroom settings. Correlational analyses showed a negative relationship between cost and both expectancies and values, as well as grades and long-term interest [6].

After a thorough investigation of STEM measures of student motivational beliefs we have found that there is no instrument that focuses solely on engineering students and takes into account the latest contributions on the cost construct. Moreover, in some cases the theoretical implications of the unexpected findings have not been discussed. This suggests the need for developing an instrument to study the motivations of engineering students using the most up to date research on the literature.

3) Operational Definitions of the Constructs

Based on our research on the theoretical and empirical definitions of the expectancy, value, and cost constructs, we offer preliminary working definitions of these constructs within the context of engineering (Table I).

B. Development of the ESMBS Scale

TABLE I.

Operational Definitions of the ESMBS constructs	
<i>ESMBS Construct</i>	<i>Working Definitions</i>
Expectancy	The confidence that engineering students have in their current and future abilities to do well in the engineering major.
Value	Positive beliefs about engineering as a field of study and as a profession.
Value - Attainment	The importance students assign to being engineering students or becoming engineers.
Value - Interest	Level of interest students have for the engineering major.
Value - Utility	Usefulness that students grant to engineering as a major and as a profession.
Cost	Sacrifices in time and other resources students have to make in order to do well in engineering, including the drawbacks related to student involvement in the major.
Cost - Loss of valued alternatives	Sacrifices that students need to make in order to do well in the engineering major.
\Cost - Effort related to engineering	Effort students require to allot to the engineering major related activities in order to do well in the major.
Cost - Effort not related to engineering	Effort or time expended in activities not related to engineering.
Cost - Psychological cost	The mental stressors associated with the major.

In the current section, we describe the development of the ESMBS scale based on the findings of the literature review. Specifically, we explain the item generation process, the content experts' analysis of the items, and the use of two think-alouds to evaluate and clarify the items and measure.

Based on the working definitions developed in the initial stage of this investigation, 10 items were developed referencing existing items observed in other EVT-related measures. In the developing process, the research team also took into account recommendations provided by a group of EVC content experts on how to measure the expectancy, value, and cost constructs. For example, following one of these recommendations [16], instead of wording the items as statements, we worded the items as questions (e.g., "How confident are you with your current abilities to do well in the engineering major?") and developed a different scale for each item (e.g., from 1 "Not confident at all" to 7 "Very confident"), so that the scale directly responds to the specific question. Thus, three expectancy items, three value items (attainment, utility, and interest), and four cost items (loss of valued alternatives, effort related to engineering, effort not related to engineering, and psychological cost) were created in this process.

Engineering content experts and research methodologists evaluated the list of 10 items, which were then modified following the experts' feedback. For example, based on previous research showing the difference between an engineering student identity and an engineer identity [17][18][19], the engineering content expert suggested creating two attainment value items, each addressing a different kind of identity: a student and a professional identity. The engineering content expert also suggested creating an additional utility value item focused on the social aspect of engineering. According to the expert's experience in the field, women tend to be more focused on the social impact of engineering whereas men tend to focus more on the financial aspect [19].

After creating and modifying the items, team researchers conducted two think aloud sessions with engineering students (one female and one male) for evaluating sources of response error in the survey. Specifically, following Willis' [21] guide for cognitive interviewing, the sessions were focused on whether the items were interpreted as expected. After conducting the think aloud, some items were modified for

language clarity, avoiding language ambiguity or imprecision. The final ESMBS scale (see Table II illustrating sample items and their sources) is comprised of 3 expectancy items, 5 value items, and 4 cost items. Each question is answered using a 7-point Likert scale. For each subscale, responses are averaged, with the lowest score for each subscale being a 1 and the highest score being a 7. Following Flake and colleagues' [6] work on cost, question number 11 (i.e., effort not related to engineering) is reverse coded.

IV. STRUCTURAL PHASE

The purpose of the structural phase is to evaluate the psychometric properties of the instrument. We conducted a small sample size study to obtain preliminary data on the internal consistency of the ESMBS items. Future directions for further analysis of the internal structure of the instrument are discussed at the end of the section.

A. Psychometric Properties of the ESMBS Scale

Cronbach's alpha, item-to-item correlations, and item-subscale correlations were calculated in order to conduct a preliminary investigation into the structure of the measure. Spearman's non-parametric correlations were used, as recommended in the case of small sample size studies [22]. Given the small sample size of 19 students, no exploratory or confirmatory factor analyses were conducted.

1) Participants and Procedures

Twenty-one engineering students from a mid-Atlantic comprehensive university participated in this study. The survey was administered towards the end of the fall freshman semester. Incomplete surveys, surveys completed in less than 5 minutes or reflecting clear response bias (e.g., selecting only the highest point in the Likert scales throughout the entire survey) were not used. A final number of nineteen participants (3 females and 16 males) were included. Participants received an email that contained informed consent information and a link to the online survey.

2) Results and Discussion

Before examining the relationships among items and between items and subscales, data were examined for normality. Finney and DiStefano [23] suggest that skewness greater than |2| and kurtosis greater than |7| be considered indicative of univariate non-normality. An examination of ESMBS items (Table III) reveals that all skewness and kurtosis values for all the items fall within the acceptable range. However, a review of item-level scatter and Q-Q plots raised concern regarding the normality and linearity of the items, as did the restricted range of responses associated with many of the items observed in Table III. This, along with the small sample size, suggested the need for non-parametric analyses.

Cronbach's alpha was calculated for each subscale as a measure of internal consistency. For ESMBS, internal consistencies for the three subscales were 0.89, 0.87, and 0.71 (expectancy, value, and cost, respectively). According to Kline [24], values greater than .70 are considered acceptable.

TABLE II.

ESMBS Sample Items and their Sources		
Item Type	ESMBS Item	Sources
Expectancy	How confident are you with your current abilities to do well in the engineering major?	"How much confidence did you have in your ability to excel in your engineering major over next semester?" [2]
Value (utility)	How useful do you find engineering in bettering the world around you?	Content expert recommendation
Cost (effort related to engineering)	How much effort do you think is typically required to do well in the engineering major?	"This class requires too much of my effort" [13]

TABLE III.

Item-Level Descriptive Statistics					
Items	Range (actual)	M	SD	Skewness	Kurtosis
Exp 1	4 - 7	5.05	1.13	0.92	-0.42
Exp 2	3 - 7	5.11	1.29	0.48	-0.94
Exp 3	4 - 7	5.11	1.10	0.61	-0.87
Value 1	4 - 7	6.21	1.18	-1.13	-0.37
Value 2	3 - 7	5.74	1.37	-0.92	-0.28
Value 3	4 - 7	5.95	0.91	-0.87	0.54
Value 4	4 - 7	6.32	1.06	-1.35	0.54
Value 5	4 - 7	6.42	0.90	-1.52	1.59
Cost 1	3 - 7	5.53	1.43	-0.44	-1.13
Cost 2	4 - 7	6.42	0.90	-1.52	1.60
Cost 3*	4 - 7	5.37	1.01	0.58	-0.66
Cost 4	4 - 7	5.42	1.02	0.06	-0.98

* Cost item 3 is the only item negatively worded.

TABLE IV.

Spearman's correlations between expectancy, value, and cost items and their subscale total			
Items	Spearman's r_s (effect size r_s^2)		
	Expectancy Total	Value Total	Cost Total
Expectancy1	.871* (0.759)	—	—
Expectancy2	.898* (0.806)	—	—
Expectancy3	.873* (0.762)	—	—
Value1	—	.668* (0.446)	—
Value2	—	.896* (0.803)	—
Value3	—	.881* (0.776)	—
Value4	—	.718* (0.516)	—
Value5	—	.725* (0.526)	—
Cost1	—	—	.709* (0.503)
Cost2	—	—	.770* (0.593)
Cost3	—	—	-.138 (0.019)
Cost4	—	—	.810* (0.656)

* Statistically significant results at .01. Cohen's recommendation for categorizing p effect sizes for the social sciences: 0.1 is small, 0.3 is medium, and 0.5 is large [25]. Medium to large effect sizes have been bolded.

While the expectancy and value subscales appear to show satisfactory internal consistency, the cost subscale only minimally meets Kline's acceptable range. Table IV shows the relationship between each item and its corresponding subscale. As expected, each of the items, with the exception of cost item 3, moderately to highly correlates with its respective subscale.

A review of the inter-item correlation matrix (Table V) gives us additional insight into how the items function in relationship to one another. Items should correlate highly with other items measuring the same construct and correlate only moderately with items measuring different constructs. In the

case of the ESMBS, we would expect the expectancy, value, and cost items to relate more closely with items within their respective subscales than with items from other subscales.

In examining the inter-item correlations (Table V), we do see that the expectancy items moderately correlate with one another. This suggests that all three expectancy items may pertain to the same factor. We have a similar scenario when observing the correlations among the five value items. However, with the cost items, cost item 3 (i.e., effort not related to engineering) does not appear to relate to the other items on the cost subscale in a way that would lead us to believe it is measuring the same construct as the other cost items. Thus, in examining only how items relate to other items on the *same* subscale, the subscales (again, with the exception of cost item 3) appear to have satisfactory internal consistency. Nevertheless, when examining how items relate to items from *other* subscales, we see some issues. For example, although value and expectancy items present practically significant correlations, only *some* on these correlations are statistically significant. Also, some of these correlations are stronger than the correlations these items have within their own construct. Value item 2, for example, is more strongly correlated with the expectancy items than with the majority of the value items. This is problematic because as one would expect expectancy and value items to be positively correlated [4][12], value items should not correlate *more strongly* with expectancy items than with other items measuring the value construct. There are a couple of reasons why this may be happening. One is that the developers may have written these particular items in a way that makes their interpretation by subjects problematic. Another reason could be that the items may actually be measuring the same construct. Either way, this would indicate the need for further study (e.g. larger sample size to verify findings) and item revision.

Of particular interest, surprisingly, cost items 1 (loss of valued alternatives) and 2 (effort related to engineering) are positively correlated with all the expectancy and value items. This finding does not align with motivational beliefs theory, as costs are defined to be in tension with expectancies and values, and to hinder motivation [4]. However, research conducted by the EVC research team could help to interpret these findings. Qualitative research found that related-effort is not always perceived negatively [13], which resonates with findings in other studies [26][27]. Thus, in order to truly capture the *negative* aspect of cost the items should measure not simply effort but *overwhelming* effort [4]. In that sense, one possible explanation for the positive relationship observed between the ESMBS cost 1 and 2 items and the expectancy and value items could be the wording of the cost items. It could be that cost items 1 and 2 do not really represent *overwhelming* cost, at least not to the engineering students. This last point is important as the way students perceive cost could be related with the specific student culture. The engineering culture, for example, is known for its grit—or “perseverance and passion for long-term goals” [28]—and appreciation for sacrifice and effort [29]. Under such a culture,

TABLE V.

Items	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Expectancy 1	1.000	—	—	—	—	—	—	—	—	—	—	—
2. Expectancy 2	.764**	1.000	—	—	—	—	—	—	—	—	—	—
3. Expectancy 3	.587**	.690**	1.000	—	—	—	—	—	—	—	—	—
4. Value 1	.421	.424	.407	1.000	—	—	—	—	—	—	—	—
5. Value 2	.593**	.754**	.805**	.462*	1.000	—	—	—	—	—	—	—
6. Value 3	.554*	.573*	.703**	.552*	.799**	1.000	—	—	—	—	—	—
7. Value 4	.339	.331	.432	.419	.559*	.521*	1.000	—	—	—	—	—
8. Value 5	.430	.305	.349	.493*	.512*	.561*	.694**	1.000	—	—	—	—
9. Cost 1	.308	.297	.491*	.679**	.346	.332	.260	.175	1.000	—	—	—
10. Cost 2	.430	.427	.325	.826**	.469*	.552*	.449	.523*	.626**	1.000	—	—
11. Cost 3	-.535*	-.636**	-.690**	-.552*	-.650**	-.611**	-.234	-.251	-.578**	-.411	1.000	—
12. Cost 4	-.021	-.166	-.029	.568*	-.045	.216	.170	.220	.348	.500*	.034	1.000

Note: * $p < .05$, ** $p < .01$

certain aspects of cost could certainly be valued positively. To our knowledge there is no research on variations on perceptions of cost across academic fields. It would be interesting to see if certain academic fields (e.g., engineering) tend to perceive cost more positively than others, and what the implications are for measuring cost in those specific settings.

Another interesting finding is that cost item 3 is negatively correlated not only with all the expectancy items and some of the value items, but, surprisingly, also with the other cost items. One possible reason for this result could be the wording of the item. This is the longest item on the scale and combined with the negative wording this item could have caused participants some confusion. It is also important to consider that this item was created based on a new construct (i.e., “outside effort”) developed by Flake and colleagues [6], and might require further evaluation.

B. Conclusions of the Structural Phase

The evaluation of the psychometric properties of the ESMBS scale has provided valuable information regarding how the initial ESMBS items are functioning. The expectancy items present a good internal consistency, and are strongly correlated among each other and with the expectancy subscale. The same holds for the value items. However, the strong relationship among some of the value items and some of the expectancy items suggest that these items may be assessing similar constructs. The cost items present a more complex picture and require further evaluation, particularly item 3. The positive relationship observed among some of the cost items and the expectancy and value items certainly requires additional study. Future steps for evaluating the internal structure of the ESMBS scale include collecting data from a new and larger sample and conducting a confirmatory factor analysis.

V. EXTERNAL PHASE

In a construct validation process, the purpose of the external phase is to provide evidence of the relationship between the focal constructs and other constructs with which they are theoretically related [9]. The EVC motivational model suggests that students’ expectancies and perceptions of the values and costs of studying engineering are related to their engagement in engineering [4]. In a study conducted with undergraduate engineering students at a large university, Jones and colleagues [2] found that as students’ expectancies for success in engineering courses and perceptions of the intrinsic, attainment, and utility values decreased, engagement in the major also decreased. Thus, not surprisingly, when students had lower confidence in their abilities in engineering and did not value as much engineering, they tended to be less engaged in the major than when they expressed a stronger confidence in engineering and perceived its value more positively.

Unfortunately, to our knowledge, little research has focused on investigating the relationship between student engagement and students’ motivational beliefs in the context of engineering. Some research findings outside the field suggest that such a relationship does exist, though. In the school context, for example, the relationship between students’ motivational beliefs and engagement in the classroom is widely recognized [30][31][32]. Moreover, within the field of reading motivation, seminal motivation theorists have claimed that motivation is “what activates behavior” and therefore is essential to engagement [33]. These and other findings support the hypothesis that engineering students’ level of confidence in the matter and perceptions of the values and costs of engineering are related to their level of student engagement.

A. Correlations between ESMBS and Student Engagement

A small sample size exploratory study was conducted for evaluating whether the ESMBS constructs are related to student engagement as expected.

1) Participants and Procedures

The data for this study were collected under the same circumstances of the previous one, and therefore the participants and procedures are the same.

2) The Student Engagement Survey

Engineering students' level of engagement was measured utilizing the Student Engagement (SE) Survey [34]. This survey was developed utilizing the National Survey of Student Engagement [35]. Fourteen questions from the NSSE were selected for assessing student engagement, specifically collaborative learning, cognitive development, and personal skills development. Psychometric information reported by researchers provides good support for the reliability and validity of the SE. The alpha reliability for the SE was 0.84, and, when compared to the NSSE's Engagement Score, the SE provides similar values [34]. In the current study, the instructions for the three subscales (collaborative learning, cognitive development, and personal skills development) were modified for targeting the entire engineering major and not only one class.

3) Data Analysis

We examined the relationship between student engagement and expectancy, values, and costs. Given the small sample size and the non-normal distribution of the data, Spearman's non-parametric correlations were used to assess the relationship between student engagement and the ESMBS constructs [22].

4) Results and Discussion

a) Relationship between Expectancy and Student Engagement

The correlation between students' expectancy scores and student engagement was not statistically or practically significant (Table VI). This finding is particularly surprising

as higher scores in the SE represent high level of cooperative learning, cognitive level, and personal skills and development. We would expect that students with high confidence in engineering also have high levels of participation inside and outside the classroom, are engaged in high cognitive processes (e.g., they prefer to analyze instead of simply memorize), and belief that engineering provides them the tools to develop professionally and personally. More research is required to see if this finding truly represents the engineering student population.

b) Relationship between Value and Student Engagement

Statistically significant correlations were only found between student engagement and the utility value, which had a small positive correlation ($r_s=.455$, $p=.050$, $r_s^2=.207$). Thus, the more engaged students report to be, the more they report to value the utility of engineering as a source of financial stability and/or for bettering the world around us. This is expected from anyone who reports an interest in a domain: to value the utility of the domain. Contrary to what we anticipated, on the other hand, attainment, interest, and the total value constructs were not statistically significantly correlated with student engagement. However, there are some trends in the data that do align with the literature. For example, as expected, all the value constructs have a positive relation with student engagement. Again, these findings are not strong enough to make conclusions about the validity of the scale but represent trends that are worthy of attention and further evaluation.

c) Relationship between Cost and Student Engagement

Cost items 3 (effort not related to engineering) and 4 (psychological cost) were not statistically or practically related to student engagement. Interestingly, student engagement did have a small *positive*, though non-significant, correlation with the other two cost constructs: loss of valued alternatives (item 1) and effort related to engineering (item 2). This trend does not align with the main literature on cost. From the motivational beliefs literature, valuing a domain as costly will most likely go hand in hand with disengagement from that domain [4]. The misalignment between the theory and the direction that the obtained results are trending could be an indicator of the inability of our cost items 1 and 2 to accurately measure the cost constructs *within the engineering context*. As mentioned earlier, within engineering, sacrifice and effort are not perceived as negative as theory would expect. Some students might consider, for example, that it is worthwhile to make some sacrifices for becoming successful engineering students and professionals. They could be recognizing the large amount of effort and the loss of other valued alternatives that engineering comprises, but, at the same time, are willing to invest that to stay in the major or career. This would suggest the need to adjust our cost items (specifically 1 and 2) to truly represent *negative* cost, a level of sacrifice and effort that undermines students' motivation in engineering.

TABLE VI.

Correlations of student engagement with expectancy, values, and costs		
	Correlation (Spearman's r_s)	Effect size (r_s^2)
Expectancy	.197	0.039
Value: Attainment	.376	0.141
Value: Interest	.220	0.048
Value: Utility	.455*	0.207
Value: Total	.391	0.153
Cost: Loss valued	.242	0.059
Cost: Effort related	.287	0.082
Cost: Effort not related	-.206	0.042
Cost: Psychological cost	-.078	0.006
Cost: Total	.071	0.005
*Statistically significant results at .05. Cohen's benchmarks: 0.1 is small, 0.3 is medium, and 0.5 is large.		

B. Conclusions from the External Phase

With some exceptions, the relationships observed between student engagement and the expectancy, value, and cost constructs were not as predicted. Cost items 1 and 2 reported an unexpected positive—but not statistically significant—correlation with student engagement. This could be an indicator of a need to evaluate the wording of the items to better represent cost within engineering. Expectancy, attainment and interest value, effort not related to engineering, psychological cost, and the cost total, were also not statistically correlated with student engagement. This certainly requires attention as it could indicate that there is, in reality, no relationship between these variables, or that those ESMBS items are not accurately capturing the EVC constructs. However, the absence of significant patterns could also be due to a restriction of range issue. The student engagement scores do not represent a full range of engagement, as they only go from fully engaged to moderately engaged. The same is observed in the case of the expectancy, value, and cost scores. Finally, another possible contributing factor for the non-significant correlations could be the student engagement measure utilized in this study. The Student Engagement Survey operationalized student engagement as a combination of cooperative learning, cognitive level, and personal skills. This could be considered a somewhat narrow understanding of student engagement, as this construct has been defined by seminal thinkers in the area as both the amount of time and effort a student puts forth in activities that are related to desired outcomes of college and how the university propagates these activities in students [36][37].

VI. GENERAL DISCUSSION AND FUTURE DIRECTIONS

In the current study, we followed a construct validation process for developing the Engineering Student Motivational Beliefs Scale. In the initial phase, an extensive literature review of the theoretical and empirical definitions of the expectancy, value, and cost constructs was the basis for developing working definitions of these constructs within the context of engineering.

Based on these definitions and after an extensive evaluation of all the items, a 12-item instrument was created for measuring engineering students' expectancy and perspectives about the values and costs of engineering. Cronbach's alpha, item-to-item correlations, and item-to-subscale correlations were used to conduct a preliminary examination of item functioning and scale structure. Finally, the relationship between each of the ESMBS constructs (expectancy, value, and cost) and student engagement was evaluated using the Spearman's correlation analysis.

These findings provide some preliminary support for the internal consistency of some expectancy and value items, while raising questions about other items. For example, some expectancy and value items seem to be measuring the *same* construct or do not show a strong association with their corresponding constructs. Cost items 1 and 2 were positively correlated with the expectancy and value constructs; whereas cost items 3 and 4 were negatively correlated with the

expectancy construct and—mainly in the case of item 3—with the value construct. From the standpoint of the literature on motivational beliefs and cost, these are puzzling results and the initial step should be to evaluate the quality of the items and see whether they are truly measuring cost. It is important to note that cost items 1 and 2 also presented a small—although not statistically significant—correlation with student engagement. The specific participants' culture could help to explain these findings. In the think aloud sessions, for example, students indicated that while there are sacrifices and costs associated with engineering, some are positive and beneficial, teaching them valuable skills. Thus, within engineering, certain dimensions of cost (i.e., “loss of valued alternatives” and “effort related to engineering”) could be perceived as a necessary investment for being successful in the field. This resonates with what has been observed in other studies [26][27][13]. One way to address this issue could be adjusting the highest scale point on the cost item to represent an *overwhelming* level of cost (e.g., “too much effort” instead of “large amount of effort”).

The current study is a preliminary evaluation of the ESMBS scale. Initial results indicate a need for further scale development. Data are currently been collected from a new and larger sample of engineering students. So far, initial findings concerning freshmen students (N=28) show similar trends to the current study. Additional analyses, such as a confirmatory factor analysis, will allow us to examine the ESMBS structure in more detail.

A. Limitations

There were several limitations to the current study. The small sample size constrains our analyses. Findings should be interpreted cautiously. This study provides only general guidelines for future steps in the development and evaluation of the ESMBS scale. Special attention should be given to the possibility that students who participated in our study are not representative of the general engineering population. It is likely that students who chose to participate are in general more engaged than those who did not participate in the study, which is represented by the restriction of range described earlier. Also, as mentioned before, the Student Engagement Survey utilized in the study understands engagement as cooperative learning, cognitive level, and personal skills and development, which could be considered a somewhat narrow definition of student engagement. In that sense, it would be interesting to see if the relationships between expectancy, value, costs, and student engagement observed in this study are confirmed when utilizing a different measure of student engagement.

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Experiments with Personal Ownership of Quality at the University of Texas at El Paso

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Abstract – The lack of commitment to create quality work is a long-standing problem in education, and it is a direct negative driver of student performance, disturbing students' ability to: apply imparted concepts, build team quality work, and foster industry's economy. The quality of delivered work is poor mainly because students do not spend needed time and effort to review their own work; e.g., research papers, group projects, and assignments.

At the University of Texas at El Paso (UTEP), experimental developments targeted students' commitment to create quality work, creating infrastructure to conduct personal reviews for different types of work products, and teaching students to conduct effective personal reviews of their own work. A partial implementation of check lists, review processes, and teaching material has been used in courses at UTEP. The work to be developed includes measuring time distributions of effort (time to build the product vs. time to correct the product), recording the defects injected in products, creating checklists based on the recorded defects, creating a process to review products, and defining a defect log. The goal is to create a habit within students to create quality work by using personal reviews to improve the quality of submitted work.

Keywords: *Quality, Personal Review, CMMI, Personal Software Process (PSP)*

I. INTRODUCTION

There is an increasing trend of higher systems' complexity in the last century across all Science Technology, Engineering, and Mathematics (STEM) disciplines. Systems are no longer built by single individuals or by groups from a single discipline. All types of scientific, engineering, technology and management disciplines must work synergistically to build complex solutions and products. These complexity challenges affect all STEM areas, but, for simplicity, we will discuss engineering. To cope with system complexity, engineers have used verification and validation techniques such as pilots, mock ups, rapid prototyping, simulations, model checkers, theorem proving, peer reviews, audits, and testing.

Another method used by industry to handle the complexity of systems is specialization. There is a trend toward the specialization of engineers in

specific functional areas or phases of the production lifecycle; e.g., project management, business analysis, programming, architecture, and testing. Although specialization has its advantages, it creates a narrower view for individual engineers. Furthermore, the loss of the "big picture" may create mental or bureaucratic silos that reduce commitment toward the desired final outcome.

Specialized engineers concentrating on a single lifecycle phase may not feel personal ownership of the quality of the whole system, and they may subrogate the responsibility of the system quality to a supporting group (testing, quality assurance, auditors, and peers). The end result is inadequate and dangerous cultures, where the responsibility for and ownership of the system quality is not the responsibility of all contributors, but has instead been delegated to a given support group or to peers. As a result, there are many products, services and systems delivered with poor quality in industry. According to the Standish Group [1], of projects developed in companies: only 9% were successful, 31.1% were cancelled before they ever get completed, and 52.7% cost 189% of their original estimates. In the academic settings, a similar phenomenon occurs when students working in teams and group projects do not review their work and expect that their classmates should conduct reviews to remove their defects.

Reviews have been used in industry for a couple of decades. A brief description for some types of reviews, as well as standards for lifecycles, quality models, and frameworks that make use of review techniques follow.

A Peer Review is a process or a meeting during which an artifact, or a set of artifacts, are presented to project personnel, managers, customers, or peers for comment or approval [2]. A peer is a professional with the same set of skills. A review is the examination of an internal artifact and/or product or deliverables by a colleague with the purpose of finding errors within the scrutinized artifact. The effectiveness of the review process is dependent on the formality of the implementation

and the culture to invest in prevention and review activities rather than in re-work activities.

Peer reviews are defect removal activities. Peer reviews can be applied to any document or object at any phase during the lifecycle. Peer reviews can be performed a) synchronously: the author of the document and his/her peers examine the document together, or b) asynchronously: the document is sent to his/her peers who review the document individually and report back their findings.

An inspection is a type of formal review invented by Michael Fagan at the IBM T.J. Watson Research Lab in 1976 [3]. Inspections were needed because the cost of rework in software projects at IBM ranged from 30% to 80%. After refining the process during several years, the inspection process proved to be very effective because it achieved both reduced number of defects found by final users and increased development productivity.

Reviews have been included in standards, quality models, and process frameworks; for instance, the ISO 15288:2008 standard for Systems and Software Engineering cover the System Life Cycle Processes [4]. The Capability Maturity Model Integration (CMMI) created by the Software Engineering Institute (SEI) includes peer reviews to contribute to the quality of systems, products, and services [5]. CMMI includes a process area called Verification (VER) that addresses peer reviews to confirm that products (services) being built (deliver) are correct and comply with the specification. Also, there is a process framework called Personal Software Process (PSP), developed by Watts Humphrey at SEI [6]. Although ISO 15288 and CMM include reviews; only PSP promotes personal reviews as the key element to achieve personal quality work.



Figure 1. Skills developed by PSP.

The Personal Software Process addresses the lack of personal commitment to build quality work. PSP raises a commitment to personal quality by making the author of the artifact conscious about his/her own defect injection rate and removal cost for each defect type. PSP develops the skill to remove the author's defects through the use of personal reviews, which make use of a personalized

checklist with common defects and a revision process. PSP has made both a cultural change and a significant increment in the quality of products or systems built in the organizations where it has been applied. Figure 1 shows skills developed by PSP.

Some implementations of PSP in academia and industry had been reported. According to Guoping Rong et al., PSP was implemented with pair programming at the summer school in the Software Institute of Nanjing University, leading to higher students' involvement, more process discipline, and a workload reduction in evaluating assignments [7]. Moreover, Lutz Prechelt, and Barbara Unger, mentioned that the use of PSP improved software quality by focusing on defect content [8].

We propose to make a cultural change in STEM students by seeding the principle of personal ownership of quality work. The ultimate goal is to achieve a cultural change where teachers nurture each engineer to do quality work until he/she is proud of her work. This research focuses on developing students' skills to implement the personal review technique.

Personal reviews can increase the effectiveness of peer reviews by requiring, as a precondition, the execution of a personal review of the product. Peer reviews have been used for several decades in industry. Quality models such as CMMI require the execution of peer reviews. Also, team Software Process (TSP), created by the SEI, requires the execution of peer reviews. TSP call for all team members to have taken the PSP training. Moreover, TSP requires the execution of a personal review before a peer review.

Can individuals review their own work? Three positions are discussed: 1) personal reviews are not possible, 2) personal reviews are not needed, and 3) personal reviews are powerful techniques to remove defects. There is a myth that an individual cannot find his/her own defects because an individual is too blind and too biased to identify his/her own defects. A personal review executed in an unstructured and informal way may support this claim. An unstructured personal review may have the following characteristics: a) no set of criteria to look for, b) no process for conducting the review, c) no log to register the defects found, d) lack of analysis of results found, e) conducted too fast, and f) distractions while reviewing. The output of these unstructured ways of conducting personal reviews produces an indisputable outcome: inefficiency in finding defects and a waste of resources.

Under position 2, personal reviews are not needed, as some people believe that they do not introduce defects. In other words, they believe that

they are so good and too perfect that there is no need to look for defects. The ‘inexplicable’ truth stands up when the system fails when it is put in production. The system has so many defects and these people yet ask themselves: Who injected the defects? The answer is simple, no one but themselves. The fact is that, all human beings inject defects while developing products and systems.

For position 3, personal reviews can remove defects. A formal and structured personal review that makes use of his/her defect injection history can guide an individual to find and remove his/her own defects. With practice and discipline, Watts [6] has reported an efficiency to remove defects with structured personal reviews from 50% to 70%. TPS has achieved a 0.06 defects density (# defects / 1000 Lines of Code, LOC). This value is almost two orders of magnitude better than 1 defect/KLOC achieve by CMMI level 5. The use of personal reviews improves the quality of systems as reported in PSP [6] and TSP implementations.

Why do personal reviews work? Human beings are very predictable and they inject the same type of mistakes over and over. A key factor is finding the type of mistakes introduced while developing a given type of work. Examples of types of work include documents, reports, plans, designs, and artifacts. A Pareto analysis in defect frequency and defect cost is suggested to identify a potential type of defect to be included in the checklist as a criterion. The criterion provides a hint to the reviewer to look for that specific defect when examining a type of work. The key aspect of the criterion is to become a strong and useful guide. To be effective, a criterion should come from your own history of defect data.

II. Components for successful personal review

Personal review may include a checklist, review process, a defect log, and data analysis. A brief description of each follows:

1. *A checklist* includes a list of criteria, which are common defects that are injected when developing a document or product. A “defect” is any occurrence of an error that is injected into a document/ product and requires any rework to fix the document/ product. Checklists provide structure to the review and guide the reviewer to look for these types of defects within a document. Related criteria (aspects to review) are classified into categories. Each criterion targets a historical type of defect injected by the individual. Table I shows a checklist to verify Internal Block Diagrams and category “Intended use” includes historical defects related to adding components that are not needed. The structure of the checklist is suited for criteria

that apply to all the sections of a document, for multiple documents of the same type, and for several instances of a given section.

TABLE I. Example template for the IBD checklist.

IMS Systems Engineering					
Checklist template for general criteria of the "IBD Design" review					
Purpose	Review and identify all the general defects injected in the Internal Block Diagram (IBD)				
Entry criteria	Completed "IBD" document for VERIFICATION				
		Component 1	Component 2	Component 3	
Category	Criteria Description				Comments
Flow Ports	Contains all inputs and outputs from the BDD		x		
	Ports show that they are inputs/outputs				
	Number of ports, its placement, and names are consistent with BDD	x		x	
	Port placement is consistent with BDD		x		Port allocated to wrong component
Interfaces	Port names are consistent with the BDD	x			
	All ports have a corresponding connection	x			Port with no connection
	Interfaces show what is flowing			x	
	Interfaces show the direction of flow				
Semantics	Output/input port attributes are consistent	x	x		
	Output ports are linked to input ports				
	Symbols are used correctly	x			
	Components contribute to a service			x	
Intended Use	Services can be provided with the components		x		
	Total defects per component	5	4	3	
	Total defects identified		12		

2. *A review process* provides the means to achieve consistency in the review activity. The process indicates a) the inputs to start the activity (e.g., a finished document/ product, and a checklist tailored to it), b) the steps to conduct the review activity, and c) the exit criteria. The checklist classifies common injected defects into categories. To perform a review, first, the whole document is reviewed against the criteria included in that specific category; second, the defects found are recorded in the defect log. These two steps are repeated for each category. At the end of the review, the number of defects and review time are logged in the checklist.

3. *A defect log* provides guidance and structure to record the defects found during the review. The same defect log is used to record the defects found in all the documents reviewed within a project, or product development effort. The defect log facilitates quality data analysis of the whole project, system or lifecycle. When a defect is found, it is entered in the defect log and detailed information shall be provided; e.g., the document or component name, the injection phase, the removal phase, the defect type, fix time, and the defect description, as shown in Table II. The purpose of the description is to identify common defects that may be used in the future as new criterion in the checklist. Criterion will allow the reviewer to find defects in the future.

4. *Data analysis* facilitates the generation of quality metrics such as defect densities per phase, most frequent type of defect, defect types with highest costs to fix, and the yield or efficiency of the reviews (number of defects removed divided by the total number of defects in the document). The defect log provides the required data to conduct the data analysis. The analysis of this data supports a) updating the criteria included in the checklist, b)

making consciousness on the Cost of No Quality (cost to fix the defects), c) finding most common defect types, and d) identifying process improvement proposals. According to Watts [6], gaining consciousness of a specific defect type that is repeatedly removed and logged during the reviews can reduce defect injection up to 50%.

TABLE II. Template for defect log

MS Systems Engineering			Project Practicum		
Defect Log					
Removal phase: Problem Definition Review, Analysis Review, Functional Analysis Review, Design review, SEMP review					
Defect type: Incomplete, Incorrect, not clear, ambiguous, inconsistent, interface, logic, etc					
Review Time:					
Document or Component	Defect type	Injection phase	Removal phase	Fix cost (min)	Defect description
			Total time	0	

III. Building personal ownership of quality at the University of Texas at El Paso

Nine steps have been conducted at UTEP to develop a personal commitment and ownership of creating quality work. The first step is to create student's awareness about the impact that the lack of commitment to create personal quality work has in both the school and their professional life. For instance, a commitment to quality impacts their ability to a) understand concepts covered in the courses, b) integrate their work into team or group assignments, and c) work efficiently as professionals. Also, the components of the Cost of No Quality (prevention, assessment, internal failure and external failure) are introduced. Students compare the low cost to fix defects in earlier stages of product/system development versus the high cost to fix defects at later stages during testing. Moreover, the efficiency of review techniques versus testing is discussed. Lastly, students are trained to conduct personal reviews that use tailored checklists, review processes, defect logs, and data analysis activities. In the second step, it is important to identify a set of intermediate and final documents/products to build a project or system. In our case, this set of documents is very different for each of the classes considered in this research. In the third step, the training to develop the assigned document is given, as well as the assignment to create it. Notice that students are not using a checklist yet and no structured review is conducted. The step fourth is done during class time. The delivered documents are skimmed by the class and common defects found in the documents are listed. The class analyzes the defects and paraphrased the defects as criteria. Criteria (type of defects to look for) that are related to a given aspect, characteristic, activity, or process are allocated into categories (e.g., defects related to the design of *Flow Ports* will be place in the "Flow Port" category) as shown in Table I. In step fifth, a checklist is created with all the criteria allocated in their corresponding

category. It is important to note that the identified criteria correspond to real defects injected in the delivered documents. In step sixth, students are required to perform a personal review using the checklist, review process and defect logs. Students shall submit the following: previous and new versions of the document, a marked checklist, and their defect log. For step seventh, steps 3 to 6 are repeated until all intermediate and final documents of the project or system are finished. Eighth, once the product or system is completed, several quality metrics can be derived; e.g., number of defects injected by document or phase; number of defects removed by review type, frequency of defect type, and fix cost by defect type. Notice that a defect can be injected in one document and found later on in another document created downstream. For step nine, at the end of the semester, students are asked to analyze their defect data and metrics. Students create a self-reflection report about their own quality and skills and promise to create quality work.

IV. Future work

The work will continue in refining some of the templates and training material generated so far. More work is needed to start another goal of the research: develop STEM students' skills to analyze defect data. As a result, students can achieve consciousness of the high cost to remove their defects at the end of the lifecycle and to recognize how this cost is reduced by removing defects earlier in the lifecycle through personal reviews. In addition, material has to be generated to facilitate data analysis; e.g., automating the generation of metrics from the defect logs. Ultimately, a designed experiment will be needed to prove the efficiency of the method with different samples.

V. Conclusion

The purpose of this research is to achieve a cultural change in STEM students by seeding the principle of personal ownership of quality work. The goal is that teachers nurture engineers to create quality work such that he/she is proud of his/her own work. In our professional and academic experience, many industry process improvement projects fail because organizations are reluctant to make the cultural changes necessary for quality; e.g., reward and encourage early removal or prevention of defects, establish relevant management and process controls, and provide the required training. The proposed cultural change in the STEM students will facility new process improvement projects in companies where quality models such as CMMI and TSP may be implemented. Quality in real projects does not happen by accident; it must be planned and implemented by trained and committed technical and management personnel.

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Teaching Metacognition: Helping Engineering Students Take Ownership of Their Own Learning

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Abstract— In this Work In Progress paper, we describe an NSF-funded research project designed to generate transferable tools that can be used to teach and evaluate undergraduate engineering students' metacognitive skills. Metacognition, defined as the knowledge and regulation of one's own cognitive (or thinking) processes, is critically important to student learning and particularly instrumental in problem-solving. Nonetheless, much of the research has occurred in controlled research settings and little is known about how to help students develop metacognitive skills in classroom settings. Through this project, we are working to close this gap by creating and testing a set of interventions designed to help students develop metacognitive skills and to help faculty teach and evaluate this important skill.

Keywords—metacognition, reflection, problem-solving

I. INTRODUCTION

Metacognition, defined as the knowledge and regulation of one's own cognitive (or thinking) processes [1], is critically important to student learning and is particularly instrumental in problem-solving [2, 3]. Nonetheless, much of the research has occurred in controlled research settings and little is known about how to help students develop metacognitive skills in classroom settings. Further, there are significant bodies of research on the role of metacognition in writing and solving math problems, but little work has been done on the role of metacognition within engineering disciplines. Metacognition is particularly important in the training and development of engineers as problem solvers [2].

Researchers have argued that one way good and poor problem solvers are differentiated is by their ability to reflect on and regulate their problem solving activities [4]. Specifically, metacognitive processes aid engineers in identifying and defining problems, mentally representing problems, planning solution procedures, and evaluating solution progress and the final solution [5]. Researchers have also enumerated other metacognitive strategies employed in problem-solving including establishing task demands,

formulating and executing action plans, finding similarities between problems (task knowledge), recognizing inconsistencies and confusion, identifying constraints, switching from one representation to another, activating prior knowledge, and assessing problem difficulty [6]. All of these metacognitive strategies support one's ability to navigate and persist through solving ill-structured problems.

To address this critical need for metacognitive skills in engineering students, we will generate transferable tools that can be used to teach and evaluate undergraduate engineering students' metacognitive skills. To accomplish this, we designed a three-phase project in which we first use research methods to test an intervention designed to facilitate development of students metacognitive skills and associated indicators, i.e., assessment tools instructors can use evaluate student's progress with regard to developing metacognitive skills. In Phases 1 and 2 the elements of the metacognitive intervention will be developed, implemented, and evaluated across multiple contexts. In Phase 3 the focus will be on developing lessons learned from implementing within different contexts, training faculty at the host institutions, and developing online training materials for a broader audience of engineering educators.

II. FRAMEWORK

There have been many developments and interpretations of the formal elements of metacognition in the time since Flavell's classic paper on metacognition [1]. However, there is broad agreement in the two main components of metacognition: knowledge of cognition (metacognitive knowledge) and regulation of cognition (metacognitive regulation). Some researchers consider self-regulation as a separate element, but closely related or intertwined with metacognition [7]. The metacognition framework we use in this study is depicted in Figure 1. Where, self-regulated learning is a broader construct, which wholly includes this structure of metacognition and expands to include other forms

of self-regulation, regulation of environment, behavior, motivation, and affect [8].

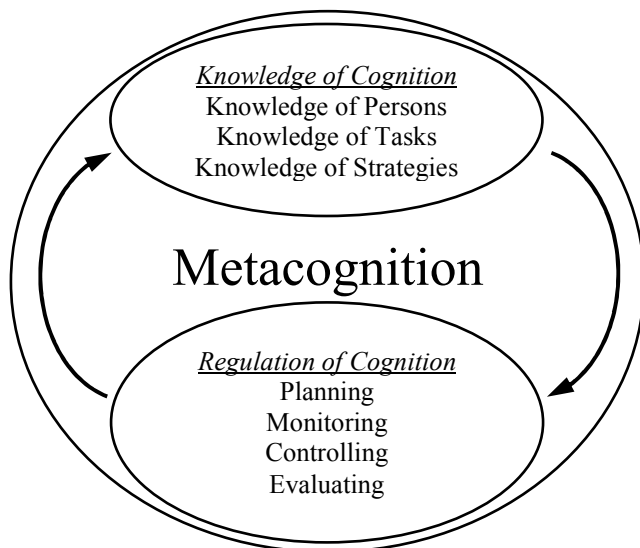


Figure 1: Conceptual Framework of Metacognition

The variables within **knowledge of cognition** have persisted from Flavell's early work [1, 9]. As shown in Figure 1, the variables include knowledge of persons, which includes self and others, knowledge of the task, and knowledge of strategies. The variables within **regulation of cognition** have been more fluid, but there seems to be reasonable agreement in including planning, monitoring, control, and evaluation, or similar elements [2, 9, 10].

The elements of metacognitive knowledge and regulation are not hierarchical, rather they interact and reinforce each other to a high degree [3, 9]. Specifically, regulation draws on and is informed by knowledge of cognition and knowledge of cognition is built, in part, through the practice of regulating one's cognition. Similarly, the elements under knowledge of cognition and regulation of cognition are interrelated with each other. These interdependencies are emphasized in the following descriptions of the sub-elements of metacognition listed. We bold and italicize the key terms in this section to facilitate connections back to the framework diagram.

Knowledge of persons can be further subdivided into self, others, and universal properties of cognition [1]. Within the dimension of self, Pintrich identifies knowledge of one's strengths and weaknesses, the extent and limits of one's knowledge, one's tendencies toward one particular strategy or another, and one's beliefs about their own motivation [3]. Our knowledge of our abilities can impact our view of the difficulty of a given task, facilitate or impede our performance, and direct our selection of strategies to approach a task. Knowledge of others mirrors knowledge of self, but is directed towards others. It facilitates self-assessment in comparison to others and impacts our individual performance and our interactions with others on a task. Knowledge of universal properties of cognition refers to elements such as knowing there are different degrees and kinds of understanding, like the difference between recall and recognition, or the transience of our memory recall [1]. Such knowledge interacts with our

knowledge of strategies and within **regulation of cognition** our abilities to *plan* and *control*. Mis-assessment or inaccuracy in one's knowledge of self can be particularly problematic, especially when it comes to using that knowledge [3].

Knowledge of task includes a variety of task dimensions, for example task demands, goals, difficulty, complexity, context, and comparisons with other tasks [1-3, 9, 10]. These dimensions are strongly related to when and why to apply specific strategies to a task. This implies a strong interaction with *knowledge of strategies* and strategy selection in *planning*, *controlling* and *knowledge of persons*.

Knowledge of strategies includes general cognitive strategies for learning, thinking, and problem solving [3] and task specific strategies [10]. General strategies are applicable across different tasks and tasks from different disciplines. An example of a task specific strategy is knowledge of the principle of Conservation of Energy in engineering analysis, and has significant connection to *knowledge of task*.

While **knowledge of cognition** is essential, it is not enough to have such knowledge. Instead, we must access and use this metacognitive knowledge to reason and make metacognitive decisions to benefit from having such knowledge. This is the essence of the **regulation of cognition**, or metacognitive regulation, which draws on metacognitive knowledge and transforms it into actions through *planning*, *monitoring*, *control*, and *evaluation*.

Planning involves using *knowledge of persons*, *knowledge of tasks*, and *knowledge of strategies* in combination to select an approach to a task [10]. The knowledge is brought together in activities such as predicting task outcomes and scheduling and sequencing sub-tasks [11]. Ambrose et al. discussed breakdowns in students' assessments of assignments and their strengths and weaknesses, which resulted in poor or inappropriate plans [12]. Generally, the more robust a student's knowledge is, the more accurate their self-assessment is, and, conversely, the more sparse and disconnected a student's knowledge is, the more they are prone to over-estimate their abilities.

Monitoring is the ongoing review of one's performance while working on a task. *Monitoring* involves tracking progress on the task, effort expended, checking for errors, self-correcting, and checking and correcting peers [10]. These efforts may be exhibited by students asking themselves, "Is this strategy working, or would another one be more productive?" [12]. The studies cited also revealed that the learning gains from *monitoring* result whether students naturally develop self-monitoring or students are explicitly taught self-monitoring strategies.

Control is the adjustment of one's approach to a task or the strategies employed, in response to *monitoring* [10]. This can be exhibited by an adaptation or change in strategy to improve task effectiveness, repeating a strategy to validate its effectiveness, transfer of a strategy to a new situation, or adopting a modeled cognitive behavior to a task. However, awareness of a deficiency in one's approach to a task does not guarantee that a change will be made.

Evaluation refers to reviewing task performance and effectiveness of the process(es) used to complete the task after concluding the task. Specifically, students assess performance by examining the products of their learning and assess their processes by reflecting on how they navigated the task, *i.e.*, how they *controlled* their behavior during the task [11]. Through the reflective practices of *evaluation*, metacognitive knowledge (*i.e.*, **knowledge of cognition**) is built and refined [11], which implicates a feedback loop where new and better knowledge is used for **regulation of cognition**, for example, resulting in better *planning* in the future.

III. METHODS

The purpose of our project is to generate transferable tools that can be used to teach and evaluate undergraduate engineering students' metacognitive skills. To accomplish this, we designed a three-phased project in which we first use research methods to test and refine an intervention designed to facilitate development of students' metacognitive skills and associated indicators, *i.e.*, assessment tools instructors can use to evaluate students' progress with regard to developing metacognitive skills. The intervention consists of training videos on metacognitive knowledge and awareness, contextualized classroom modules, and metacognitive assignment modifications to provide opportunities to practice metacognitive regulation. The first phase focuses on the development and pilot implementation of metacognitive interventions, and assessing student's metacognitive development for a sophomore engineering course at a small undergraduate-focused engineering school. In this phase, we answer the research questions: *To what degree does a teaching intervention contribute to improved student metacognition? What are some easily accessible indicators of metacognition?* In the second phase, we use the research outcomes from Phase 1 to revise the set of interventions for use in the original context and translate them for a second engineering context, a freshman course at a large comprehensive land-grant university. The goal of the revisions is to improve the interventions and to focus on the transferability of both the intervention and the indicators. The research aspect of Phase 2 refines the Phase 1 research questions and adds the focus on understanding what elements of an intervention and context are most relevant when considering transferability. In this phase we answer the research question, *Considering context and course content, what factors are relevant to transferability of the intervention and indicators?* Finally, Phase 3 will focus on faculty/instructor training and dissemination of intervention materials and answers the question, *What recommendations would help teachers to adapt and use the intervention and indicators in their own classroom contexts?* We will develop recommendations for instructors on how to further translate our intervention for use in their own classroom contexts. Further, we will develop and conduct faculty/instructor training at the host sites. These training sessions will also be used to develop online training videos to be deployed in an online repository hosting training, intervention materials, user submitted materials, and an asynchronous discussion forum for users. The third phase is particularly important as research

shows that transferring teaching innovations can be challenging and can be a barrier to adoption [13-15].

A. Phase 1

The purpose of this phase is to develop, implement (as a pilot), and evaluate teaching interventions (described at the beginning of this section) designed to improve student metacognition. Overall this phase will use an experimental design. The context for this phase is a sophomore level course focused on conservation and accounting principles: conservation of mass, momentum, and energy and accounting of entropy. The course is offered in the first quarter of the academic year and is essentially the foundation to the integrated sophomore curriculum as it outlines core principles within a common framework. The course is required for Mechanical and Biomedical Engineering students and typically has an enrollment of approximately 200 students per quarter. The course has multiple sections of approximately 25 students each enabling the use of intervention and control groups.

Data Collection and Analysis: We will use multiple research methods to calibrate indicators. We anticipate that indicators will predominantly come from classroom assignments and activities and assignment modifications created as part of the intervention itself. We anticipate seeing growth in students' metacognitive abilities as they become more aware of their metacognitive knowledge and through cycles of intentional practice of metacognitive regulation and corresponding correction and expansion (improvement) of their metacognitive knowledge [16]. It is this change over time that we are looking for as an indicator that our intervention is working. The use of an experimental design provides an understanding of what metacognitive changes typically happen during the same time period as a part of academic development in the absence of any explicit metacognitive interventions. This will help us to understand the appropriateness of our interventions with regard to challenging and pushing possible developmental norms and gauge the effectiveness of our interventions.

Student interviews: We will conduct interviews at the start of the term and again at the end of the term with ten students each in the experimental and control conditions. We will treat each pair of interviews (and survey responses) as a case such that we can compare and contrast changes with time and across cases [17, 18]. We will use early quarter interviews to gauge students' initial understanding of metacognition as well as to describe the practices in which students currently engage. By asking similar questions at the end of the semester, we can gauge changes across time. By also asking about the specific intervention activities we designed, we can gauge student's perceptions of which activities worked best and why.

Student surveys: We will also use quantitative measures of metacognition. We will adapt questions from existing instruments [19-21] for appropriateness in college engineering courses. For example, we would draw on questions that are consistent with our intervention and focus on how students evaluate their own learning such as "I ask myself questions to make sure I understand the material I have been studying in this class". We will use pre- and post-test measures (matched by participant) so that we may assess changes in individual

student use of metacognitive strategies. We will use descriptive statistics and comparative t-tests. The surveys will also help provide a backdrop against which we can situate interview findings for greater transferability and generalizability.

Indicators: Interviews and surveys are research-tested ways of identifying metacognitive engagement. However, they can be cumbersome and time-consuming to implement, making them difficult to use for in-class assessments. They can also be in formal language that does not match typical student/instructor vernacular. Our development of indicators will focus on equipping instructors with tools (e.g., rubrics) to assess metacognitive engagement in the classroom and on homework extensions during the learning process. Potential indicator assessments include the use of reflective writing assignments, short think aloud opportunities, and direct observations of students at work. Previous work in identifying metacognitive engagement will be used to inform the development of these in class indicators [22-24]. We will then use interviews and surveys to corroborate the effectiveness of the indicators that are designed into the course.

B. Phase 2

The purpose of this phase is to refine the pilot metacognitive teaching interventions and to test the transferability of the interventions and assessment tools for the instructors to evaluate students' development of metacognitive skills. To do so, we will repeat the implementation at the primary site with improvements based on outcomes from Phase 1. We will also develop contextually relevant materials and test them at a second site. The second site is an introductory course in a first-year engineering program at a large land-grant university in the mid-Atlantic region of the United States. At the course level, the context change specifically consists of changes in student level, student major, and course content providing an opportunity to study whether the metacognitive teaching videos function well in both contexts relative to topics and delivery. The order and the timing of the sequence of paired videos, in-class modules, and assignment extensions may need to be altered for different contexts, although the introductory overview video will be kept first. At the university level, one school is a teaching focused technical school and the other is a research intensive school. The new context will engage multiple instructors, including faculty and graduate teaching assistants, compared to one or two instructors in the pilot, which may necessitate refinements for consistency and ease of transfer, while maintaining effectiveness.

Data collection and instruments: The interview and survey methods described in Phase 1 will also be used in Phase 2. We anticipate only minimum adaptations in these research tools, particularly for context, but will make other changes as necessary. We also anticipate that the indicators will be similar to those used in Phase 1 adapted for the contextual differences. For example, some of the assignment modifications will have to be adapted to the new context. It is also likely that the scope and instructions for assignment modifications be altered to reflect different student levels and course content. There is still debate as to whether metacognitive engagement is domain general (common skills

across all domains) or domain specific (specific skills necessary for different domains) [25]. Thus, the adaptations to indicators and survey methods will relate to difference in context as well as the differences in domain content. As the developmental process of metacognition is understudied in higher education and specifically, engineering, we do not yet know if there will be differences between first- and second-year engineering students. Therefore, piloting of survey methods and indicators will also focus on ensuring that these methods are suitable for different developmental stages.

C. Phase 3

The purpose of this phase is to create resources that can be disseminated to other faculty to support transformational change in undergraduate classrooms, specifically with regard to helping students develop metacognitive abilities, and to provide faculty/instructor training on what metacognition is and how to use these metacognitive teaching interventions. Because our approach in designing interventions is grounded in theories on learning, we expect it to be widely applicable with relevant adaptations for context. Our basic approach to student learning involves a pairing of developing knowledge with practice and intentional feedback [16, 26]. The resources will comprise two sets. The first set will come directly from our research including descriptions of the metacognition interventions and indicators and guidelines for adapting them to different contexts. Because we have intentionally examined two different research sites with specific contextual differences (university and course-specific differences), we will have identified factors in tool adaptation that matter. These resources will facilitate transformation because knowledge of pedagogy alone is not enough; knowing how to make pedagogy work in different settings also matters as has been demonstrated by recent research on transfer of innovations in teaching [e.g., 13, 14, 15]. The second set of tools will be a set of suggestions for developing effective researcher-teacher partnerships. These will emerge from formative and summative reflections generated by all research team participants.

IV. RESULTS

We are currently in the first phase of this project collecting interview and survey data relative to student's metacognitive beliefs and practices. Simultaneously, we are developing the intervention materials including the training videos on metacognitive knowledge and awareness, contextualized classroom modules, and metacognitive assignment modifications to provide opportunities to practice metacognitive regulation.

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Predicting Students' Final Exam Scores from their Course Activities

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Abstract— A common approach to the problem of predicting students' exam scores has been to base this prediction on the previous educational history of students. In this paper, we present a model that bases this prediction on students' performance on several tasks assigned throughout the duration of the course. In order to build our prediction model, we use data from a semi-automated peer-assessment system implemented in two undergraduate-level computer science courses, where students ask questions about topics discussed in class, answer questions from their peers, and rate answers provided by their peers. We then construct features that are used to build several multiple linear regression models. We use the Root Mean Squared Error (RMSE) of the prediction models to evaluate their performance. Our final model, which has recorded an RMSE of 2.93 for one course and 3.44 for another on predicting grades on a scale of 18 to 30, is built using 14 features that capture various activities of students. Our work has possible implications in the MOOC arena and in similar online course administration systems.

Keywords—automatic assessment; score prediction; peer-assessment;

I. INTRODUCTION

Automated prediction is a technique that has become prevalent in several fields and sectors including education, medicine, biology, politics, and finance. This prevalence is strongly attributed to recent advances in machine learning techniques.

Although the approaches adopted by prediction systems may vary, they all follow the same notion – make an *educated* guess about the value of a parameter by observing what variables affect that parameter and how they have affected it in the past. Ideally, the explanation that this guess is not random but educated is provided by the factoring of historical data about the variables and how they relate to the parameter into the prediction process.

The amount of data needed to make a *good* prediction depends on how complex the parameter being predicted is. That is, it depends on how many variables affect the value of the parameter. In reality, parameters to be predicted are fairly complex and large amounts of data are usually required to build decent prediction systems.

The availability of data does not necessarily guarantee that the prediction will perform well. Modelling the parameter to be predicted by identifying the variables and weighing their impact is a challenging task essential to the realisation of a successful prediction system.

In higher education, such systems have been used to predict the intermediate and final scores of students at different levels. Timely prediction of scores facilitates early intervention to identify students that may require special supervision and can be used to provide students with progress feedback.

Automated score prediction could also have a significant implication in the Massive Open Online Courses (MOOC) arena. Predicting the performance of students could help provide early insight into the attrition rates of courses administered in MOOC format. Such early indication would allow MOOC providers to explore corrective measures accordingly in order to increase the retention rates of their courses, as the majority of today's MOOCs suffer from immense attrition rates [10][18].

Student assessment techniques such as standardised tests and exams are able to obtain information about specific traits of students at a certain point in time. Gathering information about students that could explain their progress requires continuous recording of their activities using more sophisticated techniques. If designed well, such techniques could capture data that explain how students behave, communicate, and participate in learning activities and have the potential to predict how they would perform on end-of-course exams.

One practice that engages students in activities intended to improve their learning by evaluating other students' work is peer-assessment. Topping [24] defines peer-assessment as "...an arrangement in which individuals consider the amount, level, value, worth, quality, or success of the products or outcomes of learning of peers of similar status."

The reliability and validity of peer-assessment as either a formative or summative assessment tool has been studied in detail. Although there is agreement over the perceived values it brings to students and teachers, uncertainties remain regarding its use as an effective practice. A meta-analytic review by Falchikov and Goldfinch [25] and a critical analysis of peer-assessment studies by Topping [26] reveal these uncertainties.

Regardless of these uncertainties, peer-assessment provides a rich platform to gather significant information about students as they engage in assessing the works of their peers. In this study, we use an online peer-assessment framework to gather such information about students, which we then use to build our prediction model. Students participate in online peer-assessment task by submitting questions on pre-specified topics, by answering questions from their peers, and by rating their peers' answers.

In this paper, we present a linear regression model that utilises data generated by the activities of students in two courses to predict their final exam scores. This paper is organised as follows: In section II, we discuss several peer-assessment systems that are currently used in education in order to provide a comparative view of our peer-assessment framework and review previous work in score prediction. We then briefly discuss our peer-assessment framework and describe our prediction model in section III. In section IV, we provide details of the experiments and the results we obtained. We conclude our discussion in section V with a review of our work and our plans for the future.

II. PREVIOUS WORK

A. Peer-Assessment

Although they may differ in the techniques they use or their overall design, all peer-assessment methods involve the practice of having students evaluate the works of their peers. Peer-assessment methods have been in use in education and other institutions for decades. See [13] for a detailed review of peer-assessment tools. Here, we discuss four peer-assessment platforms that we believe are relevant to our work.

PRAISE (Peer Review Assignments Increase Student Experience) is a generic peer assessment tool that has been used in the fields of computer science, accounting and nursing [3]. It has been used in introductory programming courses by students coming from different disciplines. Before distributing assignments, the instructor will specify criteria. Once assignments are distributed, students review details of each assignment and submit their solutions. The system waits for the number of submissions to reach a specified number and assigns review tasks to students. Students then review the solutions of their peers according to the criteria. Once all reviews for a solution are complete, the system checks if all reviewers agree according to the criteria and suggests a mark based on the criteria. If there is a disagreement among reviewers, the system submits the solution to the instructor for moderation. The instructor then needs to decide a mark and confirm the release of the result before a student can see their overall mark for the assignment.

PeerWise is a peer assessment tool, which students use to create multiple-choice questions and answer those created by their peers [4]. When answering a question, students are also required to rate the quality of the question. They also have the option comment on the question. The author of a question may reply to a comment that has been submitted by the student who rated the question.

PeerScholar is another peer-assessment tool that was initially designed for an undergraduate psychology class. It

aims to improve writing and critical thinking skills of students [17]. First, students submit essays. Next, they are required to anonymously assess the works of their peers, after which they have to assign scores between 1 and 10, and write a comment for each of their assessments. Students are also allowed to rate the reviews they have received.

Workshop is a peer-assessment module for the Moodle E-Learning platform that lets students view, grade and assess their work or that of their peers [16]. The instructor coordinates and controls the assessment phases and is able to monitor the involvement of each student in each task. The instructor also has the ability to specify the criteria for computing grades and is also able to give different weights to different questions. The tool also allows assigning separate grades to submission of answers and assessment of submitted answers.

B. Score Prediction

The prediction of certain traits of individuals and groups from data generated by social networks and other platforms has been explored in several sectors. However, the vast majority of studies that relate to prediction of performance of students have had a particular focus on either computer science or computer literacy courses.

One early study conducted by Alspaugh [1] uses test results from three standardised tests – Thurstone Temperament Schedule [21], IBM Programmer Aptitude Test [14], and the Watson-Glaser Critical Thinking Appraisal [22] – and concludes that students who possess second level college calculus skills, have low levels of impulsiveness and sociability, and high reflectiveness have a good aptitude for computer programming.

Several studies have also investigated factors that can be used to predict the final scores of students. Fowler & Gorfeld [7] build a logistic classifier based on students' current GPA, math skills, SAT scores, and students' ages, which classifies students as having high or low aptitude for programming. The model is built using data from 151 students, 122 (81%) of which it classifies correctly.

Evans & Simkin [5] use six outcome variables as measures of computer proficiency – homework scores, scores in a BASIC programming exam with 19 matching questions, scores in a BASIC programming exam with 15 fill-in-the-blank questions, and first and second midterm scores. 49 predictor variables grouped into four categories – demographic, academic, prior computer training and experience, and behavioural – were used in building the models. A stepwise multiple regression model was built for each of the six predicted variables. The performance of these models was reported in terms of the coefficient of determination (R^2), with the model predicting homework scores having the highest value of 0.23.

Wilson and Shrock [23] conducted a study involving 105 students to predict success in an introductory college computer science course by examining twelve factors. Among these, three factors – comfort level, math skills, and attribution to luck for success – were found to be more important in

predicting mid-term scores. The performance of the linear model was reported to have an R^2 value of 0.4443.

As discussed above, most previous work in predicting the performance of students focused on very similar factors for making such predictions. Of these factors, the most common were math skills, high school scores, and standardised test scores.

Recent work has sought to exploit other more latent factors to predict success in computer science courses. Keen & Etzkorn [11] have built a model for predicting the average test scores of students of a computer science course by observing the buzzword density (the ratio of computer science related words to the total number of words) in the teacher's lecture notes. The intuition that higher buzzword density would imply more complex lecture notes and would, as a result, lead to lower average scores was supported by a strong negative correlation of -0.521 between buzzword density and average scores.

A recent study by Fire et al. [6] investigates the impact of interactions among students on their success in computer science courses as well as the correlation between students' scores. The study uses data from 163 students and applies graph theory and social network analysis techniques to predict students' final test scores and final grades. The features used for predicting students' final test scores include personal information features such as assignment scores and students' departments as well as topological features such as students' number of friends in the social network, which is built from homework assignment data and website logs, and friends' scores. Using these data, a single linear regression model is built to explore relationships among students. Another multiple linear regression model with stepwise inclusion is built to predict whether a student would score below 60, the passing mark for the course. The multiple regression model produces an R^2 value of 0.174 and Mean Absolute Error of 10.377.

Performance prediction has also been applied in MOOCs. One study uses students' performance on assignments from the first week together with their activity in the discussion forums and their peer-assessment task completion rate to build two logistic regression models that predict whether students will earn certificates of completion and whether they will achieve distinction, with accuracy levels of 79.6% and 92.6%, respectively [9].

Another study uses student behaviour data in a course administered in a MOOC format to predict whether a student will provide the correct answer for an in-video question at the first attempt [2]. Summary quantities such as the fraction of the video played and the number of pauses are extracted from clickstream data for each video-student pair and used to predict the likelihood of a student correctly answering questions in that video at the first attempt.

Automated prediction in MOOCs has however focused on early prediction of attrition rates from student behaviour. See [12], [19], and [20] for such studies.

III. BUILDING THE PREDICTION MODEL

A. The Peer-Assessment System, Participation, and the Data

The prediction model was built on data that were generated from the activities of students enrolled in two undergraduate level computer programming courses, Informatica Generale I (IG1) and Programmazione II (PR2), at the University of Trento in Italy. The central mechanism of the data collection required students to participate in a set of peer-based online homework activities throughout the course.

The online homework activities were carried out using a web-based peer-assessment platform that we built specifically for this purpose. The homework activities included three main tasks – *Ask A Question*, *Answer A Question*, and *Rate Answers*. Every week during the course, students would ask questions about topics that had been discussed in class, answer other students' questions, and vote for answers submitted by other students. They would also rate the levels of interestingness, relevance, and difficulty of questions.

The week starts with the teacher assigning the 'Ask A Question' task to all students, in which students submit questions regarding topics specified by the teacher that had already been discussed in class the previous week. After the deadline for completing the task has passed, the teacher filters the questions and selects a subset that will be used in the next task. The peer-assessment process is designed to obtain at least four answers to each question. Hence, the system recommends the number of questions to be selected by the teacher, taking into account the number of students participating.

The teacher then assigns the 'Answer A Question' task to all students. The system handles random assignments of the selected questions. It also guarantees that students will not be asked to answer their own questions and that each student is assigned only one question. When submitting their answers, students rate the difficulty, relevance, and interestingness of the questions on a scale of 1 (lowest) to 5 (highest).

The last task of the cycle is the 'Rate Answers' task, which asks students to rate the correctness of answers provided by students for the questions that had been selected on a scale of 0 (incorrect) to 5 (excellent). During assignment of the tasks, the system guarantees that the student that had asked the question is asked to rate the answers for their question. The system also guarantees that each question-answer set is assigned to at least four students and that the assignment of the tasks remains random for those who had not asked the questions that were selected by the teacher.

The web-based peer-assessment system was accessible through the Internet and students could complete their tasks at a location of their choice. Anonymity was preserved as students did not know whose question they had answered and whose answer they had rated or vice versa. All student activity including time of completion of tasks was logged by the system. Details of the design and implementation of an earlier version of the peer-assessment system are discussed in [15].

Because participation in the online peer-assessment activities was optional, some students did not participate at all while others opted out at several points during the course.

The university's exam policy permits students to withdraw from an exam without having their work assessed. Usually, students who expect to score lower than the minimum passing mark, 18 out of 30, either withdraw from or do not sit the exam, which, depending on the course, was either oral or written.

Although it is still possible to fail an exam, all students whose data were used to build the prediction model had passed their exams. The implication of this is that the model could not predict grades below 18 and was not able to predict dropping out. It is possible that future editions of the courses will record failing students, whose data can then be used to train the model to make such predictions.

Students also have the option to sit an exam in any of the five sessions available in an academic year. Therefore, although some students participated in the online peer-assessment activities, their final grades were not available as they had not sat their exams at the time of this experiment.

Consequently, although a total of over 400 students participated in the online homework activities for the two courses together, data from only 206 students were used in our experiment.

B. Preliminary Investigation

One of the online peer-assessment tasks requires students to evaluate a set of answers provided by other students for a question by assigning votes to the answers. At the end of the course, the number of votes a student has earned for all their answers will, among other measures of activity, constitute the overall degree of performance of the student in the online homework activities.

An intuitive approach to predicting the final scores of students using such data would be to explore the relationship between the number of votes a student has earned for their answers throughout the course and their final exam score.

This final exam score is represented as a whole number ranging from 18 to 30. We were not certain about finding a strong relationship, however, as these votes are assigned by students themselves and may, as a result, be inconsistent and inaccurate due to several factors such as inexperience of students in evaluating answers. A preliminary investigation of the existence of such a relationship and its strength would then be necessary to address this uncertainty.

We carried out this investigation by clustering students according to the number of votes they earned, which ranged from 0 to 21, and by computing the average final score for each cluster. We observed a rather weak relationship. We found that a linear fit hardly captured any relationship and that, although a better fit, a fourth degree polynomial was not an ideal model either. Attempting to model this relationship with polynomials of higher degrees would have eventually led to over-fitting.

This led us to conclude that student votes alone would not be strong predictors of final exam scores. We therefore decided to proceed with exploring more parameters that would explain the performance of students such as the amount of tasks they completed and the perceived level of difficulty of the questions they provided answers for.

C. Features of the Prediction Model

Our initial investigation explored 7 parameters in order to build a linear regression model. 16 additional parameters, most of which were computed from the initial 7 parameters, were later used to create more models. In favour of brevity, only a list of the parameters of the final model is presented below.

Tasks Assigned (TA) – The number of tasks that were assigned to the student

Tasks Completed (TC) – The number of tasks that the student completed

Questions Asked (QAS) – The number of 'Ask a Question' tasks the student completed

Questions Answered (QAN) – The number of 'Answer a Question' tasks the student completed

Votes Cast (VC) – The number of 'Rate Answers' tasks the student completed

Questions picked for answering (QP) – The number of the student's questions that were selected by the teacher to be used in 'Answer A Question' tasks

Votes Earned (VE) – The number of votes the student earned for their answers

Votes Earned Total Difficulty (VED) – The sum of the products of the votes earned for an answer and the difficulty level of the question, as rated by students themselves, for all answers submitted by the student

Votes Earned Total Relevance (VER) – The sum of the products of the votes earned for an answer and the relevance level of the question, as rated by students themselves, for all answers submitted by the student

Votes Earned Total Interestingness (VEI) – The sum of the products of the votes earned for an answer and the interestingness level of the question, as rated by students themselves, for all answers submitted by the student

Selected Q total difficulty (SQD) – The sum of the difficulty levels of the student's questions, as rated by students themselves, which were selected to be used in subsequent tasks

Selected Q total relevance (SQR) – The sum of the relevance levels of the student's questions, as rated by students themselves, which were selected to be used in subsequent tasks

Selected Q total interestingness (SQI) – The sum of the interestingness levels of the student's questions, as rated by students themselves, which were selected to be used in subsequent tasks

Number of Attempts (NA) – The number of attempts the student made to pass the course

D. The Prediction Model

The data were normalised using min-max normalisation, which converts the values of each parameter into a value between 0 and 1. We used the Weka data-mining toolkit [8] to build three sets of linear regression models – one for each course and an additional set using the combined dataset from both courses. First, we built models using the initial 7 features. We then built more complex models by adding a set of the computed features step by step. As a result, 3 sets of 7 linear regression models each were built.

Each model was tested using 10-fold cross-validation. The Root Mean Squared Error (RMSE) of the models was used for performance evaluation.

The model with the least RMSE was built using the 14 features discussed in III.C. The final score prediction model m is given by:

$$m(i) = C^T S_i + 27.8967 \quad (1)$$

, where S is a 14-by- n matrix built from the 14 parameter values for n students, S_i is the i^{th} column in S representing student i , C^T is the transpose of the column vector C given by,

$$C = \begin{bmatrix} -3.98 \\ -0.32 \\ 0.63 \\ 0.68 \\ -2.16 \\ 0.10 \\ 0.71 \\ 22.92 \\ -16.29 \\ -5.02 \\ 4.54 \\ -3.71 \\ 0 \\ -4.42 \end{bmatrix}, \text{ and } S_i = \begin{bmatrix} TAI \\ TCi \\ QASi \\ QANi \\ VCI \\ QPi \\ VEi \\ VEDI \\ VERi \\ VEIi \\ SQDi \\ SQRi \\ SQIi \\ NAI \end{bmatrix}, \text{ for } i = 1, \dots, n.$$

As can be observed from the column vector C , the model rewards students for earning votes for answering difficult questions as well as for asking challenging questions.

We believe that the two features that capture this information, VED and SQD, are good discriminators among students of different performance levels. This characteristic of the model is also coherent with the manner in which a teacher would award points to students.

I. EXPERIMENTS AND RESULTS

A. Testing with Unseen Data

The final model was built on data from the IG1 course only. This provided us with the opportunity to test how the model

would perform on data coming from another course. We thus tested the model with 101 instances from the PR2 course. The RMSE was found to be **3.44**. This result is encouraging, taking into account the fact that the test data come from a different course. Although the levels of the two courses were different and were attended by different groups of students, the prediction errors of the system were comparable when predicting performance of students attending the PR2 course using data from the IG1 course.

B. Is the Prediction any Better than Random Guessing?

In order to determine if our prediction model outperformed random assignment techniques, we developed several mechanisms of random guessing. First, we assigned a grade to each of the 206 students by randomly selecting a number from the valid range of grades, 18 to 30. We performed this random assignment 10000 times and evaluated the average RMSE of these assignments. We performed this grade assignment for students of both courses IG1 and PR2. The average RMSE for this technique was computed as **5.04**.

We then performed a systematic random assignment of grades by sampling from a prior distribution of grades from previous editions of the courses. As shown in Fig. 1, the distributions of grades for the two courses are not similar. We therefore decided to sample grades from separate prior distributions, one for each course.

After exploring several probability distributions, we found that the best possible fits for both courses were kernel distributions. Fig. 2 shows these distributions plotted against the probability density function plots of the two courses.

For each course we sampled from its respective distribution and assigned grades to students. We performed this assignment 10000 times, averaged the RMSEs of all assignments, and obtained an average RMSE of **4.94** for IG1 and **5.01** for PR2.

Finally, we sampled from the prior distribution of grades by assigning an index to each grade and by randomly selecting a number from these indices, which formed a uniform distribution. This would allow us to include instances which would not be captured by the kernel fits shown in Fig. 2.

We performed this sampling for the two courses separately. As before, we performed the random assignment 10000 times and averaged the RMSEs, obtaining an average RMSE of **4.89** for IG1 and **4.96** for PR2. Tables I and II provide a comparison of the random assignment techniques and our model. As our model is tested with the respective data for each course, there is a variation, albeit slight, in its performance on data from the two courses.

The histograms in Fig. 3 show the prediction errors. In an ideal prediction model, errors would be significantly low. Hence, the histogram of such a model would have a slender shape, with its peak near the centre of the horizontal axis.

Although our model outperforms all random assignment techniques, its strength is evidenced in how it outperforms assignment techniques even when random assignment is aided by information from previous editions of the courses to reduce the frequency of assigning grades that were not common. The

strength of our model is also reflected by the fact that none of the 10000 assignments for each technique scored an RMSE lower than that of the model.

TABLE I. EVALUATION OF PREDICTION METHODS FOR IG1

Prediction Method	RMSE
Sampling from a uniform distribution	5.04
Sampling from a kernel distribution	4.94
Sampling from previous scores directly	4.89
Linear regression model	2.93

TABLE II. EVALUATION OF PREDICTION METHODS FOR PR2

Prediction Method	RMSE
Sampling from a uniform distribution	5.04
Sampling from a kernel distribution	5.01
Sampling from previous scores directly	4.96
Linear regression model	3.44

II. FROM PREDICTING SCORES TO PREDICTING GRADES

It would be interesting for teachers to group students into several categories based on their performance. While scoring on a scale of 18 to 30 may be too broad a range to provide such information, grades, numerical or otherwise, provide this functionality. Such grading systems may also be fine-tuned to decide the granularity of these groups.

Here, we transform the scores of students on an 18 to 30 scale to numerical grades on a scale much similar to the A to F grading system. Numerical grades range from 0 to 4, with a grade of 4 corresponding to an A, 3 to a B, and so on. Scores are converted to numerical grades by assigning a single grade to a range of scores. Hence, scores 28 to 30 will be assigned a grade of 4, 25 to 27 a grade of 3, 22 to 24 a grade of 2, 18 to 21 a grade of 1 and those below 18 a grade of 0.

In order to perform this experiment, we used the same features explained in section III.C, to build a new model that predicts the numerical grade of a student using the newly transformed data. As before, we used 10-fold cross-validation to evaluate the performance of our model. The model that was built using data from the IG1 course performed better than that built on the PR2 course, albeit slightly. We therefore report the performance of the winning model only.

Although it might seem that this way of predicting grades is a 5-class classification problem, the fact that the input variables assume continuous values makes the classification task impossible. Indeed, classifiers such as Naïve Bayes Classifier, Decision Trees, and Logistic Regression have prohibitively poor performance.

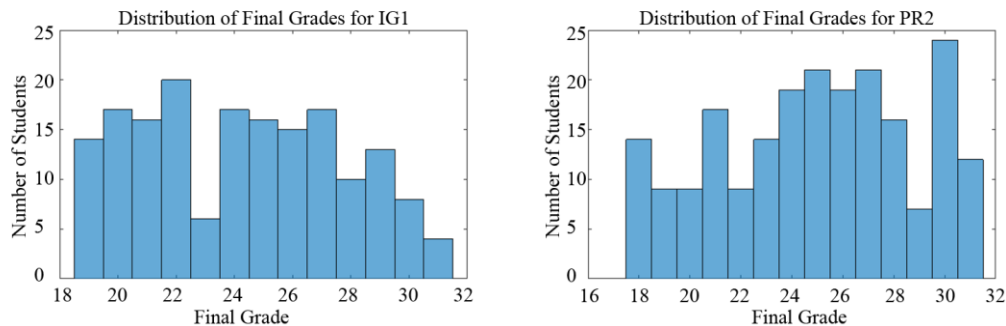


Figure 1. Distributions of grades for IG1 (left) and PR2 (right)

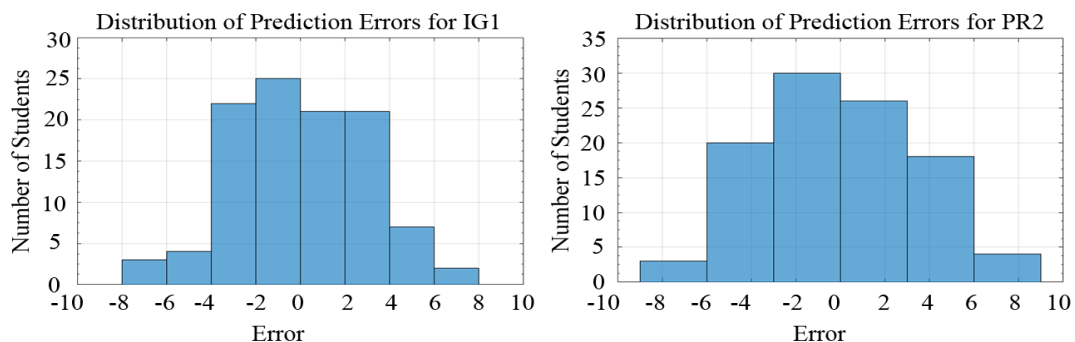


Figure 3. Histograms of the prediction errors for IG1 (left) and PR2 (right)

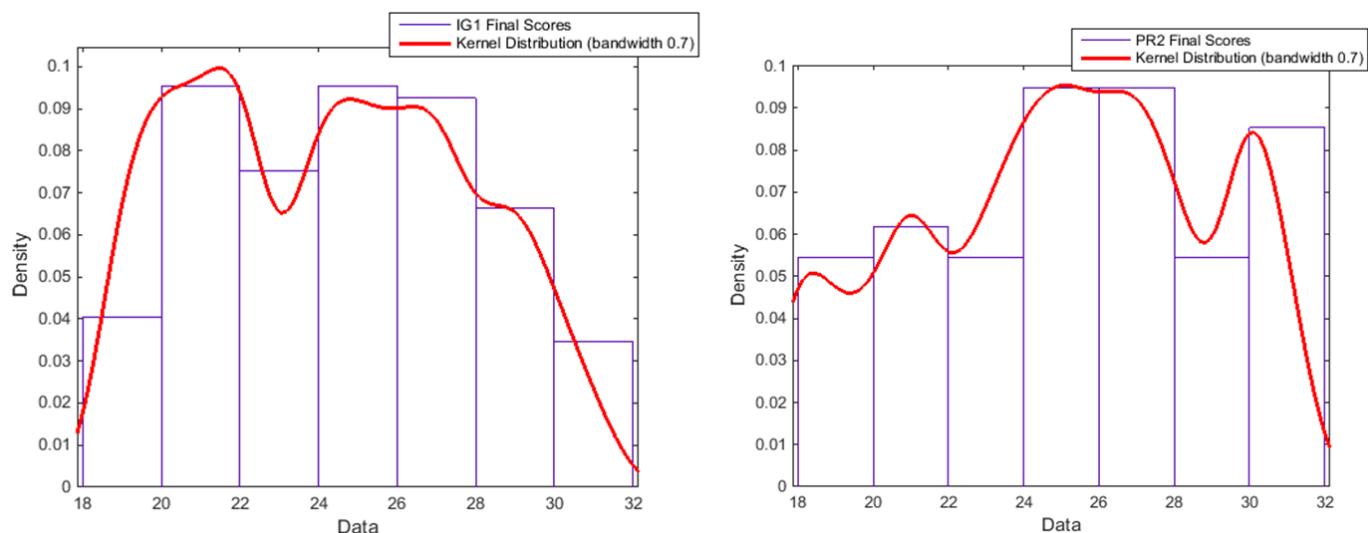


Figure 2. Histograms of the final scores of students of IG1 (left) and PR2 (right) plotted against kernel distributions

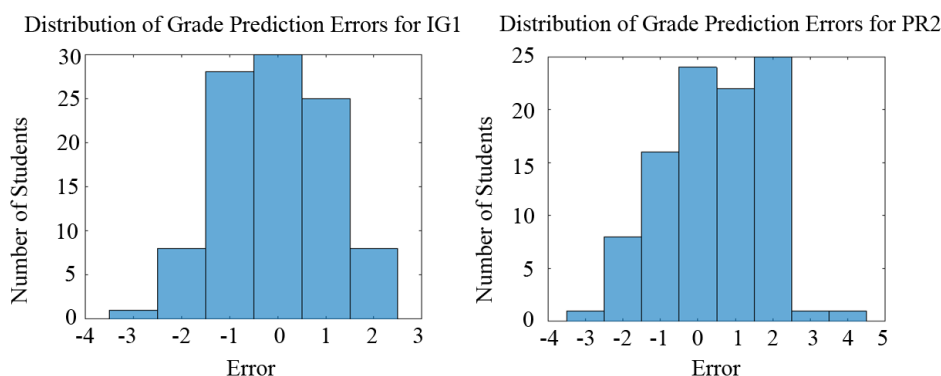


Figure 4. Histograms of the grade prediction errors for IG1 (left) and PR2 (right)

Linear regression, on the other hand, can handle such data as the grades are still numerical. However, the prediction values are continuous and do not necessarily map into one of the five grades. We therefore use a function that rounds prediction values to the nearest integer to make the prediction valid. As a result, the RMSE of the rounded predictions, which is slightly higher than the RMSE computed on the actual predictions, is reported.

The winning model scored a 10-fold cross-validation RMSE of **1.12**, a significant decrease from the previous value of **2.93** when predicting numerical scores. When tested on unseen data from the PR2 course, the model scored a much lower RMSE of **1.44** than the previous score of **3.44**. The prediction errors of this model for both courses are depicted in the histograms in Fig. 4.

In the following tables, we report comparisons between our model and baselines constructed in the exact manner as before.

Here, we sample from normal distributions instead of kernel distributions as they fit better the grade distributions for both courses.

TABLE III. EVALUATION OF GRADE PREDICTION METHODS FOR IG1

Prediction Method	RMSE
Sampling from a uniform distribution	1.83
Sampling from a normal distribution	1.68
Sampling from previous grades directly	1.53
Linear regression model	1.12

TABLE IV. EVALUATION OF GRADE PREDICTION METHODS FOR PR2

Prediction Method	RMSE
Sampling from a uniform distribution	1.86
Sampling from a normal distribution	1.65
Sampling from previous grades directly	1.53
Linear regression model	1.44

Table V shows the performance of the grade predictor in terms of accuracies. For IG1, 83% of its predictions fall within the range 0 to 1 grade point difference whereas for PR2, it performs less, with 63% of its predictions falling in the same range.

TABLE V. PREDICTION ACCURACIES OF THE MODEL

Course	Exact Prediction	Within 1 Grade Point	Within 2 Grade Points
IG1	0.30	0.83	0.99
PR2	0.24	0.63	0.97

The grade prediction model m is given by:

$$m(i) = C^T S_i + 5.75 \quad (2)$$

, where S is a 14-by- n matrix built from the 14 parameter values for n students, S_i is the i^{th} column in S representing student i , C^T is the transpose of the column vector C given by,

$$C = \begin{bmatrix} -0.16 \\ 0 \\ 0.06 \\ -0.02 \\ -0.01 \\ 0.05 \\ -0.47 \\ 6.29 \\ -4.95 \\ 0.16 \\ 2.10 \\ 1.55 \\ -3.53 \\ -0.30 \end{bmatrix}, \text{ and } S_i = \begin{bmatrix} TAi \\ TCi \\ QASi \\ QANi \\ VCi \\ QPi \\ VEi \\ VEDi \\ VERi \\ VELi \\ SQDi \\ SQRi \\ SQLi \\ NAI \end{bmatrix}, \text{ for } i = 1, \dots, n.$$

Similar to the previous model, this model rewards students who earn votes for answering questions that are regarded as difficult and interesting, as well as for asking questions which are challenging and relevant.

III. DISCUSSION AND CONCLUSIONS

Performance prediction in educational activities has been studied before. Most previous studies, however, were limited to analysing previous performance information of students to make such predictions. Most of this information came from high school level performance data and college entrance examination scores.

Today, students themselves generate significant amounts of data throughout their studies. The major goal of our work was to take advantage of such information in order to predict student performance. In this paper, we presented a linear regression model for predicting final exam scores of students by observing data that are generated from their online course activities. We implemented our web-based peer-assessment system in two courses and used the data from the system to build our model. The preliminary results of our prediction model are encouraging.

We believe the techniques and settings we used to generate data about students and make predictions about their performance are novel. Although work in predicting student success has recently gained more focus, most of the attention has been directed towards predicting attrition rates in courses administered online, specifically MOOCs. Studies in close supervision of students and early detection of at-risk individuals are therefore in order and we believe that predicting student performance in higher education settings and in mandatory courses at the undergraduate level is an important part of such studies.

US-style grading techniques help group students into several performance groups and predicting grades instead of scores on longer ranges aids in this aspect. We therefore built a similar regression model for predicting the grades of students. The prediction errors are much lesser for this model and it can predict, within a grade point range, the grades of the large majority of students, as seen in table V.

In the experiments we conducted, prediction of scores was made after courses had ended and before students had sat final exams. However, prediction is only effective when it is done in a timely manner and is no good if it provides important information about students at a time when little can be changed to help them improve. In an upcoming study, we intend to apply the prediction model discussed in this work to student performance data as it is generated in order to make predictions on a weekly basis to facilitate early detection and supervision of students that may require special attention.

As more and more higher education institutions make their courses available for learners through platforms such as Massive Open Online Courses (MOOCs), the immense amount of data generated make it possible to provide continuous and automated assessment of student progress.

The peer-assessment framework that we use is complementary to traditional classroom lessons. Nonetheless, the prediction system is not tied to the pedagogy. This makes it easy to extend this approach of student supervision and assessment to non-traditional learning environments such as flipped classrooms.

We are hopeful that, although the framework we utilised in this study is not very similar to MOOCs, the way we built a prediction model on top of the data can be adopted by MOOCs and similar platforms. There are already studies that use such data to predict attrition rates of courses administered in a MOOC format but we have demonstrated in this study that it is possible to go further and learn students' trends as they participate in courses to provide timely supervision from such rich data.

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A Quantitative Case Study in Engineering of the Efficacy of Quality Cheat-sheets

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Abstract—Although authorized cheat-sheets have been widely accepted as a common examination format, their effectiveness is still being questioned. Some researchers believe authorized cheat-sheets are more like a "crutch" and have no effect on students' performance. In this study, we created a cheat-sheet rating scheme to evaluate the quality of authorized cheat-sheets collected with each exam (N=155) and investigated the effect of cheat-sheet quality on students' grades. This study reveals that 1) the average cheat-sheet's quality varies significantly between those students who scored in the top half of the class versus those whose score was in the lower half of the class; 2) students' grades are highly related to their cheat-sheet quality and 3) if students manage to improve the quality of their cheat-sheets from one examination to the next, their grades tend to improve for that subsequent examination.

Keywords—authorized cheat-sheet; examination; cheat-sheet quality

I. INTRODUCTION

The three main categories of examinations based on resources students have access to during exams are closed-book exams, open-book exams (sometimes even open-everything, including the Internet) and exams with authorized cheat-sheets. An authorized cheat-sheet (also known as "authorized crib sheet") refers to notes that test takers are allowed to make beforehand and use during exams.

A. Criticism on open-book exams

In 1951, Tussing suggested that open-book exams are a better exam format than closed-book because it 1) reduces anxiety 2) emphasizes reasoning instead of memorization and 3) reduces cheating [1].

However, in later research, open-book exams receive more criticism than praise. First, the open-book policy can be a hindrance for students' preparation before exams. Having access to teaching material can make the students take the exams less seriously than they do for closed-book exams [1]. Second, this policy does not help students, particularly weaker students learn better. Previous research found that the students who performed poorly in the closed-book exams tend to refer to the teaching material more in the open-book exams, and this does not help them perform better [2]. This is especially true for exams requiring the full period to complete.

B. Exams with authorized cheat-sheets

A fundamental reason that open-book exams do not work well is that it allows students to refer to "free" extra material that they have never assimilated. Authorized cheat-sheet policies help students focus on the higher level learning. Authorized cheat-sheets should always include restrictions such as the size of the cheat-sheets and they must be hand-written by that student. These restrictions are intended to force students to separate the essential and less important material and to, at least, become familiar with the material as they write it. In this process, students need to read through the appropriate learning material, process information actively, select and organized the cheat-sheet content [3], [4].

Exams with cheat-sheets do receive some criticism similar to that for open-book exams. For example, students may study less comprehensively [5]. Dickson and Bauer also believe that when students create authorized cheat-sheets, they do not learn the content, instead, they depend on cheat-sheets during exams [5].

In Dickson and Miller's 2005 work, they surveyed undergraduate students who used authorized cheat-sheets for multiple-choice exams. They found fewer students used cheat-sheets as the semester progressed and students only thought the cheat-sheets were useful as memory aids for low level questions. In addition, they stated cheat-sheets made fewer than half of the students less anxious about exams, and the cheat-sheet did not improve students' performance on the exams [6]. However, in 2007, Erbe claimed that cheat-sheets do have the function to both increase learning and reduce test anxiety [7]. Pedagogically it does appear reasonable that cheat-sheets would be less useful for multiple-choice exams since these exams are less likely to involve more complex ideas and reasoning for which the cheat-sheet could provide the basis.

Another recent work (2012) not in favor of authorized cheat-sheets is Mathew's [8]. Mathew reported that the students tend to overestimate the helpfulness of cheat-sheets and do not perform any better in exams using cheat-sheets than open-book. This conclusion echoes Dickson and Bauer's idea that the cheat-sheets are more of a "crutch". One can easily argue, however, that the process of creating cheat-sheets requires the student to review the material and at least become aware of key components of it. Hence, the students will learn more using cheat-sheets than they do in the open-book category. This aspect of cheat-sheets is independent of the exam scores received. We will not pursue this avenue of

research but only mention it as an added benefit of cheat-sheets exams over open-book exams.

Although researchers reached different conclusions based on their own experiments, we found that they used different courses, exams designs and dissimilar student populations. Therefore, it is hard to draw a conclusion on the efficacy of cheat-sheets from the existing publications. Also few works considered the quality of cheat-sheets (see Table I).

In our study, we consider the quality of students' cheat-sheets and try to answer the following questions:

- What feature(s) make cheat-sheets good?
- What group(s) of students make better cheat-sheets?
- Do students who create good cheat-sheets perform better than students who do not?
- Do students who improve their cheat-sheet quality also improve their examination performance?
- Are the top students' performances more related to cheat-sheet quality than that of the lower students?

II. BACKGROUND AND METHODOLOGY

We collected data including cheat-sheets and exam grades from two sections of a 400 (senior) level computer science networking course at North Carolina State University.

A. Class setting

A total of 59 students were evaluated in this study. Those sections were taught in consecutive semesters by the same instructor and TA. The instructor and the TA had previously worked together for three semesters for one section of the exact same undergraduate networking course and three graduate networking classes. The undergraduate and the graduate classes are taught at significantly different levels. The graduate courses are not considered in this study. The settings of the two sections for this study were essentially the same. Each class had two midterm exams and a final exam. Each midterm exam had approximately 20 questions evenly split between computation, explanation, and more subtle why problems. The midterm exams were allocated 90 minutes

and the final exam 180 minutes. The final was comprehensive with slightly over 50% new material and a total of 30 questions. The distribution of content for the final was similar to the midterms but with a little more emphasis on the subtle why problems. The computation questions reflected homework questions, but were significantly different. The exams were designed to use the full exam periods. For each exam, students were allowed (but not required) to create their own signed hand-written single-sided $8\frac{1}{2} \times 11$ cheat-sheet. Student were allowed one cheat-sheet for each exam, and one for the comprehensive final. They could and did bring their midterm cheat-sheets plus a new one for the final. No cheat-sheet instruction or training was given to students. Therefore, students are free to choose the cheat-sheets content.

All midterm cheat-sheets were submitted with the exam and were returned with the exam papers. We marked all the cheat-sheets with special pens so that students could not make a new one if they lost their cheat-sheet(s) or did not have one in a former exam. No backfill of earlier cheat-sheets was allowed. This was also enforced by our cheat-sheet markings. Students submitted all cheat-sheets with the final exam, but we did not return final exams or cheat-sheets for the final. The exams were of comparable difficulty but, for consistency, we normalized exam grades by scaling to the median of midterm exam 1 in session 1 for this research. For example, the median grade for midterm exam 1 in session 1 was 87 and the median grade for midterm exam 2 in session 1 was 85. To make the grades comparable, we modified the grades for midterm exam 2 in session 1 by multiplying the grades with $87/85$.

B. Cheat-sheet rating scheme

In the previous research, only two authors tried to rate or code the students' cheat-sheets. Mathew rated the students' cheat-sheets on organization and richness based on a 10 point scale [8]. However, neither justification nor a detailed rating scheme was given. In de Raadt's work, seven features in two categories were tagged, but the coding was done in a binary approach and appears to be over simplified [9]. We found, for example, that the density of the cheat-sheets grouped around the mean of "moderately dense" but there were numerous outliers at the extremes from nearly empty to essentially no space left at all. There was no reasonable way to represent this with binary encoding as required in de Raadt's work.

Before we devised our rating scheme, we reviewed 20 students' cheat-sheets (namely, all the students in midterm 1 of section 2) and identified a set of features which varied significantly between students:

- density
- organization
- number of sample answers
- number of formulas
- number of graph representations.

Based on these observations, we tagged these five features first. Density was tagged in the Likert Scale, namely, from "very sparse" to "very dense". However, we

TABLE I. COURSE LEVELS AND DATA COLLECTION ON RELATED TOPIC IN RECENT 10 YEARS

Authors	Course Level	Data Collection
Mathew [8]	Undergraduate psychology/ statistics	Student survey, exam grades
de Raadt [9]	Undergraduate programming	Cheat-sheet quality, exam grades
Butler & Crouch [10]	Undergraduate statistics	Student survey
Dickson & Bauer [5]	Undergraduate psychology	Exam grades
Erbe [7]	Statistics, research methods, methods of teaching mathematics, and computer use in education	None
Stangl, Banks, House and Reiter [11]	Undergraduate statistic	Exam grades
Dickson & Bauer [6]	Undergraduate psychology	Student survey
Skidmore & Aagaard [12]	Undergraduate teacher education	Exam grades

did not use the Likert Scale to tag organization because it is more subjective. Instead, we rated it "well organized", "moderately organized" or "poorly organized". For the remaining three features, we counted the number of sample answers, formulas, and graphs.

When we rated the cheat-sheets density, we assign 1 to "very dense" and "very sparse", 2 for "somewhat dense" and "somewhat sparse", and 3 for "moderate density". The reason is that we offered larger cheat-sheets (compared with Dickson and Miller's 5×8 inches in [6]) and students do not generally need to write down complete information if they have good understanding of the material. Students with a solid grasp of the topics tend to write outlines of topics and methods rather than a complete discourse. Another reason that we do not believe dense cheat-sheets indicate a good understanding of the course material is that at one time the teaching staff allowed printed cheat-sheets. Extremely dense cheat-sheets were observed multiple times and, in general, the instructor observed that students with very dense cheat-sheets unfortunately, performed poorly on the exam. The result of this experience has been to require all cheat-sheets to be hand-written in the student's own hand and signed. In discussions with students with these dense cheat-sheets, they indicated that they felt they were not able to get prepared properly for the exam and the cheat-sheets were considered as somewhat desperate final attempt to get the material into a form where it could be used on the exam. However, without enough understanding, the dense cheat-sheets were not terribly helpful and during exams, the students spent considerable time searching for information (one of them even brought a magnifying glass to the exam) and were not able to complete the exams. We also argue that a very sparse cheat-sheet indicates either the student did not have enough time to prepare for the exam, or did not have an adequate idea of what to write down. The instructors regularly tell the students they need to prioritize the material that is included on the cheat-sheets and this should be done well ahead of the exam and, for most part, as the material is presented. We have observed over many years a few, very few, cases where a student did not prepare a cheat-sheet or only used cheat-sheets with limited content but they still did very well on the exam.

We assign 1, 2, and 3 to "poorly-organized," "moderately organized" and "well organized" cheat-sheets respectively. The reason for this rating is a well-organized cheat-sheet indicates that the student has a clear idea on how to effectively organize the content to make the cheat-sheet useful for exams. Conversely, a poorly organized cheat-sheet indicates that student does not have a clear plan on what or how much material to write on the cheat-sheet. A well organized cheat-sheet can significantly improve access to the material on it during the exam and the opposite is true for a poorly organized cheat-sheet.

A cheat-sheet receives a "number of sample answers" score of -1 if it contains more than twice the median number of sample answers, otherwise it receive a -0. In the cheat-sheet review phase we found the students who wrote down many sample answers performed poorly. In this class the students had seven homework assignments with a total of 67

questions and most of these had multiple parts. We provided answer keys for the homework totaling 38 pages. No student could possibly obtain adequate coverage of the material by copying homework answers or previous test solutions. Hence, they would have limited coverage of the material and could not do well using this as a basis for their exam. Also no questions were ever repeated from homework or previous exams. Thus we can easily support our observation that extensive copying of answers is not beneficial. Please note that this approach also affects density as well and provides additional rationale that a dense cheat-sheet is not usually a good cheat-sheet. The copying of answers scoring and results is similar to de Raadt's finding [9].

Similarly, cheat-sheets which contained more than twice of the median number of formulas and graph representations received -1 on those two features. One of the reasons that the instructor first used cheat-sheets was to reduce the stress on students to remember key formulas and initially started with 3x5 inch cards. This was appreciated and successful and the students requested more space. However, we argue that students with a good understanding of the material should not and do not need to refer to the *basic* formulas. If a student uses homework answer keys as critical cheat-sheet material, they get many and too many formulas. Indeed, at least half of these formulas for the homework are considered simplistic (only 2 or 3 notations, limited log, power or square root, etc.) and intuitive (e.g. round trip time equals twice the one way trip time, $\log_{10} = 1$, etc.). We understand that students need the important formulas, but too many formulas indicates a lack of preparation, lack of confidence and can be an extra burden on finding information. If the student looks up every basic formula used throughout the exam (whether they needed to or not) they will frequently not have time to complete the exam.

We also give -1 to the cheat-sheets when the number of complete graph representations was more than twice the median for similar reasons that were used for the number of formulas. Among 67 homework questions, approximately 20 included graph representations. When one includes the graphs from the courses slides and the text we have well over two hundred graphs. This means that if a student uses the homework answers as key learning material, they may have 20+ graph representations, which take long time to draw, leave limited space for other content and each representation provides narrow knowledge coverage. If the graph representation is very modest in size and is used as a memory mnemonic, then in most cases, we do not consider it complete and is not counted.

Students without a cheat-sheet are assigned a -2. This was a very unusual case and the most common reason for it was that the student forgot to bring the cheat-sheet to the exam.

For each exam, we divided the students into two groups: more competitive students (MCS) if their grades are at least at or above the median score and less competitive students (LCS) if their grades are below the median score. We used and rated cheat-sheet scores from 59 students and 155 cheat-sheets.

III. COMPARISON OF THE MCS AND LCS GROUPS CHEAT-SHEET QUALITY

We want to determine if the quality of the cheat-sheets differs for the MCS and LCS groups.

A. Hypotheses

We used the Student's t-test for independent samples. Our hypotheses are:

H0: there is no significant difference on the cheat-sheet scores between MCS and LCS groups.

H1: there is significant difference on the cheat-sheet scores between MCS and LCS groups.

B. Result analysis

From the data analysis we find all the p-values are smaller than 1%, indicating that we are at least 99% confident that the population of the cheat-sheet scores of MCS group is different than the population of the cheat-sheet scores of LCS group (see Table II). Those p-values, together with the average cheat scores, indicate that the students who performed better on exams were better at creating high quality cheat-sheets.

IV. COMPARISON OF CHEAT-SHEET QUALITY AND EXAM PERFORMANCE

Our second analysis looked at the correlation between the quality of cheat-sheets and students' grades. Ideally, if a student spends enough time preparing for an exam and has good understanding of the material, the cheat-sheet should be of good quality and the student should get a good grade as well.

A. Hypotheses

We used the correlation coefficient test and linear regression analysis to test the relation between students' grades and their cheat-sheet quality. Our hypotheses are:

H0: there is no relationship between the scores of the students' cheat-sheets and the students' exam grades.

H1: there is a positive relationship between the scores of the students' cheat-sheets and the students' exam grades.

B. Result analysis

We performed correlation coefficient analysis between students' grades and their cheat-sheet scores for each exam. The results are shown in Table III.

There is a significant correlation between students' grades and the students' cheat-sheet scores because the p-values are less than 0.01. We also observe that the correlation becomes stronger for the final exam than for the midterms which means the students got more experienced creating good cheat-sheets through the semester and they got rewarded for doing that. This indicates that the cheat-sheet creation process may help students review the material and organize it, and the cheat-sheets later served as a helpful aid in the exams.

We also did linear regression analysis between students' exam grades and cheat-sheet scores (see Table IV). We found the highest correlation between the students' grades on the final exam and their cheat-sheet scores. The Rsquare is

the highest and the slope is more than five in final, which means that if a student's cheat-sheet score was one point more than average, the grade in the final exam was likely to be five points more than the average. The linear regression analysis for the final exam is shown in Fig. 1^a.

V. COMPARISON OF CHEAT-SHEET QUALITY IMPROVEMENT AND EXAM PERFORMANCE IMPROVEMENT

Our third analysis looked into the students' progress across the three exams and the relationship to the change on cheat-sheet quality.

A. Hypotheses

We used the correlation coefficient test and linear regression analysis to test the relationship between students' grade improvement and their cheat-sheet quality improvement where we understand improvement can be positive or negative. We compared 1) improvement between midterm 1 and midterm 2; 2) improvement between midterm 2 and the final exam; 3) improvement between average of midterms and final exam for each student with the cheat-sheet score change. Our hypotheses are:

TABLE II. COMPARISON ON CHEAT-SHEET SCORES FOR DIFFERENT STUDENT GROUPS

Group	Avg. Cheat-Sheet Score: Midterm 1	Avg. Cheat-Sheet Score: Midterm 2	Avg. Cheat-Sheet Score: Final
MCS group	3.1325	3.5438	4.0909
LCS group	1.000	2.1785	1.9231
p-value	0.0006	0.0059	<0.0001
Overall p-value	0.0003		

TABLE III. CORRELATION COEFFICIENT ANALYSIS BETWEEN STUDENTS' GRADES AND CHEAT-SHEET SCORES

Exam	Correlation Coefficient	P-value
Midterm 1	0.4661	0.0002
Midterm 2	0.3353	0.0094
Final	0.6404	<0.0001
Overall	0.4819	<0.0001

TABLE IV. LINEAR REGRESSION TEST ON STUDENTS' GRADES AND CHEAT-SHEET SCORES

Exam	Rsquare	Slope
Midterm 1	0.2172	2.2735
Midterm 2	0.1124	2.1586
Final	0.4102	5.2510
Overall	0.2323	3.0124

a. It is possible that the grades are greater than 100 because of the normalization.

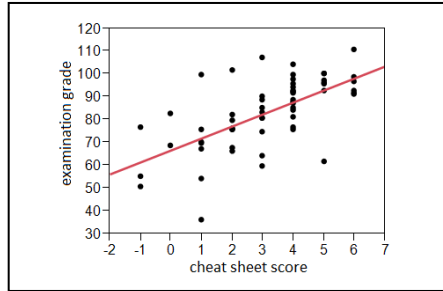


Figure 1. Linear regression result between student's grades and cheat-sheet scores on final exam

H0: there is no relationship between the improvement of scores on students' cheat-sheets and the improvement of students' exam grades.

H1: there is relationship between the improvement of scores on students' cheat-sheets and the improvement of students' exam grades.

We also looked into the MCS and LCS groups to see if their grade improvements are similarly related to cheat-sheet score improvements.

H0a: for the MCS group, there is no relationship between the improvement of scores on students' cheat-sheets and the improvement of students' exam grades.

H1a: for the MCS group, there is relationship between the improvement of scores on students' cheat-sheets and the improvement of students' exam grades.

H0b: for the LCS group, there is no relationship between the improvement of scores on students' cheat-sheets and the improvement of students' exam grades.

H1b: for the LCS group, there is relationship between the improvement of scores on students' cheat-sheets and the improvement of students' exam grades.

B. Result analysis

We performed correlation coefficient analysis between the students' grade improvement and their cheat-sheet score improvement between each test. The results, shown in Table V, all have the p-values less than 1%.

This indicates that the students' grade improvement is related to their cheat-sheet quality improvement. This again confirms that the cheat-sheet creation process is not just forcing students to write down course content without understanding but they either understood the content when creating the cheat-sheet or they figured out what is important to have on the cheat-sheets and know how they can use the content to help them during the exams. The results for the linear regression test is in Table VI and Fig. 2.

We separated our students into the MCS and LCS groups and did the same correlation coefficient analysis again. We found that with all the exams together, there is significant correlation between grade improvements and cheat-sheet quality improvement for both MCS group and LCS group. However, the correlation is stronger for LCS group. This indicates that for students who did not perform well in an early exam, we are more confident that if they prepared a better cheat-sheet, their grades will be better in later exam. This becomes a very strong argument for the use of cheat-

sheets since it helps the weaker students improve more and gives them a specific technique for doing so.

Table VIII shows the result of the linear regression between students' grade improvement and cheat-sheet quality improvement. The slope for LCS group is larger than that for MCS group. This suggests that if two students both improved 1 point on their cheat-sheet score, the LCS student would have a higher probability of a larger grade improvement on that exam as shown in the scatter plots in Fig. 3.

TABLE V. CORRELATION COEFFICIENT ANALYSIS BETWEEN STUDENTS' GRADE IMPROVEMENT AND CHEAT-SHEET SCORE IMPROVEMENT

Comparison set	Correlation Coefficient	P-value
Midterm 2- Midterm 1	0.4096	0.0013
Final - Midterm 2	0.3878	0.0024
Final - Avg. (Midterm 1, 2)	0.4666	0.0002
Overall	0.3966	<0.0001

TABLE VI. LINEAR REGRESSION TEST ON STUDENTS' GRADE IMPROVEMENT AND CHEAT-SHEET SCORE IMPROVEMENT

Comparison Set	Rsquare	Slope
Midterm 2- Midterm 1	0.1678	2.5505
Final - Midterm 2	0.1504	0.6244
Final - Midterm Avg.	0.2177	2.1731
Overall	0.1573	2.0015

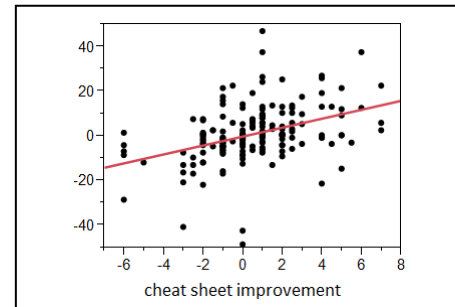


Figure 2. Linear regression result between student's grades and cheat-sheet scores on all exams

TABLE VII. CORRELATION COEFFICIENT ANALYSIS BETWEEN STUDENTS' GRADE IMPROVEMENT AND THEIR CHEAT-SHEET SCORE IMPROVEMENT IN DIFFERENT GROUPS

Student Group	Comparison Set	Correlation Coefficient	P-value
MCS	Midterm 2- Midterm 1	0.0980	0.5937
	Final - Midterm 2	0.3668	0.0424
	Final - Avg. (Midterm 1, 2)	0.2988	0.1025
	Overall	0.2058	0.0466
LCS	Midterm 2- Midterm 1	0.2476	0.2130
	Final - Midterm 2	0.3704	0.0523
	Final - Avg. (Midterm 1, 2)	0.5653	0.0017
	Overall	0.5344	<0.0001

TABLE VIII. LINEAR REGRESSION ON STUDENTS' GRADE IMPROVEMENT AND CHEAT-SHEET SCORE IMPROVEMENT IN DIFFERENT GROUPS

Group	Comparison Set	Rsquare	Slope
MCS	Midterm 2- Midterm 1	0.0096	0.6194
	Final - Midterm 2	0.1345	0.2594
	Final - Avg. (Midterm 1, 2)	0.0893	1.0687
	Overall	0.0423	0.9181
LCS	Midterm 2- Midterm 1	0.0613	1.2483
	Final - Midterm 2	0.1372	0.6357
	Final - Avg. (Midterm 1, 2)	0.3195	2.8284
	Overall	0.2856	2.9577

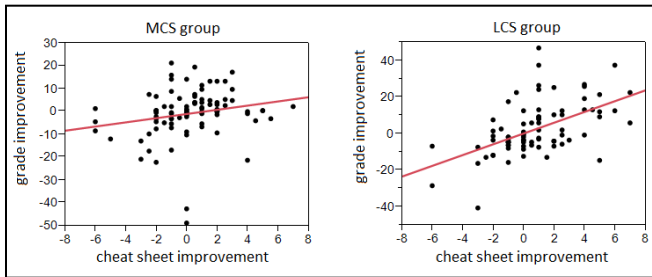


Figure 3. Linear regression result between students' grades and cheat-sheet scores on all exams for both the MCS group and the LCS group

VI. CONCLUSIONS

In this study we use data analysis to show for an undergraduate engineering course which allows students to use single page hand-written cheat-sheets:

- on average, the students who performed better in exams created better cheat-sheets;
- there is a positive correlation between the quality of cheat-sheets and students' grades;
- there is a positive correlation, sequentially across exams, between the improvement on cheat-sheet quality and the improvement on students' grades, and
- this correlation is stronger for the students who did not perform as well in previous exams.

These findings show that cheat-sheets do have a positive impact on students' performance in exams. This echoes de Raadt's work [9] and provides numerical evidence for Erbe [7]. Cheat-sheets help the weaker students improve more over the course of the semester than the stronger students. This is obviously a very desirable outcome.

These findings are based on a cheat-sheet rating scheme which we created after reviewing part of the students' cheat-sheets. Based on our observations, a good cheat-sheet should be of medium density, well organized and with a limited number of sample answers, formulas and graph representations. However, it is hard for students with poor understanding to create this kind of quality cheat-sheets. Instead, when the students manage to learn the course material well, the cheat-sheet quality can be improved naturally, and the improvement is likely to happen to their grades too. This has been proven to be especially true for students who did not perform well previously.

A. Suggestions

Based on this research, we suggest that if instructors allow students to use authorized cheat-sheets, students should be advised to:

- take cheat-sheet creation seriously, especially for the ones who do not perform well previously
- create hand-written cheat-sheets
- avoid trying to write down information exhaustively
- try very hard to organize the content, and
- avoid relying on sample answers too much.

The instructor should take a small amount of time to teach the students how to organize review material and how to prioritize material for the exams. Then the instructor can explain how these translate into quality cheat-sheets and lead to improved grades. It would appear to be tempting to provide a sample cheat-sheet for the first exam each semester. However, this would make it nearly impossible to gain the beneficial experience of creating the cheat-sheet and, in a real sense, defeats the purpose of the cheat-sheet. These are senior students and we really should not have to teach them at this point how to prepare for examinations. Perhaps it would be beneficial to provide the students with an outline of how to create cheat-sheets (no course content involved). We think it would improve exam scores. It would be interesting to do a comparative analysis of providing the cheat-sheet outline versus the current situation of limited suggestions for material.

B. Future Work

A limitation of this study is that we did not collect data for the time and strategy that students used on cheat-sheet creation. It would be interesting to know the students' cheat-sheet creation strategy: if they do tentative cheat-sheet creations from the first day of class or create cheat-sheets as they do the reviewing, or do they review first and then determine the content for the cheat-sheets. This study suggests that cheat-sheets have a positive impact on undergraduate students' performance. We hope to do similar research on graduate courses as well as lower level undergraduate computer science courses and hope others will apply these techniques in other disciplines.

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Innovation Within the Constraints of Sustainability

Analysis of Product Development Projects

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Abstract—Innovation thrives within constraints. This seemingly counterintuitive notion is now increasingly adopted and practiced in companies known for innovation. The main question to address in this research is whether constraints imposed by such concepts as sustainability are liberation for or impediment to students' becoming more innovative and creative in their product development projects. This paper presents an on-going investigation into the theme by analyzing and reflecting on new product development projects in a course called "Sustainable Manufacturing" at Syracuse University. The new course has been developed and offered once a year since 2010. Students' projects are analyzed from initial opportunity ideas, to intermediate development stages, and ultimately to the final projects including physical prototypes, in order to measure the level of students' understanding of sustainability concepts and its impact on students' capacity for innovation and creativity as exhibited in their projects. The preliminary results suggest that imposed constraints are indeed a booster for, but at least not an impediment to creativity and innovation.

Keywords—Innovation; Creativity; Sustainability; Constraints; Product Development

I. INTRODUCTION

Innovation thrives within constraints. This seemingly counterintuitive notion is now increasingly adopted and practiced in companies known for innovation and creativity [1, 2, 3]. Notably, Stokes asserts this thesis by drawing numerous examples and data from various fields including music, art, literature, fashion, architecture and advertising [4]. Yet, no systematic investigation on the theme seems to have been reported in the field of engineering education. This paper presents an on-going investigation into the theme by analyzing and reflecting on new product development projects in a course called "Sustainable Manufacturing" at Syracuse University [5]. In the course, a main constraint is to address "sustainability" issues in every step of the way of developing new products.

A widely accepted definition of sustainability as coined by the United National World Commission on Environment and Development Sustainability is an ability to "meet the needs of the present without compromising the ability of future generations to meet their own needs" [6]. In addressing sustainability issues, the role of engineers who come up with tangible and practical solutions is becoming increasingly

important. Therefore, it is essential to educate the next generation of engineers with meaningful presence of sustainability in their curricula.

A new course on sustainable manufacturing has been developed and offered once a year since 2010 at Syracuse University [5]. In the course, students learn (i) the vision of sustainable manufacturing and product development, and its relation to larger societal issues, (ii) processes, techniques and tools for developing sustainable products, (iii) sustainable manufacturing processes and systems, (iv) how to measure sustainable manufacturing practices, and (v) effective strategies to deploying sustainable manufacturing.

One of the main components of the course is a semester-long project of developing sustainable products. Students start with conceiving new product ideas and progressively develop their products throughout a semester, culminating in their physical prototypes and detail manufacturing plans. The project also provides students with a context where they can apply methods, techniques and tools that they learn from the course. While students are encouraged to think as broad and wildly as possible, a major constraint imposed on their projects is sustainability. Students need to prove that they are addressing sustainability issues every step of their projects.

The objective of this research is to confirm or dispute the theme, "innovation thrives within constraints," by analyzing and reflecting on the last five years' students projects. The level of students understanding of sustainability concepts and its impact on students' capacity for innovation and creativity is measured, as exhibited in their projects by analyzing the projects from initial opportunity ideas, to intermediate development stages, and ultimately to the final projects including prototypes. The paper presents preliminary results as well as ideas for further investigations.

II. CREATIVITY AND ENGINEERING EDUCATION

Engineering is essentially a creative profession. The word "engineer" has its origin in the Latin words meaning "clever invention" [7]. Throughout human history, whenever engineers develop new solutions to address any technical, commercial and societal problems, their creativity are at work.

However, "few courses require or even encourage creativity" in typical engineering curriculum [8]. As a result,

students often think that creative behavior is not a desirable attribute for competent engineers, and instead focus on developing analysis aspects of engineering. Research suggests that this gap in engineering curricula needs to be addressed through necessary engineering education reforms. In recent years as the society recognize the importance of creative thinking in engineering education curriculum [9], various schools began to develop new courses, devise pedagogical methods, or conduct research on creativity and engineering education [10]. Among many areas of engineering subjects, some consider that new product development is one of the natural subjects to incorporate creativity components into [11].

III. APPROACH

A new course, "Sustainable Manufacturing" had been developed and was offered for the first time in 2010 at Syracuse University [5]. The course is an elective course available to undergraduate seniors and graduate students from any engineering field. So far, over 200 students have taken the course and nearly 70 projects have been carried out. All the projects begin with students' actively thinking about opportunity ideas for new sustainable products. From all the generated product ideas, better ideas are selected mainly by students' votes. After three or four rounds of tournament style selection process [12], final product ideas along with student teams are determined.

While students' work progresses on a weekly basis, there are three milestones in the project schedule: (i) generation of initial opportunity ideas, (ii) generation of product concepts to realizing the chosen opportunity ideas, and (iii) final projects. In the first milestone, students are generating raw ideas for new sustainable products and express them in sentence. After a couple of more lectures and assignments, students develop product concepts that illustrate how they are going to accomplish the proposed opportunity ideas. Typically students present the product concepts using drawing, sketches along with narrative descriptions. The final project is the culmination of the semester's work and comprehensive including all the details of design and manufacturing processes along with physical prototypes.

Since numerous learning opportunities for sustainability issues are provided to students throughout the semester [5], our assumption is that students' understanding of sustainability is gradually deepening as they go through these three milestone stages. Therefore, we consider that constraints imposed by sustainability become tighter and tighter as students' understanding of sustainability concepts is deepening.

In this research, students submissions in these three milestone stages are evaluated then exhibited creativity and innovation are assessed by three methods: (i) instructor's observation and assessment, (ii) quantitative analysis of past five year's student projects, and (iii) testimonies from students.

The second method uses a rubric based on the assessment rubric presented in [13]. The rubric is composed of four sections: (i) generating ideas, (ii) digging deeper into ideas, (iii) openness and courage to explore ideas, and (iv) listening to one's inner voice. Four scales of development are used in the rubric assessment. One of the used rubrics is shown in Table 1.

	Creativity Level			
	<i>Not Evident (1 point)</i>	<i>Emerging (2 points)</i>	<i>Expressing (3 points)</i>	<i>Excelling (4 points)</i>
High levels of curiosity	low level of curiosity	have high levels of curiosity but single sided	have high levels of curiosity in multiple faces	excellent to maintain high levels of curiosity in developing, marketing, technology and research
Capacity for fantasy and imagination	hard to find any fantasy or imagination	working hard to find any fantasy or imagination	have good capacity for fantasy and imagination	have excellent capacity for fantasy and imagination
Tolerance for ambiguity	unable to tolerant uncertainty or inexactness in idea/design/concept	try to tolerant uncertainty or inexactness in idea/design/concept	able to tolerant for uncertainty or inexactness in idea/design/concept	properly tolerant uncertainty or inexactness in idea/design/concept
Openness to experience ideas and not frightened by the unknown	unable to experience ideas and not frightened by the unknown	try to experience ideas and not frightened by the unknown	able to experience ideas and not frightened by the unknown	excellent to experience ideas and not frightened by the unknown

Table 1. A Part of Rubric for "Openness and Courage to Explore Ideas" in Creativity Measurement

IV. RESULTS

Preliminary results from the three methods to evaluate the levels of students' creativity and innovation are presented in this section.

A. Instructor's Assessment

The course instructor has also taught other courses that involve new product development project. They are an undergraduate-level course in manufacturing processes (9 times), a graduate-level course in manufacturing systems (2 times) and a graduate-level course in product lifecycle management (2 times), all at Syracuse University. In addition, he has taught short courses in new product development in several other countries. One main difference in these courses' projects is that no sustainability constraint had been imposed. When the sustainable manufacturing course was offered for the first time, the instructor wasn't sure of the effect of this new constraint on student projects. Also, it wasn't clear how students would respond as their understanding and knowledge on sustainability are deepening as the course progresses.

Reflecting on student projects in all these courses as well as the sustainable manufacturing course, the instructor could not tell any differences in quality in creativity and innovation. In

fact, such an observation became the main motivation for starting this research.

One notable example is from a team that has developed a portable signaling device connected to GPS via a cell phone app. Their initial idea was stated as "Create a cyclist navigation system with simple LED lights on handlebar which synchronize with the GPS and maps on users' cellphone so cyclist can reach destination without stop to seeing the phone." Such an idea statement is any less creative than other ideas presented in other courses, despite of the sustainability constraint.

That initial idea had been developed further after the students learned more about sustainability by adding the impact of bike riding on sustainability, but articulating the need for safe navigating. The student team further illustrated that improved safety and convenience in bike navigating can appeal to a wider audience so extending its impact on sustainability.

In a later stage of generating product concepts, students were further challenged to consider more sustainability issues, but such additional constraints didn't seem to withhold students' creativity and innovation. Their final project was the exhibition of most creative and innovative activities in the semester.

B. Assessment by using the Rubrics

A quantitative analysis has been devised to measure students' achievements related to the research theme. The past five year's student projects have been evaluated using the developed rubrics (Table 1). Only a portion of the results are shown in Figures 1 - 4.

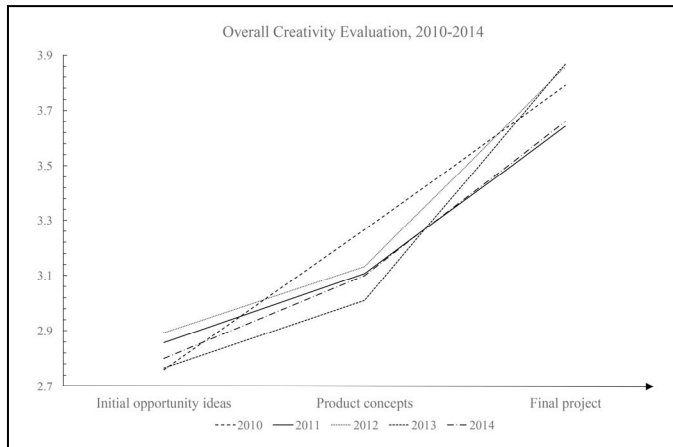


Fig. 1. Overall creativity evaluation, 2010-2014

Fig. 1 shows average composite indicator over three distinct project stages. The definite improvement is observed over the stages, although the composite indicator is mostly influenced by the factor, "digging deeper into ideas" as illustrated in Fig. 2 for 2014. However that steep pattern is common in other measures over all five years.

The factor, "listening to one's inner voice" doesn't seem to show any definite trend (Fig. 3). On the other hand, the factor, "idea generation" shows that some components are not

unilaterally improving, rather deteriorating in the concept generation stage as illustrated in Fig. 4. This might attribute to temporary set back due to students perceived additional requirements that they had to meet.

The magnitude of such contrary trends is less than the general trend of improvement over the five years, resulting in the increasing pattern of composite indicators (Fig. 1).

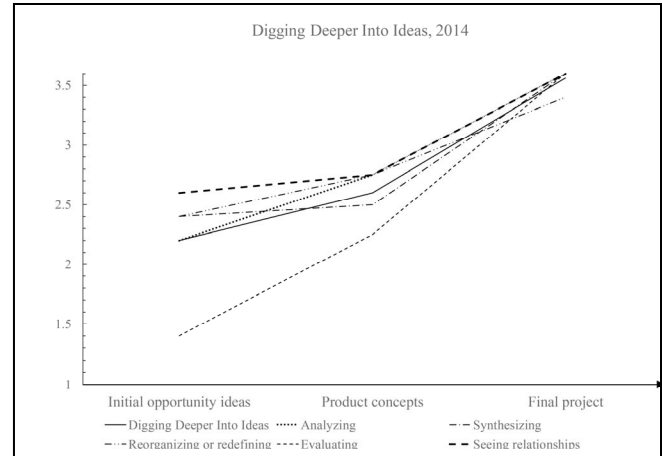


Fig. 2. Evaluation on "digger deeper into ideas" in 2014 projects

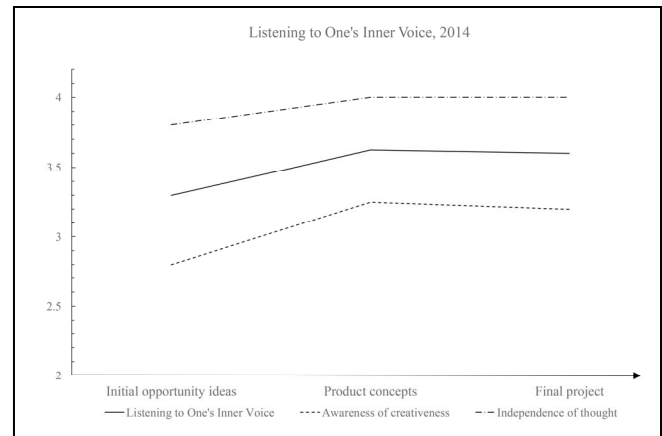


Fig. 3. Evaluation on "listening to one's inner voice" in 2014 projects

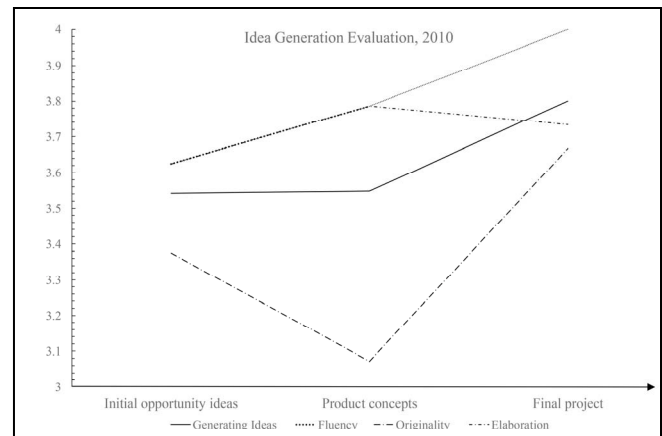


Fig. 4. Evaluation on "idea generation" in 2010 projects

C. Students' Testimonies

Numerous students provide their own assessment on creativity and innovation. For example, some example comments include:

"Initially I was concerned if I can generate enough number of ideas since we have to address sustainability in our product ideas. But I was surprised that I was able to come up with many ideas."

"Moreover, I feel more creative in class. The class creates an innovative environment would enhance awareness of creativeness too. Questions and answers interaction gets me nervous at first but activate my curiosity to explore ideas as well."

"After class, we have applied for competitions about innovation. In the Innovation and creativity competition, we used our class product and won the most creative award. And in SPARK Innovation Competition, we applied those sustainability constraints in an engineering consulting plan and won 2nd prize."

As noted in the last comment, some students grew more interested in and energized by their projects, ultimately pursuing further entrepreneurial opportunities. This again at least indirectly validates that students' creativity can be stimulated under constraints.

V. DISCUSSION AND FUTURE WORKS

The theme that innovation thrives under constraints has been increasingly adopted in corporations known for their innovation. Also it has been researched in some fields. However, to our knowledge, there is no formal investigation into this theme reported in the engineering education literature. This paper presents preliminary results by analyzing student projects of a course where sustainability has been its major constraint. Therefore, there are plenty of opportunities to extend this research.

One of the contributions of this research is to provide a way to quantify the degrees of creativity and innovation found in student project. Although the rubric (Table 1) is modified to address the research question, there is still room for improvement for future use. Especially, when multiple assessors are involved, some of the items need to be modified in order to provide more consistency over between assessors.

In the current results partially presented in Figures 1 - 4, the evaluation scores may have confounded causes beside pure creativity and innovation measures. For example, the structural approach of developing new products [11] could have been a critical factor for such evaluation results. The structural approach itself can be considered as imposing constraint. Therefore, separating such constraints' effect from that of sustainability needs to be considered in future investigations.

Another work that can be done is to create a control group and compare the results from the group and experimental groups. The current study is essentially a reflective

investigation into past data, which had been generated without anticipating such a study. With a clearer research objective established, it might desirable to create a control group and carry out comparison studies in a systematic way.

Also a same group of students may be assessed, but once before the course starts when students do not have much idea on constraints under which they will work, and another time after they are introduced to constraints under which they need to work.

Developing countries face serious challenges to work under additional constraints [14]. This course can be co-taught with partners in such developing countries. US-based students can have a chance to understand extreme conditions that other parts of the world have to face and potentially to become more creative and innovative under such additional constraints. Students in partner institutions can also benefit from different way of thinking as well as working truly as a part of one world.

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Bloom's Taxonomy in Software Engineering Education: A Systematic Mapping Study

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Abstract—Designing and assessing learning outcomes could be a challenging activity for any Software Engineering (SE) educator. To support the process of designing and assessing SE courses, educators have been applied the cognitive domain of Bloom's taxonomy. However, to the best of our knowledge, the evidence on the usage of Bloom's taxonomy in SE higher education has not yet been systematically aggregated or reviewed. Therefore, in this paper we report the state of the art on the usage of Bloom's taxonomy in SE education, identified by conducted a systematic mapping study. As a result of the performed systematic mapping study, 26 studies were deemed as relevant. The main findings from these studies are: i) Bloom's taxonomy has mostly been applied at undergraduate level for both design and assessment of software engineering courses; ii) software construction is the leading SE subarea in which Bloom's taxonomy has been applied. The results clearly point out the usefulness of Bloom's taxonomy in the SE education context. We intend to use the results from this systematic mapping study to develop a set of guidelines to support the usage of Bloom's taxonomy cognitive levels to design and assess SE courses.

I. INTRODUCTION

Learning outcomes represent the knowledge and skills that students are expected to have by the end of a course. Designing and assessing learning outcomes of a course could be a challenging activity for any instructor. Higher education courses are usually part of some degree program; the learning outcomes should synchronize and align the courses with the corresponding degree program.

The Bloom's taxonomy [1] is a classification of learning outcomes that has as one of its main goals motivating educators towards designing more holistic courses. Such taxonomy has been used in many domains and it is considered as foundational and essential by the education community. Bloom's taxonomy has been used to both design [2] and assess [3] learning outcomes.

One of the knowledge fields in which Blooms taxonomy has been applied is Software Engineering (SE), i.e. the study and usage of engineering methods and techniques to design, develop and maintain software systems. SE has its particularities that make the teaching and learning process of this discipline even more challenging. For this reason, many researchers have reported the usage of Bloom's taxonomy aiming at systematizing the design and assessment of different SE related courses. Niazi [4] reported his experience on applying

Bloom's taxonomy cognitive levels to teach a Global Software Engineering course. Khairuddin and Hashim [5] presented an approach to apply Bloom's taxonomy cognitive levels to asses SE students. O'Leary *et al.* [6] designed a software engineering curriculum for the emerging software industry in China, which was structured using Bloom's taxonomy cognitive levels.

To the best of our knowledge, the evidence on the usage of Bloom's taxonomy in SE higher education has not yet been systematically aggregated or reviewed. Therefore, the main goal of this paper is to identify and report the state of the art on the usage of the Bloom's taxonomy in SE higher education. To do so, a systematic mapping study [7], [8] was performed aiming at:

- Characterize the state of the art research on the usage of the Bloom's taxonomy in the SE education.
- Identify and analyze the reflections of the SE instructors who have used the Bloom's taxonomy in their courses.

Considering the relevance of such research topic, a systematic mapping study is deemed important as its results could inform SE educators.

The remainder of this paper is organized as follows: Section II briefly presents Bloom's taxonomy. Section III details the employed research methodology, followed by the presentation and discussion of the results of this work in Section IV. The validity threats are discussed in Section V. Finally, Section VI presents the conclusions and view on future work.

II. BLOOM'S TAXONOMY

Bloom's taxonomy has 11 levels, which are categorized in the following three different domains [1]:

- **Cognitive** - Skills in this domain are related to the way people recall knowledge, comprehend and critically think about a particular topic. The six levels of this domain are *knowledge*, *comprehension*, *application*, *analysis*, *evaluation* and *synthesis*.
- **Affective** - Skills in this domain are related to the way people emotionally react about another living being pain or joy. The five levels of this domain are *receiving*, *responding*, *valuing*, *organizing* and *characterizing*
- **Psycho-motor** - Skills in this domain are related to the way people manipulate tools or instruments (such as

hand or hammer). Benjamin Bloom never designed levels for this category. Some researchers have proposed levels for such domain, but there is no consensus about the usefulness of their proposed levels.

The cognitive domain has received more attention from Benjamin Bloom and consequently it has been applied the most by educators; no study in SE has employed the affective and psycho-motor domains (see Section IV). For this reason, herein we describe only the levels of the cognitive domain, as follows:

- 1) **Knowledge** - The student is able to recall facts, basic concepts and terms on a given topic.
- 2) **Comprehension** - The student has to be able to organize, compare, translate, interpret, give descriptions and state the overall idea related to a given topic.
- 3) **Application** - The student is able to apply the retrieved knowledge in different ways to solve a given problem.
- 4) **Analysis** - The student is able to identify motives and causes regarding a given topic, so that generalizations could be supported.
- 5) **Synthesis** - The student is able to identify patterns from different elements or combine different parts to compose a whole.
- 6) **Evaluation** - The student is able to deem information, validate ideas and evaluate quality of information using a defined set of criteria.

There is a hierarchical relationship between the above-discussed levels (Figure 1); the higher the level (evaluation), the bigger is the complexity inherent to the level. Thus, the learning process must start from the knowledge level and incrementally progress to the evaluation level.



Figure 1. Bloom's taxonomy cognitive domain levels.

Some endeavors were made over the last years to improve the levels of the cognitive domain of Bloom's taxonomy, e.g. Anderson *et al.* [9]. Notwithstanding, just the original cognitive levels were described in this paper, because they remain as the most used ones.

Note that there are other taxonomies that can be used to describe and classify learning outcomes, e.g. SOLO [10] and Finks [11] taxonomies. However, herein in this paper we considered only Bloom's, because it is the most widely adopted learning outcomes' taxonomy.

III. RESEARCH METHODOLOGY

This section details the performed systematic mapping study, which includes the research questions and the procedures employed in the performed work.

A systematic mapping study is a method that allows for categorizing and summarizing the existing information about a given research topic in an unbiased manner [8]. We employed the guidelines by Kitchenham and Charters [7] and partly implemented the mapping process provided by Petersen *et al.* [8] to conduct the systematic mapping study reported herein.

We choose the systematic mapping study method because it is a better option to deal with broadly defined research areas [7], [8], which is the case of the topic associated to the research reported in this paper. The employed systematic mapping process is detailed as follows.

A. Research questions

The following research questions were framed to guide this systematic mapping study:

- **Question 1 (RQ1)** - How Bloom's taxonomy is used in the SE education context?
 - **Question 1a (RQ1a)** - What are the SE subareas for which Bloom's taxonomy has been used in the education context?
 - **Question 1b (RQ1b)** - What are the SE program levels at which Bloom's taxonomy has been used?
 - **Question 1c (RQ1c)** - What are the objectives for which Bloom's taxonomy has been used in SE education?
- **Question 2 (RQ2)** - What levels of Bloom's taxonomy have been used in the SE education context?
- **Question 3 (RQ3)** - What are the reflections of the SE educators on the use of Bloom's taxonomy in their courses?

B. Search strategy

After defining the research questions, we set up a strategy to design a search string and, consequently, identifying the primary studies. To avoid researcher bias, we used the following procedure:

- 1) Analyze the research questions and identifying the main words;
- 2) Collect and analyze relevant papers and checking the keywords;
- 3) Identify alternative spellings and synonyms for major terms;
- 4) Use the Boolean OR to connect the identified alternative spellings and synonyms;
- 5) Link the main terms using the Boolean AND;
- 6) Pilot the search string.

To cover as many studies as possible, we included all the knowledge areas defined in the *Guide to the Software Engineering Body of Knowledge* (SWEBOK Guide) [12], as well as emergent SE subareas that are not explicitly embraced by the SWEBOK guide, such as Global Software Engineering

and Software Product Line Engineering. Finally, we explicitly included the term *programming*, since it is directly connected with one of the knowledge areas of the SWEBOOK guide (software construction) and is related to a popular course in both Software Engineering and Computer Science programs. As a result, we obtained the following search string:

("software engineering" OR "software requirement" OR "requirements engineering" OR "software architecture" OR "software design" OR "software construction" OR "software testing" OR "software maintenance" OR "software quality" OR "software project management" OR "software configuration management" OR "software engineering tool" OR "software engineering method" OR "software process" OR "software development process" OR "global software development" OR "global software engineering" OR "distributed software development" OR "agile software development" OR "agile method" OR "agile process" OR "model driven development" OR "software product line" OR "aspect oriented programming" OR "software errors" OR "software bugs" OR "software risks" OR "software defects" OR "software measurement" OR "software metrics" OR "software cost estimation" OR "software development" OR "programming") AND ("bloom's taxonomy" OR "bloom taxonomy" OR "cognitive taxonomy")

C. Search process

The employed search process had two steps: identify primary sources and search primary studies using the designed search string (Subsection III-B). Table I presents the reviewed primary sources and the number of primary studies returned by each of the primary sources.

Scopus¹, Compendex/Inspec² and Web of Science³ were the reviewed primary sources. Those primary sources cover most of the important SE databases, such as IEEE, Springer, ACM and Elsevier. In addition, we surveyed ERIC⁴, which is a data base dedicated to education-related studies. The primary studies were collected by means of a title/abstract-based search. The search process was limited to peer-reviewed conference papers and journal articles.

Table I
SUMMARY OF SEARCH RESULTS

Database name/Search Engine	Search Results
Compendex and Inspec	82
Scopus	55
Web of Science	51
ERIC	1
Total	189
Total Without duplicates	144

¹www.scopus.com

²www.engineeringvillage.com

³apps.webofknowledge.com

⁴eric.ed.gov

D. Study selection

The study selection was carried out by applying the following inclusion and exclusion criteria:

- Inclusion criteria:

- 1) Studies that are about application of Bloom's taxonomy in SE education AND;
- 2) Studies described in English AND;
- 3) Are reported in peer reviewed workshop OR conference OR journal.

- Exclusion criteria:

- 1) Studies that do NOT apply Bloom's taxonomy in SE education OR;
- 2) Studies that are NOT written in English OR;
- 3) Studies that are NOT reported in peer reviewed workshop OR conference OR journal.

We conducted the selection process using a two-stage screening procedure. The level-1 screening (first stage) consisted on reading the studies' titles and abstracts. To avoid researcher bias, the total number of 144 studies was fully screened by both authors. The results were compared and consensus was reached, so that a total of 44 studies were judged as potentially relevant.

The level-2 screening (second stage) consisted on applying the inclusion and exclusion criteria to the full-text of the studies deemed as relevant in the first stage of the study selection process. Both authors screened the full set of studies. The results were compared and consensus was reached, so that a total of 26 studies were judged as relevant. A list that contains the 26 included primary studies is available on-line⁵.

E. Data extraction

Both authors extracted data from the 26 studies selected. A data extraction sheet was designed to guide the data extraction process. Such sheet was piloted on a sample study to assess its completeness and to ensure that both authors shared a common understanding of the data extraction process. The results for the data extraction were compared and consensus was reached, so that all the data extracted for the 26 studies was analyzed.

F. Data Analysis

To draw conclusions from the collected data, both qualitative and quantitative data analysis were performed. Tables were designed in order to ease the understanding of the extracted data.

IV. RESULTS

This section details the results of the mapping study. We firstly describe the general results and then the results for each research question are presented.

A. General results

General results about country, year and venue wise distribution of the studies on application of Bloom's taxonomy in SE education are described in this subsection.

⁵<https://drive.google.com/file/d/0B2kvKpmJJREDUkd0bmgzR2NwSGc/view?usp=sharing>

1) *Country wise distribution*: The countries in which Bloom's taxonomy was reported to have been applied in SE education are displayed in Table II. Results show that the USA (13 studies) is the leading country where Bloom's taxonomy has been applied in SE higher education. Australia (3 studies), Taiwan (2 studies), Spain (2 studies), New Zealand (2 studies) and Malaysia (2 studies) are other countries wherein more than one study have been reported. It is interesting to note that almost all continents (North America, Oceania, Europe, Asia and Africa) are represented in Table II, indicating the application of Bloom's taxonomy in SE education all over the world.

Table II
COUNTRY WISE DISTRIBUTION OF PRIMARY STUDIES

Country	Study ID	Frequency
USA	2, 3, 4, 5, 6, 9, 11, 14, 20, 24, 25	11
Not stated	17, 18, 21, 22	4
Australia	9, 16, 23	3
Taiwan	8, 19	2
Spain	12, 15	2
New Zealand	10, 20	2
Malaysia	7, 13	2
UK	14	1
Norway	2	1
South Africa	26	1
Saudi Arabia	1	1
Netherlands	2	1

2) *Publication type wise distribution*: The types of publications of the included primary studies are displayed in Table III. Results show that the majority of the studies (80% - 21 studies) from the included primary studies were published as conference papers, while 20% (5 studies) were published as journal papers. Journal papers demand more rigor in the study design and execution. We believe that there is a need to conduct and report more rigorous studies on the use of Bloom's taxonomy in SE education to increase the quality of evidence of the subject matter.

Table III
VENUE TYPE WISE DISTRIBUTION OF PRIMARY STUDIES

Publication type	Study ID	Frequency
Conference	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 15, 16, 17, 18, 19, 21, 22, 23, 24, 25	21
Journal	8, 13, 14, 20, 26	5

3) *Year wise distribution*: The year wise distribution of the included primary studies is presented in Table IV. The following interesting patterns were observed in the results:

- All the identified primary studies were published after year 2000. In the past, SE had been treated mostly as a subarea of Computer Science. It is only recently that SE has been treated as a separate discipline.
- Multiple studies are published on use of Bloom's taxonomy in SE education from year 2008 onwards, thus

indicating an increase in the interest in the topic. As the search was performed in October 2014, papers published after such date were not included in the search.

Table IV
YEAR WISE DISTRIBUTION OF PRIMARY STUDIES

Year	Study ID	Frequency
2000	22	1
2001	21	1
2002	11, 20	2
2003	23	1
2004	6, 24	2
2005	19	1
2006	5, 10	2
2007	26	1
2008	4, 8, 9, 17, 18	5
2009	15, 16	2
2011	3, 13, 14	3
2012	7, 25	2
2013	1, 2	2
2014	12	1

4) *Study type wise distribution*: This section categorizes the included primary studies based on the research approach used in each study. We used an existing classification of research papers proposed by Wieringa et al. [13] and recommended by Petersen *et al.* [8] for systematic mappings studies. The categories of Wieringa *et al.*'s classification scheme are as follows:

- **Validation Research**: It involves the work that is novel and has not yet been implemented in practice. Typical example is the work done in the lab settings.
- **Evaluation Research**: Work proposed is implemented and evaluated in practice.
- **Solution Proposal**: This type of research involves proposing a solution for a problem. The proposed solution can be novel or build on top of some existing work. The applicability of the solution is usually explained with the help of small example or just by good line of argumentation.
- **Philosophical Papers**: This type of research present a new way of looking at existing things. Examples include new taxonomies or conceptual frameworks.
- **Opinion Papers**: These papers present personal opinion of authors on some intervention without taking into account related work or research methodologies.
- **Experience Papers**: These papers present personal experience of the authors related to how something has been used in practice.

Table V presents the categorization of the included primary studies according to the aforementioned classification scheme. Results show that 62% (16 studies) of the primary studies are of solution proposal type. The solution in this case is the design or revision of different SE courses for a given context. Six studies (23%) studies are categorized as experience papers, wherein the authors shared their experiences on designing or assessing SE courses using Bloom's taxonomy. No paper from

the included primary studies was found to be of philosophical or evaluation type.

Table V
STUDY TYPE WISE DISTRIBUTION OF PRIMARY STUDIES

Study type	Study ID	Frequency
Solution proposal	2, 4, 6, 7, 8, 12, 13, 15, 17, 18, 19, 20, 21, 22, 23, 25	16
Experience	1, 3, 10, 11, 24, 26	6
Validation	14, 16	2
Opinion	5, 9	2

B. RQ1: Bloom's taxonomy usage

This section presents the results for the first research question.

1) *RQ1a: Software engineering subareas*: The aim of this question was to find out SE subareas in which Bloom's taxonomy has been applied for course design or assessment. The Table VI presents the results and shows that software construction is the leading area in which Bloom's taxonomy has been used to design or assess courses (54% - 14 studies). Bloom's taxonomy has also been used for course design or assessment of SE general courses (3 studies) and program comprehension courses (2 studies). Bloom's taxonomy has been used in one study only for each of other areas listed in Table VI, which indicates the need to conduct and report more studies in those areas. The SE subareas for which no study has been published yet reporting the usage of Bloom's taxonomy are: software design, software maintenance and software configuration management.

Table VI
SE SUBAREA WISE DISTRIBUTION OF PRIMARY STUDIES

SE area	Study ID	Frequency
Software construction	7, 8, 9, 10, 11, 14, 15, 18, 21, 22, 23, 24, 25, 26	14
Software engineering (general)	17, 19, 20	3
Application/Program Comprehension	3, 4	2
Software testing	16	1
Software project management	12	1
Software engineering tools	5	1
Software requirements	13	1
HCI	6	1
Global software engineering	1	1
Cloud computing	2	1
Software quality	14	1

2) *RQ1b: Program level*: The aim of this question was to report the SE program levels at which Bloom's taxonomy has been applied. The results are presented in the Table VII and show that 85% (22 studies) of the primary studies reported the usage of Bloom's taxonomy at the undergraduate level. Only three studies were carried out at master's level. Two studies have not stated the program level for which the course

was designed or assessed using Bloom's taxonomy. One study reported the case of a SE training course wherein the Bloom's taxonomy was applied.

Table VII
PROGRAM LEVEL WISE DISTRIBUTION OF PRIMARY STUDIES

Program Level	Study ID	Frequency
Bachelor	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26	22
Masters	1, 2, 14	3
Not stated	3, 4	2
Training	2	1

3) *RQ1c: Study Purpose*: The aim of this question was to identify the purpose for which the Bloom's taxonomy has been applied in SE education. Bloom's taxonomy can be used for two purposes: course design and course assessment. The results are presented in Table VIII and show that in 38% (10 studies) of the primary studies Bloom's taxonomy was applied focusing on course assessment, while in 27% of the studies such taxonomy was applied focusing on course design. Nine studies (35%) studies employed Bloom's taxonomy focusing on both course design and assessment. These results suggest that both course design and assessment have received equal importance when it comes to the usage of Bloom's taxonomy.

Table VIII
PURPOSE WISE DISTRIBUTION OF PRIMARY STUDIES

Focus	Study ID	Frequency
Assessment	7, 9, 10, 12, 13, 14, 16, 17, 18, 23	10
Both	2, 3, 15, 19, 21, 22, 24, 25, 26	9
Design	1, 4, 5, 6, 8, 11, 20	7

C. RQ2: Bloom's taxonomy levels and version

The aim of this questions was two fold: i) To see which cognitive levels of the Bloom's taxonomy have been used during design or assessment of SE courses; ii) To identify which version (original or revised) of the Bloom's taxonomy has been applied in SE education.

The used levels of Bloom's taxonomy are displayed in Table IX. The results show that except for one study (Id 14), all other studies (25) have described the levels they have used. Most studies (85% - 22 studies) have used all six cognitive levels of Bloom's taxonomy during course design or assessment. The results also show that comprehension and application were the most frequently used levels of the Bloom's taxonomy in the SE education context. Such finding complies with the nature of SE, which is an applied discipline and its graduates are required to understand and subsequently apply its concepts, techniques and tools.

The used versions of Bloom's taxonomy are displayed in Table X. The results show that 85% (22 studies) of the

Table IX
BLOOM'S TAXONOMY LEVEL WISE DISTRIBUTION OF PRIMARY STUDIES

Bloom's levels	Study ID	Frequency
Comprehension	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26	25
Application	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26	25
Knowledge	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 19, 20, 21, 22, 23, 24, 25, 26	23
Analysis	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26	23
Synthesis	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26	23
Evaluation	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 16, 17, 19, 20, 21, 22, 23, 24, 25, 26	22
Not stated	14	1

included primary studies have used the original version of Bloom's taxonomy, while only 15% (4 studies) reported the usage of the revised version of Bloom's taxonomy. Results clearly show that the original version of Bloom's taxonomy is the one that is well received and most frequently applied by SE educators.

Table X
REVISED VS ORIGINAL BLOOM'S TAXONOMY

Taxonomy version	Study ID	Frequency
Original	1, 2, 4, 5, 6, 7, 8, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26	22
Revised	3, 9, 10, 25	4

D. RQ3: Reflections

The aim of this question was to extract and report the reflections of the SE teachers on the usage of Bloom's taxonomy in their courses. Only four studies provided such reflections. The reflections are described herein for each of these four studies.

1) *Teaching Global Software Engineering: Planning and Preparation Using a Blooms Taxonomy*: This study [4] is an experience paper in which the author reports how he employed Bloom's taxonomy to design a master's level course on Global Software Engineering in a university in Saudi Arabia. The author's reflections related to the usage of Bloom's taxonomy cognitive levels are as follows:

- **Knowledge level**: "The use of knowledge level seemed more appropriate for those students who appreciated the discussion of the basic concepts and principles of global software engineering [...] However, this level did not seem appropriate for higher caliber students."

The author find the knowledge level of the Bloom's taxonomy useful for the effective discussion and delivery of the course basic concepts; however, for the advance learning, this level is not enough in the opinion of

the author. This is understandable as for the advanced concepts and deep learning, higher levels of Bloom's taxonomy are more appropriate.

- **Comprehension Level**: "This level helped students to move from recalling state to understanding state."

The author find this level an improvement to the previous level, as he observed students moving up to the understanding state from just the memorization state.

- **Application Level**: "I have observed that some of the international students (from Asia) have difficulties in applying the concepts and theories learned in the lectures in the labs."

When students were asked to apply the concepts in the labs settings, The author noticed that some of them faced difficulties in this process. The application of the concepts is not an easy endeavor, but is crucial for applied fields like SE. When teachers use the application level of Bloom's taxonomy for designing the learning activities, it is important to provide the required support and assistance to students to facilitate the transition from the comprehension level to the application level.

- **Analysis Level**: "I have observed, in the labs, that some students were facing difficulties in breaking down the bigger problem into smaller components in order to better understand it. To address this problem I have provided students with simple problems first and then I moved them to harder problems"

The author noticed here as well that students faced problems at the analysis level when they were to divide the larger problems into smaller parts. The author tackled this problem by starting from simple problems to support the transition to the analysis level.

- **Synthesis Level**: "Students have mix responses for the synthesis level of Blooms Cognitive domain. I also think that such preliminary exercises should be done at a high school level so that when students come to Universities they should be able to understand and can complete more complex synthesis problems."

The author suggests that proper education and training at high school level could help students achieve synthesis level.

- **Evaluation Level**: "Students had some minor problems in the evaluation level of Blooms Cognitive domain."

These reflections suggest that going beyond comprehension level of the Bloom's taxonomy could impose some challenges for students and the instructors. It is therefore suggested to carefully plan the advance levels of the taxonomy.

2) *Bloom's taxonomy for CS assessment*: This study [14] is an opinion paper in which the authors used the revised version of Bloom's taxonomy to design assessments for programming courses. The authors' reflections are as follows:

- "Once staff involved in the teaching of a course were consulted, we found considerable agreement in the categorization of questions according to the Bloom taxonomy. We consider this to be a positive outcome which suggests

that the revised Blooms taxonomy can be effectively used to discuss examination questions in the programming domain.”

The authors find the revised Bloom’s taxonomy useful for the design of assessments for programming courses.

- “We felt that a shared understanding of the interpretation of the revised Blooms taxonomy to the programming domain would prove valuable to teaching staff developing examination questions, particularly in courses that involve multiple staff members.”

It is important that all teaching staff in these type of courses have a consistent interpretation of the taxonomy to achieve the desired benefits.

3) Experimentation in the computer programming lab:

This study [15] is an experience paper in which the author shared his personal experience on applying Bloom’s taxonomy to design and assess a lab based programming course at bachelors level at a university college in the USA. The author’s reflections are as follows:

- **Knowledge level:** “[...]The drill and practice component of the lab experiments supports memorization.”

The author noticed that the practice of asking students to manually enter the code from the printed lab handout served as a valuable cognitive processing tool.

- **Comprehension Level:** “The laboratory experiments are used to reinforce important concepts [...] Students are required to explain their results, describe their actions, and generalize[...].”

The author observed that the practice of asking students to describe and explain their results and actions helps in achieving the comprehension level.

- **Application Level:** “Students must draw upon learned information to satisfy experiment completion requirements. Some problems have a clear best solution while some may be solved from a variety of directions. Students collect information from readings and lectures and prepare solutions. The experiments enforce the use of learned facts”
- The author found the use of experimentation very useful to support the application level of Bloom’s taxonomy as they offer the opportunity for the students to apply the learned concepts.

- **Analysis Level:** “Students must learn to take a body of information and differentiate between important facts [...] They are required to separate the information into manageable chunks based upon limits, relevance, importance, and efficiencies.”

The author supported the students to achieve the analysis level of the Bloom’s taxonomy using exercises wherein students had to divide the information and problem into manageable parts.

- **Synthesis Level:** “Laboratory experiments reinforce and teach synthesis through the design of algorithms and solutions to challenging issues. Students are asked to revise code and rearrange data to meet the parameters of a problem. They are encouraged to try different attacks

at the solution.”

The author noted that synthesis level is achieved by employing a number of means in laboratory experiments e.g. revision in the existing code and data structures, solution testing and algorithm design exercises.

- **Evaluation Level:** “Students are asked to interpret and critique sample code. They are often required to defend their solution methods and answers in the results and experimenter notes sections of their experiment handouts.”
- In order to support the learning at this level, the students were required to review sample codes and provide their critical assessments. Students were also asked to provide clear justification for the use of particular methods in their solutions.

4) *Teaching Java backwards:* This study [16] is also an experience paper in which the author shared personal experience on using Bloom’s taxonomy for the design of a undergraduate level JAVA programming course at a South African University. The author shared following general reflection on the use of Bloom’s taxonomy during course design:

“The use of Bloom’s Taxonomy as a basis for course design is supported by the findings reported here. Students were able to move on to more advanced material in the next course, despite having a compressed introduction, compared with previous similar classes.”

The author found the use of the Bloom’s taxonomy useful in effectively teaching the basic concepts, since it was observed that students were successfully able to transition to the advanced material in the follow up course.

V. VALIDITY

The major validity threat to this work is related to the coverage of the relevant literature, i.e. whether or not the search was able to identify all relevant primary studies. To mitigate this threat, we performed a very comprehensive search strategy.

The designed search string encompassed terms related to all software engineering knowledge areas defined by the SWEBOK guide. Additionally, the terms related to emergent Software Engineering areas, such as Global Software Engineering and Aspect Oriented Programming, were also considered. Finally, we also included the term *programming*, which is directly connected to many courses in both Software Engineering and Computer Science programs.

Another threat is related to the data extraction process and inappropriate classification, i.e. the possibility of a study being classified differently by different researchers. To mitigate such threat, the selection and data extraction procedures were performed by both authors to validate each others’ decisions.

VI. CONCLUSIONS

This paper presented a systematic mapping study carried out to aggregate the evidence on the usage of Bloom’s taxonomy in the Software Engineering education. The initial search returned 144 results and the application of a 2-stage screening procedure resulted in the inclusion of 26 primary studies.

The included studies are reported from many countries across five continents, wherein the USA is the leading country in this regard. Twenty six studies (80%) were published as conference papers and there is an increased interest in the topic from year 2008 onwards. Most primary studies were categorized as solution proposals (16 - 62%) or experience reports (6 - 23%).

Software construction is the leading SE subarea in which SE educators have applied the Bloom's taxonomy for the course design and assessment. We believe that there is a strong need to conduct and report more studies in other SE subareas.

It was identified that 85% (22) of the included primary studies applied the Bloom's taxonomy at undergraduate level, while only 12% deal with master's level SE programs or courses. Bloom's taxonomy has been applied almost the same number of times for both course design and assessment, indicating the relevance of taxonomy for both design and assessment of SE courses.

The original version of the Bloom's taxonomy has been applied most of the times (85% - 22 studies), while the revised version is used in only 15% (4) of the primary studies. Majority of the studies (85% - 22 studies) applied all six levels of Bloom's taxonomy in the design or assessment of SE courses. Most frequently used levels of Bloom's taxonomy are "comprehension" and "application", which complies with the applied nature of the SE discipline.

The reflections provided in four studies on the application of Bloom's taxonomy for the design and assessment of software engineering courses clearly points out the usefulness of the taxonomy. We believe that more reflections would have further helped in understanding the usefulness of the Bloom's taxonomy in SE education.

We believe that philosophical and evaluation studies [13] should be conducted to strengthen the evidence on the usefulness of Bloom's taxonomy in the context of SE education.

We intend to use the results from this systematic mapping study to develop a set of guidelines aiming at supporting the usage of Bloom's taxonomy cognitive levels to design and assess SE courses.

AUTHORS' CONTRIBUTION

Ricardo Britto and Muhammad Usman both contributed equally in the design and execution of the study reported herein; all the work was equally divided between both of them. They also wrote and reviewed this paper jointly.

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A Project-based multi-disciplinary elective on digital data processing techniques

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Abstract— Today's era of internet-of-things, cloud computing and big data centers calls for more fresh graduates with expertise in digital data processing techniques such as compression, encryption and error correcting codes. This paper describes a project-based elective that covers these three main digital data processing techniques and can be offered to three different undergraduate majors: electrical and computer engineering and computer science. The course has been offered successfully for three years. Registration statistics show equal interest from the three different majors. Assessment data show that students have successfully completed the different course outcomes. Students' feedback shows that students appreciate the knowledge they attain from this elective and suggest that the workload for this course in relation to other courses of equal credit is as expected. **Keywords**—source coding; cryptography; channel coding; multi-disciplinary; project based

I. INTRODUCTION

Digital data processing techniques such as source coding, encryption and channel coding that are available in digital communication systems offer combined one of the largest advantages of digital communications over analog communications. Without these techniques applications such as video streaming, online commerce, and wireless communication with high fidelity would have never existed.

Typically digital communication is covered from the perspective of signals and systems and focuses on modulation and demodulation techniques at the binary and M-ary level and their performance in the presence of noise. Even a higher level elective in digital communication will usually cover wireless communication techniques such as spread spectrum, CDMA and OFDM.

Because digital data processing techniques process data instead of signals, students do not require the signals and systems background to understand them. Instead they only need a background in digital systems and statistics which is usually a common knowledge among multiple disciplines such as computer science, computer engineering, and electrical engineering. This opportunity has been utilized at XXX University in a form of a project-based multi-disciplinary elective that focuses on digital data processing techniques. The elective has been offered successfully for multiple years.

The class is divided into three modules. The first module covers a number of text, audio, image and video compression techniques. During this module, students are required to compress a scanned image of text using run-length coding.

The second module covers a number of private and public key encryption techniques such as stream encryption, RSA encryption and elliptic curve encryption. During this module students are required to build an RSA encryption technique and simulate it. The third module covers a number of channel coding techniques such as linear block codes, convolutional codes and Reed-Solomon codes. During this module students are required to build an RS encoder/decoder and simulate it. At the end of the semester, students are asked to solve a practical industrial problem that requires the combination of the three data processing techniques.

This paper describes the structure of the class and its associated projects. It also shows a sample of students' work and assessment data based on students' work and feedback and enrollment statistics.

II. COURSE ORGANIZATION

The course is designed to be offered as a senior level elective for Electrical and computer engineering and computer science undergraduate majors. It requires a background in hardware and statistics. Hence, the list of prerequisites consists of a course on digital logic and another on statistics, which are usually core courses in the three majors in most institutes. It is offered as a 3 credit, 15 week semester based course.

The first three blocks of any digital system are source coding or compression, encryption and channel coding or error-correcting codes. The class is divided into three modules that cover those three blocks in order. Every module requires students to take an exam that tests their knowledge in the material and finish a project that examines their ability to apply this knowledge. In addition, there is a final project that groups the knowledge they have learned from the three different modules. The first module covers compression techniques in 4 weeks and its associated project requires two weeks of work. Similarly, the second module covers encryption techniques in 4 weeks and its associated project requires 2 weeks. The third module covers channel coding techniques in 8 weeks and its associated project requires 4 weeks. The final project requires two weeks of work. The grading policy is as follows:

Module 1	
Exam	10%
Project	10%
Module 2	

Exam	10%
Project	10%
Module 3	
Exam	20%
Project	20%
Final project	10%

The main text book used is Digital communication fundamentals and applications by Bernard Sklar[1]. But, a number of other references are also used for extra material[2, 3, 4, 5 and 6]. A detailed description of the three different modules and their associated projects, as well as, the final project is described in the following sections.

First Module

The first module starts by introducing the different sources of data such as text, audio, image and video. The large size of data of the different sources is emphasized implying the importance of compression techniques in today's era of Big Data. In addition, there will be a general discussion on the type of redundancy in different sources and how to utilize this redundancy to achieve compression. Following this introduction, is a review of statistical concepts such as random variables, probability density functions, joint probability density functions and dependent random variables. The concepts of information theory such as entropy of discrete sources, memory/memoryless sources and first order Markov sources are discussed next.

Variable length codes are essential for compression, but unlike fixed length codes they are much harder to be decoded without favorable properties such as uniquely decodable and prefix free. Huffman Codes are prefix free uniquely decodable variable length codes that assign shorter number of bits for symbols of high probability. A famous subset of this family of codes are the run length codes that create symbols from different runs of ones and zeros. After these codes are introduced students will be ready to take their first project.

While students are working on their first project, specifics about the compression techniques of different sources are introduced starting by the Lampel-Ziv algorithm for text files and followed by audio, image and video compression. A review of sampling and quantization precedes the discussion of Differential Pulse Code Modulation (DPCM) which is considered the basis of every audio compression technique. DPCM utilize the redundancy between Nyquist samples to predict future samples from current and past samples and quantize the error in the prediction instead of the samples. This concept is also utilized in video compression using frames instead of samples.

Huffman codes achieve high compression rates for discrete sources that have large difference between the probabilities of occurrence of their different symbols. On the other hand, most natural images have almost flat histograms indicating equiprobable symbols which make them a very bad candidate for compression without a sort of transformation that can change the statistics of their symbols. Examples on such transformations are Discrete Cosine Transform and Wavelets that are used in JPEG and JPEG2000 compression techniques, respectively. In addition, it is also necessary to zero the

transformation coefficients of low magnitude to create sparse matrices that can be effectively compressed using run length codes. Hence, image compression techniques of high compression rates are not lossless. But, the data lost is not visually important.

The first module ends by discussing video compression which combines concepts of DPCM and source transformation. Frames are divided into I, B and P frames. I-frames are compressed using image compression techniques. B frames are represented by motion vectors that predict the position of each object in the frame. P frames are used to correct the error in prediction. This concept is used in many famous video compression techniques such as MPEG.

Second module

The second module starts by a hooking lecture discussing the importance of encryption in today's era of internet-of-things which is raising a lot of questions about security and privacy. Next, encryption techniques are divided into public and private key and students are asked to choose the encryption family appropriate to a specific application. For example, while private key is appropriate for applications that need subscription such as satellite broadcasting and cell phones, it is completely not appropriate for applications such as e-commerce and digital authentication that requires public key.

The purpose of any encryption technique is to make it computationally impossible for the cryptanalyst/hacker to deduce the encryption key from the cipher text and use it to decrypt the message. Shannon suggested two concepts to frustrate the cryptanalyst. Confusion involves substitutions that render the relation between key and cipher text as complex as possible. Diffusion involves transformations that smooth out the statistical differences. Any successful encryption technique, whether public or private, should have these two properties.

Private Key encryption techniques utilize Pseudo Random Generation Algorithms (PRGA) to confuse the relation between the private key or password and the cipher text. PRGA can be done either in software or hardware. They also use permutation blocks to smooth the statics of the cipher text and avoid plain text attacks. It should be noted here, that compression should always precede encryption because it helps in reducing the redundancy of the message smoothing its statistics even before encryption.

Public Key encryption techniques are based on the concept of trapdoor one-way functions. A one-way function is an easily computed function whose inverse is computationally infeasible.

A trapdoor one-way function is a one-way function whose inverse is easily computed if certain features, used to design the function, are known. Famous examples of one-way functions include Knapsack problem, prime factorization of the product of two extremely large prime numbers and elliptic curve discrete logarithm problem.

After covering these concepts, the famous Rivest-Shamir-Adelman (RSA) encryption scheme is introduced. RSA is divided into the following six steps:

1. choose three prime numbers: $d > p > q$
2. $n = pq$
3. $\phi(n) = (p - 1)(q - 1)$
4. $e \bmod \phi(n) = 1$
5. $C = M^e \bmod n$
6. $M = C^d \bmod n$

Euclid algorithm and fast exponentiation are utilized to compute steps 4 and 5/6, respectively. Both algorithms are discussed in details in the class. The second class project is based on RSA.

While students are working on their second project, elliptic curves are introduced and discretized to a finite number of points on the curve using prime fields. Next, elliptic curve arithmetics such as addition and doubling are discussed. Encryption techniques that are based on elliptic curves require much smaller keys relative to RSA. A 160-bit key in Elliptic Curve Cryptography (ECC) is considered to be as secured as 1024-bit key in RSA. These techniques are based on the fact that given a point P on the curve and a constant k , it is easy to get to the point $Q = kP$ using the addition and doubling operations. However, given two points on the elliptic curve P and Q , it is computationally impossible to find the relation between them. A cryptanalyst should start from a generating point on the curve and find the relation between all the points on the curve and this generating point to create a cyclic subgroup over this generating point before being able to solve the elliptic curve discrete logarithm problem. This module ends by discussing two basic ECC techniques: ELGamal and Menezes-Vanstone.

Third module

In today's era of data centers and cloud computing, it is becoming extremely important to protect data from any hardware faults using parity check-sums and redundant backup capabilities. On the other hands, applications on our cell phones such as video streaming has made our channels both bandwidth and power limited. In addition, both compression and encryption exaggerate the problem because compression reduce redundancy in the message increasing the effect of error and encryption smooth statistics between symbols causing an error propagation problem. Hence, channel coding should always follow those two blocks to provide us with the best tools to deal with these challenges. As a hooking experience, students at the beginning of this module are asked about the required probability of error for today's applications. For example, nowadays it is for granted that a customer can download a complete book on his phone in an extremely short time and without a single character in error.

Channel coding techniques are generally divided into three categories: linear block codes, convolutional codes and iterative codes. Under the category of linear block codes, there exist the cyclic codes that can be used for bits or symbols. A famous class of cyclic codes that work with symbols and are capable of protecting data from bursts of error are Reed-Solomon (RS) codes. Before introducing this class of codes,

students should understand important concepts such as representation of binary data in polynomials, generating code words by using polynomial multiplication between the generating polynomial and the message polynomial, calculating the syndrome of a received word using polynomial division, and decoding the error pattern from the calculated syndromes. Students should also learn how to implement a basic binary cyclic encoder/decoder in hardware.

These concepts can then be easily extended to symbols of multiple bits by using finite Galois Field (GF) arithmetic including addition and multiplication. After discussing GFs the instructor explains the hardware and functionality of an RS encoder. He also explains how to calculate the syndrome of the received vector at the input of the decoder. Decoding the error patterns from their respective syndromes is much harder in RS than in binary cyclic codes because the decoder should locate both the location and value of the error, while in the binary case only the location is important. RS decoding algorithms such as auto-regressive modeling techniques are used to decode the error pattern from the calculated syndromes. After introducing these concepts, students will be ready to take their third project.

While students are working on their third project, the instructor will describe how to enhance the capabilities of RS codes against burst errors by interleaving the message data before encoding. At the receiver side, the data will be deinterleaved transforming the burst of error into randomly distributed error. This will change the channel characteristic from a memory channel, where there is a lot of dependence between the probability of error of neighboring symbols, as close as possible to a memoryless channel. Interleaving is very famous in memory platforms such as DVDs where data is not written and read at the same time. However, the buffering memory and time required to interleave/deinterleave the message data will quickly become very costly in real-time applications.

Although, interleaving help tackle bursts of error, it does perform poorly against randomly distributed errors. In fact, it can take randomly distributed error and transform it accidentally to a burst of error. Hence, it is important to concatenate channel codes, such that one will work on the message before interleaving and the second will work on the message after interleaving. Concatenated codes are covered briefly in this module.

Next, the instructor will backup to binary linear block codes that use generating and parity check matrices instead of polynomial multiplication and division. He will also touch on the positive effect of channel symbols on the probability of error curves of different communication techniques. In general, channel codes are used to achieve one of three different things. First, reduce the energy per bit required to achieve a particular probability of error. The amount of reduction is the Coding Gain (CG) and is usually calculated in decibels. Second, increase the bit rate for the same probability of error. Because the energy per bit is inversely proportional to the bit rate, a higher bit rate is an indication of a lower energy per bit. Third, reduce the probability of error for the same energy per bit.

Convolutional codes are built to work with Close-Circuit (CC) applications such as phones and CCTV, where messages cannot be divided into different blocks or packets because they are streamed continuously. Convolutional codes are used in such applications to insert the parity bits and check them while the data is being streamed. The instructor explains the operation of convolutional encoders and their representation using Trellis diagram. He then covers the Viterbi decoding algorithm and touch on its implementation in hardware. Finally, he covers the properties of the convolutional codes and their corresponding CG for hard and soft decision receivers.

By this time, students have submitted their third project and are ready to take their fourth and final project that uses the three modules that are covered in this class. For the last two weeks in the class and while students are working on their final project, the instructor will cover iterative codes, the most recent channel coding category. The instructor will focus on how to utilize soft decisions and feedback in decoding to increase the CG. The log-likelihood algebra and the maximum a posteriori decoding algorithm are covered as part of this focus.

III. PROJECTS DESCRIPTION

Students are asked at the beginning of the year to form multi-disciplinary groups of two or three members to work on the different projects. The instructor will explain to the students, that they need expertise in different areas to finish the projects successfully and ask them to be thoughtful about picking their group members. At the end of the first week of classes, students form their groups and submit a document to the professor showing the expertise of the different members in the group and explaining how the group will be successful in finishing the future assigned tasks. The instructor will then assign group members based on students' recommendation. After the groups have been assigned, students are only allowed to change their groups between projects, if they prove to the instructor that their group lacks the necessary expertise to finish the allocated tasks, and that there is another group in the class that can benefit from a swap of expertise. There should be a mutual agreement between the two groups that want to swap their members.

All projects require a weekly progress report. The first three projects that are associated with different modules require presentation/demoing of the simulation results. The final project is in a form of a technical report that proposes a solution for a practical problem in the field. However, students should also pitch their solution to the virtual customer represented by the instructor. The grading policy of the first three projects is as follows: 20% are associate to timeliness and are based on whether the students are following the schedule correctly. 10% are associated to trouble shooting and are based on whether the students required the help of the instructor to finish their task. 40% are associated with the completeness of simulation results. 20% are associated to the presentation skills of the different members of the group. Finally, 10% are associated to the coding language used and whether students have used a high level or low level description of the system, which is as close as possible to

hardware. The grading policy of the final project is as follows: 20% are associated to timeliness, 50% are associated to the technical content of the report and 30% are associated to the pitching of the solution. The following sections describe the projects in details.

Project 1

Students are given two weeks to:

- Construct a 128×128 image in paint made up of text and save it in monochrome bit map format.
- Read the image and find its runs of Black and White.
- Find the probability of each run and construct the Huffman coding table.
- Use the Huffman coding table to compress the image.
- Add the Huffman coding table to the header of the compressed image.
- Save the file and compare its size to the original file format and calculate the saving.
- Decompress the image by reading its symbols and using its header to decode its symbols and display it.

Project 2

Students are given two weeks to realize an RSA encryption/decryption system. The block diagram of the encryption technique is shown in Figure 1. At Bob's side: given three 16-bit prime numbers d , q , and p the system will find the public key (e, n) and transmit it to Alice. Alice will use fast exponentiation algorithm to get the cyphered text C from the message M and the public key. Then Bob will use the fast exponentiation algorithm to find M from C and his private key (d, n) . Both M and C should always be less than n . Students can use any type of message data to simulate their system such as text, audio or video. Extra points are given for students who can increase the precision of the prime numbers and implement the special cases of the fast exponentiation algorithm.

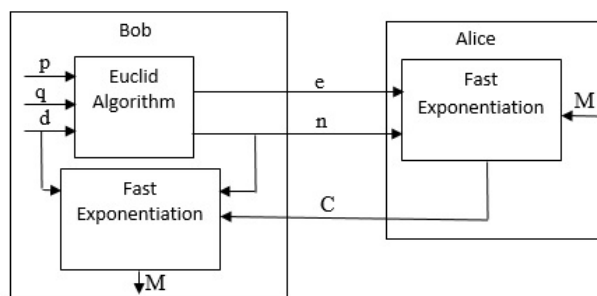


Fig. 1. Block diagram of project 2

Project 3

Students are given four weeks to build the following:

- RS encoder
- RS syndrome calculation block
- Syndrome to error pattern decoder
- A complete RS system that shows the error correction process

The RS code used is the (7,5) which is created out of 3bit symbols and can correct one symbol in each block. Deliverables and divided into four different weeks.

Week 1

- Derive the generating polynomial of the (7,5) code.
- Sketch the encoder for the (7,5) code and run an example by hand.
- Sketch the syndrome calculation block of the (7,5) code and verify the following:
 - The code word has two syndromes $S_0=S_1=0$.
 - Pick an error pattern and find its syndromes and verify that the code word corrupted by this error pattern has the same syndromes.
- Find the syndromes of all the error patterns that can be corrected. Notice that we are only interested in the five message symbols and each symbol can be corrupted in seven different error patterns. Hence, you have to calculate the syndromes for a total of 35 error patterns.

Week 2

- Describe the encoder in your chosen language.
- Run several simulations to verify that your hardware description is working correctly.

Week 3

- Describe the syndrome calculation block in your chosen language
- Run several simulations to verify that your syndrome calculation is working correctly.
- Describe the syndrome to error pattern decoder and check its functionality.

Week 4

- Describe the whole system using the previous hardware blocks.
- Find a method to induce an error pattern into the transmitted channel block and verify that the RS decoder can correct this error for single symbol error patterns.
- Verify that RS decoder cannot correct all error patterns.

Project 4

For the final project, students are given the following problem statement:

"A manufacturing company is currently installing two-wire cables in their products. The cables are used as a communication link to update the different parts of the products. The updates should be done in the fastest time possible because their customers cannot operate their products while they are in update mode. Also, the updates should be reliable and secure. Although the two-wire cables are considered old technology, they can withstand mechanical stress, typical in the product operation, better than any other

newer cables such as coaxial or fiber optics. Therefore the company is interested in achieving the fastest reliable and secure bit rate on the two-wire cables. There is also a constraint on the voltage level through the cables. The company understands that the solution to their problem will involve a combination of all the different techniques that we have studied in this class."

Students are then given two weeks to construct a proposal for the company and effectively communicate it. The proposal should include:

- The different techniques that need to be implemented to solve the problem.
- The hardware platform required to implement these techniques
- The cost of implementing these techniques in hardware.
- The time of delivery of the prototype
- Testing plan

All projects are designed to test students in their ability to effectively collaborate in a team setting and apply critical and creative thinking to ambiguous problems. In addition the final project also test the students on their ability to construct and effectively communicate a customer appropriate value proposition. All there outcomes are highlighted as key components for a successful entrepreneurial engineer/scientist.

IV. SAMPLE OF STUDENTS WORK

Through the years of offering this elective, different groups of students have excelled in accomplishing achievements beyond the required tasks of the four different projects. Highlights include:

- Design of user interfaces that can demo the different steps of the first three projects.
- Creating a new library in Matlab that can implement addition and multiplication and find the quotient and remainder of the division of binary data with user-set bit precision. The library was utilized in project 2, where students were able to show simulated data with large bit precision.
- Describing Booth multiplication and suggesting Booth-like modulo operator to be used in project 2. The results of this group of students' work were presented in the Midwestern Symposium of circuits and systems.
- Experimenting with different sources of data in project 2 and 3 such as text, audio and images.

The most impressive highlight was achieved by a group of students who are co-authoring this paper for their efforts in implementing the third project at the lowest level of hardware description, and showing both low level and high level simulation results.

The RS encoder, syndrome calculator and error decoder were described in structural VHDL at the gate level. As an example, Figure 2 shows a step-by-step demonstration of the operation of the RS encoder. In addition, Figure 3 shows a snapshot of the simulation of the whole system in Modelsim.

In addition, students were able to write a testbench that can do the following:

1. read a text file and transform it to a binary message
2. run the binary message through the RS encoder
3. insert errors at controlled locations in the encoded message
4. Validate that RS(7,5) can successfully correct all error patterns that are limited to a single symbol per code word.
5. Validate that RS(7,5) could potentially make things worse if the error exceeds its limit.

Figure 4 a shows the text message used to test the system. The corresponding binary message is shown in Figure 4b. Figure 4c highlights the error locations in red. Figure 4d shows how the system can correct the inserted errors (highlighted in green). Figure 4e shows a dramatic case where the error highlighted in red exceeds the capabilities of RS(7,5). Figure 4f shows that although RS(7,5) can still correct some bits (highlighted in green), it fails to correct other bits (highlighted in red) and may even introduce new errors (highlighted in blue).

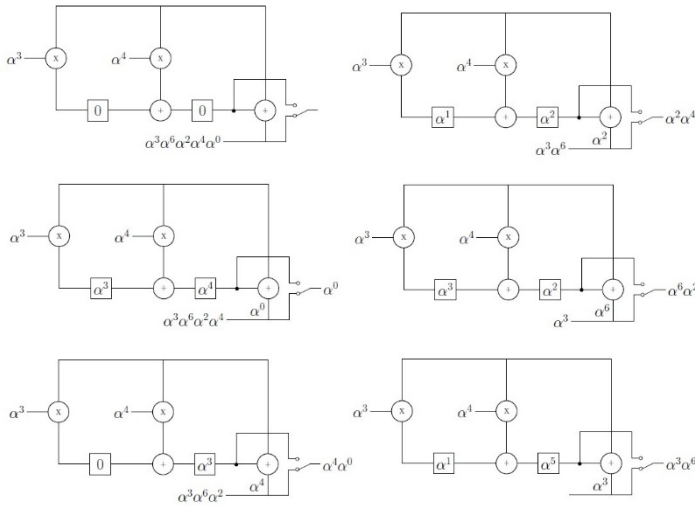


Fig. 2. A step by step demonstration of the operation of the RS(7,5) encoder.

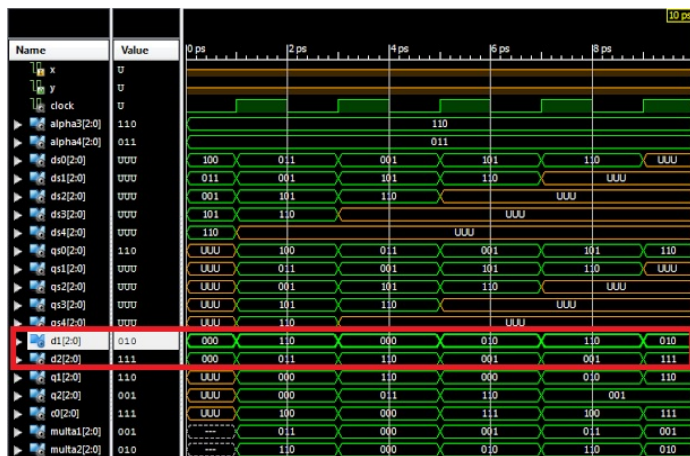


Fig. 3. A snapshot of the Modelsim simulation of project 3.

What we observe is not nature itself, but nature exposed to our method of questioning. Werner Heisenberg

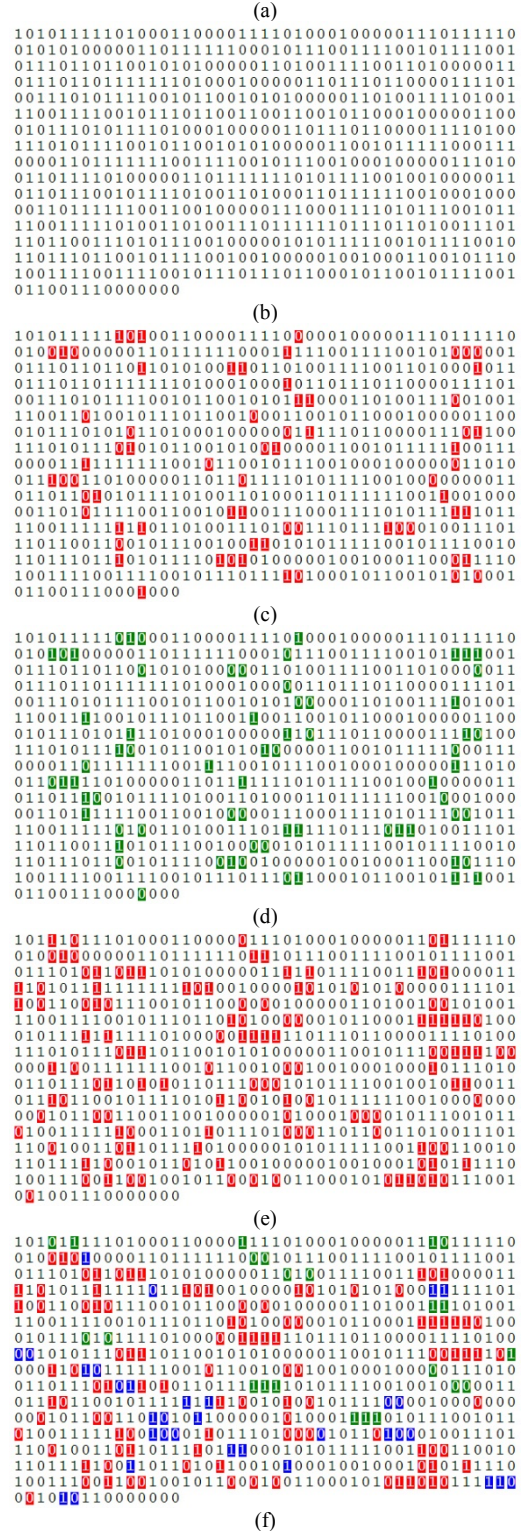


Fig. 4. High level simulation of project 3.

V. ASSESSMENT

The proposed project-based multi-disciplinary elective on digital data processing techniques has been offered for three consecutive years. Table I summarizes the number of students

from the three different majors that has registered and successfully completed this course. As shown in the table, students from the three different majors have shown equal interest in this elective.

Table I. Summary of the number of students from different majors who have registered in the class in the last three years.

CS	CPE	EE	Total
20157	2	4	13
20144	4	8	16
20130	4	6	10
Total11	10	18	39

The course have four main outcomes:

CO1: Implement and simulate digital communication systems with error correcting capabilities

CO2: Realize some encryption and decryption techniques

CO3: Implement different source coding techniques.

CO4: Construct and effectively communicate a customer appropriate value proposition

CO5: Effectively collaborate in a team setting and apply critical and creative thinking to ambiguous problems

These outcomes were assessed by the course instructor using four levels: Proficient (P), Meets expectation (M), Developing (D), and Below expectation (B). Table 2 summarizes the result of this assessment and provides the mean for every course outcome, where P, M, D and B are scaled by 4, 3, 2 and 1, respectively. As shown in Table II, all course outcomes were meet with means higher than 3.3.

Table II. Summary of course outcome assessment

	P	M	D	B	Mean
CO1 23	8	6	2		3.33
CO2 23	10	3	3		3.35
CO3 26	6	3	4		3.38
CO4 25	9	5	0		3.51
CO5 30	6	3	0		3.69

Finally, students have evaluated the course through the three different years using institution anonymous course/instructor evaluation surveys. The main statements in the survey that are related to the course evaluation are:

F1: The course was designed to foster learning of the course material

F2: The course provided me with an important skill set needed for further studies in this field

F3: The course enhanced my problem solving abilities

F4: The workload for this course in relation to other courses of equal credit was as expected.

Students comment on each statement by Strongly Agree (SA), Agree (A), Neutral (N), Disagree(D), and Strongly Disagree (SD). Table III summarizes the result of these surveys and provide the means, where SA, A, N, D and SD are scaled by 5, 4, 3, 2, and 1, respectively. Based on the table the mean of students' feedback is higher than 4.

Table III. Summary of students feedback

	SA	A	N	D	SD	Mean
F1	9	7	0	0	0	4.5
F2	6	5	3	1	0	4.1
F3	6	9	2	0	0	4.2
F4	8	7	1	1	0	4.3

VI. CONCLUSION

In conclusion, this paper provides a summary of a senior level project based elective that can be offered to three different undergraduate majors: computer science, computer engineering and electrical engineering. The paper describes the course organization and its associate projects. It shows a sample of students' work and show the assessment data for three different years of offering this course.

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Developing a Course Module for Teaching Cryptography Programming on Android

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Abstract— Mobile platforms have become extremely popular among users and hence become an important platform for developers. Mobile devices often store tremendous amount of personal, financial and commercial data. Several studies have shown that large number of the mobile applications that use cryptography APIs have made mistakes. This could potentially attract both targeted and mass-scale attacks, which will cause great loss to the mobile users. Therefore, it is vitally important to provide education in secure mobile programming to students in computer science and other related disciplines. It is very hard to find pedagogical resources on this topic that many educators urgently need. This paper introduces a course module that teaches students how to develop secure Android applications by correctly using Android's cryptography APIs. This course module is targeted to two areas where programmers commonly make many mistakes: password based encryption and SSL certificate validation. The core of the module includes a real world sample Android program for students to secure by implementing cryptographic components correctly. The course module will use open-ended problem solving to let students freely explore the multiple options in securing the application. The course module includes a lecture slide on Android's Crypto library, its common misuses, and suggested good practices. Assessment materials will also be included in the course module. This course module could be used in mobile programming class or network security class. It could also be taught as a module in advanced programming class or used as a self-teaching tool for general public.

Keywords— computer science; programming; Android programming; cryptography; security; course module; cryptography programming; SSL

I. INTRODUCTION

Mobile platforms have become extremely popular among users and hence become an important platform for developers. Computer science students are increasingly more interested in learning mobile development. Therefore, mobile application development has become an important topic in computing curricula. New privacy and security issues arise with the prevalence of mobile computing. Mobile devices often store tremendous amount of personal, financial and commercial data. As such, mobile devices attract both targeted and mass-scale attacks. Therefore, it is vitally important to provide education in mobile computing and security to students in computer science and other related disciplines.

Several studies have shown that most of the mobile applications that use cryptography APIs have made mistakes. In one of the study, the authors developed a tool that automatically check apps on Google Play market place and they found that 88% of the 11,748 apps have made at least one mistakes [1]. Some of the apps were vulnerable to chosen plaintext attacks. The common mistakes in this category include using Electronic Code Book (ECB) mode for encryption and using non-random Initial Vectors (IV) for Cipher Block Chaining (CBC) mode. The other mistakes include using constant key for symmetric key encryption, and using constant salt for password-based encryption. In another recent study, the authors studied the misuse of SSL in Android apps on Google Play. They found that 448 out of 614 apps did not verify digital certificate, which make these apps vulnerable to Man-in-the-Middle (MITM) attacks [2]. Another study analyzed 13,500 popular free apps on Google Play market place and found out that about 1,074 (8%) of them were potentially vulnerable MITM attacks [3]. Validating SSL certificates is not an easy task. A study titled "The most dangerous code in the world: validating Secure Socket Layer (SSL) certificates in non-browser software" found that SSL validation was broken even in security-critical applications [4]. Although studies have shown different statistics, it is safe to say that there are significant number of applications that have not used cryptographic APIs correctly, which can potentially harm the mobile users by losing private information to the hackers.

It is important to educate computer science students who are going to develop mobile apps in the future to know how to develop secure cipher applications. It is very hard to find pedagogical resources on this topic that many educators urgently need in their classrooms. In this paper, we introduce a course module that addresses this problem. This module contains four main components: learning objectives, lecture, hands-on assignment, and assessment. This course module could be used in mobile programming class or network security class. This project is part of a larger project of developing twelve course modules on mobile computing and mobile security and integrating them into computer science courses at the Department of Computer Science, North Carolina A&T State University. Such an approach allows universities that do not have resources to create standalone new courses on mobile computing and mobile security to introduce these concepts to

their students. This course module fits the Platform-Based Development Knowledge Area in the ACM/IEEE Ironman Draft (version 0.8) of the Computer Science Curricula [9].

The rest of the paper is organized as follows. Section 2 describes the background research on android programming with encryption, and with SSL. Section 3 introduces the course module including the learning objectives, lecture, hands-on assignment, and assessment. Section 4 concludes the paper and discusses future work.

II. BACKGROUND RESEARCH

A. Android Programming with Encryption

Android apps need to encrypt data for many reasons. Android has multiple storage options including databases, internal storage, and external storage [5]. Data that are stored in external storage with SD cards are “world-readable”, which means any app running on the same device can access them. If apps want to store data on external storage and still want to keep them private, apps need to apply encryption to the data before storing them. Data that are stored in internal storage are private to the apps that created them. However, sensitive data (e.g. third-party passwords) should always be encrypted even if they are stored in internal storage. Rooting android devices, bugs in apps, or the bugs in Android could all potentially cause the data stored in the internal storage to be lost without encryption.

Android provides system level full disk encryption (FDE), which automatically encrypts data before storing to the storage. This protects the data in case mobile devices are lost or stolen by making it very hard for hackers to recover the stored data. However, FDE usually does not apply to the external storage and not all devices have FDE feature turned on. Recently, some Android Lollipop devices do not have FDE turned on due to performance issues even though Lollipop was designed to have this feature turned on by default [6]. For Android app developers, it is always a good practice to encrypt sensitive data regardless of the status of FDE.

Android’s cryptography SDK includes Java Cryptography Extension (JCE) providers that implements common symmetric ciphers, hash functions, message authentication code (MAC) algorithms, secure random number generators, and key management. Android app developers can easily access these APIs to encrypt the data. There are two types of common mistakes when Android app developers are using the crypto libraries:

(1) Not choosing the more secure modes of operation or using the constant initial vectors (IV) for safer modes of operations. Instead of using ECB mode, programmer should use CBC mode with random IV’s to make the cipher text much harder to break.

(2) Implementing key management incorrectly. The encryption keys should not be stored together with the cipher text or hard coded into the source code. The reason is the same as why passwords should be encrypted, which are explained in a previous paragraph. The solution is to ask for the keys when encrypting or decrypting. Because random keys are almost

impossible to remember, passwords are used to generate the encryption keys. One idea is to use the passwords as the keys. Since passwords are very likely to be shorter than the keys, the passwords are padded with constant values to length of the keys. This method is not strong because people tend to use passwords that are quite easy to break with password crack tools with rainbow tables. A more secure method is to generate secure random number with the passwords as the seeds. However, the gain in security is very small. JCE provides strong password based key derivations function 2 (PKBDF2) that uses salt to make rainbow tables useless and repeat password based key generation process many times to make password cracking much slower. The suggested number of iteration is at least 1,000, which can make it even very hard to break the weaker passwords.

B. Android Programming with SSL

The secure socket layer (SSL) is one of the most common protocols for encrypting the communications between clients and servers. It is widely used to secure web applications using the HTTPS. It is also used to secure other application layer protocols including SMTP, IMAP, and POP3. SSL is based on Public Key Infrastructure (PKI) where servers send digital certificates signed by Certificate Authorities (CAs) to the clients. The format of digital certificates is specified in X.509 standard. The purpose of a digital certificate is to confirm that the included public key belongs to the included name of the server. CAs provide this confirmation by signing the digital certificates with their private keys. Currently, Android contains over one hundred trusted CAs. If a digital certificate is signed by a CA that is not in this list, the verification fails.

One of the main security threats to SSL is the MITM attacks. This type attack replaces the digital certificates with digital certificates of the attackers. Since the traffic is encrypted with the keys generated based on attackers’ public keys, attackers can decrypt the traffic and retrieve login passwords or credit card numbers. MITM attacks are easy to succeed if attackers have access to Local Area Networks (LANs), wired or wireless. One of such cases is public Wi-Fi networks or hotspots, which are increasingly popular methods of connecting to the Internet. Therefore, it is critical for Android apps to verify the digital certificates in at least two aspects. First, apps must verify if digital certificates are signed by a trusted CA. Second, the apps need to verify that if the subjects of the certificates match the hostnames of the servers. The hostname verification is important because attackers could also get digital certificates signed by a trusted CA.

In Android programming, there are two ways SSL can be used: (1) Using *HttpsURLConnection* class. Android apps developed with this class establish HTTPS connection with the web servers with digital certificates. Android APIs will automatically verify the digital certificates including the hostname verification. (2) Using the *SSLSocket* class. This library can be used to encrypt the communications of non-web applications (e.g. SMTP, POP3). Currently, Android APIs will not do host verification for *SSLSocket*. Therefore, programmers need to develop the code for this step.

There are a large number of Android apps that use SSL to communicate with servers that have only self-signed digital certificates. One of the reasons for this could be the high cost of purchasing a digital certificate from a trusted CA. The other reason could be the difference between the ways web services are accessed from desktop computer and mobile devices. In desktop environment browsers are the main software for users to access web servers. In mobile environment, service providers tend to develop their own apps that access their servers remotely. For example, desktop users use browsers to shop at Amazon.com while the mobile users tend to use Amazon's mobile apps to do the same thing. Many mobile apps communicate with the servers that are dedicated to serve their own apps only. Android APIs allow apps to develop their custom *TrustManager* and *HostnameVerifier* to bypass trusted CA requirements and even modify the hostname verification process. Therefore, there is no significant incentive for mobile developers to purchase the digital certificates from the CAs. Customizing the default Android's certificate verification process leaves huge room for making mistakes. For example, a modified *TrustManager* that accepts all certificates can make MITM attackers easily succeed by substituting the certificates with their own. Although there are security risks in using self-signed certificates for mobile apps, it can be secure against MITM attacks if the program was written correctly.

One common way of securing mobile apps with self-signed certificate is called "certificate pinning" [7]. In this method, the certificate can be hard coded into the mobile apps and loaded into *KeyStore* by the mobile apps. This method is secure but the limitation is that when servers change the certificates, the mobile apps have to be updated to accept new certificates. Another common method is to hard code the CA into the mobile app and the app load the CA to the *TrustManager*. Any digital certificates signed by the loaded CA will be accepted by the app. Google provides an automated network traffic security testing tool called "Nogotofail" [8] that can find if an Android has SSL vulnerabilities.

III. DEVELOPING THE COURSE MODULE

We are developing a course module on learning Android cryptography programming. This module contains four main components: learning objectives, lecture, assignment, and assessment.

A. Learning Objectives

Upon completion of the course module, students should be able to:

- 1) Use Android cryptography SDK to correctly implement password based encryption.
- 2) Correctly validate digital certificate and secure communication between a mobile app and web service using SSL.
- 3) Identify the weaknesses in programs that use Android Cryptography APIs.
- 4) Apply knowledge of cryptography to real-world problem solving.

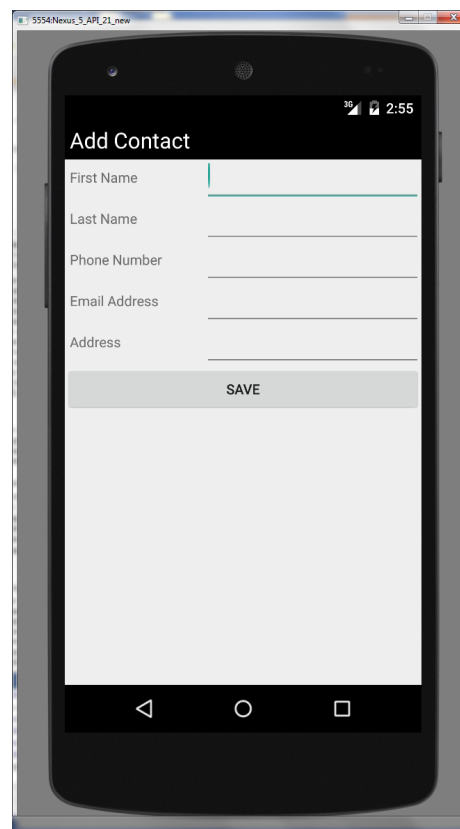
B. Lecture Component

The lecture component introduces common mistakes programmers make when developing apps that use Android cryptography APIs and SSL. Recommendations of good practices of using cryptography APIs and SSL are introduced. This lecture is intended for students with some background in cryptography who are interested in learning the application of cryptography in real world, particularly in developing secure mobile applications. This lecture is intended to cover one hour by instructors. Students will be given study materials for developing Android cryptography programs and using SSL. This lecture will lead students to the assignment components.

C. Assignment Component

This component includes a programming assignment, in which students are asked to secure an existing Android app by using cryptography APIs. This Android app is an online contact list app that allows users access their contacts from anywhere and from any Android device. This app is based on Derek Banas's Youtube tutorial on Android programming [10]. The contact list sample program allows users to create, delete, and modify contacts and save them to Android's local SQLite database. We will modify the app to make it retrieve and store the contacts on a web server with a XML based web service APIs. The web service APIs will have both clear text and SSL with self-signed digital certificate. The code given to the students will be using the clear text version. Figure 1 shows a screenshot of the app running on an emulator.

Fig. 1. A screenshot the sample app.



Students will be asked to modify this contact list app to make it a super private. The requirements are: 1) the details of the contacts are not even knowable to the server; 2) all communication between the app and web service must be encrypted. To achieve this students should need to apply both SSL and password based encryption. The login password and the password for generating the encryption keys should definitely be different. The contact information must be encrypted before using the SSL web service to store it on the server. Other than these requirements, students can apply various methods to achieve the goal. This assignment is intended for students who already had some training in Android programming.

D. Assessment Component

One good way to assess students is to let them evaluate their peer's work. After students have finished the assignment component, they will present their solutions to all students in the classroom. Students will evaluate other students' solution with criteria including strength of security, simplicity, and performance. This will not only let students know how their peers solved problem differently, but also help them think deeply by analyzing different solutions, which is another great way of reinforcing their learning. Instructors can also judge students' understanding based on the quality of students' evaluations. In this assessment module we are to develop the peer evaluation forms and the instructor evaluation forms. We all create several quiz questions to test students knowledge in this area.

IV. CONCLUSION

In this paper, we introduced a course module that are designed to teach students to develop more secure cryptography programs on Android. This course module is targeted to two areas where programmers commonly make many mistakes: password based encryption and SSL certificate authentication. The course module includes an assignment that requires students to use Android's cryptography correctly to make a "super private" contact list app. This course module could be used in mobile programming class or network security class. It could also be taught as a module in advanced programming class or used as a self-teaching tool for general public. Future work includes using the course module in classes, evaluating its effectiveness, and disseminating the course module to other educators in computer science or information technology fields. This course module will be posted on <http://williams.comp.ncat.edu/mobile/>.

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An Insider Threat Activity in a Software Security Course

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Abstract—Software development teams face a critical threat to the security of their systems: insiders. A malicious insider is a person who violates an authorized level of access in a software system. Unfortunately, when creating software, developers do not typically account for insider threat. Students learning software development are unaware of the impacts of malicious actors and are far too often untrained in prevention methods against them. A few of the defensive mechanisms to protect against insider threats include eliminating system access once an employee leaves an organization, enforcing principle of least privilege, code reviews, and constant monitoring for suspicious activity.

At the Department of Software Engineering at the Rochester Institute of Technology, we require a course titled Engineering of Secure Software and have created an activity designed to prepare students for the problem of insider threats. At the beginning of this activity, student teams are given the task of designing a moderately sized secure software system. The goal of this insider is to manipulate the team into creating a flawed system design that would allow attackers to perform malicious activities once the system has been created. When the insider is revealed at the conclusion of the project, students discuss countermeasures regarding the malicious actions the insiders were able to plan or complete, along with methods of prevention that may have been employed by the team to detect the malicious developer.

In this paper, we describe the activity along with the results of a survey. We discuss the benefits and challenges of the activity with the goal of giving other instructors the tools they need to conduct this activity at their institution. While many institutions do not offer courses in computer security, this self-contained activity may be used in any computing course to enforce the importance of protecting against insider threats.

Keywords—Software Security, Software Engineering, Computing Education

I. INTRODUCTION

Organizations devote vast amounts of time and resources protecting themselves against outside threats. These protection mechanisms include but are not limited to firewalls, data encryption, and defensive coding practices. A much more difficult threat to protect against is one which comes from within the company. An *insider threat* is a current or former employee, business partner, or contractor who has access to an organization's data, network, source code, or other sensitive information who may intentionally misuse this information and negatively affect the availability, integrity, or confidentiality of the organization's information system. Examples of insider attacks include data harvesting, abuse of privileges sabotage, and masquerading attacks. Additionally, a user could act as an insider threat and have no actual malicious intent. Inadvertent use of computing resources or data could make a system

susceptible to attack, or could unintentionally release sensitive data [6]. Insider threats are much more difficult to identify since potential threats are often users of a system which they themselves developed (potential leaving back doors and having deep intimate knowledge of the system) while, as developers, not being considered to be potential threats to the system [12]. Companies often choose mitigate the risk of insider threats through the use of policies and regulations [7].

Far too often, software engineers are not prepared to deal with fact that their co-workers, people who they should trust as allies, are in fact potentially malicious users capable of performing a wide range of destructive actions. In educational environments, students typically either work alone, or with teams — with instructors preaching the importance of teamwork and trust. While these concepts are important real-world examples dictate that the opportunity for a security threat must be considered.

At the Rochester Institute of Technology, we created an upper division Engineering of Secure Software applications course to help students understand how to incorporate proper security protection practices when designing, creating, and maintaining software. Some course topics include defensive coding practices, deployment & distribution strategies, vulnerability assessments, and threat modeling. In this course, we created an activity to help acclimate students with how to understand, protect, and recognize insider threats. Students teams are formed and students are given the task of designing a small application and planning for proper security. One student from each team is quietly pulled aside and told that they are the insider threat or *mole* for their team. Their goal is to have their team design an application containing a vulnerability which the mole would be able to later use. After the activity, the moles are revealed and a discussion takes place regarding how the moles were able to create the vulnerability, if the team recognized this vulnerability, and what could have been done to prevent this insider threat.

The rest of the paper is organized as follows: Section II describes the course including learning objectives. Section III discusses how the activity was conducted. Section IV provides student feedback about the project including quotes and post activity survey analytics. Section V presents some related works and Section VI discusses possible future work and improvements to the activity. Section VII provides concluding remarks about our work.

II. ABOUT THE COURSE

Primarily comprised of upper division Software Engineering students, the Engineering of Secure Software course¹ was created in 2012 and is focused on instructing students in the proper practices of design and creating secure software. The only prerequisite is the Introduction to Software Engineering course in which students are introduced to core concepts in software engineering such as development methodologies, team work in software development, basic testing principles, and software design.

The course has a primary learning outcome of preparing students to mitigate security threats in software systems and processes. The focus is on proper methods of designing, developing, testing, and maintaining secure software. While the course is language-agnostic and focuses on principles and practices, specific tools and technologies are used to reinforce the learning objectives of the course. For instance, Microsoft's SDL Threat Modeling Tool² is used to instruct students on the proper methods of designing the architecture of a secure system. Specific Java-based examples are used to demonstrate SQL injection attacks, log overflow attacks, hashing and salt, and path traversal exploits. Short Vulnerability-of-the-Day activities serve to introduce students to real world examples of exploits and demonstrate the importance of software security [11]. Students work in small teams on several course projects including the creation of a web fuzz testing tool and a case study which examines a real-world software project for vulnerabilities.

While we do not expect all students taking the course to become security experts, our goal is to instill fundamental principles of secure software development in the students while demonstrating its importance in the real world. Students are graded on several criteria such as three exams, several short projects, and brief in-class activities. Class size is typically 25-35 students and is a required course in the Software Engineering major.

In the course, we also discuss several ways of protecting against insider threats. While there is no easy or simple silver bullet protection mechanism against insider threats, there are some best practices which may be used to help alleviate this risk. Some of these protection practices include properly screening potential employees, implementing end point data leak protection, monitoring databases & sensitive records, and the proper use of rights management systems [15].

III. INSIDER THREAT ACTIVITY

In this section we describe the sample project, the activity conducted by the students, provide example vulnerabilities which the insider threats were able to create, and finally describe goals of the post activity discussion.

A. Sample Project

To begin, students are told that they are being asked to design a secure software system. In our course instances, we asked them to design a student grading system, much like ones which are typically used at many institutions. We selected this

example since we felt it was complex enough for students to have to actively consider numerous possible vulnerabilities and would allow for our insider threats to act maliciously, but simple enough for teams to design it in a class meeting or two. Additionally, we felt that students would be reasonably familiar with a system of this type.

Some basic requirements for this system were: Students should be able to view their grades, but not alter them or view the grades of their classmates. Instructors should be able to view the grades for all students, but only modify grades for students in the specific courses they were teaching. School administrators should be able to view and alter the grades of all students, at any time. All users are required to access the system using their username and password, and if any they have forgotten their password, the system should send a reminder to the person via email and allow them update the password from that link. The application also needed to be accessible from anywhere in the world using a basic web connection. A non-functional requirement was that the application database should be backed up on a nightly basis to an off-site location. For debugging purposes, it was required that all errors and user actions should be logged for system administrators.

B. Activity

Once students were given the basic requirements for their system, student teams of 4-6 students are formed, as this is often the size of groups in industry and has been found to be conducive to student learning in previous research [8], [14]. Before the start of the activity, a subset students were emailed asking them to be insider threats. They were asked to not share this information with anyone and to act just like any other member of the team. Their goal was to have their team design a system that would leave the door open for them to act maliciously in some manner. Examples included being able to view other student's grades view at a higher level of access, or change data which they should not be able to modify.

Example sections of our courses were offered in a 50 minute long format with this activity spanning two class periods. Teams were allowed the entire first class period to work on designing their system while the instructor answered any requirements specific questions the teams had. Teams were then asked to work on the activity outside of class. At the beginning of the second class meeting, teams were asked to review their security design and make any last minute updates. Teams were then informally polled to see how many felt their system was secure. This serves to gauge the confidence each team has in their design. Based on the confidence of the teams and the instructor's knowledge of each team's design, the team with the highest confidence and best design was asked to briefly present their design to the class and talk about why they felt it was secure. The class then asked questions about the design and try to discover any vulnerabilities.

After this brief discussion, the insider threat student for the presenting team is asked to make themselves public and describe the vulnerability they had left in the system design. The insider threats for other teams are then asked to expose themselves and describe the vulnerability they introduced into their team's design as well.

¹<http://www.se.rit.edu/~swen-331/>

²www.microsoft.com/security/sdl/adopt/threatmodeling.aspx

While the insider threats added vulnerabilities in a variety of ways, there were some commonalities in the methods chosen to ensure the application was exploitable. Most often, it was as simple as recommending poor security strategies to leave vulnerabilities in the system. In some instances, insiders would add a vulnerability into the team's design between class meetings which would not be caught during the review on the second class meeting. This mimics the real world situation of an insider adding malicious code into a project during off hours or without the knowledge of the rest of the team. Interestingly, insiders would often ensure that vulnerabilities existed in a system by simply doing nothing. They would notice their teammates leaving a vulnerability in the design due to a simple but honest mistake, doing nothing to fix this known issue.

C. Examples of Introduced Vulnerabilities

In order to provide some context regarding some of the introduced vulnerabilities, we will explain some of them in further detail and provide some examples of how they were used within the activity.

Not Limiting Failed Login Attempts

Limiting the number of failed login attempts is an important protection mechanism against brute force attacks. Without this limitation, attackers may systematically try password combinations until they achieve the correct password. This type of attack has been successfully made against a wide range of organizations, including Apple [13]. In one team, the insider made the argument that users should not be limited by their login attempts since this could be annoying to users and could hurt their user experience with the application. The team agreed and no limiting was done.

Publicly Saving Logs

A requirement of the system was to log all system errors and actions taken by users. Attackers could use these error logs to potentially gain information which could help them compromise the system. Some of this could include call stacks, information about how to create a log overflow, or any other sensitive information which was output to the log messages. Additionally, since the log files contained many alterations made to the system, this could expose potentially sensitive changes to malicious users such as the grades of students. In one team, the insider argued that these logs should be publicly available since it would provide easier access to developers when troubleshooting issues. On another team, they placed the generated log files outside of the trust zone of the system, which would expose these files to outside users. Their teams did not raise any objections to doing this.

Openly Transmitting Data Backups

A requirement was to backup the system database on a nightly basis to an off-site location. In a properly designed system, the database information would be encrypted before it leaves the trust zone, or sent via a secure or encrypted transmission so malicious users could not intercept the data being sent. Several insiders made sure that this database backup file was sent via insecure channels, meaning that it could have been

intercepted by a malicious or unintended party.

Use of Improper Cipher Techniques

Cipher techniques (which are covered in the second half of the course) are a way of encrypting information so they may not be deciphered by anyone but the intended parties. While advanced cipher techniques such as AES and RSA continue to provide high levels of security, older techniques such as DES no longer provide an adequate level of protection and can be broken with relative ease. In several groups, the insider was able to convince their team to use DES or another outdated cipher technique. This would have left the encrypted information susceptible to attackers.

Storing Passwords in Source Code

Developers should not store passwords in the source code of an application, even if it has been compiled. This creates several potential problems including the ability of a malicious user to reverse engineer the code to discover the user name and password. Since passwords should be routinely changed, altering them in compiled code is typically more difficult and much more infrequently done. In several instances, insider threats convinced their teams to store the database login information in compiled code since they argued that the information would be secure since it was compiled (an inaccurate statement) and that the passwords did not need to be updated (also inaccurate). This left the applications not only vulnerable to reverse engineering, but in the event a developer left the company, they would know that the database login and password information was unlikely to be changed making it susceptible to their attack. Interestingly, one insider was able to convince their team to make the login information be merely "root" and no password since this would be simpler for development. Giving an application root access which violates several security standards, including the *principle of least privilege* and having no password at all is bad for a variety of reasons.

Providing Too Many Privileges for User or Component

A basic principle of software security is the *principle of least privilege*, or the granting of the minimum number of privileges that an application needs to properly function [16]. Granting more privileges than the application needs creates security problems since individuals or software components could intentionally or unintentionally use these extra privileges for malicious reasons. In a few instances, insider threats observed instances of too many privileges and chose not to disclose the error, allowing it to propagate into future designs.

D. Post Activity Discussion and Goals

After the insiders were identified and the ensuing discussion about what malicious activities could have been performed on the software, a post-activity discussion takes place. The goal of this discussion is to foster student thinking about insiders, ways that insiders could maliciously act, and prevention methods against them. This discussion should be easy going to foster and encourage student led discussions and to encourage free thinking among the students. Due to

the nature of the activity, there are a wide range of potentially beneficial discussion topics. Some of these are outlined below.

Who Can Be Insider Threats?

Before the activity, many students thought of threats as being people external to the organization, and did not consider inside actors to be threats. Students who may have considered the possibility may not have realized that these threats which could be planned for. One potential outcome is a discussion of who can be insider threats. Regardless of the role on the team, each individual or group of individuals is a potential insider threat who needs to be protected against. In our activities, students discussed the various roles of teammates who were insiders and how similar roles in real-world projects could be hazardous.

What Malicious Actions did the Insiders Take?

Insiders conducted a wide variety of malicious actions in our activity using many different methods — many with relative ease. Students are encouraged to discuss the actions that insiders took on their systems and what some of the negative ramifications could have been. They are also encouraged to significantly explore and analyze the negative ramifications of the threats. As an example, in the situation where student records were publicly exposed, consequences which may not be immediately considered are the legal ramifications involved and potential lawsuits by students with publicly exposed grades. A related activity that could be done to augment this discussion would be to ask students to explore and report upon real-world examples of malicious actions taken by insiders.

What Damage Did the Insiders Cause?

In our activity instances, insider threats would have typically been able to inflict a significant amount of damage on the software project. Understanding the possible negative ramifications is a good way for students to realize the importance of protecting against insider threats and to plan for similar occurrences in their real-world development teams.

Did the Students Realize the Insiders Were Doing Anything Wrong?

In our discussions, students often reported that they had at least a feeling that the insiders were acting in a malicious manner, but failed to stop them. Some reasons included not wanting to create controversy, the feeling that security was not a prominent area of concern, or that their teammate *must have known what they were doing*. Points of discussion could include warning signs of vulnerabilities being placed in a system either for intentional or unintentional reasons, methods of alerting teammates about potential issues in a constructive manner and individual project ownership and empowerment.

How Could Thinking Like an Insider Help to Protect Against Them?

Thinking like an insider is a good way to prevent against them. If developers are always considering different ways that their system can be compromised, they will be more likely to develop their application using proper defensive

measures and to detect malicious actions by real inside threats.

What Could Have Been Done to Prevent Insider Threats?

One of the most important discussion topics should be what could have been done to prevent these insider threats (and similar ones) from occurring in future projects. Students are encouraged to discuss ways of preventing these threats from occurring in real-world projects. Some discussed methods include code reviews, internal accountability, maintaining an open culture, increasing auditability, and analysis by outside security auditors.

IV. STUDENT FEEDBACK

Students have expressed a significant amount of satisfaction in this activity and it has contributed to their overall satisfaction with the course. At the conclusion of the project, students are asked to submit an anonymous survey asking them to provide feedback regarding the project. Some of the questions were based upon the Likert scale, while other asked students to provide written feedback. Several of these questions and student responses are shown in Table I. The survey has been posed to students in the last three course offerings, all of which have used this activity component. A total of 68 students from these sections have chosen to respond.

These results indicate that the vast majority of students not only enjoyed the activity, but would also recommend it to a classmate as well. Additionally, most students felt that it reassembled a project which they were likely to encounter in the real world and were similar to tasks they were asked to complete while on cooperative internships.

The following are samples of written feedback that have been received:

“The surprise not only teaches the lesson but leaves an impression. This is probably due to the deception aspect of the activity.”

“It was really interesting to see how few people were looking for an insider threat and many threats went completely unnoticed. It showed that we weren’t prepared to consider our classmates as threats.”

“I liked how it showed me how easily insider threat can destroy a project..”

“Being continually consciously aware of all possible security threats, for not all risks lie within the implementation.”

“It might seem silly, but the first-hand experience of having someone betray the team, even on an insignificant level, leaves an impression that the same could actually happen in the real world.”

This feedback indicates that students not only enjoyed the activity, but felt that it was an effective learning mechanism as well.

TABLE I: Student Responses

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
You enjoyed the activity	19	37	10	2	0
You learned a lot as a result of the activity	14	39	11	2	0
The activity better prepared you for insider threats	21	39	5	1	2
You feel you are more prepared to deal with an insider threat	16	38	9	5	0
You would be likely to recommend the activity to a friend	16	29	15	7	0

V. RELATED WORK

Numerous works have examined insider threats from a general security perspective. Leyden [10] and Brancik [5] both discussed the importance of protecting against insider threats and the possible negative ramifications. Nostro et al. [12] developed a process for insider threat detection and mitigation using a variety of existing tools and new techniques with the goal being to define the objectives of the attacker and subsequently determining appropriate countermeasures. Other works have discussed various interesting ways of detecting insider threats; Almeahmadi et al [2] investigated the use of using physiological features to detect attackers and found that an abnormal deviation in a user's electrocardiogram amplitude could properly predict an attack before it occurred.

This activity fully engages students in the learning process, which is important as research has shown that students learn better when they are actively engaged in the process [1]. Various other learning techniques that use "active", "collaborate", and "cooperative" learning techniques have been recommended over the years [3], [4], [17], [18].

To our knowledge, this activity was the first of its kind to introduce an insider threat into a software security classroom activity. However, Krutz and Vallino [9] used a similar activity to teach freshman seminar students about problematic teammates. In this activity, moles were added to teams and performed roles such as non-contributors, side trackers and absentee team members. A post-activity discussion focused on these problematic team members and how they can be properly addressed. Creating an activity that was not only informative but also enjoyable for the students is an important objective.

VI. FUTURE WORK

This project has been utilized in several sections of our Engineering of Secure Software course and has been very successful, but there are a few enhancements to the activity and further data which may be collected. In future iterations, we would like to further record and analyze the exploits created by the insiders. This would not only be helpful for better planning future offerings of this activity, but would likely be interesting to researchers as well. Once an insider's exploit is exposed during the class discussion, a secondary activity could be for the team to resolve that exploit like they would in a real-world environment. This could include steps taken to mitigate the exploit and measures which could be taken to ensure that a similar exploit did not occur in the future.

Should instructors have more time to complete this activity, a formal code inspection by the team before revealing the insiders could be a beneficial activity, teaching the students about the code inspections themselves and helping to solidify their importance in detecting insider threats. If the team did

not identify the threats, this would help to demonstrate the many challenges in detecting an insider threat.

When conducting this activity, we chose to give the insiders a significant amount of freedom in deciding what kind of threats to add to the system since a large amount of variability existed between each team's design and the dynamics of the team. However, some insiders have expressed the desire for more direction on the types of threats they should be looking to create. Future instructors should take this into consideration, but also remember to provide balance: too much direction which would inhibit the creativity and ability of the insiders to create threats.

VII. CONCLUSION

Organizations suffer from insider threats on a constant basis — posing risks that could impact them not only monetarily, but also through the loss of invaluable and often private data. Some of this harm is irreversible for organizations from both a data and customer trust perspective. Unfortunately, students are typically unprepared to deal with this notion and do not understand that it can occur, and how it may occur.

We have described a novel and innovative activity to instruct software security students about the dangers of insider threats and some of the damaging ramifications such an actor could have on a system. Students have expressed their satisfaction with the activity from both an enjoyment and learning perspective. We encourage instructors at other institutions to use this activity in their security courses as well.

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A structured approach to training open-ended problem solving

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Abstract—Students in engineering are well trained in solving specified problems, but some have trouble when given problems where there is more than one solution. In their professional life they are much more often confronted with open-ended problems, where there may be more than one solution, and where there may be many ways to reach each one. The goals may be vague, the problem may be underspecified, and the fresh graduate frustrated by the new situation.

We present a structured approach to training students in open-ended problem solving. We have introduced a half-day workshop to help students learn to work with open-ended, ill-structured problems, using a different approach than they would for the well-structured problems they are used to.

Our results indicate that students have become more creative. Compared to previous years, the students explore more paths towards the goal, and use more elaborate methods. Their approach is similar to that typically used by the best students in previous instances of the course. Students mention creativity and group dynamics as positive aspects of the workshop and the following lab.

We conclude that with proper guidance and training, even weaker students can become more creative when solving open-ended problems.

I. INTRODUCTION

An engineering graduate is typically well trained in solving specified problems. They practice, e.g. in labs where they apply the theory they have learned in a guided and well-specified setting, essentially following a recipe designed by the teacher. By training, they learn to quickly solve many kinds of such problems, and to quickly learn how to solve such problems.

In their professional life, engineering graduates are much more often confronted with ill-structured and open-ended problems, where there may be more than one solution, and where there may be many ways to reach each one. The goals may be vague, the problem may be underspecified, and the fresh graduate frustrated by the new situation. Tackling an ill-structured problem with the methods of well-structured ones will not always work very well. Hauer and Daniels [1] consider open-ended problems to be more complex or realistic than well-structured problems, noting that in many cases, their bounds or end goals are unspecified, unclear or insufficient in various ways.

To deal with open-ended problems, a basic skill required is creativity. By training their creativity, we want to develop students' problem solving competencies.

This paper describes a workshop we designed to give the students a structured approach to the creative process, and training to tackle problems of this kind.

The results indicate that the approach has positive effects: students explore more paths toward the goal, use more refined methods, and their work is more similar to that of the best students previous years.

We also describe our plans to further develop the approach.

A. Course context

The course *Secure Computer Systems 1* is given in the fourth year of the Computer and Information Engineering programme at Uppsala University. The course is also open for international Masters students in their first year, and for exchange students in the final year of their Bachelor studies or at the Masters level. It is taught and assessed in English, which for most of the students is not their first language. The course gives 5 credits, which means that students are expected to do all course work (attending lectures, doing labs, writing reports, studying for the exam etc) in approximately 120 hours distributed over a period of 8 weeks. There are usually 40-60 students taking the course.

The course uses continuous assessment with three sets of assignments including both theoretical questions and practical tasks. Students collaborate in predefined groups, and each group is encouraged to independently discuss and develop their solutions. Assignments are assessed through both written reports and oral presentations and discussions. Solid argumentation and logical reasoning, supported by references where applicable, are required. Students train their reflective skills in several ways, e.g. by peer review of hand-ins and by structured discussion roles in assessment seminars. (A more detailed description of the course design can be found in [2].)

The third and last assignment has a practical part where the students perform penetration testing: given a set of IP addresses of computer systems, they should select the right tools and methods to try to break in¹ to the systems and find a secret file. No login accounts or other specific information about the systems is given, but the students need to discover what they need to know.

Creativity is an integral part of the third assignment. It has been argued [3] that a good penetration tester must be

¹This is done in a highly controlled environment.

both technically competent as well as creative, since the goal of penetration testing is to find solutions, paths, or security holes that no one has previously discovered. This means that students are required not only to apply the material learned throughout the course, but also to do so creatively: What clues can be found about the systems and their software, and how can these be used to find a way in? How can methods learned earlier in the course be combined in clever and constructive ways? How far can an attack go, if it is not fully successful?

B. Related work

Engineering students are typically trained in solving precisely formulated problems using detailed guidelines, e.g., in mathematics. The authors of [4] have studied to what extent students' previous education affects how they approach new, ill-structured problems. Their findings suggest that students do this differently depending on their background (primarily mathematics or design), and that students trained in mathematics tend to expect there to be only one solution that can be fairly easily found.

Open-ended problems, i.e., where there are multiple possible solutions, give students the opportunity to practice generating creative ideas [5]. Since the 1960s, many training programs have been introduced to develop students' creativity. Scott et al [6] analyze 70 studies of such programs. Their findings indicate that successful creativity training combines the development of cognitive skills with domain-specific heuristics. The students thus do not become experts in creative thinking, but they learn a *set of methods* that they can apply to solving real-world problems in more creative ways.

One of the analyzed programs is described in Cropley and Cropley [7]. They study the effect of explicit creativity training on engineering students by comparing two groups of students: both groups attended lectures on creativity, but the first group also received individual counseling based on their results on a creativity test [8]. Both groups were then given an ill-structured engineering problem and asked to solve it. The authors assess the outcomes of the training by comparing creativity test results before and after, and by evaluating the quality of the solutions to the given problem. Their results show that students who were counseled became more innovative, whereas the control group simply became less inhibited. Interestingly, the counseled students' scores on the second creativity test were less varied than those of the control group. Thus, the training appeared to reduce individual differences in creativity.

An important aspect of creativity is *divergent thinking*, which involves generating multiple ideas, generating multiple answers from the available information, producing new ideas, changing existing ones, etc. The opposite is *convergent thinking*, which focuses on using available information to find the single best solution to a problem. The differences are summarized and discussed, e.g., by Cropley [9]. Divergent and convergent thinking are combined in approaches such as *creative problem solving*.

A framework proposed by Treffinger et al [10] for assessing creativity is based on four creativity characteristics, two of which correspond to divergent thinking (generating ideas) and convergent thinking (digging deeper into ideas). Daly et al [5] use Treffinger's framework to evaluate creativity training in seven engineering courses at a US university. The course instructors had the goal of fostering creativity, but explicit creativity teaching was often not present. Students were exposed to ill-structured and/or open-ended projects as a means of training their creativity. The authors note that both instruction and assessment were focused on convergent rather than divergent thinking, meaning that students were neither taught (nor rewarded for) using their skills to find many different solutions to a given problem.

The interplay between divergent and convergent thinking is also central to Liu et al [11], who propose a model for teaching creativity to engineering students, based on the creative learning model by Treffinger et al [12].

II. METHOD

Our method closely follows the model proposed by Liu et al [11]. Their model has three hierarchical levels:

- 1) *Learning and using basic thinking tools*,
- 2) *Learning and practicing a systematic process of problem solving*, and
- 3) *Working with real problems*.

At the first level, thinking tools such as brainstorming are used. The goal is to encourage divergent thinking and help students prepare and generate ideas. At the second level, students learn and practice strategies for solving problems efficiently. Case studies, simulations, and role-playing are mentioned as examples. At the third level, students are expected to solve real-world problems.

We have introduced a half-day workshop to help students learn to work with open-ended, ill-structured problems, with a different approach than the well-structured problems they are used to. The workshop consists of three phases, each of which we detail below. Each phase relates to one of the levels in the model by Liu et al [11].

The students' task is to find as many ways as possible to break in to a computer system. The overall goal of the workshop, however, is not so much about successful hacking, but rather about guiding the students through different ways of thinking creatively about penetration testing: first, in very free and abstract terms (while brainstorming), then, in theoretical, but realistic, terms (while planning their attacks), and finally in practical terms (while attacking the system).

At the start of the workshop, students are introduced to the concept of penetration testing. We discuss what the purpose of penetration testing is: are you trying to exploit a specific vulnerability in someone else's system, or are you are trying to find as many ways to attack the system as possible? What are the challenges in each case? We also provide a brief overview of different tools that are available to them. This gives the students a platform to start from in the three following phases.

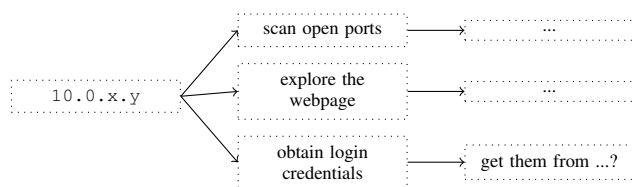


Fig. 1. Example of an attack tree after brainstorming.

Phase 1: Brainstorming

Following [13], the students are asked to come up with *many* different ideas, to withhold any criticism of other group members' ideas, and (after collecting initial ideas) to combine and improve the ideas presented. We encourage them to think about the different aspects of penetration testing, and start with questions such as

- How can we break in to a system?
- What info do we need?
- Whom can we ask?
- What sources of info can we use?
- What tools can we use?
- What vulnerabilities can we try to exploit?

The goal of the brainstorming session is for the group members to start thinking creatively about ways to attack an unknown computer system. Ideally, after the session each group has a number of different ideas that they can apply in the next phase.

Phase 2: Planning

In this phase, students start with the ideas they collected by brainstorming, and try to find sequences of actions by which they can attack the unknown system. They are encouraged to use all means at their disposal: information on the Internet, course books, experiences from other group members, the list of tools from the workshop introduction, etc. The teachers provide some guidance to help keep each group on the right track.

Each group arranges their sequences of possible actions in a tree-like structure similar to the attack trees of [14], representing possible ways to attack an unknown system. An example of such a tree after an initial brainstorming session can be seen in Figure 1. The root node represents the starting point, and each other node in the tree represents a possible step on the way to attacking the system. During the planning phase, the groups discuss and research possible ways to extend and refine the initial attack tree. When this phase is finished, each group hands in their attack tree.

We believe that the attack tree has several properties that can be useful both for penetration testing, for group work in general, and for assessment. First, organizing attack attempts in a tree can help the students understand their methodology and improve attacks in a structured way, rather than simply trying different methods or tools haphazardly. Second, the attack tree can be used by the group to help facilitate communication and division of labor, e.g., by assigning different branches to different group members. Third, the attack tree both allows and

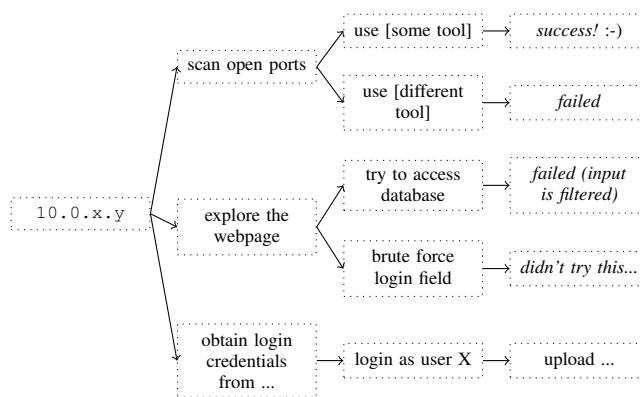


Fig. 2. Example of an attack tree after the practical phase.

encourages the representation of partial attacks, which means they are available for assessment (rather than discarded for being unsuccessful).

Phase 3: Attacks in practice

Using the attack trees as guidelines, students now begin actually attacking the unknown computer systems. During this phase, they also extend and refine the attack trees by noting when attacks fail or succeed, and by adding more actions as necessary. They are encouraged to split up and attack several computers at the same time within the group. An example of an attack tree after this phase can be seen in Figure 2. Here, some leaf nodes represent successful or failed attacks, while others represent partial attacks that are not yet finished.

After this phase, the smaller groups are dissolved, and students gather to discuss the results of the workshop. They share their experiences from brainstorming, planning, and attacking. The following week, the students work in their original group with the full lab.

III. EVALUATION AND RESULTS

The four-hour workshop was not mandatory, but 34 out of 38 students (89%) participated. Approximately half the students attended one day, and half the other day.

We evaluate the workshop in two respects: its implementation and its effects on students. Can we shift the focus from practical (but haphazard) hacking to incorporate more of creatively finding ideas and planning the work?

a) *Implementation*: In order to evaluate the workshop implementation, we used an anonymous questionnaire at the end of the workshop, where we simply asked what was good about the workshop, and what could be improved. We also observed the students during the workshop, how they interacted with each other, and what types of questions they asked. The students recognized the advantage of working in a new group during the workshop: instead of assuming their usual roles in their standard group, they contribute more equally. Different perspectives were seen, and students reflected in their questionnaire responses that they helped in tackling the problems.

Our (informal) observations indicate that most of the students were active in researching possible attack paths. They discussed with each other and drew attack trees together. Questions were mostly asked by the group as a whole, and not by individuals.

b) Effects: Our evaluation of the workshop effects was based on observing the students plans and results in different stages.

We collected the attack trees (a) after Phase 2 of the workshop, (b) at the end of the workshop, and (c) with the hand-in for the finished lab. The initial development during the workshop (a–b) demonstrate the effects of reflecting on the practical work in Phase 3 of the workshop: the trees gain detail, both in depth and breadth, and in descriptions in nodes in the tree (cf. Fig. 1 vs Fig. 2).

We also did a qualitative comparison with the student group of the most recent course instance, focusing on the quality of attempted solutions and approaches rather than only on whether or not the attacks were successful. The solutions in the previous course instance had a greater variation between the stronger vs weaker groups: the weaker groups had narrower approaches, tried fewer alternative solutions, and typically presented less refined solutions. This year, after the workshop, the broader approaches (wider trees) and more refined solutions (e.g. deeper trees) of the current students indicated that they were using strategies similar to those of the stronger students in the previous cohort.

The attack trees in step (c) show that students have broader approaches, but also that more attacks were tried in practice (not always successfully). The previous cohort asked for examples or templates, and had problems when such were not provided. Some students in the current group also asked for walk-throughs or demonstrations, but only at the end of the workshop, not during the following actual lab work.

IV. CONCLUSION AND FURTHER DEVELOPMENTS

We have presented a structured approach to training students in open-ended problem solving, by means of a workshop at the start of a lab period. We combine free brainstorming, graphical planning, and practical experiments.

Although our developments are not completed, our results indicate that the approach has positive effects in at least two main directions: students explore more paths toward the goal, and there is less variance in the student group.

After the workshop, we noted that more students than in previous years tried many different ideas (demonstrated by the broader attack trees) and presented more refined solutions (using deeper attack trees). In general, their behavior resembled that of the more successful students in previous years. This is an indication that the students have become more creative, and a preliminary result similar to what Cropley and Cropley found in their study [7].

Encouraged by these results, we plan to improve the workshop further.

One improvement would be to elaborate the brainstorming phase and give more structure to this “chaotic” creative process. Using the principles of Rossiter and Lilien [13], not much time would be needed for brainstorming, but structure and instructions are more important. In the model of Liu et al [11] which we followed in our workshop, a range of alternatives to brainstorming are presented; some of them, e.g. *idea checklists* or *attribute listings*, could perhaps be applied in our context to encourage students to think of the attacks in new ways. Elaborating further, the brainstorming and planning phases could both be integrated in a case study-like framework to emphasize the connection to real-world problems.

We will continue to use the attack trees as documentation of the students’ ideas, and will thus be able to follow up on how well the creativity training works. One option is to also let the students take a creativity test (e.g. [8]) before and after the workshop and course, to assess their strengths and weaknesses. This could also help emphasizing the creativity aspect, making the students more consciously aware of it. Giving individual feedback on how to behave more creatively, as suggested by, e.g., Cropley and Cropley [7] should also help improve the training.

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Mobile Security Education on Portable Labs

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1. Abstract

Mobile computing has become extremely popular in our daily lives [1] and hence it is an important platform for software developers. Mobile platforms enable students to learn in a modern context when they are used as teaching tools in Computer Science (CS) or Information Technology (IT) education. Meanwhile, mobile security is an important topic in security curricula partly due to the popularity of consumer mobile devices and a shift in computing landscape towards mobile devices' apps development. Due to the rapid demand and popularity of mobile devices [2-3], the security of mobile computing is vital to the growing army of users and for the future of our social, economic and political systems. Hence, it is important and needed to develop hands-on learning materials on mobile security that produce a well-educated and trained workforce, who understands the many concerns of security, privacy, integrity and reliability, and is able to develop strong protection mechanisms and apply fundamental principles and best practices in solving real world problems [4-6]. Many colleges and universities are developing and offering courses on mobile programming and development. However, pedagogical materials based on real world applications running on a portable isolated network are still in infant stage.

2. Significance and Contribution

The Information Assurance and Security (IAS) is the leading national concern, in which mobile security is growing important because of the popularity of mobile devices. It is well known that the best way to learn is by doing it [7-8]. Although IAS had been added as a new core knowledge area in the ACM/IEEE Computer Science Curricula 2013 [9], most universities found difficulties to teaching this subject due to a number of factors including running short of lab resources, lack of faculty expertise, and hard to implement online labs. We propose to develop a series of hands-on learning modules based on a low cost portable lab. The hands-on learning labware design based on the portable lab makes it possible and affordable to offer online lab intensive curriculum on IAS. The significance and contribution of this project is three-fold. First, the learning labware design is based on an affordable portable lab (PLab), which allows online courses to include intensive lab assignments. Second, the isolated network configuration of the PLab provides an independent platform for secure software testing. This isolated network is achieved by USB reverse tethering [10], which connects a laptop and an Android device without other routing devices. Third, the state-of-the-art technology to solving real world problems better prepare students for the demanding workforce. This significance of this topic is

also reflected in the job trends, in which mobile application developers are the best computer job through 2020 [4].

3. Related Work

Despite a number of educational research projects have been proposed to improve curriculum and laboratory materials in mobile security education [11-20, 34-37], to our best knowledge, curriculum or laboratory material development of networking and security based on the PLab-like architecture has not been explored before. Yang et al. has developed a mobile security that covers secure coding, cryptography, security architecture, network security, web security, and security policy and management for faculty capacity building [34]. Wagner et al. developed a content delivery system based on a laptop for security education [35]. Bhattacharya et al. proposed to develop a mobile security curriculum that teaches student mobile threats and protections [36]. Yang et al. developed a module based computer security course and laboratory based on campus networks [37]. Shetty et al. proposed to build a Smartphone Virtual Computing Laboratory (SVCL) for teaching smartphone application (app) security, smartphone operating system (OS) security, smartphone cloud security, and smartphone network security [38].

4. Learning Module Description¹

The proposed labware is designed according to the IEEE/ACM CS 2013 [9]. Each module is independent and self-contained to be easily integrated into existing courses. The labware consists of 5 self-contained learning modules, as depicted in Table 1, and each of which is designed for inclusion in a set of suggested courses. Each learning module may be tailored to accommodate an instructor's need based on content and time of a course. Currently, the network security module is near complete. The rest will be completed within 2 years.

The labware covers fundamental concepts in security and important mobile threats/attacks along with countermeasures. Each module includes pre-lab activities (concept introduction and lab preparation), hands-on lab activities (pairs of hands-on labs on domain concepts and security issues in each subject), and post-lab

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activities (review questions, assignments, and case study). An open repository has been configured to host the labware for wide access and collaboration at <https://sites.google.com/site/iasoncs/>.

Table 1 The Proposed Learning Modules in the Project and its Mapping to IEEE/ACM CS 2013

Module	Topics	Mapped IAS Topics Recommended by IEEE/ACM CS 2013
Network Security	<ul style="list-style-type: none"> Internet protocol (IP) IP Spoofing and countermeasures TCP 3-way handshaking protocol, TCP SYN flood attack, Man-in-the-middle attacks and countermeasures Sniffing and traffic redirection (routing) attack with their countermeasures Network intrusion detection and prevention Cryptography (secure/unsecure channels, attackers and their capabilities, encryption, decryption, keys, signatures, cipher types, public key infrastructure, etc.) 	<ul style="list-style-type: none"> Fundamental Concepts in Security Defensive Programming Threats and Attacks Network Security Cryptography Secure Software Engineering
Database Security	<ul style="list-style-type: none"> Security challenges for databases Access Control(authentication and authorization) Data protection with encryption SQL Injection Attack examples Preventing attacks 	<ul style="list-style-type: none"> Fundamental Concepts in Security Principle of Secure Design Threats and Attacks Network Security Cryptography Web Security Security Policy and Governance Secure Software Engineering
Defensive Programming	<ul style="list-style-type: none"> Secure input validation and output handling buffer overflow attack and prevention Access Control and Confidential Information Injection and Inclusion Accessibility and Extensibility Mutability Serialization and Deserialization 	<ul style="list-style-type: none"> Fundamental Concepts in Security Principle of Secure Design Defensive Programming Threats and Attacks Security policy and Governance Secure Software Engineering

Web Security	<ul style="list-style-type: none"> Web server security (Mutillidae) Web App security Cross-site scripting Custom Application Scripting HTTP/HTTPS Authentication Cookie Manipulation Frames busting Browser security 	<ul style="list-style-type: none"> Fundamental Concepts in Security Principle of Secure Design Defensive Programming Threats and Attacks Secure Software Engineering
Systems Fundamentals	<ul style="list-style-type: none"> Root of Trusts Secure Application Programming Interfaces Policy Enforcement Engine Memory protection hardware (DEP) Instruction set architecture: privileged instruction and dual mode operation Encryption/decryption hardware Assembly programming 	<ul style="list-style-type: none"> Fundamental Concepts in Security Principle of Secure Design Threats and Attacks Network Security Cryptography Platform Security Security Policy and Governance

Though the labs are developed based on PLab, the nature of the network programming and vulnerabilities remain the same as they are applied to other platforms. Therefore, the labware would also help students understand IAS in such platforms.

Network Security Module: This module brings the IAS aspect into the network domain. Our curricular designs focus on the vulnerability of a protocol or a network component. For example, when introducing TCP 3-Way hand shaking protocol, we will also illustrate if an attacker is trying to initiate lots of TCP connections at once, which typically will crash a server, and is known as TCP SYN flood attack. Topics in this module include foundational concepts in network security such as CIA (confidentiality, Integrity, Availability), concepts of risk, threats, vulnerabilities, attack vectors, traffic engineering, and network intrusion detection and prevention.

Database Security Module: This module overviews security challenges for databases such as confidentiality, integrity, and availability. Topics include access control (authentication and authorization), data protection with encryption, SQL injection, attack examples, and preventing attacks. A hands-on tutorial is included for an SQL injection instance, along with techniques in its protection.

Defensive Programming Module: This module provides learning materials that allow students to avoid common security defects, to analyze the relationship between defensive programming and confidentiality, integrity and availability, and to write a secure program. Topics include defensive programming, Secure input validation and output handling, buffer overflow attack and prevention, vulnerabilities in mobile programming, access control and confidential information, mobile malware, restriction on access to components, and isolation of file system and database, injection and inclusion, accessibility and extensibility, mutability, and serialization and deserialization.

Web Security Module: Web application development is one of the popular jobs for CS/IT graduates. The Web security model will educate students in understanding root causes of web-based attacks, countermeasures for those attacks, and secure web application development. Topics include overview of Web App security, web-based threats such as user interface impersonation, client side attacks, server side attacks, security policy and governance such as secure browser, cross-site scripting, custom application scripting, HTTPS, authentication, cookie manipulation, and frames busting.

Systems Fundamentals: This module aim to provide IAS learning materials from the systems perspective, including hardware, application programming interface, and operating systems. According to the guidelines on hardware rooted security in mobile devices, mobile devices are required to implement the following fundamental security primitives: roots of trust, an application programming interface (API) to the platform, and a policy enforcement engine. We believe it is important to verify these primitives' integrity with hands-on experiments. Another focus in this module is low level programming (assembly programming in X86, ARM, or MIPS), and software reverse engineering, which are mandatory requirements for designation as a center of academic excellence in cyber operations by National Security Agency. Spyware will be exercised in this module along with its countermeasures. We will demonstrate and analyze a sample malicious application using OllyDbg and IDApro.

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6. Conclusion and Future Work

The advancement in mobile devices makes them a perfect instructional tool. This project aims to develop a new, portable, affordable, isolated networking platform (PLab) with easily-adoptable modular labware by making use of the existing mobile devices to enhance networking and security education. This real world relevant labware content can be easily integrated into multiple existing CS/IT courses. The goal of this project is to use mobile device based computer network labs to help students better understand networking and security fundamentals via hands-on practice and immersive experiences. Modern mobile smart devices are playing more and more important roles in all aspects of our society nowadays. It is essential for computer science undergraduate students to be exposed to the concepts of wireless mobile networking and security. We have successfully implemented critical components in the PLab such as reverse tethering, and network programming interfaces with preliminary learning modules developed and tested. In the future, we will be working on the rest of the learning modules including labs and real world projects.

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Special Session: Introduction to Systematic Reviews in Engineering Education Research

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Abstract—Systematic reviews are a new, fundamentally different approach to synthesizing engineering education research. The primary goal of the session is to increase the awareness and knowledge of engineering educators about systematic review methods. Systematic review methods, widely used in fields such as medicine, psychology and education, have only recently been applied in engineering education to analyze the state of the art. The paper presents steps to illustrate processes involved in a systematic review, sources of standards for systematic reviews, and strategies for information retrieval.

Keywords—literature; synthesis; review

I. INTRODUCTION

One of the characteristics indicating progress in a field in science and engineering education is the development of distinctive theories and other syntheses of the field that provides foundations for further development [1]. In engineering education, the most common form of synthesis has been the narrative review. Multiple notable examples of narrative reviews and the methodologies used to perform them exist in engineering education literature [2-6]. In this session, we present an alternative type of methodology, termed “systematic review,” which has been and is being frequently used in fields of such as medicine, psychology, education, and medical education. Systematic reviews are a new, fundamentally different approach to engineering education. Despite its broad use in another fields and potential utility to enhance engineering education research, many researchers are not familiar with methodologies associated with systematic reviews. Therefore, this special session will provide participants with an introduction that will (within the

constraints of a special session) enable participants to decide how appropriate systematic reviews are for their work and to formulate approaches to developing a systematic review. The session will also describe roles of meta-analysis within systematic review, and how systematic review is different from other approaches to literature review or meta-analysis.

II. GOALS AND OBJECTIVES

The primary goal of the session is to increase the awareness and knowledge of engineering educators about systematic review methods. Specifically, participants will be able to:

- Describe the benefits of systematic review and the differences between systematic reviews and other types of literature reviews
- Locate recent systematic reviews on engineering and computing education topics
- Describe the basic sequence of steps in conducting a systematic review
- Develop a preliminary plan for conducting systematic review on a topic relevant to their own research
- Identify librarians and other prospective collaborators for conducting a systematic review
- Locate resources for additional guidance on conducting a systematic review
- Describe how to talk with librarian about documentation needs for review

III. DESCRIPTION

Systematic review refers to a growing set of research methodologies that critically appraise and synthesize research to inform policy and practice. Systematic review methods, widely used in fields such as medicine, psychology, education and medical education, have only recently been applied in engineering education to analyze the state of the art [7]. In our prior work, we have identified high quality systematic reviews on engineering and computing education topics that may be of interest to FIE conference attendees [7]. These serve as examples of how systematic review methods can be applied in engineering and computing education. In this session, we will use examples from [7] to familiarize participants with systematic review methods. Specifically, participants will work in small groups to complete an exercise that utilizes a form structured according to the systematic review process to learn details of a published systematic review. Through this exercise, participants will become familiar with various key aspects of conducting a systematic review, such as search terms, selection criteria, and number of studies identified. Then, participants will develop their own ideas for additional topics appropriate for systematic review and work together to develop preliminary plans for conducting a review.

IV. SESSION AGENDA

Table I shows the agenda for the special session.

TABLE I. TABLE I. AGENDA OF PARTICIPANT ACTIVITIES

Time (minutes)	Activity
5	Participant and presenter introductions
10	Introductory presentation
30	Small Group Activity: Participants will evaluate existing systematic reviews using the Campbell Collaboration Education Coordinating Group Systematic Review Checklist [8]
15	Small Group Activity: Participants generate potential ideas for systematic review topics
15	Small Group Activity: Participants develop questions, search terms, and inclusion/exclusion criteria for a specific systematic review topic
10	Generate next steps including: potential collaborators, potential funding sources, and publication venues
5	Report back and wrap up

V. STEPS IN A SYSTEMATIC REVIEW

The following steps in a systematic review are intended to illustrate the process; they are not intended to be definitive in the sense that alternative processes would not be appropriate. The steps are taken from an introduction to systematic reviews for engineering education [9].

- (1) **Deciding to do a Systematic Review:** Quantity, quality, and accessibility of primary studies will determine whether a systematic review is feasible. Preliminary searches, sometimes referred to as scoping searches, can be done to estimate the quantity of primary studies as well as locate related reviews to determine the novelty of the proposed review question and as well as potentially situate its contributions in the context of prior work.

- (2) **Identifying Scope and Research Questions:** Like other research methodologies, formulating research questions is a crucial step that influences many of the subsequent decisions. The guidance for formulating research questions for a systematic review is similar to the guidance for any research study.
- (3) **Defining Inclusion Criteria:** Unlike research methodologies that generate empirical data, empirical data for a systematic review are studies that have been done. The purpose of this step is to decide the characteristics of primary studies to be synthesized.
- (4) **Finding and Cataloging Sources:** Searching literature databases (see following section) provides a main approach to locating primary studies that are candidates for the set of studies that will be synthesized.
- (5) **Selecting Primary Studies:** Once potential primary studies have been identified, researchers apply the inclusion (and exclusion) criteria to construct the set of primary studies that will be synthesized.
- (6) **Critique and Appraisal:** “After the primary sources have been selected, identified, and sorted, the next step is to systematically assess the quality of each primary study” [9].
- (7) **Synthesis:** Although presented here as only one step in the systematic review process, this step will occupy a considerable amount of time in the systematic review process. Scope of this introductory article does not allow space to explore methods and options for this step.
- (8) **Limitations, Validity, and Reliability Concerns:** Systematic review, like any research methodology, has limitations. These limitations, as well as threats to validity and reliability of the systematic review should be acknowledged.

VI. STANDARDS AND GUIDES

There are three important organizations which provide standards to consider when conducting education-related systematic reviews:

- Institution of Education Sciences developed a website, What Works Clearinghouse, that collects and promotes systematic reviews [10].
- Campbell Collaboration is an international non-profit organization that seeks to provide a forum and guidance for education, criminal justice, and social work.
- Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement provides a checklist of items to report when publishing a review as well as flowchart. Although this developed in medicine, its terms are generic enough to match any discipline [11].

VII. INFORMATION RETRIEVAL STRATEGIES

When searching for studies, there are several strategies that can be utilized, with the most important being bibliographic databases. Table II shows a sample of the bibliographic databases that could be used for engineering education research. The Campbell Collaboration provides a policy brief providing a longer, more detailed list [12].

TABLE II. LITERATURE DATABASES

Database	URL
Interdisciplinary	
Academic Search Complete	https://www.ebscohost.com/academic/academic-search-complete
JSTOR	http://www.jstor.org/
Subject specific	
Compendex	http://adat.crl.edu/databases/about/compendex
ERIC	http://eric.ed.gov/
Education Full Text (EBSCO)	https://www.ebscohost.com/academic/education-full-text
PsycINFO	http://www.apa.org/pubs/databases/psycinfo/
Citation tracking	
Scopus	http://www.scopus.com/
Web of Science	http://wokinfo.com/

Each database has a set of fields, e.g., title, abstract, body, and author that can be searched by keyword. Complex search strings can be composed by using logical connectives (e.g., AND, OR), wildcards, and database-specific functions to limit returned articles to the ones most likely to help address your research. Here is an example of a search string that was used in ERIC to search for systematic reviews related to engineering education :

Search String: ((SU.EXACT.EXPLODE("Engineering Technology") OR SU.EXACT.EXPLODE("Engineering") OR SU.EXACT.EXPLODE("Engineering Education")) OR all(engineer*)) AND (SU.EXACT.EXPLODE("Meta Analysis") OR ti(review) OR abs(("systematic review" OR "meta analysis")))

To use some of these databases, participants may need to gain access through their institution's library. Collaboration with librarians skilled in systematic review methodologies considerably facilitates the process, giving the ease and power with which your research team can find relevant databases and construct appropriate search strings.

Additional search methods include citation searching, requesting studies, hand searching, and unpublished studies. Citation searching involves searching through references of included and relevant articles and those articles that cited the selected articles after publication. Requesting articles is conducted by posting the description of the review and inclusion criteria to appropriate sites or listservs. Hand searching is the manual browsing of selected journals and conferences abstracts that are not well indexed by

bibliographic databases. Unpublished studies, sometimes referred to as grey literature, can be searched through institutional repositories, government documents, dissertation and theses databases, the Internet search engines (Google Scholar) and specific grey literature databases.

VIII. ACKNOWLEDGMENT

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Exploring the Black Box of Dissemination

The Role of Professional and Organizational Development

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Abstract— The field of engineering education has initiated a focus on ensuring engineering education research is disseminated and implemented within the classroom. Numerous researchers have investigated the reasons for the adoption of evidence-based practices, or, more often, the lack thereof. The Professional and Organizational Development (POD) network community is an underutilized potential ally for ensuring the implementation of engineering education research due to their focus on organizational change and improving teaching practice. Using the Diffusion of Innovation framework and best practices for adoption, this session will guide faculty in envisioning a wide variety of channels for moving engineering education research into the classroom. Participants in this special session will brainstorm ways to encourage collaboration between these two communities culminating in a "message in a bottle" to the POD community to help them understand the activities and needs of engineering education researchers. This message will be delivered to faculty development professionals, centers for teaching and learning, organizational change specialists, and others in the POD community at their annual conference in November 2015.

Keywords—*Faculty development; dissemination; professional and organizational development*

I. GOALS OF THE SESSION

Through this session, we hope to enhance the connection between engineering education research and the day-to-day teaching practices of university instructors. Specifically, we will pose the Professional and Organizational Development (POD) network community (which includes Educational Development Offices, Centers for Teaching & Learning, etc. as well as a national organization linking such centers) as a venue whose existing initiatives provide opportunities to disseminate engineering education research to a wide variety of faculty members. Participants will leave with concrete methods and contacts for engaging the POD community in their own research-to-practice efforts.

II. DESCRIPTION OF TOPICS/SUBJECTS/CONTENT OF SESSION

Over the past several year, creating a seamless research-to-practice cycle has been a central focus within the engineering education community [1, 2]. In this time period, numerous researchers have investigated the reasons for the adoption of evidence-based practices, or, more often, the lack thereof [3-

9]. Using the Diffusion of Innovation framework [10] and best practices for adoption, this session will guide faculty in envisioning a wide variety of channels for moving engineering education research into the classroom.

Specifically, the facilitators will guide the participants in a brainstorming discussion around the following scenario: you are writing the job description for 1-5 new hires that will disseminate your engineering education research group's results into engineering education practice. What would you want that position to look like? What specific requirements would you include? What would the new hire(s) need to be able to do for which communities? What shouldn't be in the job description?

Having articulated the "ideal" setup for a "dissemination position" as a group, we will then investigate what the Professional and Organizational Development ("POD") community offers while highlighting any overlapping features. Participants will explore their knowledge of local and national POD resources (campus Centers for Teaching and Learning, etc.) and work to create a plan to engage with them. During these discussions, participants will also collaboratively create an "FIE message-in-a-bottle," a time-capsule-like snapshot of the current work, needs, and concerns of the engineering education research community. This message-in-a-bottle will be opened several weeks later during a linked session at the 2015 POD Network conference, and used to start a dialogue with professional and organizational development professionals there.

III. SESSION AGENDA

(0-15 min) **Icebreaker/Community Building:** An important element of adoption is knowing your audience and their needs. To begin this process, the session will open with an icebreaker activity to help identify the different levels of experience that are present at the session. We are hoping to engage a variety of participants with varied levels of experience with POD or similar communities. Following the group icebreaker, participants will be divided into small groups so they can get to know each other better; creating social connections can also aid in the adoption of new ideas and practices.

(15-20 min) **Introductions:** Facilitators will briefly introduce themselves and the goals and schedule of the session.

(20-35 min) **Inspired Brainstorming:** Small groups will be given the “write a job description” scenario previously described. Guided by facilitator-provided discussion questions, each group will create a list of desired “features” for the hypothetical new hire(s). Each feature should be supported by a specific need of at least one person at the table. Every need and its corresponding feature/solution will be written on a separate notecard. Two examples are shown in Table 1.

Table 1: Examples for the Inspired Brainstorming

Feature(s)	Underlying Need
<ul style="list-style-type: none">• The new hire(s) would continuously offer lunch seminars on my campus that are based on my research on teaching.• They would be available for 1:1 chats with curious faculty.• They would let me know about new insights/observations that pop up in those conversations.	<ul style="list-style-type: none">• Colleagues know I do research on engineering teaching, and they keep asking me the same questions on how to apply it, even after reading my papers. I feel like I’m having the same conversations over and over again, but my colleagues genuinely need to talk with somebody about this.
<ul style="list-style-type: none">• The new hire(s) would curate an annual summary for practitioners that explains how to apply the education research generated by my institution, not just my group.	<ul style="list-style-type: none">• I want something to hand out at technical conferences when people ask me about teaching.• I don’t know what other education research groups on my campus are doing. Maybe I could apply their work to my teaching, too.

(35-50 min) **Feature request synthesis:** Without speaking, participants will carry their table’s “features” and “needs” notecards to the front of the room, and synthesize them into one large table of features/needs by merging/clustering their ideas with the ideas from other tables. Tape will be provided. (If there are too many participants to do this as one large group, we will split into 2-3 large groups.)

(50-60 min) **Presentations and discussion:** Each large participant group will present/explain their synthesis to the room in 90 seconds or less. These will be used to start a whole-room discussion.

(60-65 min) **Presentation of POD resources:** Facilitators will briefly explain the POD network and some of the resources they offer, as well as examples of POD groups (Centers for

Instructional Excellence, etc.) working specifically with engineering education. Diffusion of Innovation (Rogers, 1995) will be used to highlight the benefits of using these new resources for dissemination. Dearing’s list of “Top 10 dissemination mistakes” (2009) will also help to highlight the benefits of bringing in POD resources to aid in dissemination.

(65-80 min) **Development FIE “Message-in-a-bottle”:** Participants will discuss the group feature map and think of potential overlaps between their group’s 5 most important features and potential or existing POD resources. The groups will also be asked to make a list of the top 5 most important things about engineering education that they would like to be shared with POD practitioners.

(80-90 min) **Unlocking the Black Box of Dissemination Debrief & Wrap Up:** Groups will share their lists, followed by a short wrap up by the facilitators.

IV. BRIEF DESCRIPTION OF PROPOSED PEER-REVIEWED FULL PAPERS FROM SESSION PRESENTERS

Mel Chua is a PhD candidate in Engineering Education at Purdue University. She was a POD Donald H. Wulff Diversity Fellowship in 2014. She has studied conceptual change in engineering faculty workshop participants [11, 12] and the teaching practice shifts of computing professors working with open source communities [13, 14]. Her ongoing dissertation portrays engineering and technology faculty as learners within their own narratives of large-scale, design-centered curriculum revisions.

Alexandra Coso Strong graduated from Georgia Tech in May 2014 with a Ph.D. in Aerospace Engineering. Her dissertation focused on the development and implementation of tangible tools that faculty could use to support students’ understanding of design in a senior design capstone course. She is currently an assistant professor of systems design and engineering at Olin College. In 2014-2015, she was a postdoctoral scholar in Georgia Tech’s Center for Excellence in Teaching and Learning where she works closely on programming to support graduate students as they prepare for academic careers [15]. She has been an active member of ASEE since 2008 [16] and attended her first POD Network Conference in 2014.

Stephanie Cutler graduated from Virginia Tech in May 2013 with her PhD in Engineering Education. Her dissertation research focused on faculty adoption of research-based instructional strategies [7, 8, 17]. She currently works for the Rothwell Center for Teaching and Learning Excellence at Embry-Riddle Aeronautical University’s Worldwide campus. She presented at the POD Network conference in 2014 regarding her Center’s work on helping faculty to adopt inquiry-based learning [18].

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Transitioning Students Navigating Engineering Identities

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Abstract— How do transitioning underrepresented minority (URM) students evaluate their engineering ability? To investigate this question seven students in a summer pre-college program provided insight on their confidence in their abilities and were asked to recollect the experiences which helped them make sense of these developing identities. As part of a larger study to investigate the impact of a Midwestern University's Minority Engineering Program's (MEP) impact on the success of its participants, the objective of this component of the study is to qualitatively explore the experiences of Academic Boot Camp (ABC) participants throughout their first year in college. Participants of ABC are students who have been accepted to the University's college of engineering and intend to enroll at the University in the fall semester. ABC is a rigorous five week program which simulates the students' first semester course work to support the students' transition from high school to college. The purpose of this paper is to explore the diverse ways that URM students, who are transitioning into a college engineering program, perceive their confidence in their abilities using Figueiredo's (2008) quadrant of engineering epistemologies. In this study, the engineering epistemologies are also considered engineering identities. Based upon data gathered from the interviews and from the research team's interactions with the students, we can infer that their participation in the Academic Boot Camp supports the students' goals. For these students, goals typically include developing time management strategies, mastering course material, learning and exposing oneself to engineering skills and habits, successfully transitioning from high school to college and remaining true to one's identity. The findings from this study may not only provide qualitative support for the impact of the Minority Engineering Program and its Academic Boot Camp but may also provide insight into ways engineering educators can support the development of both the students' individual and engineering identities.

Keywords—Engineering Identity; Transition Programs; Underrepresented Minority

INTRODUCTION

How do transitioning underrepresented minority (URM) students evaluate their confidence in their engineering ability? To investigate this question students in a summer bridge program provided insight into their perceived abilities, their engineering identities and were asked to recollect the experiences which help them make sense of these developing identities.

As students are transitioning from the high school environment to the college engineering environment, almost

all students face challenges[3]. However, in addition to those commonly experienced challenges URM students face additional obstacles which may cause them to differ in the way they view themselves and their abilities Such as racial identity issues, isolation and academic under preparedness [4-7]. This paper will focus on these students at the moment in time when they are initially transitioning from high school to the college of engineering at their Midwestern University, via a summer college prep program.

The research question guiding this study is: How do incoming first year engineering students perceive their confidence in their engineering abilities? The purpose of this paper is to explore the diverse ways that URM students, who are transitioning into a college engineering program, perceive their abilities using Figueiredo's [1] quadrant of engineering epistemologies (what engineers know and how they know it). In this study, the engineering epistemologies are also considered engineering identities. A recent study has shown that summer programs like the Academic Boot Camp ABC can have a positive impact on participants' perceptions of their engineering identities[2]. The findings from this study may not only provide qualitative support for the impact of the Minority Engineering Program and the Academic Boot Camp but may also provide insight into ways engineering educators can support the development of both the students' individual and engineering identities.

BACKGROUND

As part of a larger study to investigate the impact of a Midwestern University's Minority Engineering Program's (MEP) impact on the success of its participants, the objective of this component of the study is to qualitatively explore the diverse ways that incoming college engineering students perceive their engineering abilities. The participants of this study were members of an incoming cohort students who have been accepted to the university's college of engineering and intend to enroll in the fall semester. The participants attended the Academic Boot Camp (ABC) ahead of the start of the semester. The ABC is sponsored by the MEP and is a five-week simulation of the first semester, where students take non-credit bearing courses in STEM and learn engineering using a project based learning approach. They are introduced to the campus and its resources and are engaged in professional development through networking with alumni and future peers[8].

PERSPECTIVES

How does one make sense of the transitioning student's developing engineering identity? This following discussion will address perspectives of development and cognition which relate to self-efficacy, motivation, identity and engineering epistemology.

Chemers, Hu and Garcia [9] conducted a longitudinal study on students over the course of their first year in college. The data show that students with high self-efficacy have high academic expectations and the high academic expectations positively impacted the students' academic performance. These findings support Chemers et al. [9] claim that individuals who set specific and difficult goals usually perform well. By setting goals individuals are creating standards of performance and therefore exhibiting the motivational effects of having a positive self-efficacy.

With respect to engineering skills and knowledge, students' goal setting behaviors may align with their perception of their identity. In many arenas engineering and science have competing identities, rather than simply comparing engineering and science behaviors, attitudes and skills, Figueiredo [1] offers a different characterization of engineering. He presents the essence of engineering as operating in four dimensions as illustrated in Fig. 1. Figueiredo, as cited in Adams et al. [10] suggests that as engineering educators who engage future engineers, we must allow them to experience the "unique identity of engineering" and the various combination of its four dimensions. Students can learn to work within and across these dimensions even as they are developing their own engineering identity.

Due to the strong academic records of the participants, the Academic Boot Camp under study uses a model that focuses on transition as opposed to academic remediation. Dickerson et al. [11], conducted a study which supports that programs such as ABC positively impact its participants in areas such as first semester retention and academic performance, as well as on social, emotional, and affective dimensions. Stolle-McAllister [12] contends that transition focused bridge programs are particularly helpful in assisting the students navigate their identity by raising their social capital. Through summer pre-college transition programs students develop community and networks on and beyond campus which they can access as they develop as individuals and as engineers. This supports successful academic transition from high school to college.

It is also important to note the role of intersectionality in this study. Participants in this study may be affected by both their race and gender in complex and interconnected ways. In addition to the common hurdles that transitioning students face, students who are members of 2 or more underrepresented groups often face increased challenges due to their race/ethnicity or gender. Factors such as: "gendered stereotypes, pedagogical techniques, limited exposure to technology and role models, which may lead to lower academic preparation for STEM disciplines, work in tandem and serve as obstacles for minority women[13]. Furthermore, compared to their representation in the United States

population, African American and Latina women are underrepresented in STEM. This may lead to isolation and academic difficulties during the college transition and matriculation, unless these students are supported appropriately.

METHODS

Throughout the participants' five week ABC experience, the research team engaged with the students in diverse ways in order to establish rapport[14]. At camp registration, the research team provided information about the study along with performing onsite interviews. Once each week, the interviewer co-lead a workshop focused on developing self-discipline. This allowed for engagement with the students and allowed the students to feel comfortable volunteering for interviews throughout the camp. Student-researcher interaction was also helpful because this is the first phase of an on-going study with the same population of students.

The relationship formed between the students and the research team, helped to make their interviews more accessible. Students appeared more comfortable sharing this information as they had increased encounters with the interviewer. The interviews were designed to take 10-15 minutes. The actual time spent interviewing varied with the amount of information the students shared.

Participants were informed that they would be participating in a self-guided video recorded interview but that the researcher may have additional follow-up questions. The interview protocol invited students to respond to questions related to campus resources, their confidence in their abilities and what they hoped to learn from their experience during the ABC.

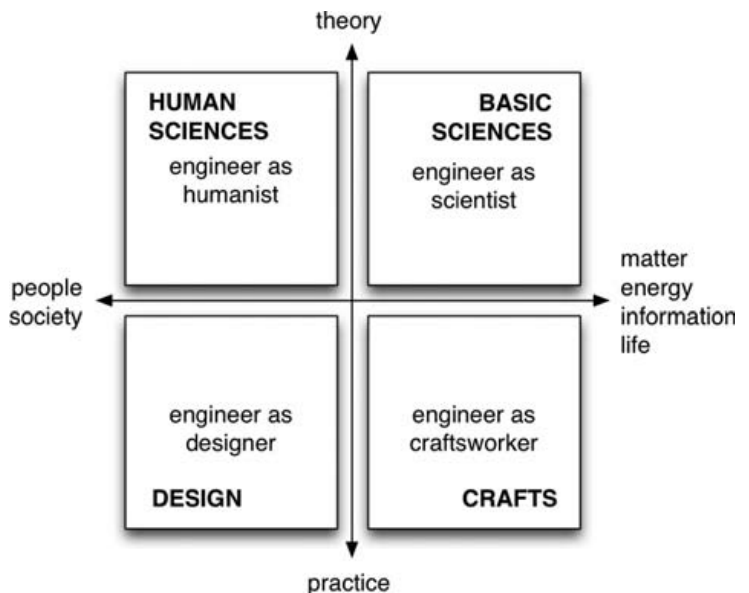


Figure 1. Four dimensions of engineering

RESULTS

Seven students volunteered to be interviewed. Each student responded to seven questions related to their expectations for the program, resources available to them on the Midwestern University's campus and their confidence in their abilities along the four dimensions of engineering epistemology. The results discussed in this paper will specifically address the initial findings from the students' responses to the following questions:

Q1. On a scale from 0 – 10, (where 0 is not confident at all and 10 is extremely confident), how confident are you in your ability to do [basic and natural science, human science, open ended tasks or craft work]?

a. What experiences led you to rate yourself that way?

Q2. Order the four categories below from 1 to 4, with 1 being the category you enjoy most or most, excel at and 4 being the category you least enjoy or least excel at.

a. Craftwork

b. Human Sciences

c. Design

d. Basic/Natural Sciences

The students' ratings for each of the identities (categories), which they most and least excel/enjoy, are tabulated in Table 1. Statistical analysis was not performed in order to determine statistical significance; however, the differences may surface from the students' responses to the follow-up question: "What experiences led you to rate yourself that way?"

The research team provided descriptions of each engineering identity in the interview protocol, which the

students read. The engineer as scientist identity was described as basic and natural sciences were represented as logic, analysis, math, physics, chemistry and biology. Human sciences abilities, which represent the engineer as humanist, were described as including social sciences, business, communication and political science. The engineer as designer identity from Figueiredo's quadrant was characterized by open-ended tasks with more than one solution, synthesis, creativity, innovation. Engineer as a craftwork was characterized by the students' confidence in their ability to craftwork, including physically making or building things, drafting and art.

On average, the participants had higher confidence in their ability to do craftwork and use basic sciences. This is consistent with their academic backgrounds. Students who choose careers in engineering and science often state that they were good in the basic sciences (i.e. logic, analysis, mathematics, physics and chemistry) or told that were good at craftwork (i.e. physically making or building, art and drafting). The two categories represent common narratives used to suggest that students have engineering potential. Often in high school classrooms and in extracurricular activities, engineering is not perceived as something that relates to the human sciences (i.e. social science, business, communication) and students are often given closed ended design tasks. This might contribute to the participant's lower overall confidence rating in these two identities. This idea is demonstrated in the following excerpt:

I am able to find a solution to a task that is given to me. I feel that the way that I have been taught in school growing up, that they always give you a worksheet to go through as a path that they give you. So I will probably end up struggling with open ended tasks where it's not a clear path- Darek

			Rating from 0-10 (where 0 is not confident at all and 10 is extremely confident)				Most Excel	Least Excel
Participant Pseudonym	Gender	Ethnicity	Basic Sciences	Human Sciences	Design	Craftwork		
Catalina	Female	Hispanic	6	7	8	5	Design	Craftwork
Jennifer	Female	Black	5	5	5	7	Design	Basic Sciences
Michele	Female	Black	7.5	8.0	5	5	Basic Sciences	Design
Andres	Male	Hispanic	8	7.5	6	9	Basic Sciences	Craft Work
Damon	Male	Black	8.5	7	9	10	Craftwork	Human Sciences
Darek	Male	Black	8	7	7	7.5	Craftwork	Design
Jacob	Male	Black	5	6	7	6	Design	Human Sciences
Overall Average			6.9	6.8	6.7	7.1		
Female Average			6.2	6.7	6.0	5.7		
Male Average			7.4	6.9	7.3	8.1		

Table 1. Students' self-reported rating on Figueiredo's four dimensions of engineering
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Across all four identities, female participants rated themselves lower than their male colleagues. For some of the students, external factors and lack of previous experience and exposure led them to have lower perceived confidence. Catalina's response supports this idea:

Because I went to a small all-girls school in Houston and I think it was mainly focused towards the liberal arts especially like in English and social studies. And it is slowly trying to gear its way into the STEM fields but it still isn't all that way [yet]. ..I would say the school I went to was mainly geared toward the liberal arts and I have really been prepared that way.

Catalina's (and the other female participants') lower confidence is supported by literature which suggests that women exhibit lower self-confidence than men in achievement settings. However, this does not mean that they actually have lower achievement [15].

Students also shared experiences that led them to have lower confidence in these identities. They expect that the ABC and additional engineering experiences will help them overcome these deficiencies. Andres and Michele shared their past challenges with open ended tasks and are able to identify their strengths as well:

I am a really creative person and I do like finding solutions to things that have more than one answer but I do tend to bog down...every idea I had I would just shoot it down – Andres

I don't have any creative ability, really at all. I'm more of a give me [how to] structure it the way it's supposed to be and I'll do it. But if I have to structure it myself, and come up with the ... design and aspects [then] I struggle with that a little bit. So I have to go and ask for help...I can't just come up with it on my own. – Michele

Throughout the interview students provided experiences that supported their confidence with respect to specific engineering identities. For example Darek reflects on his logical nature as he discusses his confidence in his basic and natural science ability:

In terms of logic and analysis, I always found myself as a logical person and always find efficient ways to get things done...Math is kind of the result of logic and analysis.

The students in this study were members of the 2014 college of engineering cohort of first-year engineers. How might these students' most and least excel or enjoyed categories compare to other members of their cohort? All students (N=106) in one section of an introductory engineering course (ENGR 131) were asked: "Which category do you enjoy most/least or most/least excel at?" The results are as follows. Most excel: Basic Sciences (48%), Craftwork (26%), Design (22%) and Human Sciences (4%). Least excel: Human Sciences (70%), Craftwork (19%), Basic Sciences (6%) and Design (6%).

Although, the number of participants in this study is a limitation to doing direct statistical comparisons between the groups, the ABC students do appear to represent the 2014 cohort. At first glance there appears to be a difference between the 2014 cohort and the ABC students' experiences with design and craftwork categories. This difference would best be investigated with a larger ABC population and could be a potential direction for future work

SIGNIFICANCE

This study is phase one of a recently launched effort to measure the impact of the Academic Boot Camp on its participants. The objective of this work is to investigate student experience in the program and help to provide qualitative evidence for the impact that this summer bridge program has on the students' transition and identity development. Although more data will be collected, from the available data it appears that students choose to participate in ABC because it will help them accomplish academic, personal and professional goals. This may be an indicator that the students have academic expectations which could lead to high academic performance. Students clearly articulate that they believe MEP and their experience in the Academic Boot Camp will provide them with knowledge or skills which they can apply as they transition to college.

Based upon data gathered from the interviews and from the researcher's interactions with the students, we can infer that their participation in the Academic Boot Camp is aligned with the students' cognized goals. For these students, goals typically include developing time management strategies, mastering course material, learning and exposing oneself to engineering skills and habits, successfully transitioning from high school to college and remaining true to one's identity.

To the transitioning student, retaining their identity even while navigating the college and engineering identity is a concern for the students. Although these students may express deficiencies, their academic backgrounds indicate that these students have strong potential for success in the college of engineering. These participants believe that with practice, the areas of lack can be strengthened. The diverse ways that students perceive their engineering identities may impact the ways that they engage in classroom tasks and activities. As students contend with competing identities and recognize their strengths and weaknesses across the engineering epistemologies, it is important that curricula and programs are designed to support their development across all four dimensions of engineering identities.

ACKNOWLEDGMENT

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Is changing pedagogy a good bait in attracting students to engineering?

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Abstract— In line with the new policy on pedagogical innovation adopted by Victoria University (VU) Policy in 2005, engineering schools at VU decided to introduce Problem-Based Learning (PBL) into their undergraduate engineering programs. It was hoped that such an action would attract more students to engineering courses at VU with higher equivalent national tertiary entry ranking (ENTER) cut off scores, be more attractive to girls and therefore address the predominating gender imbalance in engineering professions. The introduction of PBL was followed by intense publicity in secondary schools and vocational colleges. The management of both engineering schools at VU decided base their PBL model on one adopted on and used for a number of years at Aalborg University in Denmark. The initial implementation begun in some subjects in 2006 and by 2007 half the subjects in engineering curricula were designated for PBL delivery. Yet, despite the substantial investment in human resources and capital dedicated to the construction of PBL learning studios, there was little to show for the investment. There was a relatively little increase in popularity in attracting greater number of students to engineering at VU, which in terms of attractiveness remaining lowest in the packing order among engineering education providers in Melbourne. The proportion of girls selecting VU engineering as their course of study remained low. Surveys taken since 2008 among second year engineering students were part of a study to determine students' perceptions and motivations for choosing engineering as their course of study, and choosing VU engineering. The study hoped also to explore the effect PBL had on popularity of studying engineering at VU. This is the subject of this paper. The survey results revealed a mixed-bag. There was some good news. Over the seven years, the awareness of PBL at VU amongst final year secondary students has risen. More students indicated that knowledge of PBL would be more likely to attract them to VU engineering than act as a disincentive. It must also be noted that almost half of students were neutrally disposed towards PBL. Despite the liking PBL pedagogy, large proportion of students felt preferred the subject delivery was to be done in more traditional pedagogies. It suggested that students liked constructivist approaches within a more accessible framework. The relative high proportion of students indicating their desire to transfer to another university or course is a concern and needs to be addressed by the curriculum planners.

Keywords— *Engineering pedagogy, engineering attractiveness, problem-based learning*

I. INTRODUCTION

In contrast to other 1 courses for professions such as medicine, dentistry and law, students entering engineering education have diverse range of Australian tertiary admission ranking (ATAR) scores. Victoria University (VU), sited in the lower socio-economic western Melbourne regions, attracts students with lower cut off ATAR scores for most its courses, including engineering, than the other universities in Melbourne. The lower ATAR scores translates into having a relatively high proportion of students entering engineering at VU being ill-equipped for university studies. The lack of inadequate knowledge base in fundamental sciences and mathematics and poor communication skills has a profound effect on course standards and student attrition rates.

The decision by the university in 2005 to introduce a new pedagogical paradigm was driven by the desire to reduce the relatively high attrition rates and improve the attractiveness of VU as a study destination. It was also hoped that these changes would also address external perceptions of poor academic standards, and allow the university to reposition itself in the student market. It was hoped that such educational shift would assist in raising the profile of VU engineering and lead to:

- Educational differentiation from other universities translating into greater interest among senior secondary students to consider engineering as a course of study at VU;
- Generating greater interest in engineering among senior secondary students. This may lead to a greater participation in engineering education at all universities and address concerns of current and future shortages of professional engineers in Australia [1],[2];
- Enhancement of professional graduate attributes such as the ability to work in teams and autonomously, communication skills and social awareness, ability to contextualize engineering work in terms of economic, sustainable, social, ethical and political frameworks

and instil good habits of life-long learning-curiosity;
and

- The reduction of attrition rates and the improvement of progression rates in engineering at VU. Approximately 10-12% of undergraduate engineering students at VU complete their course in the minimum time. Poor completion and retention rates of domestic engineering students have been of particular concern [2][3].

In 2006 problem-based learning (PBL) pedagogy was introduced in 50% of curricula at both engineering schools at VU. This was immediately followed by an extensive publicity and marketing campaign in the press and at secondary schools throughout Melbourne. Whereas prior to 2006 the marketing of engineering at VU was largely based on course offerings, the new and more intensive marketing included pedagogical differentiation as a selling point. The objective of this project is to ascertain the effectiveness of the marketing campaign and evaluate whether any positive outcomes could be attributed to either pedagogical differentiation or just increased marketing of engineering courses at VU.

II. METHODOLOGY

The enquiry used a simple questionnaire shown below to evaluate:

1. Reasons why student pick engineering as their choice of course of study among their two top initial preferences prior to the change of preference period. Latter student preference selections are likely be influenced by students' academic outcomes.
2. Students' preferences of choosing VU engineering among the first cycle of selection of preferences.
3. Students' awareness of PBL delivery prior to their selection of primary preferences and its influence on choosing VU engineering.
4. Students' attitudes to PBL delivery and how such attitudes affected their likelihood on continuing with their course.

The investigation was restricted to domestic students in the School of Architectural, Civil and Mechanical Engineering and relied on, with one exception, to 30 to 90 responses. School of Electrical and Electronic Engineering was ignored in the survey because of its low domestic student enrolment. The survey based on the questionnaire shown in Table A was restricted to first semester second year students because they were already well exposed to PBL teaching and were still in position to make a decision concerning their future academic path. Surveys were conducted in weeks 8-9 of the semester during common classes such as solid mechanics or materials technology.

TABLE A. Student questionnaire

(Tick the appropriate answer)	
Did you place engineering as a preferred course prior enrolling at VU? (Was engineering amongst your top two preferences?):	
<input type="checkbox"/> Yes	<input type="checkbox"/> No
Was VU amongst your first two preferences (before change of preferences) on your selection of university 6 months before enrolling at VU?	
<input type="checkbox"/> Yes	<input type="checkbox"/> No
Were you aware of PBL pedagogical course delivery in engineering course delivery prior to enrolling at VU?	
<input type="checkbox"/> Yes	<input type="checkbox"/> No
Would the knowledge of PBL as a teaching method make a choice of engineering at VU?	
<input type="checkbox"/> A more attractive option 6 months before you selected your preferences	
<input type="checkbox"/> A less attractive option 6 months before you selected your preferences	
<input type="checkbox"/> No difference in selecting preferences	
Do you prefer PBL subjects to delivered:	
<input type="checkbox"/> In the current form of discovery and working in teams	
<input type="checkbox"/> The PBL subjects delivery be supplemented with lectures and tutorials	
Given another chance would you enrol into a different engineering discipline course?	
<input type="checkbox"/> Yes	<input type="checkbox"/> No
Are you considering transferring into another (other than engineering) course?	
<input type="checkbox"/> Yes	<input type="checkbox"/> No
Are you considering transferring to another university?	
<input type="checkbox"/> Yes	<input type="checkbox"/> No

III. RESULTS

The results outlined in this paper cover the period 2008-2013 inclusive. The first second-year cohort was not included in the survey because it was not till 2008 PBL pedagogy was shaped to resemble current the form. Earlier data has been published elsewhere [4]. The first two questions were designed to ascertain whether choosing engineering as a course of study was given a high priority by students in their first preference selection cycle. The data is presented in table1. The results of the survey showed that a relatively high proportion of second year VU engineering students placed high preference for engineering as their choice of course (Table1-figure1). These figures varied between 82 to100 percent. The proportion of students choosing engineering at VU was lower in comparison to students choosing engineering as a course of study Nevertheless, with the notable exception for 2011, a respectable 50-60 percent of second year students placed VU engineering in their final year at school amongst their top two preferences.

Table I. Proportion (%) of students who initially selected engineering in top 2 preferences

YEAR	2008	2009	2010	2011	2012	2013
Overall	88.1	100.0	95.4	94.1	90	82.4
For VU	48.8	57.1	60.5	25.0	55.2	56.3

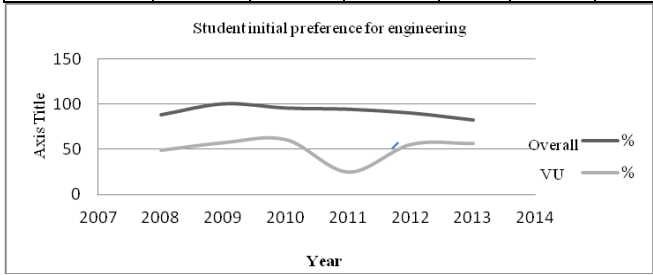
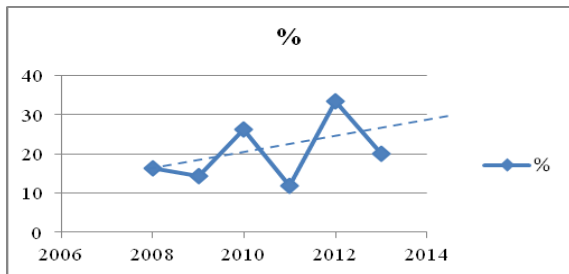


Figure I. Graphical representation of table I.

The third question tried to evaluate the effectiveness of the publicity campaign informing secondary students of the new pedagogical pathway in the delivery of engineering education at VU (tableII-figure II). Unfortunately the publicity penetration was fairly disappointing. Only a third of second year students in 2013 had any awareness of PBL suggesting that the 2010 publicity campaign effectiveness declined.

TableII. Proportion (%) of students being aware of PBL at VU engineering prior choosing their initial preferences

YEAR	2008	2009	2010	2011	2012	2013
%	16.3	14.3	26.2	11.8	33.3	20.0



FigureII. Student awareness of PBL at VU engineering prior choosing their initial preferences

By the end of the first semester, second year students have been exposed to at least 3 semesters of PBL pedagogy allowing them to form concrete views on PBL delivery. TableIII and figureIII indicate that substantial (but decreasing) proportion would have been influenced in preference selection in their final year at school had they have known more about the practical aspects of PBL pedagogy.

Table III. The impact of student awareness of PBL on likely preference selection of VU

YEAR	2008	2009	2010	2011	2012	2013
Overall	69.8	66.7	52.6	46.7	57.1	35.3
Students with a positive attitude to PBL	69.8	33.3	48.8	13.3	50.0	17.6
Students with a negative attitude to	0.0	33.3	3.8	33.3	7.1	17.6

PBL						
Δ (Positive-negative)	69.8	0.0	45.0	-20.0	42.9	0.0
$R = \Delta / \text{Students with neutral attitude to PBL}$	2.31	0.0	0.86	-0.38	0.85	0.0

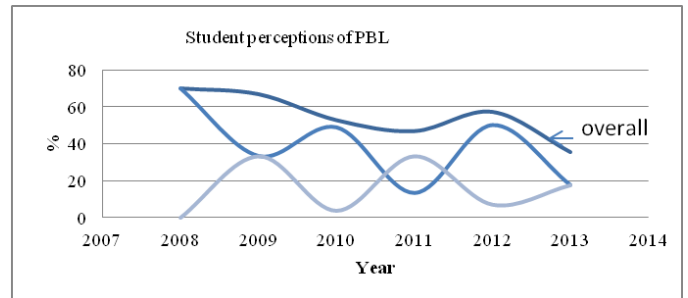
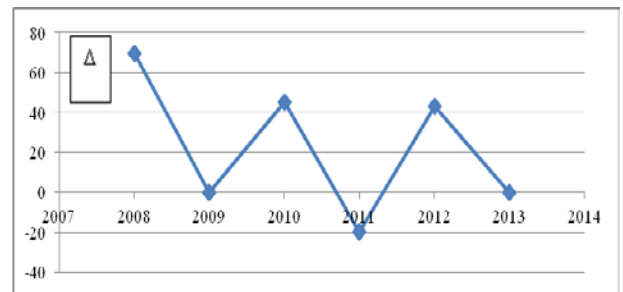


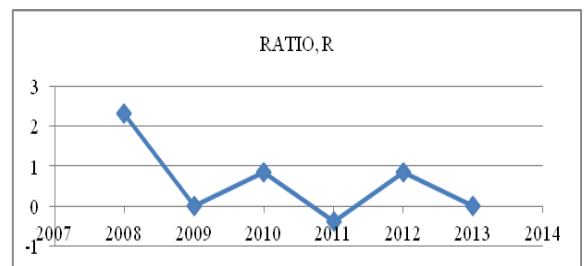
Figure III. The impact of student awareness of PBL on likely preference selection of VU

Students would be more likely to preference VU engineering on the basis of their positive PBL educational experience. Students would be less likely to preference VU engineering on the basis of their negative experience with PBL. Table III (figure IIIa) suggests that the net positive empathy Δ for PBL varies between 70 to -20%. It needs to be noted that 30 to 65% of students have neutral attitude towards PBL.



FigureIIIa. Difference between students having positive and negative perspectives on PBL

Table III introduces a ratio R , which quantifies the impact of PBL on engineering attractiveness at VU. Positive values of the Ratio R indicate positive impact of PBL. With the exception for 2008 the impact of PBL on placing VU engineering high on selection preference would be minimal or negative.



FigureIIIb. Graphical representation of table 3

Students were asked to suggest whether an augmentation in PBL pedagogy can be achieved by using traditional instructive teaching of lectures, tutorials, seminars. Table IV provide student attitudes to PBL.

Table IV. Proportion (%) of students who prefer the inclusion of traditional teaching delivery in PBL subjects

YEAR	2008	2009	2010	2011	2012	2013
Overall	67.4	71.4	62.8	47.1	59.3	76.5
Students who are positively disposed to PBL		71.4	56.5	0.0	46.7	68.0
Students who are negatively disposed to PBL		55.6	53.3	47.1	36.7	40.0
Students who are neutrally disposed to PBL		66.7	69.4	0.0	71.4	80.6

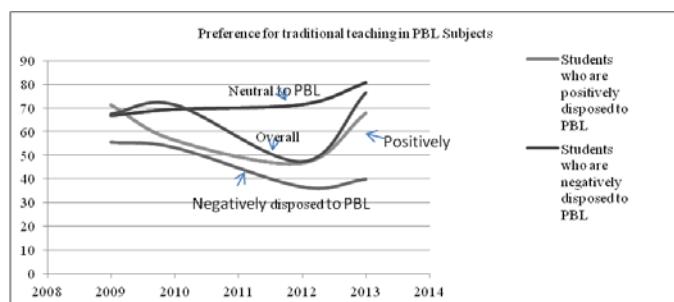


Figure IV. Student preference for PBL subjects to include instructional teaching delivery

An area of concern is the relative high attrition rates of engineering undergraduate students at VU. One of the objectives was to evaluate the impact of PBL pedagogy on students' retention. The results are shown in table V.

Table V. Proportion (%) of students considering transfer to another university

YEAR	2009	2010	2012	2013
Overall	49.4	33.6	33.7	38.2
Students who have a positive view of PBL	42.9	32.6	18.2	52.6
Students who have a negative view of PBL	77.8	46.7	23.4	33.3
Students who have a neutral view of PBL	48.9	31.6	32.5	46.4

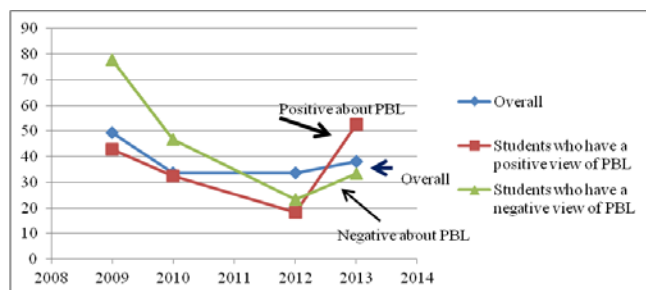


Figure V. Overall proportion (%) of students considering transfer to another university

IV. DISCUSSION

The good news (figures I&II) is that over 80% of second year students chose engineering as their preferred course of study. Furthermore, more than 50% of students picked VU engineering amongst their top two destinations of study. Given the status of VU in the ranking amongst Melbourne universities, VU engineering certainly punches above its weight. However, it needs to be pointed out that student choice is not often based on reality of well thought out reflection. Choosing engineering does not necessarily translate into passion for studying engineering. Owore et al, in an American study, showed that engineering students often had wrongful impressions of engineers' work restricted to fixing and building [6].

The enrolment growth in engineering at VU, based on 2004 data, for domestic students commencing studies was healthy (figure 6). This rate of domestic student enrolment was above the national domestic commencing engineering student growth rate till 2012 [7]. It needs to be noted that some universities have weaned themselves on the dependence on domestic enrolment. The same statistical data also shows that both RMIT and SUT, with similar historical profile to VU, had a relatively high proportion (between 40-55%) of commencing engineering students are full-fee paying overseas students. In comparison, the proportion of commencing overseas student enrolment in Mechanical, Architectural and Building engineering at VU varied between 8 and 20%. SUT, for instance, reduced its dependence on domestic student market by placing a strict academic entry criterion for domestic students. This was reflected in comparatively low growth rate in commencing domestic student enrolment. The downturn in the commencing growth rate at VU from 2010 could be attributed to the uncapping of university places at Australian universities.

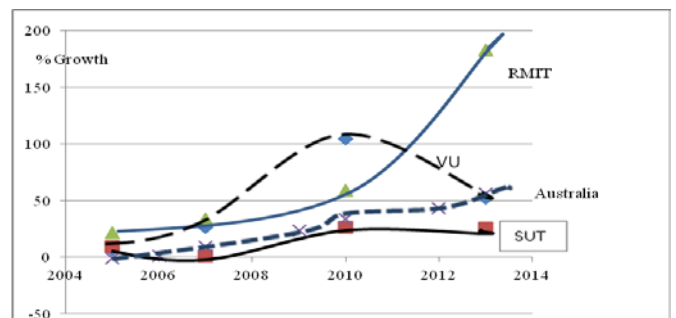


Figure VI. Comparison of growth rates in domestic commencing engineering students with the national with RMIT and SUT, both institutions with comparable history and traditions to VU.

The marketing accompanied by the publicity in extolling the virtues and differentiation of PBL pedagogy in education showed to be clearly ineffectual (figure II.) Marketing and publicity penetration was relatively modest and the with majority of students who chose engineering at VU were unaware of PBL teaching and learning approach prior to their enrolment. It was hoped that word of mouth

could improve both students' quality and quantity enrolment in engineering at VU. Students communicate their educational experience to friends, their siblings and other relatives. Figure III shows that initially 70 % of second year students expressed that had they been more aware in their final year at school about PBL delivery, they would be more likely to choose engineering at VU. However, the consolidation of PBL teaching at VU over the years did not lead to better outcomes. Figure III suggests that the impact of PBL on students had not lived up to expectations. This could be due to the fact that PBL constructivist pedagogy may itself be problematic. The process by which students acquire knowledge and intellectual skills by working in small teams on allocated projects must be placed in students' socio-economic contexts. PBL education requires students' high participation in team meetings to meet their project objectives. It is not an ideal educational situation for students who are balancing paid work with academic demands. PBL is also a natural learning process for self-starters and good learners but is problematic for students who are not well prepared for university education. New ways of learning can be alienating for students who at their early years of a university course expect their learning experience to mirror one of secondary school [8]. It is the expectation of teaching rather than learning. Figure IV demonstrates that students irrespective of their attitudes to PBL would prefer their PBL subjects to be augmented by traditional instructional methods. Surveys showed that majority of students felt that lectures were beneficial to their learning [9]. Disengagement from the education process translates in student leaving for other academic pastures. An unusually high proportion of students, at the end of their first semester of second year course, are considering transfer their studies to other universities (figure V).

Another approach in determining a success of a four-year engineering course is by comparing published data of the proportion of commencing domestic students who complete their course in four years (figure VII). This aggregate data includes attrition rates (indicating whether a course is unpopular), latter year entries from other institutions (course is popular), as well as remaining students who are at various stages in their course. Such figures can therefore exceed 100% [5]. It is a "rough" measure but provides a relative snapshot of progression rates and course popularity of courses at other universities.

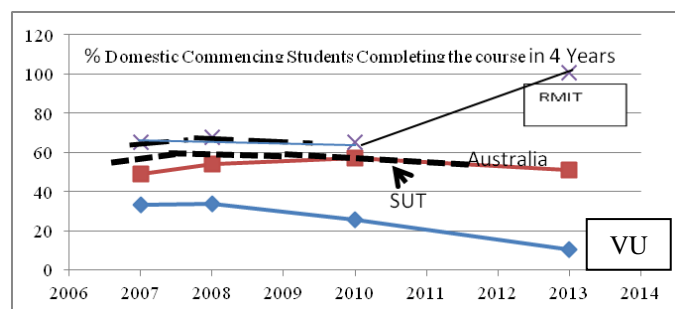


Figure VII. Ratio (%) of domestic graduates to commencing domestic students 4 years earlier

The educational output at VU engineering clearly demonstrates undesirable attrition rates. It does not necessarily reflect management of PBL delivery. Rather whether PBL education is appropriate or introduced too early. Attrition rates have also been shown to be a consequence of the socio-economic profile of the student body, attractiveness of other institutions and student to staff ratio, which is significant. The student to staff ratio at VU engineering is more than 20 % higher than at SUT and 10 % greater than at RMIT. This is a problem because PBL pedagogy requires greater pastoral involvement than the traditional instructional delivery.

V. CONCLUSION

Attracting more and better academically qualified students to engineering courses by introducing new pedagogies could be effective if better information concerning the new pedagogy and how it would enhance students' educational experience and outcomes was provided to secondary colleges. The publicity and marketing programs of VU engineering has had a modest impact at best. Successful publicity of a product works best if the product itself is attractive. Students in general were not inspired by the programs run at VU with majority preferring supplementary traditional instructive teaching methods such as problem solving learning (PSL). Obviously either the current PBL curricula need to be re-designed or introduced in the third and fourth year of the engineering course. That itself would present a dilemma in trying to differentiate engineering at VU from engineering at other universities. Though large amount of capital and financial resources were invested in teaching and learning spaces, it was not accompanied by investment in human resources, which are needed to support PBL programs because of their pastoral demands. The university needs to shift its balance from research to teaching to ensure the viability of Engineering at VU.

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Using Peer-Led Team Learning to Build University-Community College Relationships

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Abstract— Through support from the National Center for Women & Information Technology (NCWIT), the University of Texas at El Paso (UTEP) and the El Paso Community College (EPCC) began a program to collaborate on adoption of Peer-Led Team Learning (PLTL) at EPCC. The NCWIT-funded effort aims to transfer this effective retention practice to the EPCC in order to establish early connections with female students, create community, and provide activities that improve students' problem-solving skills. PLTL provides an active learning experience for students and creates leadership roles for undergraduates. For the peer leaders, the experience of working with faculty and guiding their peers through a challenging course is rewarding, and they learn communication, teaching, leadership, and interpersonal skills. Peer leaders become more confident about their career path, and many continue to be involved in the department through undergraduate research positions. This is important for retention and advancement efforts, since the peer-leading experience influences the students' motivation to attend graduate school. This paper describes how the UTEP-EPCC partnership was structured, how the practice was transferred, and the challenges that were encountered. It also presents the evaluation results.

Keywords—*Peer-Led Team Learning; peer mentoring; community-college relationships; retention in CS*

I. INTRODUCTION

According to the Bureau of Labor Statistics, the number of jobs in computer science is projected to increase by 15 percent from 2012 to 2022, faster than the average for all occupations [1]. Despite the growing demand, women have historically been underrepresented in lucrative computing positions. The Taulbee Survey [2] reports that in 2012-2013 only 14.2 percent of bachelor's graduates in computer science were

female. Committed to correct the imbalance of gender diversity, the National Center for Women & Information Technology (NCWIT) serves as the lead organization for addressing the advancement of women in computing fields through a variety of programs. One such program is the NCWIT Extension Services for Undergraduate Programs (ES-UP). ES-UP, which employs a multi-pronged strategic planning model, provides customized consultation to undergraduate departments of computing to help them develop high-impact strategies for recruiting and retaining more women students.

The University of Texas at El Paso (UTEP) was one of the first of two cohorts of 15 universities that were funded by the NCWIT ES-UP program in 2013. Peak Research worked with the department to analyze departmental data, define strategic plans for recruitment and retention, and learn about research-based practices to support their efforts. In 2013, UTEP set forth a plan that included introducing the Peer-Led Team Learning (PLTL) effective practice [3] [4] to the El Paso Community College (EPCC) to increase students' computing knowledge, confidence, motivation, and course completion rates in critical, "gate-keeper" courses for CS majors. This proven practice emphasizes student achievement through active learning activities in peer-led sessions. PLTL also cultivates student pedagogical leaders, who serve as role models for undergraduates, and it supports the advancement of students along the academic computing path. By hiring female peer leaders, the effort aims to establish early connections with female students.

Section II provides a background of the universities involved to provide a context for the initiative. Section III describes the initiative, followed by the initial evaluation

results. The paper ends with a summary and a discussion of next steps.

II. BACKGROUND

Overviews of UTEP and EPCC are provided in the subsections that follow. A discussion on UTEP's adoption of PLTL is included in the UTEP subsection.

A. The University of Texas at El Paso

The University of Texas at El Paso (UTEP) is a minority-serving institution located on the U.S./Mexico border serving a largely Hispanic population in a region of Texas with one of the lowest median incomes. Computer Science (CS) is one of six departments in the UTEP College of Engineering.

In fall 2013, the ES Consultant conducted a survey of UTEP's CS and Electrical and Computer Engineering pre-engineering students. The survey found that 70% of new pre-engineering majors reported that they live off campus. One quarter (28%) of incoming students declared that none of their parents attended college. UTEP is their main source of information regarding professional opportunities and role models. In addition, 50% of incoming students reported that they must work to support their studies. Under the guidance of the ES Consultant, the CS Department created Recruitment and Retention Plans using the NCWIT Strategic Planning for Recruiting (Retaining) Women in Undergraduate Computing Workbooks and taking into consideration the aforementioned factors. The retention plan includes the adoption of PLTL at the local community college using female peer leaders and integrating the training with UTEP peer leaders.

UTEP is the lead institution for the Computing Alliance of Hispanic-Serving Institutions (CAHSI), which was founded in 2006 as a consortium of over ten institutions focused on the recruitment, retention, and advancement of Hispanics in Computing [3]. The founding institutions are UTEP, California State University-Dominguez Hills (CSU-DH), Florida International University (FIU), New Mexico State University (NMSU), Texas A&M-Corpus Christi (TAMU-CC), University of Puerto Rico Mayaguez (UPRM), and University of Houston-Downtown (UHD). CAHSI's motivation lies in the rapid growth of the Hispanic population and the urgency of building a U.S. computing workforce to maintain the nation's prominence in technology. It is critical for the economic and social health of the United States that we maintain a globally competitive STEM workforce and expand our engagement of diverse individuals who can contribute to innovation and advancement in STEM areas. Engaging large segments of our society who have traditionally not been involved, i.e., students from underrepresented groups, is critical in addressing workforce needs and innovation, especially in technical fields. CAHSI has been making a difference by sharing resources and promoting effective, evidence-based practices.

CAHSI activities and initiatives allow students to develop social networks of academically-minded computer scientists and engineers among their peers at their university and beyond. The major initiatives include: *CS-0*, a pre-CS course that uses graphics and animation to engage and prepare students who have no prior experience in computing; the

Affinity Research Group model and course that emphasizes the deliberate and intentional development of technical, team, and professional skills and knowledge required for research and cooperative work; Mentor-Grad, an initiative designed to engage under-graduates in experiences and activities that prepare them for success in graduate studies and onto the professoriate; Fellow-Net that focuses on mentoring students to support the submission of competitive fellowship applications; and PLTL. CAHSI sponsored several workshops in coordination with City College of New York to introduce UTEP and other CAHSI institutions to the PLTL strategy [5] [6].

At UTEP, PLTL is used in the first three computer science courses. The first two fundamental courses, CS1 and CS2, are four-credit courses with closed labs that meet for three-hours per week. Each lab has a teaching assistant assigned to it. Peer leaders also work with students during the lab hours. CS3 has an open lab, although a teaching assistant and a peer leader are assigned to the course.

B. The El Paso Community College

The EPCC offers several associate degrees in information technology; one of them is the associate in arts in computer science. EPCC offers four fundamental courses in CS, these include CS1, CS2, CS3, and computer organization and machine language. In these courses, several instruments are used to articulate the student learning outcomes established by the institution.

Computer Science courses meet two days per week with each session lasting two hours. EPCC offers smart classrooms where every student has a computer and the faculty can monitor the student's workstation through a master computer. Due to the long period of time the lecture meets, the instructors have designed activities using inquiry-based techniques and active learning [7] [8] to keep the students' engaged. Traditional evaluation instruments are used in CS1 to evaluate student-learning outcomes; these include weekly quizzes, programming labs, hands-on activities, exams, and a final exam. The computer programming labs use hands-on activities that are based on cooperative learning techniques.

For CS1, EPCC has adopted a progressive and constructivist approach [9] where the student learns the fundamentals of computer programming by developing assignments based on implementations of previous assignments. As a result, the student is responsible for his or her own learning by adding new programming components to previous work. Faculty at EPCC have proposed a series of sequential computer programming assignments that assess the CS1 learning outcomes. One of the purposes of these assignments is to motivate the learning process of the student by developing a real-world application in addition to smoothing the transition between courses so students can transfer successfully to UTEP or other institutions.

Students work on hands-on activities every week with classmates selected randomly for team assignments. Activities are designed to provide problem-solving techniques, pseudo code practice, and finally implementation of the code. Each member has a different duty depending on the problem, and at the end of the implementation, each team must present his or

her work in front of the class. The students provide discussion and feedback of each implementation.

C. Articulation Agreement

UTEP and EPCC entered into an Articulation Agreement in 2007 as a mechanism to align the courses listed as the field of study curriculum for Computer Science, i.e., CS1, CS2, and CS3. Identifying essential elements for assuring that the course content and delivery are comparable is an important step in facilitating the success of students transferring from EPCC into the CS program at UTEP. The agreement outlined that UTEP and EPCC CS faculty will align the outcomes and assessments of the CS courses, and UTEP agreed to accept EPCC's CS1, CS2, and CS3 as credit toward UTEP's Bachelor in CS. In addition, UTEP and EPCC agreed to meet each semester to discuss course assessment results, curriculum changes in the fundamental areas, and student-support strategies and opportunities.

UTEP and EPCC also have a reverse Articulation Agreement that allows students to transfer courses from UTEP to EPCC. The long-standing relationship between the leadership from both programs has laid the foundation for the PLTL initiative.

III. PEER-LED TEAM LEARNING

A. Overview of PLTL

Peer-Led Team-Learning (PLTL) was first developed by the City College of New York in 1990 [4] [10]. The approach is based on strategies of collaborative learning and problem solving. The model uses small group sessions, which are led by near peers, to assist students in mastering complex concepts. The sessions provide students with extra time to work on problems and get questions answered. A feature of the approach is that students build a sense of community in which they can learn from each other, and they take responsibility for their learning. Students gain confidence as they develop problem-solving skills, and they acquire team and communications skills.

A critical component of PLTL is the training provided to the peer leaders, who receive a stipend for their efforts. They attend an orientation and weekly meetings facilitated by a faculty member(s) who works with them to ensure that the problems presented to students are well aligned with the topics covered in class. The training sessions include review of problem-solving strategies and reasoning that are integral to the group sessions.

The CAHSI PLTL model, as implemented throughout CAHSI, hinges on the components found in cooperative learning [11] [12] [13] [14]: positive interdependence, face-to-face promotive interaction, individual accountability, professional and interdisciplinary skills, and group processing. A short description of these essential elements follows:

1. *Positive Interdependence*: Students are linked to others in the team in such a way that they cannot succeed unless their teammates do and that they must coordinate their efforts with the efforts of other members to complete a task.

2. *Promotive Interaction*: Members of the team promote each other's success by sharing needed resources and helping, supporting, encouraging, and praising each other's efforts.
3. *Individual Accountability*: Each member must be accountable for contributing his or her share of the work. Individual accountability exists when the performance of each individual student is assessed, the results given back to the individuals and the group, and the student is held responsible by team members for contributing his or her fair share to the group's success.
4. *Professional and interpersonal skills*: Group members must know how to communicate and function as a team. Skills must be taught, modeled, and practiced.
5. *Group processing*: Group processing refers to reflecting on a team activity to describe which team behaviors were helpful and not helpful and to make decisions about what actions to continue or change.

During the PLTL group sessions, students create a learning environment that is far different from the traditional classroom. In this non-traditional setting, cooperation and participation are encouraged over competition and individualism. PLTL is based on the Peer Cooperative Learning Program (PCLP), which is embedded within the course. It shares commonalities with two other PLCP programs, namely the "Emerging Scholar's Program" (ESP) of Treisman in the early 1980's at Berkeley [15] [16] and the Video-Based Supplemental Instruction (VSI) developed at University of Missouri at Kansas in late 1980's [17]. The philosophy driving cooperative programs like these is that institutional structures need to adapt to meet students' needs, rather than focusing on students' deficits.

Extensive studies involving students from different majors and different have shown that students using PLTL methods consistently perform better than their counterparts who used traditional methods of learning [3] [4] [6] [18]. PLTL at CAHSI institutions has significantly contributed to students' persistence in the major [19]. Prior to the implementation of PLTL in "gate-keeper" courses in the major, only 77% of students completed the course, while 87% of students completed the course after the advent of PLTL. This ten percent increase in course completion rates is statistically significant ($\chi^2(1, N=5195) = 53.07, p < .01$). Likewise, Hispanic students showed a six percent increase in course completion ($\chi^2(1, N=2716) = 17.4, p < .01$) after PLTL was implemented, also statistically significant.

B. The UTEP-EPCC PLTL Initiative

The UTEP-EPCC initiative, which has been in place for two semesters, transferred this effective retention practice by establishing early connections with female students, creating community, and providing activities that improve students' problem-solving skills. EPCC and UTEP peer leaders share strategies and lessons. The PLTL effort supports academic performance and retention in the gatekeeper courses by providing role models to boost students' confidence and knowledge. One of the significant reasons for failure is lack of

support inside and outside the classroom, and PLTL addresses this.

Students are chosen as peer leaders based on their performance in the CS1 course. The EPCC initiative identified three female peer leaders for the CS 1 course only. UTEP incorporates PLTL in its CS1, CS2, and CS3 courses. For the peer leaders, the experience of working with faculty and guiding their peers through a difficult course is rewarding. They learn communication, teaching, leadership, and interpersonal skills. Peer leaders become more confident about their career path, and most of them decide to apply for research positions or internships at a later time. This is very important to our retention efforts, since this experience influences the students' motivation to attend graduate school.

In PLTL sessions, small groups of students meet weekly for 30 minutes outside of class time to solve carefully developed sets of problems under the guidance of peer leaders. The differences in the course taught at UTEP and the EPCC course is that UTEP students register for a specific lab and, therefore, have assigned lab times. At EPCC, students have open lab hours.

UTEP hosted a six-hour orientation for the UTEP-EPCC peer leaders in which the activities were conducted in a cooperative learning environment. During the orientation, peer leaders learn and practice the elements of cooperative learning. In addition, the orientation emphasizes the basic premise of PLTL, i.e., creating sessions that facilitate problem-solving, which distinguishes PLTL from tutoring and assistance. Activities include having peer leaders develop an activity to be used during the first PLTL session of the semester based on the lecture schedules provided by the course instructors. As part of the peer leaders' integration, EPCC team leaders attended a peer leader session at UTEP each semester. This helped them understand the program and the activities by experiencing the sessions themselves, and it supported their integration with the UTEP PLTL team and faculty. The UTEP/EPCC peer leaders not only worked together in providing sessions, but also shared their personal recommendations and challenges based on their own experiences. In addition, the EPCC peer leaders made new connections with UTEP faculty and students who were involved with research.

The peer leaders are required to attend all lectures for the class to which they are assigned. They are also required to attend weekly meetings with the program coordinator for discussion about and peer review of the previous week's activity along with additional training. Each peer leader is required to document their activities. The reports include what went well and what could be improved with suggestions for improvement. The peer leaders are required to meet regularly with the instructor of the class to which they have been assigned to provide feedback about problem areas they found during the PLTL sessions and to make sure that the activity belongs to the scope of the material covered in class.

Every week, the peer leaders design a group activity based on the current material the faculty is covering in the classroom. The PLTL activities emphasize problem-solving techniques. The students in the courses are required to attend

the sessions, although it is difficult in the EPCC courses because of the open lab concept. To address this, peer leaders at EPCC schedule sessions on different days, e.g., Wednesdays, Thursdays, and Saturdays, with the purpose of reaching students who have different schedules. Peer leaders at both EPCC and UTEP work 10 hours per week.

In the PLTL sessions, the students are randomly assigned to work in teams of 3 to 5 people to complete the cooperative learning activity presented to them. The activities are typically visual, active, and memorable. Since the purpose of the sessions is to reinforce the information covered in lecture rather than introduce new material, the peer leaders are trained to question and assess the teams' approaches and solutions and not simply provide the answers. The peer leaders encourage the teams to use multiple approaches to solve a problem along with promoting equal participation of all team members.

In fall 2014, peer leaders and faculty from both UTEP and EPCC attended the "Stereotypes & Stereotype Threat Affect Computing Students" presentation from NCWIT. The group discussed various personal experiences in relation to stereotype threat. Everyone agreed that there is a need to address stereotype issues in the programs. The group noted that having informed advocates and peer leaders (male and female) is key to addressing these issues. As a result, the presentation will now become part of the required meetings.

C. Example Activity

The activity below is an example lesson that guides the peer leader.

Algorithm Lesson

Purpose: To reinforce students' understanding of algorithms.

Group Size: 3

Method for Assigning Students to Groups: Count the number of students in the class, divide by 3, count off from 1 to the quotient, and group identical numbers.

Materials: Handout (one copy per group) with the task description and questions to be answered at the end of the session

Roles: Robot, recorder, and direction giver

Individual Accountability: The size of the group will be small to make sure everyone can participate. Also, each group will be observed during the activity to make sure all members are contributing.

Activity Summary:

1. Each group will prepare a written algorithm for getting a "robot" to reach a pre-determined location.
2. The algorithm will be given to a different group to verify that it works. This time the "robot" (student) will be blindfolded. The robot will be given the written instructions. If it does not work, the group that designed the algorithm will revise their algorithm and try again.

Group Questions:

Have the groups discuss what is needed to write an effective algorithm. They will answer the following questions:

- What did you have to consider when writing an algorithm?
- What changes did you have to make to the algorithm after you tested it?
- Why is verification important?
- What did your experience teach you about writing computer algorithms?

IV. EVALUATION

A. Evaluation Results

Surveys were developed to assess student attitudes about the PLTL course and computing both before and after the PLTL experience. Nine pairs of statements were rated by students with a retrospective pre-test and post-test design. IRB delays prevented administration of a true pre-test, but use of this method allowed participants to reflect on changes that occurred over the semesters, providing both pre- and post-ratings after the intervention. This method reduces rater bias and has comparable validity to standard pre-post methods [20]. Participants often comment that they overinflate pre-test attitude ratings with traditional survey design because they do not yet know what they do not know.

Surveys were administered to 139 total undergraduate students at UTEP (n=120) and the EPCC (n=19) who participated in a PLTL course over two semesters (spring 2014 = 51 participants; fall 2014 = 88 participants). Survey results are shown in Tables 1 and 2.

TABLE 1. SIGNIFICANT IMPROVEMENTS WITH PLTL PARTICIPATION

Increased Persistence in Computing	Increased Engagement in Computing	Increased Confidence in Computing	Increased Computing Skills
Significant increase in grades ($p < .01$) from pre to post PLTL	Significant increase in feelings of belonging in the major ($p < .01$) from pre to post PLTL	Significant increase in confidence in computing ($p < .01$) from pre to post PLTL	Significant increase in programming skills ($p < .01$) from pre to post PLTL
Significant increase in confidence about earning degree in CS ($p < .05$) from pre to post PLTL	Significant increase in enjoyment of programming ($p < .01$) from pre to post PLTL	Significant increase in interest in a computing career ($p < .05$) from pre to post PLTL	Significant increase in understanding of CS course materials ($p < .01$) from pre to post PLTL

Increases in eight of nine key Mini Grant goals were significant from pre- to post-PLTL experience. These improvements included: increased feelings of belonging in the PLTL course, increased confidence in computing, increased understanding of CS course materials, increased enjoyment of programming, increased programming skills, improved grades, increased intent to earn CS degree, and increased interest in a career in computing. Survey items were rated on a 4-point scale from low to high, “Strongly Disagree” to “Strongly Agree.”

The only PLTL goal that did not achieve significant increases in ratings of agreement was plans to major in CS. Ratings of this statement were positive both before the PLTL course (mean score = 3.38), and after the PLTL experience (mean score = 3.45).

B. Qualitative Peer Leader Reflections

The PLTL coordinator met with the peer leaders each week to plan activities. EPCC peer leaders reflected on the experience of working in this role and provided the following insights and outcomes:

- PLTL participation needs to be mandatory to be most effective.
- Faculty communication was useful to peer leaders and also made them feel supported.
- The UTEP and EPCC collaboration improved communication and made everyone feel like a part of the team.
- Two of three EPCC peer leaders have transferred to UTEP and will continue to study CS.
- One of these transfer students will continue in her role as a peer leader at UTEP.
- One transfer student has joined an undergraduate research team at UTEP because of her experience with the PLTL project.
- The remaining PLTL peer leader will continue in that role at EPCC until she transfers.
- This peer led approach provided an effective transition for students who may have struggled as they transferred from community college to university programs in Computer Science.

C. EPCC Reflections

EPCC faculty have observed a positive effect with the PLTL model mainly in two aspects: increased motivation in team work and retention in CS2. The experiences have provided students with an opportunity to meet other students in the program and to become more conscious about time constraints (regarding budgeting the time to finish an activity). In particular, students have learned problem breakdown (divide-and conquer) techniques and task delegation when the main task has been assigned to a team. It is important to note that the majority of students in the spring 2015 semester who have continued to the CS2 course are those who attended the PLTL sessions in fall 2014.

The EPCC students had a positive reaction to the PLTL sessions. Several students claimed that the sessions have helped them gain a deeper understanding of the concepts they learned in the classroom. In addition, the PLTL sessions helped them improve their problem solving skills in quizzes and tests. Students have adapted successfully to PLT because of the way that it complements with the cooperative learning techniques that faculty apply in the classroom. Other students suggest that it is less intimidating to work with peer leaders because of their accessibility. The EPCC peer leaders reported that being a peer leader was challenging at the beginning because they never believed that they would be leading class

activities. Their experience has increased their confidence in the field of computer science. They also note they have better understanding of the material for CS2, since they now have the ability of synthesize information learned in the classroom.

Finally, the peer leaders have expressed their desire to transfer to a four- year institution after they complete their associates in computer science at EPCC.

TABLE 2. COMPARISON OF PLTL OUTCOMES WITH RETROSPECTIVE PRE-POST TEST DESIGN – PAIRED SAMPLES T-TEST

	<i>n</i>	<i>Mean</i>	<i>SD</i>	<i>Standard Error Mean</i>	<i>t</i>	<i>df</i>	<i>Significance (2-tailed)</i>
PAIR 1 - Before: I feel like I belong in PLTL After: I belong in PLTL	133 133	2.92 3.27	.68 .67	.06 .06	-6.02	132	.00
PAIR 2 - Before: PLTL will improve my confidence in computing After: PLTL improved...	132 132	3.17 3.48	.61 .61	.05 .05	-6.00	131	.00
PAIR 3 - Before: PLTL will increase my understanding of the material covered in CS Courses After: PLTL Increased...	132 132	3.32 3.53	.61 .61	.05 .05	-3.61	131	.00
PAIR 4 - Before: PLTL will increase my enjoyment of programming After: PLTL increased...	133 133	3.04 3.44	.77 .71	.07 .06	-6.32	132	.00
PAIR 5 - Before: PLTL will make me a better programmer After: PLTL made me a better programmer	132 132	3.26 3.52	.61 .60	.05 .05	-4.59	131	.00
PAIR 6 - Before: PLTL will improve my CS grades After: PLTL improved...	131 131	3.22 3.43	.65 .66	.06 .06	-3.66	130	.00
PAIR 7 - Before: I plan to major in CS After: I plan to major in CS	133 133	3.38 3.45	.93 .91	.08 .08	-1.22	132	.23
PAIR 8 - Before: I will earn my degree in CS After: I will earn my degree in CS	133 133	3.30 3.42	.94 .92	.08 .08	-2.38	132	.012
PAIR 9 - Before: I am interested in a career in computing After: I am interested in a career in computing	133 133	3.46 3.58	.77 .74	.07 .06	-2.30	132	.02

D. Evaluation Challenges

Our project team encountered several challenges related to working with two academic institutions. The first involved different Institutional Review Board (IRB) requirements and standards for working with students and administering surveys. The second involved the use of laboratory time for PLTL sessions. Because open lab periods were used, and attendance was not required, it was challenging to ensure that students were able to attend group sessions.

CAHSI evaluation of peer leaders has revealed that being a peer leader also boosted students' oral communication, teaching, leadership, and interpersonal skills. Most peer leaders (94%) of respondents agreed or strongly agreed that being a peer leaders had improved their oral communication skills. Almost all (97%) agreed or strong agreed that PLTL had developed their teaching and leadership skills. All

respondents agreed or strongly agreed that leading PLTL had improved their interpersonal skills, i.e., their ability to cooperate with others.

V. SUMMARY

This paper describes the NCWIT Extension Services Mini Grant project that was designed to address multiple retention challenges faced by CS students transferring from the EPCC to UTEP. Using a data-driven approach, team members identified four strategies to improve retention for these students: 1) rebuild a collegial relationship between the academic institutions with the current Articulation Agreement to ensure adequate preparation and equitable retention; 2) create opportunities for transfer students to engage in research, leadership opportunities, and relationship-building activities to increase their connections and supports at UTEP; 3) increase opportunities to spend

more time on campus to increase success, as UTEP has a large commuter population; and 4) increase confidence, sense of belonging, understanding, and persistence with innovative methods, such as PLTL, to help EPCC transfer students, who exceed the number of UTEP freshmen, find their place. As many as a quarter of students surveyed said they plan to change major at least once, so creating a sense of place and feeling of belonging might help these students excel.

Nine goals were identified for PLTL participants. These goals addressed known retention indicators, such as increased confidence in earning a CS degree, interest in the major, intent to pursue a CS career, and improved grades.

PLTL participants reported significant improvements in eight of the nine goals after just one semester. Only plans to major in CS did not increase significantly, possibly because ratings of intent were high in both pre- and post-PLTL.

The PLTL course collaboration between EPCC and UTEP was effective in implementing all four retention strategies. Collaboration improved the relationship between the institutions, increased communication about Student Learning Outcomes for equitable courses, and increased understanding of the PLTL method. Peer leaders reported increased understanding of the content areas taught, as well as increased opportunities to participate in research and leadership activities once they transferred. Participants reported significant increases or improvements in eight of the nine PLTL participation goals.

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The Creation and Inauguration of Engineering Leadership

UTEP and Olin College Innovation Project

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Abstract— The Franklin W. Olin College of Engineering (Olin College) and The University of Texas at El Paso (UTEP) are partnering in a project to create a new engineering program that educates career-ready engineering innovators while simultaneously increasing recruitment and retention among historically underrepresented students. Through the *Olin-UTEP Partnership for Change: Adoption and Adaptation of Innovative Practices for 21st Century Engineering* project, supported by the Department of Education and the Argosy Foundation, UTEP is pioneering a novel undergraduate engineering leadership program (E-Lead), focused on innovation, collaboration, communication, and human-centered engineering embedded in rigorous technical education. The program is being modeled on the curriculum and pedagogy of Olin College, a private, highly selective engineering college respected and nationally recognized for its premier innovative engineering education. The adaptation to UTEP is of national interest, since UTEP is a public, urban institution with a 21st-century demographic [1] and successful transformation of Olin approaches to UTEP can demonstrate scalable impact broadly pertinent to many other commuter campuses and public institutions. By conveying these approaches to UTEP, a minority institution serving a largely Hispanic population in the region of Texas with the lowest median income [2], we aim to demonstrably adapt and scale successful innovation-supportive pedagogies to meet important national needs for a diverse and empowered 21st century engineering sciences workforce.

Keywords—engineering leadership, Olin, UTEP, innovation

I. INTRODUCTION

Traditional engineering programs at public urban institutions across the United States largely focus on distinct disciplinary education [3]. In contrast, the new undergraduate program in engineering leadership at UTEP is designed to emphasize the broad, interdisciplinary education that is necessary to develop innovation leaders of the 21st century, along with the skills of communication, collaboration, and sustainable, and systems engineering thinking, needed by industry and reflective of our complex technical society needs. This is not to say that the E-Lead program does not emphasize technical skills, for it is a very carefully developed degree plan that is designed to maximize

learning of engineering problem solving, amidst pathways to gain critical educational experiences in business, education, or traditional disciplines. In this regard, the program includes minors in engineering disciplines as options available to students. The goal is to provide flexibility to meet targeted individual needs – oftentimes now called personalized learning [4] – while maintaining emphasis on engineering leadership and professional competencies acumen as being the program core. This approach is just the opposite of that adopted in traditional engineering programs, where professional skills are developed subsequent to emphasis on engineering problem solving (technical skills). To achieve this transformation in engineering education at UTEP, Olin College is working closely with UTEP's new Department of Engineering Education and Leadership, established to advance new paradigms for engineering education at UTEP.

Olin and UTEP are working in partnership to translate the Olin College philosophy and practices of innovative, interactive and student-centered engineering education into the new E-Lead program in the UTEP College of Engineering. The partnership supports this innovative engineering education approach with an aim to introducing and sustaining the program at UTEP through its institutionalization and our hope provide similar mentorship beyond UTEP to other engineering programs interested and ready to adopt new approaches to engineering education. In the current work a major outcome for this cooperative project is to attract, retain, and graduate an increase in throughput of minority students, especially Hispanic engineering students, resulting in higher graduation rates and shorter time to graduation.

The results of the Olin-UTEP partnership can have broad applicability for a growing number of public, urban institutions, educating diverse students for the benefit of our community and local west Texas region, the state of Texas and the nation.

II. GROWING STUDENT-CENTERED ENGINEERING EDUCATION

Educational emphasis on leadership, innovation and

pedagogical format and process is central to growing student-centered engineering education. Engineering leadership (E-Lead) at UTEP is advancing pedagogical paradigm shift in higher education to 24-h learning environments, encompassing several delivery formats including online courses, blended/hybrid designed courses, and the traditional face-to-face (f2f) lecture classes have increased student access and engagement into global, lifelong learning [5]. There is a synergistic interest in these learning approaches at Olin and UTEP.

E-Lead classes are being taught in a studio environment, typically utilized in advanced courses at Olin, where students participate in developing engineering competencies through project-based learning. E-Lead's multidisciplinary projects play a critical role in the E-Lead educational paradigm because they challenge students to apply their knowledge to deliver a tangible project. This learning experience requires students to work in highly collaborative groups and, unlike many other engineering degrees, E-Lead students develop a vital sense of community among themselves and their professors, allowing students to learn the power of teamwork. Community is built in and outside of the classroom to ensure the E-Lead experience is more than a classroom activity.

The E-Lead program also develops a culture where students actively contribute to their own education and where individual contributions are valued and important. E-Lead students strive for excellence because they have a sense of ownership and power over their own education.

Most people view leadership as a process or endpoint. At UTEP students and faculty perceive it as a cycle of leadership trait self-development shared and perpetuated through encouraging and building such traits in the people around them. At the core of engineering leadership studies at UTEP is the effort to kindle an understanding of leadership practice founded on the development of students' character, competence and capacity. The approach is indeed similar to that embedded in innovative companies, of all sizes and kinds, where leadership is every employee's opportunity and responsibility. At UTEP, character, competence and capacity symbolize the three pillars upon which engineering leadership education is structured. Thus it forms the foundation of growing leadership styles.

III. ENGINEERING LEADERSHIP EDUCATION AT UTEP

Engineering Leadership (E-Lead) is the first degree of its kind in the nation, involving collaborations with key entities such as Olin College, West Point, and other key educational institutions, the curriculum designed for E-Lead seeks to transform the classroom experience of engineering students. E-Lead moves beyond content and focuses on project application and the integration of the students' skills and knowledge in real-world scenarios.

E-Lead creates a culture of innovation, excellence and collaboration from its students, meant to extend beyond their years of undergraduate study. Grounded in leadership development, E-Lead maximizes each student's collaborative capacity. Mentoring character and personal growth helps students reach a level of personal and professional achievement that goes beyond traditional instruction. E-Lead develops the student into an action-driven leader with an innovative mindset.

Students see leadership growth as a cycle in which everyone in a cohort develops leadership traits in themselves and in those around them. At the core of engineering leadership studies is the effort to imbue leadership practices founded in the development of student character, competence and capacity [6]. Character, competence and capacity are thus the foundation of creating leadership styles and can serve as the three pillars upon which engineering leadership studies, content, and experiential learning are structured [7]. When the three pillars of engineering leadership are assimilated through experience and learning, the result is a cohesively competent graduate – one who is ready to face the challenges of the 21st century.

A. Leadership Character

Character is about discovering the truth, deciding what is right, and demonstrating the courage to act accordingly [8] and is impacted by personality, values and conduct [9]. Students in engineering leadership are encouraged to be individuals who boldly advance shaping their individual values, integrity and personality, which is at their core. To achieve this, the engineering leadership faculty and students cultivate an environment where individuals are encouraged and mentored to grow and develop an inherent understanding of their true selves, to become people of integrity and to nurture selflessness. Without character, leadership is incomplete. Good leaders care about the improvement of the lives of all, in a holistic sense, they become involved in their community – including professional, local community issues, regional concerns and global challenges. This one trait alone greatly reflects the intentions of the students in this program.

B. Leadership Competencies

Leadership competencies are leadership skills and behaviors that contribute to superior performance. By using a competency-based approach to leadership, organizations can better identify and develop their next generation of leaders [10]. Essential leadership competencies and global competency development strongly impact future business trends and engineering leadership education strives to advance the development of leadership competencies.

While some leadership competencies are essential to all firms, an organization should also define what leadership attributes are distinctive to the particular organization to create competitive advantage, according to the Society for Human Resource Management (SHRM), which identifies top workplace trends [11]. Among these, building leadership

capability through attracting, growing and leveraging organization talent were seen as vitally important for organizations to differentiate and thrive in the next decade. Collaborative, project-based learning experiences help students apply leadership theory, and synthesize and identify those leadership opportunities, all while applying their technical knowledge. Engineering leadership further develops competence by diversifying subjects and allowing students to focus on tracks that pique their interests. Engineering leadership gives students a synthesized, multidisciplinary education that prepares them to thrive in today's world.

C. Capacity for Leadership

Leadership is about learning that leads to constructive change [12]. Thus leadership is about capacity and those such as Lambert [13] who are redefining leadership situate it in the processes among us, rather than in the skills or disposition of a leader. As a concept separate from, yet integrated with, leader, leadership (notably a *verb*) stands as a broader notion, a more encompassing idea. This breadth is evident when we consider the connections or processes among individual leaders that are embedded in the context, the culture of an organization. These processes include problem-solving; broad-based, skillful participation (leadership capacity); task enactment, conversations, and stories. These processes engender a wave of energy and purpose that engages and pulls others into the work of leadership.

Engineering leadership students at UTEP are presented with diverse team-based challenges that incorporate multiple disciplines from day one of class. From project managing to research, students have the ability to excel at diverse roles, even teaching, widening the future possibilities available to them. Engineering Leadership develops capacity by providing students with multiple opportunities to apply and synthesize diverse competencies, thereby building experience.

IV. ENGINEERING LEADERSHIP DEGREE AND CHARACTERISTICS

The Bachelor of Science in Engineering Leadership (E-LEAD) degree program was approved for offer at UTEP by The University of Texas System in mid-2014 and ratified by the Texas Higher Education Coordinating Board in November 2014. The goal of the E-LEAD program is to offer students a world-class innovative engineering education experience that is ABET-accredited.

The innovative engineering degree program features a practice-based approach to graduate engineers who shall complete and themselves possess a broad-based, multidisciplinary engineering education incorporating a balanced set of technical skill and attainment of professional competencies. In aggregate it is these skills will position E-LEAD graduates to becoming shining stars, so to speak, not just in practicing engineering but contributing to business, industry, government and professional services, such as medicine,

law, and other emerging service sciences. Figure 1 summarizes the curriculum plan for the Bachelor of Science in Leadership Engineering program.

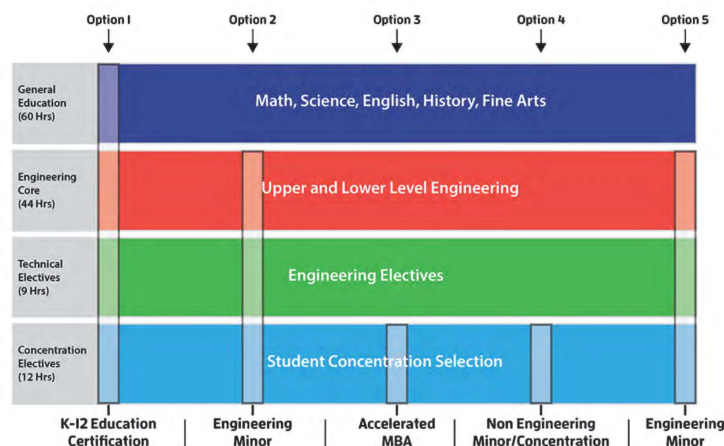


Figure 1. Engineering leadership curriculum overview.

The engineering leadership program is designed to meet engineering accreditation requirements (see www.abet.org/accreditation). It is a very innovative program, which is understood in the context of a historical perspective, namely IBM's contribution to the establishment of the now ubiquitous undergraduate programs in computer science/engineering, discussed next.

V. ESTABLISHING NEW ENGINEERING DOMAINS

Back in the 1950s, when IBM was seeking to ensure the availability of professionals capable of driving adoption and utilization of IBM mainframes, the company, both directly and through organizations like the Association of Computing Machinery (ACM), partnered with universities to create Information Science curricula and courses. These efforts, combined with similar actions by dozens of other IT vendors and organizations, spawned generations of professionals that have been instrumental in establishing IT as a critical foundation of virtually all 20th century organizations. [14]. UTEP's new engineering leadership program is comparable with computer science/engineering when it was an emerging undergraduate program across the U.S. in the 1960s.

Within the current paradigm, engineering education is reforming in piecemeal fashion. Yet the converging competitive and market forces require sweeping change in engineering education through a change in paradigm from the land grant/flagship institutions of the 19th and 20th centuries to possibly the university of the 21st century—a regional, urban institution like UTEP with demographics more closely matched to the future demographics of the U.S. where the majority will be Hispanic.

While a common objective of U.S. engineering programs is to produce future engineering leaders, few programs have curricular content specifically designed to develop the skill set of leaders. Many current engineering leaders developed

their skills through post-graduate leadership training (for example, by obtaining an MBA) or in industry settings (such as the Lockheed Martin Engineering Leadership Program [15]. In their investigation of existing undergraduate programs in engineering leadership worldwide, Graham, Crawley, and Mendelsohn [16] found leadership programs to be either extra-curricular or adjunct (i.e., ranging from a single course to a full minor) to an existing undergraduate engineering program in a traditional discipline. They define these programs as those that develop all or a portion of the following general skill set: Initiative and decision-making, systems thinking, networking and relationship building, creating a compelling vision, teambuilding and management to project completion, problem solving and critical inquiry. Of particular interest to us is the aforementioned skill set defined in these various leadership programs—a targeted competency set of the UTEP engineering leadership program.

Moreover, STEM educators and professional societies such as ABET, the American Society for Engineering Education (ASEE), and the National Science Foundation (NSF), have long understood that the development of life-long learning capabilities is vital for students' success in today's global and rapidly changing engineering environment. With this in mind, Olin College faculty have historically devoted significant effort in designing courses with an aim of instilling a set of skills in students that allow them to pursue knowledge long after they have left the academic environment; in short, they "learn to learn" and become life-long learners. This is accomplished in part through curriculum equipped with the safety net of a supervised pedagogic environment that nurtures in students the curiosity to know [17], [18].

For many institutions, including UTEP, the development of this curiosity to know, or life-long learning skill, in our students is an unmet need. Many STEM curricula create an enormous gap between the highly teacher-directed experiences comprising the vast majority of each student's education and the ambiguous challenges that they face in the workforce. For most of their education, students are told what to study, how to study it, and when to do so. Only when they leave school – or perhaps in a culminating capstone experience – do they confront the need to decide what to learn and how to acquire that knowledge. Scaffolds build on learners' prior knowledge in order for them to facilitate learners in expanding their capacity to learn; thus, learners become more knowledgeable.

VI. THE OLIN-UTEP PROJECT EXPERIENCE

The Olin-UTEP cooperative project builds on an emerging partnership between UTEP and Olin College supported by the Argosy Foundation [19.] A core part of the Argosy-supported effort is a "Collaboratory" [20], a program designed to catalyze educational innovation through cross-campus collaboration. The exchange creates partnerships with departments or programs committed to educational

change, embedding faculty from partner schools for year-long residencies at Olin College, providing participants with time, space and support for planning transformative activities at their home campuses. Partnerships are typically expected to include two consecutive years of residencies at Olin, with varying faculty participants. The multi-year program will include a comprehensive assessment of the exchange's impact on the partner schools as well as Olin.

In the Olin-UTEP program, faculty members from the UTEP College of Engineering are undertaking residencies at Olin College, immersing in Olin's approach to engineering curriculum and pedagogy and collaboratively re-designing UTEP engineering courses.

Shane Walker, a Civil Engineering professor at UTEP has reported on his experiences [21], Stella Quinones, an Electrical and Computer Engineering professor at UTEP has also spent a semester at Olin, and currently co-author Meaghan Vaughn is serving as a visiting Associate Professor at Olin, during spring semester 2015. The collaboration has been vital in underpinning this emerging partnership through its provision of significant support for the development of UTEP's BSLE program, including renovation of space to support interactive, studio-style pedagogy crucial to the education of engineering innovators; support for the UTEP program leadership to pursue innovation and professional development; and extended engagement by Olin faculty members in the development of the UTEP BSLE program.

Working with Olin College provides the opportunity for UTEP to plan, reflect, and undertake continuous quality improvements from E-LEAD program startup through regularly meeting to review progress toward achieving student outcomes in courses, methods, and approaches to teaching and implementation. Olin and UTEP faculty are sharing best practices, and UTEP is benefiting from the learning process undertaken through Olin College's own process of start-up and ongoing efforts to achieve outstanding results for students.

The specific characteristics of Olin's approach to curriculum design being embraced and customized to the UTEP BSLE Program are: (1) Curricular frameworks and instructional approaches for student-centered learning, and (2) Techniques that foster intrinsic motivation, self-direction, and autonomy through authentic project, professional practice and leadership experiences, and (3) Culturally and socially responsive curricula, in which students creatively investigate and solve social problems through innovative technological design.

The principal components of the *Olin-UTEP Partnership for Change* is: (1) Design of undergraduate engineering courses for the UTEP Bachelor of Science program to incorporate student-centered innovative

curriculum design approaches adapted from Olin College; (2) Faculty development to build capacity for implementing the curricular and pedagogical approaches of the Adoption and Adaptation of Innovative Practices into the BSLE program courses; (3) Renovation of UTEP spaces into studio classrooms to support the newly-created undergraduate BSLE courses that will be centered on design; and (4) Institutionalization of innovative curriculum and pedagogy at UTEP with a view to expand beyond UTEP to other MIs (Minority Institutions) and HSIs (Hispanic Serving Institutions).

VII. DESIGN & TRANSFORMATION OF OLIN COLLEGE APPROACH IN UTEP LEADERSHIP ENGINEERING COURSE INNOVATIONS

The following is a summary of course innovations and emphases in the engineering leadership program completed to the present time.

A. *EL 1050 Engineering Leadership I & EL 1205 Graphic Fundamentals*

The EL1050 curriculum developed and taught in Fall 2014, for example, focused on three major disciplines: leadership identity development, innovative thinking, and hands on skills. The EL1250 course content, on the other hand, focuses on developing spatial reasoning skills and communication of ideas graphically. These disciplines were taught in a studio environment through group discussions and interactive individual and group projects. This summer, students will again be redesigning this curriculum for the incoming class and the focus of the curriculum may shift based on the needs of the incoming students identified by the current students.

Taught simultaneously as co-requisites during the first semester of the BSEL degree plan, these courses are designed to foster fundamental engineering skills as well as establish the culture of the Engineering Leadership program. These courses are unique, however, in that they are not designed and led by faculty - but by second year E-Lead students.

During a faculty led workshop each summer, a group of students who took the courses the prior fall redesign the courses. By allowing students to design and teach the EL1050 course in particular, retention increased from 60% in 2013 to 92% in 2014 [22]. More importantly, this experience of being placed in the curriculum development driver seat, also served to help the second year students to redefine leadership, gain a better understanding of leadership, and increase their leadership skills (4.5, STDV 0.55; 4.67, STDV 0.52; 4.67, STDV 0.52; based on an ordinal scale with 1 being strongly disagree and 5 being strongly agree; [22]).

The purpose of these co-requisite courses is not only to give second year students a leadership opportunity and an understanding of the importance of guiding people, but also to introduce a unique culture being created in the Engineering Leadership program and provide leadership models for incoming students to learn from second year students.

B. *EL 1301 Introduction to Engineering Leadership & Design & EL 1200 Design Nature*

This course is typically taken during the Spring Semester by students enrolled in their first year of the Engineering Leadership program. The course has been designed with the assistance of colleagues from the Olin College of Engineering. Though its structure is unique to UTEP, the course draws partially from the practices and principles set forth in Olin College's course, ENGR 1200 - Design Nature.

EL 1301 provides an introduction to mechanical design and prototyping imbedded with a semester leadership experience plus readings and focused assignments to connect students to business thought and connection to current world events. On design, we take nature as a theme and develop bio-inspired ideas into functional prototypes.

Students complete individual and team projects in a studio environment where we seek to develop a shared practice and understanding of engineering design. The project focuses on mechanisms that hop and are eventually integrated into a larger board game format. Projects are evaluated by faculty, the students themselves and the "customer" (the end users of the board game; typically middle school-age children).

In addition, students choose a semester long "leadership activity" to begin the process of integration into the university or community environment. This is a co-curricular activity that students have a chance to develop on their own and evaluate how they integrate effectively with the selected community. Students also read a seminal book on business or leadership that is assigned by the professor. Weekly discussions are held on the book. Students are also required to keep up with current world events and seek to understand the effect that these events have upon the broader aspects of our culture, specifically in how leadership played a role in these developments.

Team building skills are an important part of the latter half of the course. Students take individual lessons learned and combine them to produce a more sophisticated project integrated into a larger framework of a board game for an end user. Team development and interactions are focused upon and evaluated.

C. *EL 2301 – Engineering Leadership I & EL 2302 – Engineering Leadership II*

The EL 2301 course is typically taken during the Fall Semester by students enrolled in their second year of the Engineering Leadership program. The course has been designed with the assistance of colleagues from the Olin College of Engineering. Though its structure is unique to UTEP, the course draws heavily from the practices and principles set forth in Olin College's course, MTH 1111 (Modeling and Simulation of the Physical World.)

EL 2301 provides an introduction to mathematical modeling and computer simulation. Through examples that are drawn from the physical world, students learn to model systems. The course begins with the study of discrete time systems which can be modeled using concepts from sequences and difference equations. In the second half of the course, physical phenomena that can best be modeled using continuous time systems are introduced. This segment of the course involves fundamental concepts from differential and integral calculus, including differential equations. MATLAB provides a programming platform upon which computer simulations can be developed. These simulations allow students to conduct experiments to test the validity and utility of scientific hypotheses.

In addition to the development of student competencies in qualitative and quantitative analysis, the course seeks to develop teamwork and communication skills. Students work in a laboratory environment on a number of open-ended projects throughout the semester. Faculty take care to provide appropriate scaffolding of projects early on in the course to promote student confidence and achievement.

Both individual and team-based projects are features of the class. Latitude in the choice of projects is given to students in the selection of their capstone team-based project. The semester culminates in a formal poster session open to the public in which students present the results of a team-based project.

The EL 3302 – Engineering Leadership II – course is typically taken during the Spring Semester by students enrolled in their second year of the Engineering Leadership program. As is the case with EL 2301, the course has been designed with the assistance of colleagues from the Olin College of Engineering. The course draws together concepts and topics from two courses that are offered at Olin: ENGR 110 (Introduction to Modeling and Control) and ENGR 1121 (Real World Measurement.)

EL 3302 provides an introduction to the fundamentals of electric and electronic circuits and how they can be used to develop measurement devices. Through a sequence of hands-on laboratory experiments, students are given the opportunity to build, test, and de-bug circuits. This process strengthens student competencies in bread boarding, circuit hygiene and diagnosis of problems. Special emphasis is placed on the building of circuits that perform basic operations with which the students have some familiarity. Examples include the construction of electronic differentiators, integrators, and filters.

In the course students learn to build the electronics necessary to produce measurement data which can be collected by means of computer based data acquisition systems. Along these lines, students learn to use various elements of MATLAB programming to process and analyze data.

The course seeks to build teamwork and communication skills of student. All laboratories are conducted by teams of students and require the submission of informal and formal reports. Teams of students also complete a capstone design project at the end of the course.

D. EL 3331—Systems Engineering & EL 3304 – Engineering Leadership III

In development is the Systems Engineering course to be taken during the fall semester of the third year in the BSEL degree plan. This course, to be offered for the first time in the fall of 2015, will focus on Human Centered Design techniques as students learn to design a product, service, or system relevant to their target user group. This particular course is part of a Design and Entrepreneurship sequence of courses and will therefore flow directly into the spring BSEL course Engineering Leadership III (EL 3304).

Together, these courses allow students to work the engineering design process from initial interaction with users through to final deployment of a relevant product or service in their own business or non-profit. During the courses, students learn to work in teams, interact with a user group, learn and apply project specific engineering principles, prototype, develop and business model, and communicate their work. Like other engineering leadership courses, these offerings will be taught as project based courses in a studio environment.

VIII. FINAL REFLECTIONS

Unparalleled converging factors, notably including changing demographics coupled with competitive market forces, impacted by an unanticipated era of engineering-enabled technological changes, provide new opportunities for imagining and creating appropriately reconfigured and inspired new engineering education pathways. In lockstep with James Duderstadt's vision for new paradigms, presented in "Engineering for a Changing World [23]" the new program being developed by Olin and UTEP is going to create a new cohort of engineers, who are as comfortable with leadership roles in community and public organizations, as they are within technical problem solving places, long the self-perceived domain of engineering undergraduates. These graduates are those being sought after by businesses, companies, education providers, and innovative enterprises.

We know they are sought after, because our program has its roots in the call for change not only by distinguished engineering individuals (such as Duderstadt) and influential engineering policy makers (such as the National Academy of Engineering), but also by companies such as IBM, nurturing T-type engineering education, and Halliburton, seeking leadership engineers to guide complex technical systems of engineering.

In some useful comparison, our new undergraduate degree also parallels the medical school training model that is credited with propelling advancement in medical practice during the last century, where the BS degree includes a broad-based curriculum of engineering design, project management, technology, ingenuity and innovation, along with business, communication, ethics, and social sciences. Through this contribution we will expand on the attributes of the new degree, and provide insight into the challenges (and opportunities) it provides when making a “new start” in engineering education that is so inclusive of leadership development that it is included in the degree title.

Developing such competencies is vitally important. For, as Halliburton Energy Services’ President and CEO David Lesar has asserted, engineers lacking 21st century competencies will be unable to move into senior leadership positions within organizations [24]. Such assertions have been supported by National Science Foundation data, suggesting that engineers who have master’s degrees in fields other than engineering are more likely to become senior managers [25]. Engineers seeking to advance to management positions within companies will need a much broader, more liberal arts oriented background than most engineering programs currently offer to students. The E-LEAD program at the UTEP attempts to provide this “liberal education” within a highly structured engineering program.

In a survey of 465 UTEP engineering students in 2011, 43 percent indicated an interest in leadership studies, and 71 percent showed an interest in using leadership coursework as documentation for employers and graduate schools. In 2012, a follow-up survey of 145 high school seniors, 112 engineering freshmen, and 28 engineering seniors also revealed strong student support for a Engineering Leadership degree program: 98 percent of the high school seniors surveyed indicated they would be “likely” or “very likely” to choose the proposed E-LEAD program as their field of study. Similarly, 71 percent of UTEP engineering freshmen surveyed indicated they would be “likely” or “very likely” to choose the E-LEAD program, and 36 percent of graduating engineering seniors indicated that they would be “likely” or “very likely” to choose the program.

Based on our polling of students involved in the Hispanic Engineering Institute (HELI) at UTEP, it has been estimated that about 35 students would apply to the proposed program and that approximately 21 new full-time and four new part-time students would enter the program each year, with an annual increase of five students in years 2-5.

Strong support for the E-LEAD program has been received from several corporations in Texas, such as

AT&T, IBM, and Halliburton Energy Services. These corporations have already agreed to partner with our program and to provide student internships.

It is anticipated that job opportunities for our E-LEAD graduates will be promising, including those seeking engineering jobs in Texas. Our initial review of a national engineering jobs source [26] in October 1, 2012 suggested that E-LEAD graduates would qualify for 30 of the 93 engineering jobs in the El Paso region; 75 of the 470 engineering jobs listed for the West Texas region, and 3,470 of the 15,351 jobs listed in Texas. The actual number of jobs that BSLE graduates would qualify for may actually be higher since we anticipate three primary markets for our graduates: industry, secondary education, and graduate engineering education.

Much progress has been made in our longitudinal pathway to inaugurating the degree, commencing with ideation in 2007, through to conceptualization during 2009, followed by planning, and necessary iteration processing during 2011, application for offering in 2012, and inauguration in 2014. This journey is well worth sharing, to help innovators in engineering understand the practices and procedures involved in causing change at the fundamental program level. We also share their impact on traditional engineering programs, and current experiential learning occurring through implementation. In many ways a journey, and definitely finding a destination, our student mavericks are our future ambassadors for this intriguing entrance into the new discipline of engineering leadership.

The partnership in faculty professional development activity with Olin College has promise to transform engineering education at UTEP. What we learn in this project can lead to transfer of a model of innovative engineering education practices to other minority institutions with an aim of increasing retention and persistence to graduation.

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Becoming Boundary Spanners in Engineering:

Identifying Roles, Activities, and Competencies

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Abstract—Engineers are increasingly acting as “boundary spanners” who coordinate, collaborate, and communicate across many different kinds of boundaries. The research project described in this work-in-progress paper is shedding additional light on this trend by responding to two main research questions: 1) What specific boundary spanning roles, activities, and competencies are most important and prevalent for early career engineers, and 2) How do early career engineers experience boundary spanning challenges? One major goal of this project is to generate a typology of boundary spanning roles, activities, and competencies for multiple engineering fields. This paper more specifically describes methods and reports preliminary findings for the initial phases of our research. The first phase involves a systematic review of more than 80 journal articles and book chapters on boundary spanning and related concepts using established procedures for literature meta-analysis. In this paper we summarize the major themes and categories emerging from this process. The second phase of the project involves semi-structured interviews with engineering students and early career engineers. In this paper we focus on our interview methods, including development and use of a “primer” document to familiarize subjects with boundary spanning. We conclude by discussing the implications of our work, especially in relation to leading-edge approaches for instruction and assessment.

Keywords—*boundary spanner; boundary spanning; competencies; early career; engineering education; engineering practice; global; professional*

I. PROJECT BACKGROUND

Future engineers will be *boundary spanners*, capable of connecting teams in disparate geographic locations, translating stakeholder needs into effective design solutions, and leveraging expert knowledge from multiple disciplines. They will be empathetic in the midst of diverse perspective, adept as listeners and messengers, able to cultivate trust and mutual respect, and skillful at seamlessly integrating the social and technical aspects of their work. In short, boundary spanning engineers can effectively *communicate, collaborate, and coordinate across organizational, disciplinary, geographic, demographic, stakeholder, and other boundaries*. These next generation professionals are also ideally positioned to advance organizational and national competitiveness, address global grand challenges, and become leaders.

While the need for such capabilities can be traced back many decades, it has intensified due to trends like globalization pressures, organizational restructuring, and rapid technological change. As aptly framed by former NAE President William Wulf, “understanding other cultures, speaking other languages, and communicating with people from marketing and finance will be just as fundamental to the practice of engineering as physics and calculus” [1]. Bordogna similarly asserts that “[d]emands are increasing for a holistic breed of engineers—graduates with the skill to work across intellectual, social, and cultural boundaries” [2], while Duderstadt advocates for “fluency across boundaries” and “integration of knowledge across an increasingly broad intellectual span” (p. 45) [3].

A growing body of literature adds further weight to such assertions. Studies by Lynn and Salzman, for instance, lead them to conclude that engineers urgently need “cross-boundary skills” to enable working “across disciplinary, organizational, cultural, and time/distance boundaries” (p. 82) [4]. Research by Hanneman & Gardner has similarly identified boundary spanning skills and competencies as a key emerging requirement for college graduates, including engineers [5-6]. Demand for such capabilities also persists as professionals progress in their careers. In one study, 86% of more than 100 senior executives indicated it is “extremely important” for them to work effectively across boundaries, yet only 7% believed they were “very effective” at doing so [7].

Nonetheless, a persistent lack of alignment between current workplace realities and the capabilities of graduates means that most early career engineers are simply not ready for boundary spanning work. As Brunhaver et al. describe, many students leave school with “narrow views of professional practice” and employers find that most engineering graduates are “unprepared to practice” [8]. These gaps are exacerbated by compartmentalized learning outcomes coupled with a segmented and crowded engineering curricula, which in turn reinforces the boundaries between the technical and social/professional aspects of engineering practice rather than integrating them in a more holistic and authentic manner [9-10]. In addition to generating disillusioned students and employers, maintaining this status quo may erode the diversity, relevance, and influence of engineering degree programs and their graduates. Concerns have also been raised that such issues

may be exacerbated by ABET's recent proposal to streamline accreditation criteria for engineering degree programs [11].

This project responds to these challenges by proposing *boundary spanning* as a core *meta-attribute* for engineering graduates and early career professionals. This approach provides a powerful framework for relating and uniting a host of complimentary technical and social/professional capabilities, including multiple ABET accreditation criteria, while opening up new opportunities for innovations in instruction and assessment. However, there remains a lack of understanding regarding what counts as boundary spanning in engineering practice, including across sectors and career levels. Further, we know very little about how engineering students and early career engineers experience boundary spanning challenges, much less what instructional strategies best cultivate boundary spanning competence. These gaps are addressed through the project's three primary objectives, which are organized around a competency-based approach [12] to defining, developing, and assessing boundary spanning capabilities in engineering:

- Objective 1: Develop a typology of boundary spanning roles, activities, and competencies for multiple engineering fields.
- Objective 2: Design and evaluate an instructional framework to instill a *boundary spanning mindset* among engineering students and early career professionals.
- Objective 3: Create and pilot a situational judgment test (SJT) to assess key dimensions of boundary spanning competence in engineering practice.

This work-in-progress paper describes methods and presents preliminary findings for the initial two phases of research, which primarily support the first project objective. The sections that follow describe these phases in more detail, with particular attention to methodological considerations.

II. PHASE I: LITERATURE META-ANALYSIS

The first phase of this research project involved conducting a systematic literature review [13] to collect relevant literature discussing multiple facets of boundary spanning, including definitions, boundaries spanned, typical boundary spanning behaviors, and related competencies. The literature search and selection process followed the PRIMA process [14], as suggested by Borrego et al. [13]. The primary criteria initially used to identify literature for this study involved asking whether a given candidate paper: 1. was explicitly and substantially focused on boundary spanners, boundary spanning, and/or closely related topics (e.g., knowledge brokers/brokering), 2. discussed boundary spanning at the individual level, in whole or in part, and in contrast to focusing on the group or organizational level, and 3. was published since 2000 in order to better capture the contemporary state of the literature. To further improve the quality of results while keeping the scope of our efforts more manageable, we limited our search to book chapters and journal articles.

The first step in our process involved searching for relevant literature in the Engineering Village database, resulting in 213

unique articles. Second, we screened all of the associated abstracts and discarded 171 papers because they were not relevant for the scope of this study based on the preceding criteria. We then appraised the full text and discarded an additional 19 articles because they did not meet the requirements for inclusion.

Additionally, while appraising the papers, we used a snowball approach to identify other relevant papers cited by the papers themselves. This process added 21 more papers to our collection. Finally, we added 19 more papers to the collection that we had known about and referenced in the original grant proposal for this project, and which had not shown up in our systematic literature search. These two steps also involved relaxing our initial evaluation criteria, especially to bring in a number of influential historical sources that were frequently cited by other papers in our data set. We ultimately identified a total of 82 papers for further analysis.

The analysis of the papers was conducted using a hybrid deductive-inductive thematic analysis as suggested by Fereday and Muir-Cochrane [15]. The first round of analysis was primarily deductive. To start, we documented a number of descriptive characteristics, including whether a given paper was empirical or conceptual, the primary discipline(s) of the author(s) and/or publication outlet, and whether or not each paper explicitly discussed engineers or engineering. We also examined each paper based on four pre-defined themes: 1. specific types of boundaries discussed, 2. definitions of boundary spanner and related concepts, including more specific boundary spanning roles, 3. descriptions or definitions of boundary spanning activities and processes, and 4. specific individual attributes and competencies associated with boundary spanning. These themes were identified based on the focus of the larger project and authors' pre-existing knowledge of the phenomenon of interest and associated literature. However, the researchers were also encouraged to take notes on other concepts and themes that did not fall in these four categories but might be worthy of further exploration. At least two researchers analyzed every paper and then met to discuss and compile results in an Excel spreadsheet, which included researcher notes supplemented with quotes from the original papers. Having multiple researchers involved in this process increased the amount of information we were able to glean from each paper, while also allowing us to collaboratively refine our interpretations and understandings of each text.

The second round of analysis was inductive, allowing us to identify emergent themes within the four pre-defined topic areas noted above. The two lead authors searched for themes independently and then met several times to compare, contrast, redefine, and finalize themes. These results are currently being written up for publication as a journal paper. Yet as detailed in the following section, we also used our findings to develop a new "primer" document that we are leveraging in related data collection and instructional/training efforts. In the following section we give an overview of this document, with special attention to how our expanding knowledge of the extant literature helped ground its development.

An Introduction to *Boundary Spanners* and *Boundary Spanning*

Most generally, *boundary spanners* are people who link or connect with others across various kinds of boundaries. Three kinds of boundary spanners are shown below (with boundary spanners shown in red).

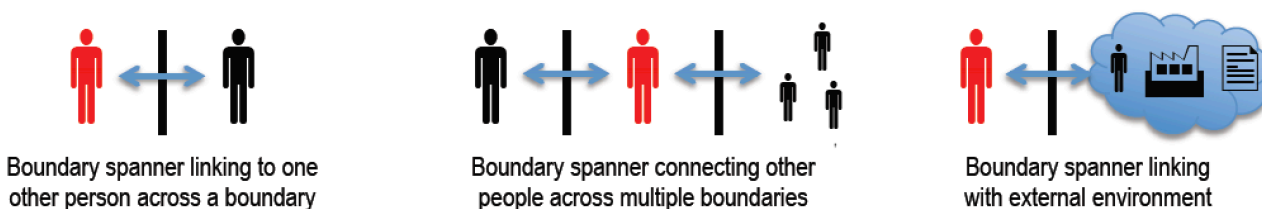


Fig. 1. Header text and illustrations from boundary spanning primer document

III. PHASE 2: INTERVIEWS WITH EARLY CAREER ENGINEERS

In parallel to our literature review efforts, the lead author conducted two pilot interviews with early career engineers. The subjects were both undergraduate engineering students in their final year of study at a large Midwestern research university. Each of these students had completed two prior internship experiences at two different companies. In line with the larger focus of this project, both students' experiences were in manufacturing or related work environments. One student's disciplinary background was in mechanical engineering, while the other was in chemical engineering. After having each participant complete a brief demographic survey, interviews were carried out with each student following a semi-structured format with a duration of 60 minutes or less. The protocol for the pilot interviews was in part based on a critical incident approach [16], coupled with the lead author's pre-existing knowledge of boundary spanning and related concepts. As noted below, the lead author also conducted a second, follow-up interview with one of these individuals. Data collection was carried out under Purdue IRB protocol number 1208012567.

Transcripts from the two pilot interviews were reviewed and discussed by members of the lead author's research group, along with one external colleague who agreed to provide feedback after reading one of the transcripts. This process led to a number of suggestions for improving our data collection procedures, including some new question prompts, as well as the idea of creating a primer document to help sensitize subjects to the primary phenomenon of interest (i.e., boundary spanning). The authors in turn realized that their literature review efforts could be very useful in guiding creation of such a document.

The resulting primer was developed based on our growing knowledge of the extant literature, and is organized around four major sections. To make the primer as usable and accessible as possible, we limited its length to just one page, and tried to avoid excessive use of jargon. The first part of the document, as shown in Figure 1, gives a broad definition of the term *boundary spanner*, followed by illustrations showing boundary spanners in three typical kinds of connecting or linking situations. These portrayals were informed by the results of our literature meta-analysis, namely in terms of

seeing boundary spanners often framed in the extant literature as: 1) "linking pins" that connect people to other people and/or to the external environment [17], and/or as 2) individuals who link otherwise disconnected individuals, i.e., they bridge "structural holes" in social networks [18].

The second section of the primer briefly describes three typical kinds of *boundary spanning activities*, namely:

- Coordinating work tasks with others
- Strategically managing relationships with others
- Enabling the movement of knowledge and information

Identification of these three types of activities emerged through inductive analysis of the papers in our literature collection. While these types of activities appear frequently in the extant literature, we also acknowledge that effective boundary spanning may involve or even require various other kinds of actions and behaviors. Additionally, these three activities compliment and extend how we had conceptualized boundary spanning in previous proposals and presentations, namely as being comprised of the "three Cs": coordination, collaboration, and communication.

The third section of the primer summarizes many different *types of boundaries* often encountered by professionals. A major first category centers on organizational boundaries, which can further be subdivided by considering: *horizontal* boundaries involving different business units, divisions, teams, etc.; *vertical* boundaries among lower and/or higher-ranking colleagues; and *job/functional* boundaries that separate people with different roles and responsibilities. The other types of boundaries presented in the primer include:

- Between an organization and external organizations or stakeholders, like customers or vendors.
- Across disciplines, professions, specialized areas of expertise, etc.
- Across geographic locations, including local, region, and global.
- Between different cultures and languages, whether in the same or different locations.
- Involving demographic characteristics like gender, race/ethnicity, and socioeconomic status.

This list was developed based on deep engagement with the prior literature, and was particularly inspired by other papers presenting similar overviews [19]. This list is also not fully inclusive, as our in-depth literature review revealed other important kinds of boundaries that receive extensive discussion in the literature but are not as easy to communicate with individuals who are new to the concept of boundary spanning, e.g., the idea of “knowledge” boundaries [20].

Fourth and finally, the primer gives two brief examples or vignettes that illustrate typical boundary spanning situations encountered by technical professionals. The first vignette, which we titled “Wafer Fab Debug”, was adapted from an empirical case study included in our literature collection [21]. The second example, presented in Figure 2, was drawn from one of our pilot interviews. This example was intended as a realistic portrayal of boundary spanning as encountered by a typical subject in our study, namely an engineering student working as an intern within a large company.

Example 2: Cafeteria Co-op

As a summer co-op employee at a food processing plant in the central U.S., engineering student Natalie reports to a facilities manager who oversees all on-site construction and maintenance. Natalie has been asked to help coordinate a remodeling project in the plant’s cafeteria while her manager is on vacation. She quickly finds herself in the middle of many boundary-spanning situations as she interacts with the human resources staff who originally requested the project, the contractors doing the actual remodeling work, and higher-level managers inquiring about budgets and timelines.

Fig. 2. Sample vignette from boundary spanning primer document

After developing the primer document, the lead author conducted a second interview with one of the original pilot interviewees. (The other student had gone on to enroll in graduate school, and therefore no longer met the criteria for participating in the study, i.e., early career engineers working in the private sector.) The primer was shared with the interviewee prior to the scheduled conversation. While the primer did not receive much explicit attention during this interaction, the interviewer found that it was a very useful document to have close at hand, especially to provide guidance and inspiration in posing follow-up questions and making sure that the phenomena of interest was explored in sufficient breadth and depth (e.g., by explicitly asking the interviewee about types of boundaries which had not already surfaced in the conversation). The interviewee also indicated that the “Cafeteria Co-op” example was a reasonable representation of the actual experience as it was described in the first interview.

IV. FUTURE PROJECT PHASES

The authors’ near-term work on this project is continuing in two major directions. First, results of the literature meta-analysis are being written up for publication as a journal paper. This will be a foundational outcome for this project, helping to establish a firm conceptual and theoretical basis for subsequent project phases. Secondly, the authors are conducting additional interviews to evaluate how well the primer document works in orienting new study subjects to boundary spanners, boundary

spanning, and related concepts. This process will spur further refinements to the interview protocol, which will ultimately be used to collect interview data from at least 15-20 subjects. The authors are also exploring the possibility of collecting reflection data from interviewees [22]. Engineering students in internships or practicing engineers within the first year or two of graduation would be asked to complete 3-5 reflections over a period of 2-4 months. The prompts would ask participants to report and reflect on boundary spanning incidents and situations using a critical incident framework and informed by the primer document.

Over a longer period, this project will begin to transition toward greater emphasis on instructional interventions and assessment, or Objectives 2 and 3 as noted above. Regarding the former, the authors see the primer document as a first step toward creating workshops and other kinds of instructional interventions designed to enhance the boundary spanning capabilities of early career engineers. The authors are also planning to generate new assessment strategies and tools related to boundary spanning in engineering. At least three possibilities are being explored. First, the literature review is allowing us to identify a variety of attributes and capabilities that may undergird effective boundary spanning, and could potentially be measured using existing tools. For example, capabilities such as empathy and perspective taking may be important antecedents for boundary spanning [23-24]. If this proves to be the case, a measure such as the Interpersonal Reactivity Index (IRI) could serve as an important predictor of an individual’s predispositions and/or actual capabilities related to boundary spanning [25]. A second, complimentary assessment method involves developing a set of items that can be used to rate one’s own or other’s boundary spanning capabilities. This approach is commonplace in engineering education, as in many ongoing efforts to evaluate ABET learning outcomes [26].

Third and finally, the authors are especially excited about creating and using scenario-based and situational assessment tools to measure meta-attributes such as boundary spanning [27]. As we have argued elsewhere, this assessment approach is promising for many reasons, including scalability through the use of multiple choice questions, potential to measure behavioral tendencies in realistic situations, and resistance to faking and other shortcomings often associated with self-rated items. Our efforts to develop such assessment tools will build on parallel research, including a current project that involves generating and validating large back of situational judgment test (SJT) questions and online assessment platform focused on global engineering competency [28]. While the existing pool of scenarios all focus on doing technical work across countries and cultures, the present study would extend this work through creation of new scenario prompts that focus on other kinds of boundaries, e.g., organizational, knowledge, demographic, etc. Ultimately, we see considerable potential for creating and deploying a suite of high quality, validated assessment tools that can be used to measure the boundary spanning capabilities of engineering students and practicing professionals, including to detect possible changes over time related to both work experiences and targeted interventions. Through these efforts to relate research and practice, we hope to contribute to broader

efforts and initiatives that aim to prepare engineers for the current and future realities of professional practice.

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Pivot Thinking

Predicting Entrepreneurial Intent among Engineering Students and Faculty using Problem Solving Style Preference

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Abstract— This research explores the concept of “pivot thinking” or the ability to pivot between domain specific problem solving heuristics, and the impact of this cognitive trait on entrepreneurial career intent. A review of popular problem solving heuristics is presented for comparison purposes. The research sample includes engineering and science-trained students and faculty ($n = 114$) and measures both business skill self-efficacy and cognitive problem solving style using a four-factor psychometric instrument called the Herrmann Brain Dominance Indicator (HBDI). Results show that both higher levels and a balance between problem solving styles of analytical-factual (Factor A) and conceptual-intuitive (Factor D) predict entrepreneurial intent. Business skill self-efficacy is also an important predictor of entrepreneurial intent with emphasis on understanding business finance and communication skills. The implications of this research on engineering and entrepreneurship education are discussed.

Keywords—*pivot thinking, macro pivot, micro pivot, entrepreneurship, entrepreneurial intent, problem solving style, domain specific heuristic*

I. INTRODUCTION

Over time certain domains of thinking have developed to serve the particular type of problems encountered by those domains. Art and design domains have developed problem solving heuristics that meet the needs encountered in the production of art or the design of goods and services. The field of engineering has developed an engineering problem solving heuristic; business problems lead to a business problem solving heuristic, and so on for many domains of expertise.

In teaching and apprenticeship within these domains, problem solving is often taught as a unique, domain-specific heuristic. For example, engineering students are trained in the “engineering problem solving process” and rewarded for following this process in homework and on exams. Research tends to support this approach, showing that successful problem solving is enhanced when domain specific knowledge is coupled with a domain specific problem solving heuristic to solve domain specific problems [1]. The challenge, of course, is when students (or faculty) cross over domains, into areas of new domain knowledge that require new domain specific problem solving heuristics.

Fortunately, students with knowledge of domain specific problem solving heuristics often have a range of alternative,

nascent problem solving heuristics acquired through their lifetime of experience. These alternate problem solving heuristics are rarely or never their first choice for problem solving but may be recruited and developed with practice. When a person shifts their fundamental domain specific problem solving heuristic, typically to meet the requirements of a new domain, it is termed pivot thinking.

Pivot thinking may be a particularly valuable skill for engineering students considering a career that spans a variety of domain specific problems – such as technology entrepreneurship, which bridges the domains of engineering and business. There has been little research done of the pedagogical techniques that encourage pivot thinking and even less is known about the connection between pivot thinking and entrepreneurship.

II. COGNITIVE PROBLEM SOLVING STYLE

Cognitive style is a well-researched psychological construct representing how a person thinks. The study of cognitive styles define “individual differences in preferred ways of organizing and processing information that cut across the personality and cognitive characteristics of an individual” [2]. Researchers such as Witkin et al. characterize cognitive style as simply “individual differences in the way people perceive, think, solve problems, learn, and relate to others” [3].

Individual cognitive styles are acquired and reinforced through life experiences such as education and work. Kozhevnikov states that “cognitive styles can be viewed as distinctive patterns of adjustment to the world that develop slowly and experientially as a result of the interplay between basic individual characteristics and long-lasting external requirements” [4]. These “distinctive patterns of adjustment” frequently align with domains of knowledge and practice, such as engineering or business or music, and they tend to attract individuals with cognitive styles that have a propensity for these patterns.

Individual cognitive styles (ICS) often lead an individual to a domain of study or practice where that particular cognitive style is effective at problem solving, as shown in Fig. 1. For example, individuals who have an individual cognitive style that favors mathematics may gravitate toward science or engineering domains of knowledge and practice. In the teaching and apprenticeship of these domains, distinctive

patterns are often reduced to domain specific problem solving heuristics that are reinforced, practiced and rewarded which can lead to students whose cognitive styles are more similar than different. Once a student is skilled in a domain specific problem solving heuristic there may be little incentive and even less ability to employ an alternative problem solving heuristic.

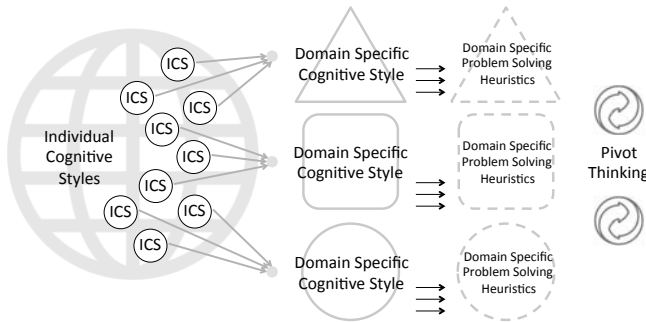


Fig. 1. Pivot Thinking Theoretical Framework

III. DOMAIN SPECIFIC PROBLEM SOLVING HEURISTICS

Problem solving heuristics are often codified, defined and taught within a specific domain of practice. In a typical, post secondary learning environment student are likely to specialize in one domain and seek to become expert in its problem solving heuristics. An engineering student will likely become proficient in engineering problem solving heuristics, and in some cases may be exposed the problem solving heuristics of other domains.

An overview of selected domain specific problem solving heuristics typically found in a post secondary learning environment is shown in TABLE I.

TABLE I. DOMAIN SPECIFIC PROBLEM SOLVING HEURISTICS

Domain	Heuristic Theme	Problem Solving Tools	Outcome
Engineering Problem Solving	Analyze your way forward	Equations, Analytics	Single point best answer
Business Problem Solving	Optimize your way forward	Maximizing, Satisficing	Single point sufficient answers
Design Problem Solving	Build your way forward	Empathy, Prototyping, Iteration	Multiple possible novel answers
Artistic Problem Solving	Feel your way forward	Qualitative, Experiential	Multiple possible balanced answers
Research Problem Solving	Logic your way forward	Deduction, Induction, Abduction	Internally consistent answer

A. Engineering Problem Solving

As plainly stated by the *National Academy of Engineering in The Engineer of 2020: Visions of Engineering in the New Century*, “Engineering is problem recognition, formulation, and solution”[5]. Post secondary, entry-level engineering education often includes a description of the “engineering way” to solve problems, with notable examples such as the NSF funded Dartmouth Project for Teaching Engineering Problem Solving [6] or the popular mechanical engineering statics textbook by Sheppard and Tongue [7]. The Sheppard and Tongue model of engineering problem solving is shown in Appendix A-1.

Most engineering problem solving heuristics begin by encouraging the problem solver to understand the problem solving goal, then moves through a roughly linear process of defining assumptions and selecting the appropriate formulas or equations to solve the problem. As a result, engineers are taught to “*analyze your way forward*,” seeking a single point answer that can be checked/confirmed with the original problem statement. This problem solving heuristic values showing the process as much as the answer, and correctness is often confirmed by drawing a box around the answer in summation. This heuristic is most valuable when both the problem and problem space are well defined and a specific answer is required that can be verified.

B. Business Problem Solving

Roger Martin, in his book *Playing to Win* [8], describes the essence of successful business strategy as “*a set of choices about winning*.” These choices often fall into the rubric of “*must win*” challenges and “*good enough*” trade-offs. Nobel laureate Herb Simon noted that organisms in nature, when seeking food, rarely seek the optimal answer, rather they “*satisfice*” or seek a good enough solution [9]. Driver et al. describe the tension between maximizing and satisficing in business as “*dynamic decision making*” [10] and display this on a utility curve as shown in Appendix A-2.

Business school students are taught this heuristic as part of strategic decision making and it is often summarized as the “*80/20 rule*” where a decision that captures 80% of the possible benefit from a solution for 20% of the investment required to execute the solution is a good outcome. Students optimize their way forward, examining the tradeoff between maximizing and satisficing. In entrepreneurship, this heuristic is often expressed as “*the hedgehog concept*,” defined by Berlin quoting the Greek poet Archilochos [11] and popularized for entrepreneurs by Jim Collins in the book *Good to Great*. [12] This heuristic, “*the fox knows many things, but the hedgehog knows one big thing*,” suggests its best to do one thing better than any competition while satisficing on everything else.

C. Design Problem Solving

This problem solving heuristic addresses the concept of “*wicked problems*” as popularized by Rittel and Webber [13] and Buchanan [14]. Rittel and Webber describe problems found in the domains of science and engineering as “*tame problems*” where “*the mission is clear*” and it is known “*whether or not the problem has been solved*.” (p160) By contrast, design problem solving, which Rittel calls “*wicked problems*,” have no clear path to solution, no understanding of when a successful answer is achieved and are often a symptom of another, higher-level problem. Over the years, many design problem solving heuristics have been developed, often under the banner of “*design thinking*,” and a representative version of this heuristic is shown in Appendix A-3.

The design problem solving heuristic incorporates empathy for the user (or customer) while prototyping and rapidly iterating through possible solutions. In this heuristic, the problem solver is encouraged to “*build your way forward*” and in the process often discovers many, novel solutions to the problem. However, unlike engineering or business problem

solving, there is no sense of “the best” answer or even an answer that is sufficient, only answers that are possible. It has also been said that “*the three most important words in design thinking are – change the problem,*” [15] meaning that within this design problem solving heuristic is the ability to change the problem statement completely as a way to achieve a novel or superior solution. This kind of problem solving flexibility is not often taught to engineering or business students.

D. Artistic Problem Solving

The French impressionist painter Claude Monet, during the period of 1889-1891, painted a 25-canvas series that has come to be known as “*Haystacks*” [16] The subject of these paintings were the harvest haystacks near his home near Giverny, France and this systematic, thematic repetition has come to represent the heuristic of how artists solve problems. Monet painted the haystack at various times of day, in varying weather, and in different seasons as a way to build knowledge – conceptual and experiential knowledge.

The artistic problem solving heuristic is explored in Hilary Austen’s book, *Artistry Unleashed* [17] where she describes an artist’s tension with balance between gaining mastery of the medium and the inherent search for originality, as shown in Appendix A-4. Austen explains:

Working with artistry means grappling with the interplay between mastery and originality in practice and on an ongoing basis. In this effort, you will find yourself working your way from one extreme to the other, passing through happy moments of perfect balance that can be expressed in what you do, make, and say. (p67)

The artistic problem solving heuristic encourages practitioners to “*feel your way forward,*” using qualitative tools and emphasis on the experiential, resulting in a “*balanced*” answer. Austen describes this balance as the “*continuous oscillation between mastery and originality*” which are “*places artists pass through*” rather than a final destination. The artist gains knowledge in the problem solving process: directional knowledge that motivates the artist, conceptual knowledge that structures artistic learning and experiential knowledge that shape the artistic medium to produce results. The artistic problem solving heuristic has no notion of a correct answer or best answer, only a balanced answer.

E. Research Problem Solving

The final domain specific problem solving heuristic likely encountered by a student on the typical post secondary campus is that of research problem solving. In this heuristic, the practitioner is encouraged to “*logic your way forward*” using the classic tools of deductive, inductive and abductive reasoning. The goal is an answer that is internally consistent with the parameters set by the process. An example of the research problem solving heuristic is shown in Appendix A-5.

Krathwohl refers to this research problem solving heuristic as a “*chain of reasoning*” and describes it as “*the context in which the researcher works*” [18]. Research problem solving begins with a thorough of previous work in the area, the adoption of a theoretical framework or model. This is followed by a statement of the research question, followed by a

description of the research design and methodology. Data is collected and analyzed, then formed into conclusions which bridge to the next step in the study process. Again, there is no correct answer, no best answer, only answers that are internally consistent with the research process.

IV. PIVOT THINKING

Psychologist and psychometrician Raymond Cattell put forward a theory that individual cognitive differences are result of an individual's lifelong pursuit of neurocognitive advantage [19]. Cattell believed that individuals are born with a unique fluid intelligence capability to solve particular problems. As they go about life solving problems, they acquire crystallized intelligence that helps solve those same problems more successfully [20]. In turn, the individual seeks more of the problems they solve successfully and acquires more of the successful problem solving skills. Cattell refers to this as cognitive “*investment theory*” where an individual gravitates toward problem-solving situations where they have skill and have experienced success in the past.

The challenge, of course, is when a problem solver encounters a problem that does not easily yield to their default heuristic. For example, when the product design engineer encounters consumer preferences that value aesthetics over performance or the social entrepreneur discovers that their product solution is not compatible with socio-economic needs of their target user. In each case, the successful problem solver must *pivot to another domain specific problem solving heuristic* – something called a **pivot**.

Nobel laureate Daniel Kahneman and his research partner Amos Tversky established that humans tend to be “*cognitive misers*” when problem solving, meaning that they rely on their default heuristics and jump quick, intuitive (and often incorrect) answers [21], [22]. In his recent book, *Thinking, Fast and Slow* [23], Kahneman explains the dual system of thinking embraced by most cognitive scientists. System 1 is “*fast thinking*” and results in the ability “*to perceive the world around us, recognize objects, orient attention, avoid losses, and fear spiders.*” (p22) System 2 is “*slow thinking*” and involves “*the conscious, reasoning self that has beliefs, makes choices, and decides what to think about and what to do.*” (p21)

Pivot thinking is a form of System 2 thinking yet it is more; it occurs when a problem solver shifts or changes the domain specific heuristic that guides System 2 thinking. When the use of a default heuristic involving both conscious and reflective reasoning fails to yield a successful answer, the problem solver initiates a macro pivot to an alternative heuristic system. This happens when the engineering student turns to a design problem solving heuristic or the business student reaches an artistic problem solving heuristic to find a successful answer.

There is evidence that very few people can easily accommodate a macro pivot. Researchers in the field of “*heuristics-and-biases*” use an instrument to measure this cognitive shift called the Cognitive Reflection Test (CRT) [24]. This three-question, open answer, correct/incorrect instrument that measures respondents’ tendency to reflect on problem solving strategies inherent with System 2-type thinking. In a

recent study, 56% of respondents got no answers correct, indicating the difficulty in shifting System 2 thinking, while only 7% of respondents got all three correct, showing how rare pivot thinking is within the general population [25].

At some point, the problem solver engages in a micro pivot, switching from divergence to convergent and back to divergence throughout the problem solving process. This micro pivot can happen second-by-second, minute-by-minute or day-by-day. It is not clear what triggers a micro pivot and this is a fertile area for additional research, unfortunately outside of the scope of this study.

V. RESEARCH QUESTION

The purpose of this research is to better understand the role of pivot thinking and the impact it may have, if any, on entrepreneurial intent. Therefore, the Research Question guiding this study is:

Among engineering trained participants, does the ability to “pivot think” or shift between domain specific heuristics predict entrepreneurial intent?

VI. RESEARCH SAMPLE

The sample for this for this research includes a total of 114 participants, collected over the 2013-2014 academic year.

A. Undergraduate Engineering Students ($n = 31$)

These participants were enrolled in a one-quarter design-build class during Spring 2014 at a private, western US university. The mean age was 20.3 years, 84% were engineering majors, 13% were science majors, and 52% were female.

B. Masters-Level Engineering Students ($n = 43$)

These participants were enrolled in a three quarter capstone design-build class during 2013-2014 at a private, western US university. The mean age was 23.6 years, 100% were engineering majors, and 52% were female.

C. Engineering Faculty ($n = 40$)

These participants were selected to take part in a 10-week entrepreneurial training experience during Fall 2013 at a private, western US university. All participants were faculty in engineering and science programs at a range of Polish universities. The mean age was 35.2 years, 95% were PhDs, 55% were engineering-trained, 32% were science-trained and 27% were female.

VII. MEASURES

A. Measure of Career Intent

This measures is the dependent variable for this research. During the first week of their classroom experience undergraduate and masters-level students were asked about their career intention using the question, “Looking into your future, over the 5 years from your graduation how likely are you to do any of the following?” Engineering faculty was asked the same question without the words “from your graduation.” The choices included *founding a company, working for a small business/start-up, medium or large size US-based business, multi-national global business, government*

and *non-profit*. Responses were collected using a 5-point Likert scale of likelihood ranging from Very Unlikely (1) to Very Likely (5) with (3) as neutral. This question was adapted from a longstanding alumni survey instrument. (28, 29)

B. Measure of Business Self-Efficacy

During the first week of their classroom experience respondents were asked about their confidence to perform in a series of business-related skills. This item was drawn from previous studies on engineering. (30) The question was “How confident are you in your ability to do each of the following at this time?” The eight choices included *recognizing a good idea, financing a new business, selecting a marketing approach, negotiating prices with a supplier, leading a team of people, and promoting accomplishments*. Responses were collected using a 5-point Likert scale of confidence ranging from Not Confident (1) to Extremely Confident (5) with (3) as neutral. The self-efficacy ratings of business-related skills showed high reliability ($\alpha = .88$), so the items were averaged to give an so the items were averaged to give an overall pre-and-post business skill self-efficacy score.

C. Herrmann Brain Dominance Indicator (HBDI)

Problem solving preferences is measured using the Herrmann Brain Dominance Indicator (HBDI). Ned Herrmann, a long-term General Electric executive, was interested in the thinking and problem solving preferences. Herrmann’s belief was that most people have one of four thinking styles that is a result of their training and life experiences. Some people have are overwhelmingly dominant in one style, while others balance thinking styles into what he calls “whole brain” thinking [26], [27] The HBDI has been in use for over 30 years and has collected 1.4+ million records. The HBDI is judged to be both a valid and reliable psychometric instrument. (33, 34)

The HBDI is a 120-item preference instrument, measuring respondents’ preference for certain types of cognitive problem solving processes. It results in a four-factor model with two opposing modalities. The four factors are (A) Analyzing, (B) Chronological, (C) Interpersonal and (D) Imaginative, as shown in TABLE II.

TABLE II. HERRMANN BRAIN DOMINANCE FACTOR DESCRIPTION

Factor	HBDI Style	Behavioral Characteristics	Typical Vocations
A	Analyzing	Logical, Factual, Technical, Analytical, Quantitative	Engineer, Financial Manager
B	Chronological	Structured, Sequential, Organized, Detailed, Planned	Operations, Accounting
C	Interpersonal	Emotional, Empathetic, Sensory, Social, Relational	Sales Manager, Nursing
D	Imaginative	Visual, Intuitive, Conceptual, Innovative, Holistic	Strategic Planner, Marketing

In *The Whole Brain Business Book*, [27] Herrmann links each of these factors with a series of behavioral characteristics (p23) and to typical vocations (p31). He defines this in terms of dominance by one cognitive style factor over the other factors:

“As dominance of one [factor] over its partner develops through life experiences, the degree of that dominance becomes evident from the mental preferences the person exhibits.” (p17)

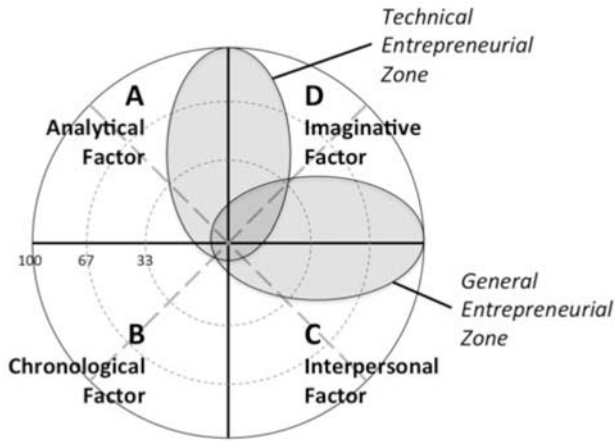


Fig. 2. HBDI Factors and Technical Entrepreneurship

Herrmann devotes an entire chapter of *The Whole Brain Business Book* to the problem solving preference styles of the entrepreneur. Herrmann's data indicates that entrepreneurs are not "whole brained" in their approach to problem solving, rather he reports a Factor D dominance, as shown in Fig. 2.

Herrmann further distinguishes between "technical entrepreneurs" who have balanced scores between Factor D and Factor A (formula 1) and "general entrepreneurs" who have balanced scores between Factor D and Factor C preference (formula 2). This study was conducted among engineering students and faculty, so "technical entrepreneurship" should be evident in the relative balance between Factor D and Factor A scores.

$$\text{Factor}_{AD} = |\text{Factor}_A - \text{Factor}_D| \quad (1)$$

$$\text{Factor}_{DC} = |\text{Factor}_D - \text{Factor}_C| \quad (2)$$

D. Data Analysis

For the data analysis we conducted one-way analysis of variance (ANOVA) using Tukey posthoc tests with a significance reported at the $p < .050$ level. The Pearson product-moment correlation coefficient (r) was used to report correlations with significance determined at the $p < .050$ level. Multivariate linear regression generated fitted models using the least squares approach with significance determined at the $p < .050$ level. All analysis was done in R [28] with a variety of package components [29]–[31].

VIII. RESULTS

A. Career Intent

Career Intent scores (measured on a 1-5 "likelihood" Likert scale) showed the highest career interest in working for a small business (3.84) and the lowest career interest in working for a non-profit organization (2.62), as shown in TABLE III. Career interest in founding a start-up was above average (3.43 with 3.00 being neutral) and not significantly different that career interest in working for a medium-large US business (3.59) or a multi-national global business (3.49).

TABLE III. CAREER INTENT SCORES AND CORRELATION

	Career Intent	Mean	SD	$p <$	d	r
1	Founding a Start-Up	3.43	1.29	Base	Base	Base
2	Small Business	3.84	1.02	.000	.35	.54
3	M-L US Business	3.59	.98	.349	.14	-.23
4	Global Business	3.49	1.17	.912	.01	-.08
5	Government	2.84	1.22	.001	.59	-.04
6	Non-Profit	2.62	1.04	.000	.81	.00
Bold – significant $p < .05$ Cohen's d medium effect size $> .30$ Pearson's Product Moment Correlation Coefficient - r						

Not suprisingly, correlation analysis shows a significant negative correlation between career interest in founding a start-up and working for a medium-large US business ($r = -.23$) and a lesser, non-significant negative correlation with career interest in global business.

B. Business Skill Self-Efficacy

Business self-efficacy scores (measured of a 1-5 "confidence" Likert Scale) showed a significant advantage for participants interested in founding a start-up, as shown in TABLE IV. The eight business skills measured factored into two groups, Operational Skills ($\alpha = .81$) and Interpersonal Skills ($\alpha = .70$). Interpersonal Skills (3.62) showed a significant advantage over Operational Skills (2.75, $df(113)$, $t(14.44)$, $p < .000$, $d = 1.18$) indicating a greater confidence in working with others than in their operational business skills. Of note, the lowest scoring self-efficacy measure was "finance a new venture" (2.21) significantly lower than any other Operational Skills measure.

TABLE IV. BUSINESS SKILL SELF-EFFICACY SCORES

	Total (n = 114)		Start-Up (n = 60)				
Business Skill	Mean	SD	Mean	SD	Diff	$p <$	d
recognize an idea	2.94	.96	3.22	1.01	.28	.082	.28
finance a venture	2.21	1.08	2.70	1.08	.69	.005	.45
marketing approach	2.74	1.05	2.97	1.06	.23	.174	.22
supplier pricing	2.99	1.15	3.25	1.14	.26	.159	.23
estimate cost	2.86	1.02	3.13	1.02	.27	.094	.27
Operational Skills	2.75	.79	3.05	.80	.30	.017	.39
lead a team	3.75	.85	4.08	.72	.33	.007	.42
communicate ideas	3.79	.88	3.95	.89	.16	.258	.18
promote self	3.32	.95	3.57	.83	.25	.070	.28
Interpersonal Skills	3.62	.69	3.87	.61	.25	.016	.38
Business Self-Efficacy	3.07	.69	3.36	.65	.29	.008	.42
Bold – significant $p < .050$ Cohen's d medium effect size $> .30$							

The sample was split by participants who expressed career intent to found a company (4 or 5 rating on the career intent measure) and those who did not (1, 2 or 3 rating), resulting in a sub-sample of 60 respondents who expressed some level of interest in founding a company. This entrepreneurial sub-sample was significantly different in two business skill self-efficacy areas from the overall sample – "financing a venture" (2.70 vs. 2.21) and "lead a team" (4.08 vs. 3.75) – that are two skill areas important to entrepreneurial success.

C. HBDI Scores

The HBDI Factor Scores (range from 0 to 100, with the mean at 50) were significantly higher for the problem solving style preference Factor A (58.8) and Factor D (61.8) than for Factor B (35.1) and Factor C (32.6), as shown in TABLE V.

There were no significant differences between problem solving style preference Factors A and D or Factors B and C.

TABLE V. HBDI SCORES AND CORRELATION WITH CAREER INTENT

HBDI Factor Scores	Mean	SD	Career Intent Score - <i>r</i>	
			Start-Up	M-L US
A – Analytical, Factual	58.8	27.5	.08	.16
B – Sequential, Structured	35.1	26.2	-.20	-.13
C – Social, Empathetic	32.6	25.8	-.14	-.16
D – Intuitive, Conceptual	61.8	27.3	.21	.01
Indicators				
[A-D] Technical Entrepreneur	42.1	25.1	-.19	-.09
[D-C] General Entrepreneur	35.5	24.4	.25	.14
Bold – significant $p < .050$				
Pearson's Product Moment Correlation Coefficient - <i>r</i>				

Entrepreneurial career intent scores were significantly, negatively correlated with the Factor B score ($-.20, p < .04$) and significantly, positively correlated with the Factor D score ($.21, p < .02$). This indicates that the more interested a participant was in founding a start-up the lower they scored on Factor B (associated with a preference for sequential, structured problem solving) and the higher they scored on Factor D (associated with a preference for intuitive, conceptual problem solving). Recall, there was a strong, negative correlation between career intent scores for “founding a start-up” and “working for a medium-large US company” (see TABLE III.) Unlike, entrepreneurial career intent scores, there were no significant correlations between HBDI problem solving style preferences and medium-large US company career intent scores.

Importantly, there was a significant negative correlation ($-.19, p < .04$) between entrepreneurial intent scores and the [A-D] Technical Entrepreneur indicator (a measure of the balance between Factor A and Factor D scores with a lower score indication more of a balance). This supports Herrmann's assertion that technically oriented entrepreneurs will have higher Factor A and D scores and these scores will tend to be balanced between each other, indicating an equal preference for both analytical, factual and intuitive, conceptual problem solving styles. There is also a strong, positive correlation ($.21, p < .01$) between the [D-C] General Entrepreneur indicator and entrepreneurial career intent scores mean these technically trained participants show greater difference (less balanced) in Factor D and C scores and do not resemble the General Entrepreneur profile described by Herrmann.

D. Multivariate Linear Regression Models

The determinants that may predict entrepreneurial intent were evaluated with multivariate linear regression. The dependent variable was the career intent measure “founding a start-up”, a continuous Likert variable from 1 (Very Unlikely) to 5 (Very Likely). A total of 17 independent variables were incorporated into the modeling process – 8 business self-efficacy (BSSE) measures, 7 HBDI Factors scores and indicator variables, and the demographic variables of age and gender. Step-wise linear regression was used to optimize model fit while reducing the number of variables. The resulting model is referred to as “Best Fit Model.”

TABLE VI. LINEAR REGRESSION MODELS OF CAREER INTENT

Dependent Variable:	Best Fit Models							
	“Found a Start-Up”				“M-L US company”			
	<i>B</i>	<i>SE</i>	<i>t</i>	<i>p</i> <	<i>B</i>	<i>SE</i>	<i>t</i>	<i>p</i> <
Factor A	.01	.00	2.22	.028	.01	.00	2.24	.027
Factor D	.01	.00	3.23	.002				
[A-D] Indicator	-.01	.00	-1.72	.089				
“finance a venture”	.43	.10	4.15	.000	-.28	.09	-3.14	.002
“promote self”	.19	.12	1.58	.118	-.20	.11	-1.78	.078
Age	.03	.01	2.35	.021				
<i>Adjusted $r^2 = .37, p < .000$</i>								
Factor B					.21	.11	1.97	.052
Factor C					.01	.00	2.08	.040
“communicate ideas”					.01	.00	2.55	.012
<i>Adjusted $r^2 = .19, p < .000$</i>								
Bold – significant $p < .050$								

There were six variables that combined to have the best fit with entrepreneurial intent, as shown in TABLE VI. The HBDI Factor A and Factor D were significant predictors and the balance indicator ([A-D], where the lower the score the more balanced) was important, which suggests that these two problem solving styles are not only essential but must be in balance in terms of preference allowing the problem solver to readily pivot between these two different styles. In terms of business skill self-efficacy, “finance a venture” is a significant predictor and “promote self” and important predictor of interest in an entrepreneurial career, which seems consistent with this career path. Finally, age is a significant predictor, with older participants more likely to be interested in an entrepreneurial career. Overall, this model had a excellent fit (adjusted $r^2 = .37$) and was statistically significant ($p < .000$). These variables did a poor job of predicting career intent of working for a medium or large US business, the career option with the highest negative correlation with entrepreneurship, with a significantly lower model fit (adjusted $r^2 = .11$).

By contrast, career intent of working for a medium and large US business was predicted by a different set of variables. All HBDI Factor except Factor D were significant or important model contributors and this suggests that conceptual and intuitive problem solving are less important styles to participants with this career intent. The business skill self-efficacy measure, “communicate ideas” with “finance a venture” were both significant predictors, while age was not.

IX. DISCUSSION

The results of this research suggests that the ability to pivot or shift between problem solving styles, particularly analytical problem solving (HBDI Factor A) and intuitive problem solving (HBDI Factor D), is an important predictor of entrepreneurial career intent among engineering students. Pivot thinking is then defined as both a preference for a problem solving style and balanced preference with other problem solving styles. Importantly, entrepreneurial career intent suggests an emphasis on different problem solving styles than a corporate career path with more weight placed on conceptual and intuitive problem solving.

Business skill self-efficacy also plays a role in career intent. It seems that the more a student knows about money and finance, the more likely they are to be interested in entrepreneurship. Communication skills was an important contributor to career intent, either in the ability to promote personal accomplishments or enroll others in ideas.

A limitation of this research may be the implicit assumption underlying the measurement of “pivot thinking” where a balance in cognitive problem solving style preference is the indication of a “pivot thinker.” In fact, it is only evidence of balance, perhaps the precursor to the act of pivot thinking, but not an indicator of the actually shift in problem solving heuristics. The measurement of a heuristic problem solving shift requires different research tools.

Another important limitation of this research may involve the sample cohorts. While the participants were largely from the field of engineering the age range was significant, spanning from undergraduate engineering majors to senior engineering faculty (mean 27 years, range 19 to 60 years). It is possible that sampling from this wide range of cohorts in very different stages of life development, may have skewed results toward “older” participants who are at the stage of their career where entrepreneurship is a more attractive career option.

Finally, these results suggest important changes for the approach on engineering education. Engineers pride themselves on being problem solvers, when in fact, they may only be solving a narrow range of problem types. Engineering education would benefit by incorporating greater emphasis on problem identification and the teaching of a range of heuristic problem solving approaches. The broad incorporation of engineering ethics case study education (“ethical problem solving” is a discrete heuristic, see Harris et al. [32]) is an example of this that can be extended to other domains like business, design and artistry. This type of pedagogy will not diminish engineering education, rather it will enhance it.

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Selected Models of Domain-Specific Problem Solving Heuristics

```

graph LR
    Goal[Goal] --- Given[Given]
    Given --- Assume[Assume]
    Assume --- Draw[Draw]
    Assume --- Formulate[Formulate Equations]
    Assume --- Solve[Solve]
    Draw --- Formulate
    Formulate --- Solve
    Solve --- Check[Check]

```

The graph illustrates the relationship between Information Use (X-axis) and Value of Information (Y-axis). The curve starts at the origin and rises steeply, then levels off. Point B, labeled 'B Satisficer', is on the steep part of the curve. Point A, labeled 'A Maximizer', is at the end of the curve where it levels off. A vertical line from point B is labeled 'One or more "good enough" solutions'. A vertical line from point A is labeled 'Best solution'.

```

graph LR
    A[EMPATHY] --> B[DEFINE]
    B --> C[IDEATE]
    C --> D[PROTOTYPE]
    D --> E[TEST]
    E -.-> A
  
```

The diagram illustrates the relationship between three types of knowledge: Directional Knowledge, Conceptual Knowledge, and Experiential Knowledge. Directional Knowledge is associated with 'Originality' and leads to Conceptual Knowledge. Conceptual Knowledge leads to Experiential Knowledge, which is associated with 'Mastery'. Both Conceptual and Experiential Knowledge lead back to Directional Knowledge, forming a cycle.

```

graph LR
    DK[Directional Knowledge] --> CK[Conceptual Knowledge]
    CK --> EK[Experiential Knowledge]
    EK --> DK
    CK --> DK
  
```

The diagram illustrates the research workflow, showing a central cycle of activities. The central cycle is labeled "Work Flow" and is represented by a circular arrow. Surrounding this central cycle are eight ovals, each representing a stage of the research process. The stages are arranged in two columns. The left column includes "Previous Research", "Theory, Rationale", "Questions, Models", and "Research Design". The right column includes "Link to Next Study", "Conclusion", "Statistical Analyses", and "Data". A dashed arrow points from "Link to Next Study" back to "Previous Research", indicating a feedback loop. A solid arrow points from "Data" to "Procedure", indicating the flow of information from data collection to the final procedure.

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Creating a New Civil Engineering Program in the 21st Century

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Abstract – Starting a new engineering program in the 21st century that fulfills ABET 2000 requirements is a major undertaking. In this paper, the authors will discuss the process of implementing a new civil engineering program at West Texas A&M University in Canyon, TX (in the Amarillo metropolitan area), starting with planning, offering initial discipline-specific courses in Fall 2010, graduating the first cohort of students in 2013, and concluding with an ABET accreditation visit in Fall 2014. This process includes the development of a suitable curriculum using existing and new courses, development of the new civil engineering specific courses and laboratories, the senior design experience, assessment, and final preparation for an ABET accreditation visit. The discussion of the curriculum includes general education, mathematics, applied sciences (chemistry, physics, and biology), general engineering, and civil engineering specific courses is discussed. In particular, emphasis on the unique approach to the senior design capstone experience is described here. Engineering course outcomes are mapped to a modified Bloom's Taxonomy and to ABET 2000 Outcome 3 a through k. A new program must also meet the requirements of regional and community stakeholders and fit with the unique service population in the greater Texas Panhandle region. West Texas A&M University is also on the verge of becoming a Hispanic Serving Institution (HSI, 25% or more of enrolled population) and is seeking to improve participation of women and underserved populations in STEM fields, such as with engineering. An overview of the process of preparation of the ABET self-study is described, including development of assessment tools necessary to determine the effectiveness of the new engineering program. Lessons learned and future improvements for the civil engineering program at West Texas A&M University are discussed.

Keywords – ABET, accreditation, ASCE, civil engineering, curricula, Bloom's Taxonomy, Body of Knowledge, Hispanic Serving Institution, senior design, WTAMU

I. INTRODUCTION

West Texas A&M University (WTAMU) is one of eleven universities comprising the Texas A&M System, enrolling nearly 9000 undergraduate and postgraduate students. In cooperation with local and regional stakeholders, WTAMU established undergraduate programs in mechanical (2003), civil (2010), and environmental engineering (2012). These programs were joined with existing engineering technology and computer science programs to form what is now the School of Engineering and Computer Science (ECS). ECS has expanded to over 600 students as of Fall 2014, of which over 500 are engineering and engineering technology majors. It is expected that ECS will enroll approximately 700 students in these majors in Fall 2015. Growth has been rapid but the school still maintains a very hands-on and personable approach to instruction with faculty instructing all lectures and laboratory courses.

ECS enrolls about 50% of its students through transfers from partner institutions such as Amarillo College [1], South Plains College [2], and Lubbock Christian University [3]. The transfer credits align fairly closely with the pre-engineering program at WTAMU. This corresponds roughly with the requirements of an engineering associate's degree program. This policy also ensures that upper division engineering students will thrive in their program of choice because they know that the basic engineering, math, and science courses are foundational to what they will be expected to do in their junior and senior undergraduate years of study. WTAMU requires that at least 39 credit hours of junior and senior level courses be taken in residence at the university in order to earn a degree from the institution.

In order to move from the pre-engineering to the civil engineering program, a student must complete the fundamentals of engineering, drafting, chemistry I and II, calculus I and II, statics, and dynamics courses with a GPA of 2.75 or greater, whether taken at the partner institution and/or at WTAMU.

It is also of note that in addition to having a large

transfer contingent is that about 50% of students are first-generation college students. Furthermore, the university population is nearing the threshold (23% vs. 25% required) of becoming a Hispanic-serving institution (HSI) [4,5], reflecting the population diversity of the state of Texas and the surrounding service area. The university has a border-state tuition rate [6] (WTAMU defines border states as New Mexico, Oklahoma, Colorado, and Kansas) that has attracted students from these areas due to favorable costs and desirable university majors, such as those in ECS.

The engineering faculty at ECS includes five full-time mechanical engineering, two full-time civil engineering faculty, two full-time environmental engineering, one shared full-time civil/environmental engineering faculty, one full-time engineering technology faculty, and one full-time engineering instructor. Between these faculty, all required general engineering, required general civil engineering, and elective civil engineering courses can be covered. Two of the mechanical, the two civil, and the one shared civil/environmental engineering faculty are licensed professional engineers. The two environmental engineering faculty are EITs and working toward gaining professional licensure. The civil and environmental engineering faculty function as a unit within ECS in regard to their respective programs since they are interdependent on one another and form a natural grouping within the ECS hierarchy.

It is important to note the state of professional licensure because ABET and ASCE prefer that civil engineering faculty to be licensed in order to teach any course with significant *design* content, typically reflected in the course title and catalog description. This will also be important for the environmental engineering program, as ASCE is a major stakeholder in that discipline as well.

The balance of this paper will review the development of the civil engineering program at WTAMU, the first senior design experience, preparation for accreditation, and future changes and conclusions.

II. PREVIOUS WORK

It is helpful understand how other programs have responded to creation and accreditation of new engineering programs in the 21st century. As the population of the USA and Texas in particular grows, there is growing demand for engineers as well. The Texas Office of the State Demographer notes that the 2015 population of 27 million will grow to somewhere between 31 million (no migration, natural growth only) to 54 million (migration following 2000-2010 US Census trends) [7], spurring a strong demand for Texas institutions of higher learning to graduate more engineers. In particular, civil engineers are at the forefront of development, construction, and maintenance of the infrastructure that society is dependent upon.

One of the oldest civil engineering programs in the USA is that at the United States Military Academy at West Point (USMA), which coincidentally has been at the forefront of civil engineering education innovation. In particular, Drs. Stephen Ressler, Alan Estes, Karl Meyer, and others that have been associated with USMA have spurred this innovation out of necessity, as they need to quickly train engineering instructors in order to educate the men and women of the US Army to practice civil engineering, oftentimes under wartime conditions. They have graciously passed along this wisdom through the highly regarded ASCE EXCEED (Excellence in Civil Engineering Education) seminar series [8].

In particular, Drs. Ressler, Estes, and Meyer plus Dr. Tom Lenox from ASCE have spent significant effort in tying the ABET 2000 Outcome 3c [9] and ASCE Body of Knowledge (BOK) 2 [10] to contemporary civil engineering education [11-15]. In short, Appendix H of the BOK 2 neatly ties the ABET 2000 3c Outcomes a-k that many engineering faculty are familiar with to the requirements for the civil engineering discipline in the 21st century. These references validate the process that WTAMU has gone about to pursue accreditation for the civil engineering program. Ressler [11] also validates the need to add biology to the WTAMU civil engineering program, discussed in the next section on curricula.

One reference of note by Lambrechts [16] describes the process of elevating a civil engineering technology program to a full civil engineering program. This change was initiated due to the National Council of Examiners of Engineers (NCEES) adopting ASCE's Policy 465 and its associated BOK 2 (summarized in its Appendix H) [10], further emphasizing the requirement to follow ABET 2000 Outcome 3c plus additional requirements for the education of civil engineers for the 21st century. It is in this light that WTAMU has formulated its civil engineering curricula, described in the following section.

III. WTAMU CIVIL ENGINEERING CURRICULA

The development of the civil engineering curriculum must be consistent with ABET 2000 [9] and ASCE Body of Knowledge 2 Appendix H [10] criteria as well as institutional and community stakeholders. The resulting civil engineering curricula at WTAMU resemble that at other ABET aligned programs.

Similar to other institutions, the civil engineering program is constrained to operating within requirements for general education coursework (English, speech, history, government, arts, etc.) as well requirements for basic science (chemistry, physics, and biology), mathematics (calculus I-III and differential equations), general engineering (fundamentals of engineering, drafting, statics,

dynamics, mechanics, etc.), and specialized civil engineering coursework. A degree checklist for the BS civil engineering degree may be found at the online WTAMU online catalog [17].

WTAMU operates on the semester credit system, the dominant system in the USA at this time. Engineering courses are typically offered in fall, spring, summer I, and summer II semesters. Like other similar engineering programs, it is designed for full time students to be completed in approximately four years with a total of 127 semester credit hours.

It should be noted that the academic year 2014-2015 degree checklist shows a total of 126 semester credit hours. Why is there a difference of 1 credit hour versus the checklist? The reason is that effective in academic year 2015-2016, the checklist will replace the 3-credit *EVEG*, *MENG*, *GEOL*, *CS*, *OR ET ELECTIVE* with a 4-credit biology course. This was in direct response to feedback from the ABET accreditation team that visited WTAMU in October 2014. It was an easy change to implement and puts the civil engineering major in better alignment with ABET and ASCE requirements for applied sciences. It is of note that currently enrolled students are already being required to take the biology course, regardless of catalog year. It is substitutes for the aforementioned elective.

In regard to civil engineering discipline specific courses, the curriculum is designed to provide at least one foundational course in all six traditional subareas (structural, transportation, construction, environmental, geotechnical, and water resources) of the civil engineering discipline. Some of these courses are cross-listed with the new environmental engineering degree program such as the introduction to environmental engineering, fluid mechanics, and hydrology and hydraulics courses.

The civil engineering program has five courses (two shared with environmental engineering, noted with *) with specific laboratory components: introduction to environmental engineering*, surveying, civil construction materials, geotechnical engineering, and fluid mechanics for civil and environmental engineers*. For the first two years of operation, the civil engineering program used the mechanical engineering fluid mechanics course but this course lacked material in regard to open channel flow, essential for the follow on hydrology and hydraulics course. The civil/environmental engineering fluid mechanics course is a 4-credit lecture/laboratory while the mechanical engineering fluids course is a 3-credit lecture/laboratory.

There are three required upper level civil engineering courses. Of these, one must be structural design (ex: steel or concrete design), one is design of any type in regard to any subarea of the civil engineering discipline, and one is a general course in any subarea of the civil engineering

discipline, directed study, or internship. It is possible that one or both of the non-structural electives may be a course shared with the environmental engineering discipline.

IV. SENIOR DESIGN CAPSTONE

The first civil engineering senior design experience was in summer session 2013. The reasoning for a summer session was to ensure that among the seven participating students, most if not all would have completed coursework in all six traditional subareas (structural, transportation, construction, environmental, geotechnical, and hydrology) of the civil engineering discipline.

This first senior design project entailed the design of an outdoor civil engineering laboratory. The project was linked to the ABET 2000 Outcome 3c and modified Bloom's Taxonomy described in the section of this report in regard to preparation for accreditation.

Seven students participated in the course. The students arranged themselves in six subarea teams, each of which had at least three students involved. This means that any one particular student was part of two or more of the smaller subarea teams. One student was chosen by the other students to be the project leader, who in turn organized meetings and met with the three faculty members that were in charge of the course.

The students had approximately seven weeks to design the outdoor civil engineering laboratory. At first glance, that may not sound like enough time, but most of these students were taking only this one course in summer. It was much like a 40-hour-a-week job in scope, a fairly reasonable and realistic scenario for the students.

Students were responsible for weekly meetings and work summaries that were submitted to the faculty in charge. Along with evaluation of an interim report with presentation and a final report with presentation, peer and faculty evaluation forms were completed for all seven students. This allowed for a final grade to be assigned to each student for his or her performance in the course. Six students were deemed to have passed with a grade of C or better. While it may sound harsh for the seventh student deemed below this threshold, it is very important for program integrity and the safety of the public that a student performing below an acceptable level not graduate until he or she demonstrates the high level of competence required in the civil engineering discipline.

The senior design project was very important from the standpoint that the graduation of the first cohort of civil engineering students triggered the year-long process for ABET accreditation of the program. An honest assessment of this project, the students, and the faculty involved is necessary for the integrity and growth of the program.

V. PREPARATION FOR ACCREDITATION AND RESPONSE

All programs undergoing the accreditation process must submit a self-study. The self-study consists of information that describes the program in details as outlined by the ABET 2000 criteria. The self-study consists of nine different criteria. Self-study materials were to be prepared by the program and submitted by the 1st of July 2014. Faculty from the civil and environmental engineering programs met frequently during the months of May through June to prepare the self-study. An excellent view from the evaluator standpoint describes this preparation process, stating that a program really only gets one chance to make a good impression and that involvement of faculty and documentation are key for gaining or maintaining accreditation¹⁵.

In addition to the self-study, faculty were also required to prepare materials for the accreditation visit. There were two major components—course binders and senior design videos. The course binders consisted of materials from selected courses taken by civil engineering students. The binders consisted of sample work (i.e. homework, exams, quizzes, and design projects) for the accreditation reviewers. The sample work was assessed by faculty to determine how well the student met metrics as discussed by the civil and environmental engineering faculty. Copies of the two senior design final presentations were placed on flash drives for the reviewers upon request. Videos of the senior design presentations were also made available for review as well.

The assessment metrics were tied directly to ABET Outcome 3c a-k with achievement tied to a modified Bloom's Taxonomy at a freshman, sophomore, junior, or senior level. The levels of achievement, in order of increasing difficulty are: *knowledge* - recall and organization of facts and figures; *understanding* - comprehending the meaning of facts and figures; *application* - being able to utilize appropriate formulas and principles to determine a problem solution; *synthesis* - being able to break a problem into components and solve by application of basic principles without reliance upon example problems; and *design* - making something that is new and unique with little reliance upon examples.

The ABET accreditation site visit occurred in October 2014. The reviewers were provided access to the self-study materials, met with faculty and administrators, and conducted focus group sessions with current civil engineering students. The comment and response period is currently on-going at the time of this writing in June 2015. It is anticipated that the conclusion of this process will occur during the summer of 2015.

VI. FUTURE DIRECTIONS AND CONCLUSIONS

Engineering curricula continues to evolve in regard to stakeholders, technology, business, society, and other outside factors. Developing new engineering programs in the 21st century requires input from these factors and a willingness of faculty to adapt and change in order to develop the problem solving skills that engineering students will need.

The lessons learned in the first senior design and initial ABET site visit have been adapted and refined in the second and third cohorts of civil engineering graduates from the WTAMU School of Engineering and Computer Science.

The civil engineering faculty decided to implement a continuous improvement program, rather than waiting until the year before an accreditation cycle to gather assessment data. Courses will be on a regular cycle for assessment to address problems and change curriculum more quickly, as needed. Making continuous improvement a part of the ECS culture will ensure the best education for engineering students.

The October 2014 ABET visit affirmed the good aspects of the civil engineering program and spurred the faculty to move quickly to address deficiencies, especially to implement a third required science with biology, even before the comment and response period is complete. The new environmental engineering program will also directly benefit from the learning process, much like the civil engineering program learned from the first WTAMU ECS accredited program in mechanical engineering.

Newer programs such as the ones at WTAMU have great flexibility in devising and implementing engineering education. Established programs can learn from and share best practices with these newer programs. In any case, the criteria of ABET and the ASCE Body of Knowledge give guidance in regard to what education of engineers in the 21st century should address and the feedback to continually improve and innovate.

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Design and Practice from the Micromouse Competition to the Undergraduate Curriculum

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Abstract—This article has probed an innovative conversion from micromouse competition to a systematic curriculum design that integrates practice with theory. Micromouse competition is an event where small robot mice are designed to solve a 16x16 maze. The process includes multi-disciplinary knowledge such as electrical and computer engineering, mechanical engineering and algorithm design. Limited by the competition rules, micromouse is easy to learn but difficult to master, which provides a high suitability with the teaching processes of foundation courses of embedded system for undergraduate students. This paper elaborates the emphasis, difficulties and innovation of the conversion process, of which the core is student engagement. In the class, students must take part in the whole micromouse design progress to comprehend the interactive method of hardware and software of embedded devices and strengthen the ability of applying professional skills. Students are required to participate in the entire micromouse building process, including welding, assembling, environment building, debugging and finishing the competition in groups. This curriculum focuses on training students' research interests, competition skills and teamwork spirit. Final examination scores are mainly based on each group's ranking in the final round, and technology innovators will be given appropriate incentives.

Keywords—Micromouse; Academic competitions; Innovative teaching; Practice course

I. INTRODUCTION

Micromouse is a science and technology competition project which began in late 1970s. It quickly swept the world after the birth. "Principles and Practice of Micromouse" is an innovation practice course designed based on the micromouse competition for the undergraduate students. As a device of mechanical and electrical integration, participating in the development process of micromouse can train the students' ability of innovative practice. Theoretical knowledge is applied in practical operation in this curriculum, which is mandatory for electronic engineering students. Moreover, the micromouse contains a wide range of disciplines. Therefore, systems integration capability and academic vision expanding are also concerned in this course.

In simple terms, micromouse competition is an event where small robot mice could solve a 16x16 maze (Fig. 1). It needs to

complete several tasks such as maze searching, path memorizing and maze solving. Winner is the fastest one [1].



Fig. 1. Standard maze for micromouse competition.

II. ADVANTAGES OF MICROMOUSE

The reason why micromouse is introduced to classroom and applied to undergraduate practice teaching is that micromouse provides a high suitability with the teaching requirements of electric and electronic majors in many aspects. The coverage of the knowledge points is the first reason.

Micromouse must have the following capabilities to complete the competition tasks [2].

- Stable and fast walking
- Accurate judgment
- Path memorizing
- Maze solving ability

In order to satisfy these requirements, the design of micromouse have to involve several subjects including circuit design, motion control, mechanical design, sensor applications, algorithms optimization and programming. These hardware and software design skills are just necessary for an electronics engineer. Based on the study of Williams, A, B [3], it can significantly improve students' technical level by using robots in engineering teaching. The process of micromouse design can show a basic development process for electromechanical systems to students clearly, and exercise their comprehensive ability of professional skills.

Secondly, micromouse possesses a simple structure and clear mandate. So it is relatively easy to understand for tyros. The students can achieve a simple control for this mobile robot through a unified basic teaching mold. In the same time, micromouse is a racing competition. Under the premise of accomplishing basic tasks, the pursuit for better performance

and better algorithm is almost a never-ending improvement direction. The characteristic of easy to learn but difficult to master ensures good compatibility with students in different stages and different abilities in the classroom.

Thirdly, combination of theory and practice is one of the most important features of the experimental curriculum. Students can achieve the real-time transformation from the voids theoretical knowledge to practical application ability by micromouse platform. This conversion process is visualized. Students can clearly observe how their modifications impact the operation of the micromouse,

Last but not least, electrical and electronic major generally use experimental box or development board as the platform for experimental courses. Compared with this, micromouse has incomparable advantages in interests, competition and teamwork. Moreover, since this course grew out of a competition, it can be considered an example of "gamification" of learning. Dominguez Adrian's research [4] shows that this teaching method can effectively increase student motivation and engagement. Once the students get interested in the curriculum, the purpose of their study could be transformed from getting good grades into meeting their own interests. Obviously, it will be beneficial to both class atmosphere and teaching effectiveness.

In summary, as a teaching platform for experimental course, it has an ideal performance in coverage of expertise, friendliness of the development process, practical ability and interests. Based on the above analysis, micromouse is boldly introduced to the undergraduate teaching. A practice curriculum named "Principles and Practice of Micromouse" has been opened in the past two years.

III. TRANSFORMATION FROM THE CONTEST TO CLASSROOM

Although the micromouse possess a natural advantage as a teaching platform, but it was developed for a technology competition after all. Its original organization and participation process have a large difference from classroom.

In the university, participations in science and technology competition mostly start from the students' own interests. Loose organization and participation mode result in the lack of competition documentation and process standards. At the same time, the goal of competition is generally simple and clear, so most students focus only on the performance but show little interests in principles. The lack of theoretical knowledge has become a very common phenomenon.

But different from technology contest, classroom has a broader audience and more stringent requirements. The classroom content must be systematic and theoretical with standard teaching documents, presentation slides, etc. The teacher should lead the classroom, act as technical heritage links, teach theoretical knowledge and basic operation and guide students to complete practical tasks. Teaching methods should be universal and reproducible. In order to improve the time efficiency, appropriate performance standards should be developed with some specific procedure.

A. Course preparation.

Because of the difference between micromouse contest and classroom, lots of course preparation should be completed beforehand, including micromouse modules subdivision, routines splitting and process standardization (Fig. 2.).

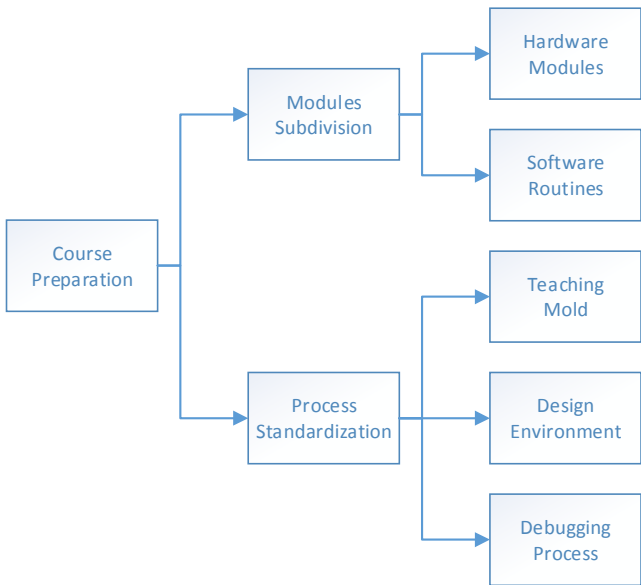


Fig. 2. Course preparation for *Principles and Practice of Micromouse*.

In the process of participating in contest, participants generally pay more attention to the overall performance and parameters of the micromouse. Someone even just focus on the most important adjustment of sensors and motors, but never note the structure, principle and function of other modules. This approach is understandable for a contest with short process and clear purpose. But as a practical course, competition process needs to be manifested in the form of academic hours. Therefore, such modules subdivision must be completed at first.

The first is the division of hardware modules. The micromouse is subdivided into the following modules based on functional clustering [5].

- Power: Provide the power to maintain the operation of the micromouse, including the power supply circuit and a battery.
- Control module: It is the control core of micromouse, including a micro-controller and its minimum system.
- Motor driver: All motor behavior of micromouse is controlled by this module, which consists of two motors and a drive circuit.
- Sensor: Detect the operational status and the external environment of micromouse by six infrared sensors.
- HCI: Display status information for assisting in debugging. Various buttons, lights, and LED digital display tubes are contained therein.

- **Interface:** Provide several common communication interfaces including serial, SPI and JTAG.
- **Mechanical structure:** Various mechanical devices are used to assemble the components into a complete micromouse.

This division is based on progressive approach to display micromouse's composition, theory and application methods. The development and debugging process of an electromechanical system is presented through this division.

The routine splitting should be also completed in the course preparation. Based on the above modules division, the original complete program is split into multiple subroutines for different modules. Each routine corresponds to only one or a few simple tasks, which can show the different functions of each module and their relationships more clearly and directly.

Moreover, because the micromouse competition with a high degree of openness almost has no constraints for micromouse design, the present micromouse are vastly different in hardware structure, development environment, design philosophy and debugging method. In terms of an undergraduate course, such characteristic is not friendly enough. So a series of standardized work is very necessary for micromouse.

- **Standard teaching mold.** Combined with available micromouse technology [6], a number of standard micromouse for classroom are completed prior to commencement (Fig. 3.). Unified batteries, chargers, emulators and related auxiliary debugging device are fully equipped at the same time (Fig. 4.).
- **Standard design environment.** Type, version, and installation procedures of IDE software, device drivers and related link library files are ordained.
- **Standard debugging process.** Adjustment of each module is provided with a standard template with detailed regulation steps. These templates can effectively reduce the difficulty of the entry in the early courses.

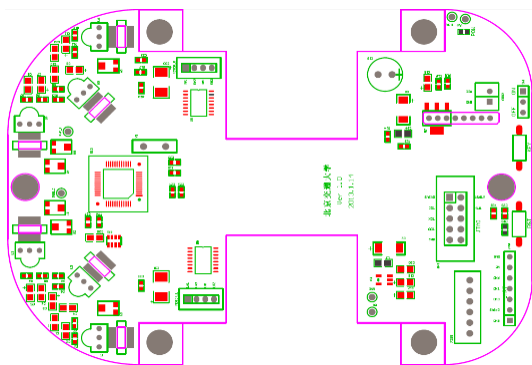


Fig. 3. Standard micromouse PCB board.



Fig. 4. Micromouse Curriculum Kit.

Standardization process does bring a lot of benefits to the classroom according to the teaching experience acquired during the past two years. First of all, students may encounter roughly the same faults in the unified debugging process. This facilitates problem solving. Then, a detailed "manual" is probably the friendliest 'Getting Started' for the novice. And it can avoid some of improper explorations to waste valuable class time or even the damage of teaching equipments. Sum up, teaching process standardization makes limited teaching resources to maximize utilization which greatly enhance the teaching efficiency.

B. Realization in classroom.

To enable students to understand how an electromechanical system containing the design of software, hardware and mechanical components is designed from scratch, the entire course is divided into several parts as hardware assembly, environmental construction, parameter adjustment, algorithm optimization and real competition (Fig. 5.).

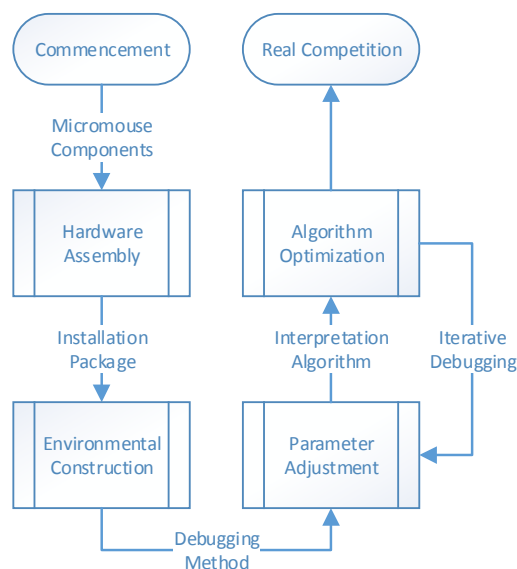


Fig. 5. Course preparation for *Principles and Practice of Micromouse*.

- Hardware assembly

At the beginning of the course, students get just some scattered parts, rather than a directly available micromouse. They are asked to weld and assemble these parts together into a complete micromouse based on the BOM and assembly drawings by themselves. Of course, this micromouse would accompany them to complete all the subsequent courses.

- Environmental construction

Before the micromouse commissioning work begins, a series of software installation and configuration must be completed on the computer. In this part of the course, the teacher would instruct students to install the driver of emulator, C language compiler (IAR Embedded Workbench 32K Free version) and some of the libraries used to support the work of the core controller, etc. The reason why software installation should be taught as a dedicated part is that different computer operating systems express different compatibilities for the software. The installation process may give rise to various problems. Uniformly solving these problems in the class can effectively improve the efficiency of the classroom.

- Parameter adjustment

After the hardware assembly and development environment building are done, the course officially entered into the commissioning phase. It is very difficult and inefficient to modify the program logic directly for people new to micromouse. Students are provided with a basic version of the operating procedures in the beginning. This program is only able to complete the most basic tasks with inefficiencies. A variety of control parameters in the program are required to make the appropriate adjustments due to the tiny differences in hardware. The design purpose of this part of the course is to guide students to develop an understanding of micromouse by modifying the values in the program. After this phase of training, students have been able to skillfully use the IDE software programming. And they may also be very clear for the general debugging method and debugging steps. Their micromouse can successfully complete a simple maze task in a more stable state.

- Algorithm optimization

In addition to a body with stable operation, micromouse also needs a smart brain to help itself perform complex calculations and solve the maze. This part of course would surely involve the program logic modifications. To complete this part of classroom tasks, students need to have a clear understanding about the overall structure of the program. And mathematical knowledge learning in other courses may be used to optimize the calculation method legitimately. It can be said that this part is the most essential part of the whole curriculum which can help students bring up code reading capability,

programming capability and conversion capability from the theoretical knowledge to practical application.

Of course, with the modification of program logic, the control parameters may also need to be amended accordingly. These processes are closely linked. And iterative improvement is necessary. Each element should be taken into consideration in the latter part of debugging.

- Real competition

As a contest-based curriculum, the best way to inspect the outcome is contest ranking. Moreover, this example of "gamification" of learning do needs a clear indicator to measure students' learning outcomes. So, all teams will be scheduled for a complete micromouse contest in the last class of each semester. The competition process is strictly enforced in accordance with the standard rules.

For the sake of fairness, the competition maze map and the order of appearance were determined by lot before the game started. Then the maze should be built on the spot. Each team played the game according to the order of the draw with three competition opportunities or fifteen minutes at most. The game used a laser sensor to detect the timing. The team which finished the game with the shortest time was the winner

The final results of this competition would account for a pretty big proportion of the student's course grade evaluation.

IV. TEACHING METHODS

The main content of this course is to show the general process of electromechanical systems design with micromouse as an experimental platform. Through the hands-on experiments, students can gain a profound understanding of how software and hardware are combined into a specific functional electromechanical system. Team is the basic unit of this course. The core concept of the curriculum is to create an atmosphere of good teamwork, healthy and interest-driven competition, and encourage innovation.

In the teaching process, every three students are teamed up as a group. They will work together to complete the teaching tasks in the whole semester. As some tasks cannot be completed by a single person, team members must learn to communicate and collaborate. They will face the competition assessment together in the end of the semester. Moreover, since the final competition rankings will largely determine the grades, in order to get a good score, students must defeat other competitors instead of an examination paper. Improving learning motivation by the sense of competition is the significance of this teaching model.

The interest-based classroom climate is another major driving force in independent study. Appropriate started difficulty allows students to adapt to the classroom content quickly. As the modular, progressive and visualization target division, students can get a great sense of accomplishment by completing each task, which can help student maintain

continuous enthusiasm. All teaching equipments are assembled, kept and maintained by the students themselves. The sense of belonging and responsibility is also able to motivate students to maintain interest and participate into the class activities.

Although the neat process facilitates the classroom a lot, students' divergent thinking is locked out, too. Conservative strategy may be able to achieve better competition results. But in such a practice classroom, the new ideas and methods with some bright spots are the most exciting. In order to encourage innovation, all reasonable unique improvements had been used as an important indicator of the final score.

The most important is that these ideas are not stuck in the theoretical design stage, but have truly happened in every classroom lesson.

V. TEACHING ACHIEVEMENT SUMMARY

In the process of teaching practice, students have completely experienced the whole development process of electromechanical systems from hardware assembly and hardware and software debugging to real competition. Theoretical knowledge has been vividly embodied by the micromouse platform. In teaching content, the works such as hardware debugging, software development and algorithm optimization can effectively train students' abilities of system integration and engineering practice.

In teaching methods, group collaboration, fixed allocation and reasonable milestones are used to mobilize the enthusiasm of independent learning and research interests while cultivating

teamwork and competition sense. Through this classroom form, the students have maintained a high degree of enthusiasm in the classroom. And great teaching effectiveness can be achieved.

By training in this course, the proportion of students to complete the end contest is 100%. The students from this course have obtained excellent results in *2014 Beijing Micromouse Competition*. On the basis of the original micromouse technology, multiple students innovative practice projects have been derived, some of which have applied for patents.

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Building Faculty Expertise in Outcome-based Education Curriculum Design

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Abstract— An information technology (IT) tool that can guide STEM educators through the complex task of course design development, ensure tight alignment between various components of an instructional module, and provide relevant information about research-based pedagogical and assessment strategies will be of great value. A team of researchers is engaged in a User-Centered Design (UCD) approach to develop the Instructional Module Development System (IMODS), i.e., a software program that facilitates course design. In this paper the authors present the high-level design of the IMODS and demonstrate its use in the development of the curriculum for an introductory software engineering course.

Keywords—instruction design; outcome-based education; semantic web-based application; user-centered design

I. INTRODUCTION

Felder, Brent and Prince [1] have made a strong argument in support of instructional development training for engineering faculty. This argument, which cites among other reasons: shortfalls in graduation rates, changing demographics and attributes of the student body, and modifications in the expectations of graduates; can be extended to encompass all STEM fields. Furthermore, studies show that for 95% of new faculty members, it takes four to five years, through trial and error (the most common method of gaining expertise in teaching), to deliver effective instruction [2]. While there are a number of options available to faculty for receiving instructional development training (i.e., training focused on improving teaching and learning), most share similar format, features, and shortcomings. For example: workshops, courses and seminar series, the most common program structures, are often offered at a cost to the institution, department or individual attendee; delivered face-to-face at specified times; and accessible to a restricted number of persons. Even when interest is high, these factors can become obstacles to participation.

Outcome-based Education (OBE) is a result-oriented approach where the product defines the process. The learning outcomes guide what is taught and assessed [3], [4]. This approach contrasts the preceding “input-based” model that places emphasis on what is included in the curriculum as opposed to the result of instruction. There is a growing demand and interest in faculty professional development in areas such as OBE, curriculum design, and pedagogical and assessment strategies.

In response to these challenges and needs, a group of faculty

researchers from two south-western universities have undertaken a project to design and develop the Instructional Module Development System (IMODS) that will facilitate self-paced instructional development training while the user creates his/her course design with the added benefits of being free to all who are interested, accessible almost anywhere through a web browser, and at any time that is convenient.

Additional key features of the IMODS are as follows:

1. Guides individual or collaborating users, step-by-step, through an outcome-based education process as they define learning objectives, select content to be covered, develop an instruction and assessment plan, and define the learning environment and context for their course(s).
2. Contains a repository of current best pedagogical and assessment practices, and based on selections the user makes when defining the learning objectives of the course, the system will present options for assessment and instruction that align with the type/level of student learning desired.
3. Generates documentation of a course designs. In the same manner that an architect’s blue-print articulates the plans for a structure, the IMODS course design documentation will present an unequivocal statement as to what to expect when the course is delivered.
4. Provides just-in-time help to the user. The system will provide explanations to the user on how to perform course design tasks efficiently and accurately. When the user explores a given functionality, related explanations will be made available.
5. Provides feedback to the user on the fidelity of the course design. This will be assessed in terms of the cohesiveness of the alignment of the course design components (i.e., content, assessment, and pedagogy) around the defined course objectives.

In this paper the authors present the high-level design of the IMODS and demonstrate its use in the development of the curriculum for an introductory software engineering course. The rest of the paper is organized as follows. Background material for this research project is presented in section 2. Section 3 presents the high-level design of the IMODS software system. Section 4 presents a case study that demonstrates the use of the IMODS framework in the development of an introductory software engineering course. The paper concludes with future work and acknowledgements.

II. BACKGROUND

A. Related Work

To justify the need for the development of IMODS we conducted a competitive analysis to determine the strengths and weaknesses of tools and approaches currently used to support course design and related training. The tools and approaches that were evaluated were categorized into five groups based on primary functions and features.

Knowledge/Learning Management System (KMS/LMS):

This group contains a number of proprietary and open-source solutions that are delivered either as desktop or web-based applications. These tools mainly facilitate the administration of training, through the (semi-) automation of tasks such as: registering users, tracking courses in a catalog, recording data, charting a user's progress toward certification, and providing reports to managers. These tools also serve as a platform to deliver eLearning to students. In that context, their main purpose is to assemble and deliver learning content, personalize content and reuse it.

Examples: Blackboard, Moodle, Sakai, Canvas, WeBWorK, and Olat

Educational Digital Libraries: These tools contain collections of learning and educational resources in digital format. They provide services that support the organization, management, and dissemination of the digital content for the education community.

Examples: National Engineering Education Delivery System (NEEDS), National Science Digital Library (NSDL) and Connexions

Personalized Learning Services: There are a number of e-learning tools that leverage semantic web technologies to support personalized learning services for their users with an ontology based framework [5]. Some of these tools function by initially profiling the learner and then, based on that profile, identifying the best strategies for presenting resources to them. They can also provide feedback to instructors on student learning, so improvements to the content and structure of the course can be incorporated. For many of these tools the ontology framework is used to bridge learning content with corresponding pedagogy; however, they seldom address assessments and learning objectives. **Examples:** Content Automated Design and Development Integrated Editor (CADDIE), Intelligent Web Teacher (IWT), LOMster [6], and LOCO-Analyst [7].

Understanding by Design Exchange (UbD Exchange): This is a software framework based on Wiggins's and McTighe's Backward Design principle [8] that is used for designing curriculum, assessments, and instruction, and integrates K-12 state and provincial standards in the design of units [9]. It provides a form-based user interface to fill in the details of the course unit that is being designed.

Professional Development Workshops, Courses & Seminars: Face-to-face training sessions in teaching and learning that are facilitated by experts in the field of instructional design.

Examples: National Effective Teaching Institute, Connect Student Learning Outcomes to Teaching, Assessment, and Curriculum, Content, Assessment and Pedagogy [10].

Our search identified very few tools and approaches that contained features or functionality that explicitly facilitated the design of course curriculum. Of these tools few of them facilitated the generation of design documentation and feedback to the user on the fidelity of the design. These are two key deficiencies that IMODS will address.

B. IMODS Framework – PC³ Model

The IMOD framework adheres strongly to the OBE approach and treats the course objective as the spine of the structure. New constructs (not included in the models previously discussed) are incorporated to add further definition to the objective. The work of Robert Mager [11] informs the IMOD definition of the objective. Mager identifies three defining characteristics of a learning objective: Performance – description of what the learner is expected to be able to do; Conditions – description of the conditions under which the performance is expected to occur; and the Criterion – a description of the level of competence that must be reached or surpassed. For use in the IMOD framework an additional characteristic was included, i.e., the Content to be learned – description of the factual, procedural, conceptual or meta-cognitive knowledge; skill; or behavior related to the discipline. The resulting IMOD definition of the objective is referred to as the PC³ model [12].

The other course design elements (i.e., Content, Pedagogy, and Assessment) are incorporated into the IMOD framework through interactions with two of the PC³ characteristics. Course-Content is linked to the content and condition components of the objective. The condition component is often stated in terms of pre-cursor disciplinary knowledge, skills or behaviors. This information, together with the content defined in the objective, can be used to generate or validate the list of course topics. Course-Pedagogy is linked to the performance and content components of the objective. The types of instructional approaches or learning activities used in a course should correspond to the level of learning expected and the disciplinary knowledge, skills or behaviors to be learned. The content and performance can be used to validate pedagogical choices. Course-Assessment is linked to the performance and criteria components of the objective. This affiliation can be used to test the suitability of the assessment strategies since an effective assessment, at the very least, must be able to determine whether the learner's performance constitutes competency. Figure 1 shows a visual representation of the IMOD framework. Learning domains and domain categories defined by Bloom's revised taxonomy [11] are used to describe learner performance. Learning domains are categorized into Cognitive, Affective, and

Psychomotor, which are further classified under various Domain Categories (Remember, Understand, Apply, Analyze, Evaluate, Create). Each Domain Category has performance verbs associated to it. Learning objective in the PC³ model is described in terms of Performance, Content, Condition, and Criteria. Performance is described using an appropriate action verb from revised Bloom's taxonomy based on the learning domain and domain category.

Criteria: Learning objective assessment criteria are categorized as quality, quantity, speed, and accuracy. Criteria for learning objectives are described in terms of one or more of these categories with a criteria value defined or determined later when the assessment is defined.

Knowledge Dimensions: The revised Bloom's taxonomy introduced an additional dimension called the knowledge dimension that was categorized as Factual, Conceptual, Procedural and Metacognitive.

Topic Prioritization: The IMODS framework uses a prioritization framework that classifies topics and subtopics of a particular course as one of the following:

- Critical
- Important
- Good to know

Achieving the right mix of the three levels of learning (priorities) is essential to planning a good course.

PC³ Model

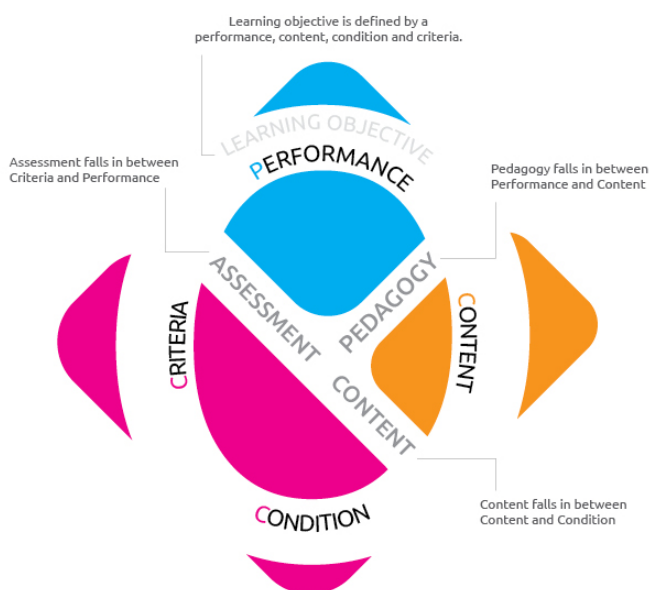


Figure 1: IMODS Framework - PC³ model

C. User-centered design methodology

The IMODS system is being developed using a user-centered design (UCD) methodology, as opposed to technology focused, methodology [13]. This approach is well suited for the project given the high cognitive nature of outcome-based course design tasks, and the high levels of interactions required between the user and the system to not only facilitate the development of course designs, but to help users build an

enduring foundation of knowledge, skills and habits of mind about curriculum development.

UCD is an emerging design method that focuses on both operational and technical requirements by observing and understanding user needs and wants, as well as by prototyping and testing software throughout all phases of software lifecycle. It enables the capturing and resolution of any mismatches between users and software early on. The main objective of UCD is to allow for a closer match between users and the software, leading to a more intuitive interaction. As a design process, it also has the objective of reaching that goal in the most resource-efficient way, in terms of time and cost through careful planning and execution [14].

The UCD process can be divided into five main phases: Plan, User Research, Design, Develop, and Measure. Thus far, the research team has completed the user research and design phases of the UCD process. In this respect, 4 focus group sessions were conducted with prospective users of IMODS to gather insights on how faculty approach the task of designing a course. At the beginning of each session all participants were asked to fill an electronic background survey that collected demographic information, primary areas of interest in teaching and research, time spent on teaching, number of courses taught per year (at both undergraduate and graduate levels), and number of new courses developed (both at undergraduate and graduate levels). Participants were also asked to fill an electronic questionnaire about curriculum design tools that they currently use to create and manage their courses (e.g. preparing syllabi; communicating with students; developing teaching materials; preparing, assigning, and delivering grades, etc.). The results of this phase were published in ASEE 2014 and FIE 2014 [15], [16]. The results from the focus group helped identify the key features of the software system; an ontology that defines the relevant terms of the domain and identifies their specific meaning as well as the potential relationships between them; and mental model, which is a tool to improve understanding of the user needs and activities. Figure 2 shows the ontological concepts and relationships between concepts as a hierarchy. Figure 3 shows the mental model that depicts an affinity diagram of similar activities organized sequentially into 9 towers in the upper half with detailed relevant activities in the lower half.

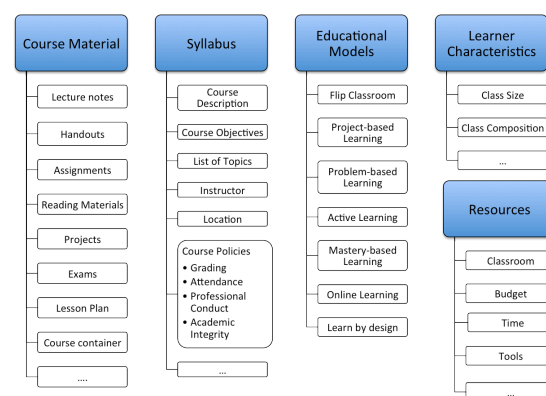


Figure 2: IMODS Ontological Concepts and Relationships

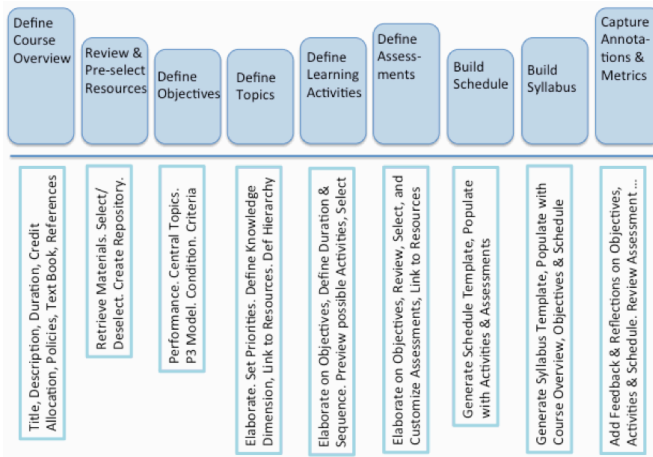


Figure 3: Mental Model

III. HIGH-LEVEL DESIGN OF IMODS

One of the biggest challenges of software design is to make sure the user has sufficient understanding to use the application successfully and accomplish the required tasks. Our User-centered design approach followed two main phases:

A. Conceptualization Phase

After the user research provided a relatively clear idea and understanding of domain- and user needs, this initial design phase provides a high-level design with concepts identification, conceptual modeling and early prototyping. During initial conceptualization and high-level design, we focused on Brainstorming sessions and contextual analysis to build an initial concept of the application. We gradually consolidated it into a set of requirements on flip charts and PowerPoint slides. The main goal of high-level design is to plot down schematic ideas and steps into visual graphs and models; an early blueprint. We started by investigating different options and providing design alternatives to make sure we have a broad view before identifying a good design. Doing this early on, at high-level, sketchy, paper-based only, and without going into details help provide several solution alternatives at a very low cost.

The IMODS system is conceptualized such that a course design is centered around the learning objectives of the course defined by the instructor (user) as shown in Figure 4. Learning objectives are directly associated with the course content, assessments, and pedagogical activities as defined in the PC³ model (Figure 5).

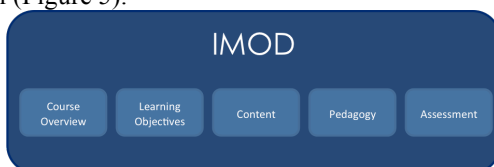


Figure 4: IMODS System Overview

The Learning Objectives component of the IMODS system was conceptualized with its various components based on the PC³ model as shown in Figure 5.

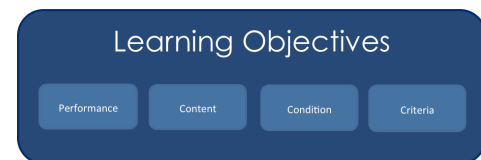


Figure 5: IMODS Learning Objective Overview

Then as we planned and executed the testing, we were able to directly ask the user to work on a “Criteria” within “learning objectives”. Our dual purpose is to let the user know that those are two concepts of the IMOD, as well as knowing the structural relationship between them.

B. Development Phase

In order to validate that we were proceeding in the right direction, we ran a series of usability tests on the application. We chose between multiple good designs instead of focusing on only one early on. The high-level design sketches were discussed with the users to make sure what they said in unstructured dialogs and vague ideas and imaginations can now be concretely captured in design artifacts for further validation and clarifications [17]. Our main goal was to evaluate the simplicity and clarity of the application structure to allow for an easy-to-recognize mental model. A mental model can be loosely defined as the user perception of the application. The opposite is the developers’ perception of the application. While the latter one is the actual structure that developers use to build the application, typically as their interpretation of the requirements, the user mental model is not necessarily the same. With the fact that users don’t normally have access to the actual structure of the application, or detailed and prolonged access to the application to know any of its internal structure, they can only perceive what’s exposed to them from the UI, and can build an “imagination: of what the application structure might look like. In ideal situations, this “imaginary” structure should match the actual structure build by developers. In reality, though, it is rarely the case. A discrepancy or vagueness on the user mental model (we can call it a delta) is typically present and expected. The problems arise when this delta is large, indicating an application whose structure is not comprehensible by the user. We have identified 2 tools that are most suitable for this project in this phase.

C. Tools

Navigation Model is one of the essential methods of design that we used. A significant challenge in complex software is not the contents of each screen, but how the user mentally build a mental view of how all screens are connected (like a city road map), and how to navigate between hundreds of screens to accomplish their task. In this regard, we have developed an effective technique, elastic prototyping, an implementation of a participatory design to help designers and users build a navigation model together, greatly reducing time and effort needed. Figure 6 shows the navigation model for the primary application. Figures 7 and 8 show the navigation model for new user registration and user login. One of the

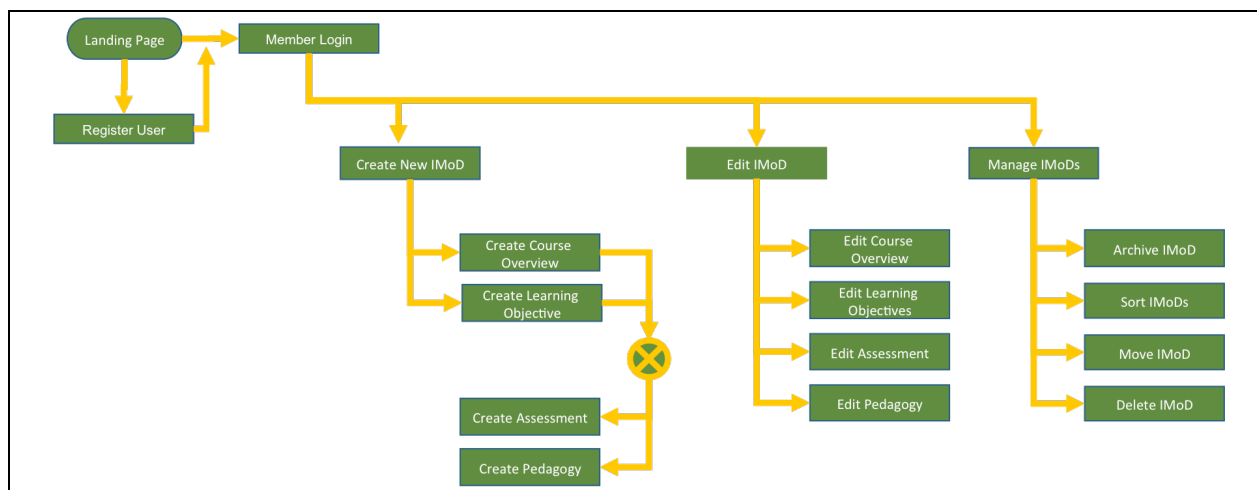


Figure 6: Primary IMODS Application - Navigation Model

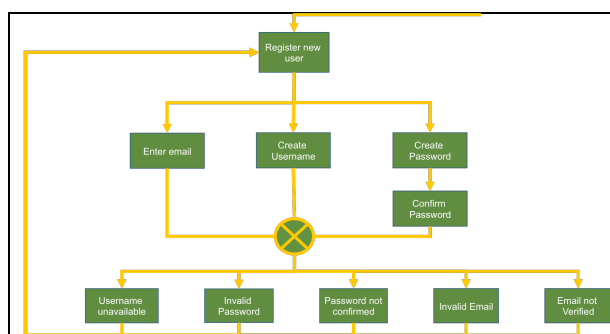


Figure 7: New User Registration - Navigation Model

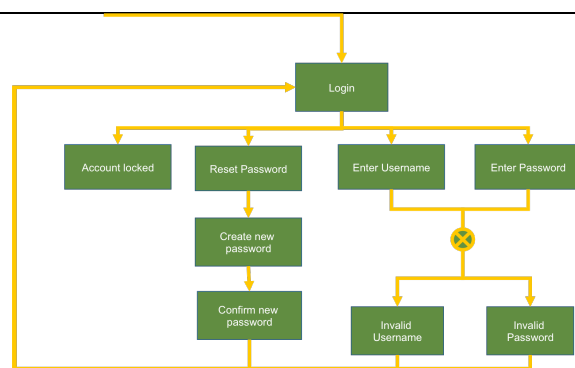


Figure 8: User Login - Navigation Model

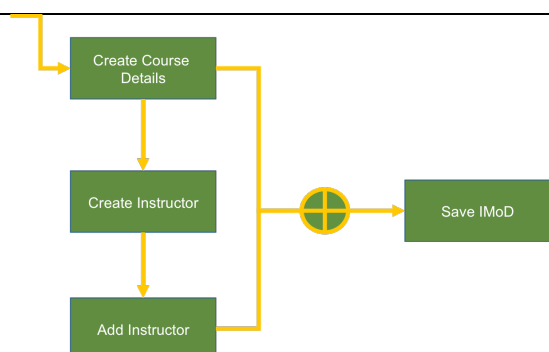


Figure 9: Course Overview - Navigation Model

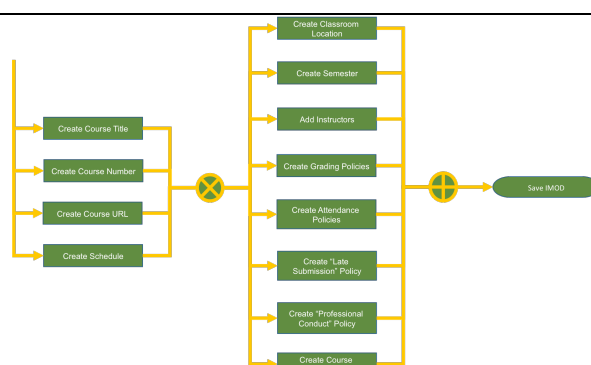


Figure 10: Course Details - Navigation Model

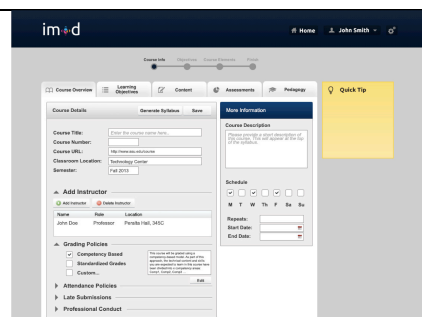


Figure 11: Course Overview Mockup

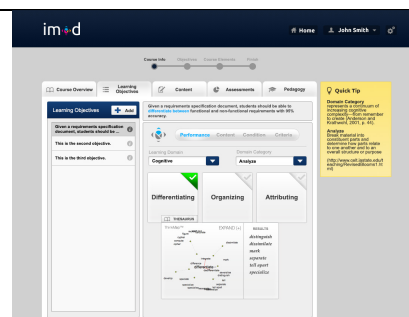


Figure 12: Learning Objectives Mockup

main components of course design is describing course overview information that includes data about course title, description, schedule, instructors, course policies, etc. Figures 9 and 10 show the navigation model for course overview data entry. In a similar manner navigation model for other screens of IMODS that are used for design of Learning Objectives, Content, Assessments, and Pedagogy were created.

Prototyping (PT) is extensively used in UCD to visualize and validate all otherwise vague ideas and unclear expectations at low cost and high effectiveness. We focused on three main categories of prototyping: Paper (low-level) PT, low-fidelity electronic (medium level) PT, and high-fidelity, detailed PT [18]. Paper prototypes are very inexpensive and help us capture several initial ideas and concepts, and validate them. After explaining their needs, users often change their minds when they see them on paper. Therefore multiple paper PT sessions gives a head start in validating what users actually mean and need. After initial concepts, design ideas and directions were identified, we moved into a medium fidelity prototyping stage where we provided a sketchy visualization of key screens without contents and gradually validated them and added initial contents. Figures 11 and 12 show the user interface mockups of Course Overview and Learning Objective components of the IMODS system

D. System Architecture

The development phase of the project included identifying appropriate technologies to be used for the development of the IMODS semantic web application, design of the back-end database schema, installation and configuration of the server-side and client-side technologies, and development of the user interface screens for login, registration, index, and creation of an instructional module and the connectivity of these web pages with the backend database. An Agile software development methodology called Scrum is being used for the development of this project. Scrum is an iterative and incremental framework for managing product development. The technologies chosen included Groovy on Grails, an open source, full stack, web application framework for the Java Virtual Machine. It takes advantage of the Groovy programming language and convention over configuration to provide a productive and streamlined development experience. Grails uses Spring Model-View-Controller (MVC) architecture as the underlying framework. MVC is a software architecture pattern that separates the representation of information from the user's interaction with it. PostgreSQL was chosen as the database management system. It is a powerful, open source object-relational database system with more than 15 years of active development and a proven architecture that has earned it a strong reputation for reliability, data integrity, and correctness. Git was chosen for source code version control. It is a distributed revision control and source code management (SCM) system with an emphasis on speed.

E. Testing

For the testing phase of the project, we opted to not have a complete discovery test, where the user would be asked to do a blind discovery of the application without any prior knowledge [19]. That would be a simulation of a completely novice user without any application background. Instead, we decided to test for an average user with some level of knowledge about the application structure. The reason is that we already have a concrete navigation model, and we can typically bring it to any user's attention in few minutes to help them in building a correct navigation model. That is one of the main advantages of using the navigation modeling method. Currently our research team is working on software development and testing phases of the project.

IV. CASE STUDY

The IMODS framework was applied to design an introductory software engineering course titled "Software Enterprise I: Personal Software Process" in B.S. in Software Engineering program. This section describes the use of IMODS – PC³ model for course design.

A. About the Course

Software Enterprise I: Personal Software Process is a sophomore course in the Software Engineering program that introduces software engineering and object-oriented software design principles using a modern programming language. Students are introduced to Software Engineering, Software Life Cycle models, Object-Oriented Programming, Personal Software process, Effort estimation, effort tracking, defect estimation and defect tracking. Students learn personal software process for individual professionalism, time and defect estimation; yield and productivity. A project-based pedagogical model is used for delivery of all our courses in Software Engineering program. Students in this course worked on a game project using Java programming language.

B. Learning Objectives

Learning objectives of this course were defined using the PC³ model. The course has 6 objectives that are categorized under Performance, Content, Condition, and Criteria as shown in the Table 1. The objectives are as follows:

- *LO1:* Design a software solution using Object-Oriented Design principles of encapsulation, information hiding, abstraction, inheritance, and polymorphism
- *LO2:* Develop a software solution in an object-oriented programming language employing standard naming conventions and making appropriate use of advanced features such as exception handling, I/O operations, and simple GUI
- *LO3:* Use object-oriented design tools such as UML class diagrams to model problem solutions and express classes and relationships such as inheritance, association, aggregation, and composition

- *LO4*: Use personal software process for individual development productivity through time estimation and tracking
- *LO5*: Use personal software process for individual development quality through defect estimation and tracking
- *LO6*: Demonstrate teamwork

Table 1: Learning Objectives based on PC³ Model

Objective	Learning Domain	Domain Category	Action Category	Action/Word Performance	Content	Criteria	Condition
LO1	Cognitive	Create	Plan	Design	Software Solution, Object-Oriented Design principles, encapsulation, information hiding, abstraction, inheritance, polymorphism	Quality (DPA**)	At completion of this course, student will be able to
LO2	Cognitive	Create	Produce	Develop	Software Solution, Object-Oriented programming language, standard naming conventions, Exception Handling, I/O operations, simple GUI	Quality (DPA**); Speed (DPA**)	At completion of this course, student will be able to
LO3	Cognitive	Apply	Implement	Use	Object-oriented design tools, UML Class diagrams, Modeling problem solutions, Classes, Relationships between Classes, Inheritance, Association, Aggregation, Composition	Quality (DPA**); Speed (DPA**)	At completion of this course, student will be able to
LO4	Cognitive	Apply	Implement	Use	Personal Software Process, Individual Development Productivity, Time Estimation, Time Tracking	Accuracy (85%)	At completion of this course, student will be able to
LO5	Cognitive	Apply	Implement	Use	Personal Software Process, Individual Development Quality, Defect Estimation, Defect Tracking	Accuracy (85%)	At completion of this course, student will be able to
LO6	Cognitive	Apply	Implement	Demonstrate	Teamwork	Quality (DPA**)	At completion of this course, student will be able to

** DPA Determined Per Assessment

C. Content

The list of Content topics and subtopics are listed in Table 2. For each topic the knowledge dimension and topic priority is defined. This information is used to find assessments and instructional activities that best fit for delivering a topic.

Table 2: Content Topics based on PC³ Model

Content Topic	Content Sub-Topics	Knowledge Dimension	Priority
Object-Oriented Design Principles	Encapsulation	Factual (F), Conceptual (C)	Critical (3)
	Information Hiding	Factual (F), Conceptual (C)	Critical (3)
	Abstraction	Factual (F), Conceptual (C)	Critical (3)
	Inheritance	Factual (F), Conceptual (C)	Critical (3)
	Polymorphism	Factual (F), Conceptual (C)	Critical (3)
	Software Solution	Conceptual(C), Metacognitive (M)	Critical (3)
Object-Oriented Design tools	Modeling Problem solution	Procedural (P), Metacognitive (M)	Critical (3)
	UML Class diagram	Procedural (P)	Critical (3)
	UML Use Case Diagram	Procedural (P)	Important (2)
Object-Oriented Programming Language	Exception Handling	Factual (F), Conceptual (C)	Important (2)
	I/O Operations	Factual (F), Conceptual (C)	Important (2)
	Simple GUI	Factual (F), Conceptual (C)	Important (2)
	Standard naming conventions	Factual (F), Conceptual (C)	Good to know (1)
	Time Tracking	Factual (F), Procedural (P)	Critical (3)
Personal Software Process	Time Estimation	Factual (F), Procedural (P)	Critical (3)
	Defect Tracking	Factual (F), Procedural (P)	Critical (3)
	Defect Estimation	Factual (F), Procedural (P)	Critical (3)
	Teamwork	-	Metacognitive (M) Important (2)

D. Assessments

Assessments chosen for this course include a mix of both formative and summative assessments. The PC³ model aligns assessments chosen for the course with the learning objectives by checking compatibility of learning domains, performance, and criteria requirements. Table 3 provides the list of assessments with their corresponding learning domain

category, knowledge dimension, and criteria type that each method is suitable for.

E. Instructional Activities

Pedagogical activities used in this course are listed in Table 4 along with the knowledge dimension and learning domain category that they are suitable for. The list of activities includes a mix of lectures, lab activities, Q&A discussions, and problem solving activities.

Table 3: Course Assessments

Assessment	Type	Domain Category	Knowledge Dimension	Criteria
Programming exercise (write formal code)	Formative	Understand, Apply, Analyze, Evaluate, Create	Conceptual, Procedural	Speed, Quality, Accuracy
Partially guided programming exercise	Formative	Understand, Apply, Analyze, Evaluate	Conceptual, Procedural	Quality, Accuracy
Guided Lab exercise	Formative	Understand, Apply, Analyze, Evaluate	Conceptual, Procedural	Quality, Accuracy
Quiz	Formative	Remember, Understand	Conceptual, Factual	Accuracy, Speed
Project	Summative	Understand, Apply, Analyze, Evaluate, Create	Conceptual, Procedural	Quality, Accuracy
Exam	Summative	Understand, Apply, Analyze, Evaluate	Conceptual, Procedural	Quality, Accuracy

F. Results

Software Enterprise I: Personal Software Process course in the Software Engineering program in School of Computing, Informatics, Decision Systems Engineering (CIDSE) at Arizona State University was designed using the IMODS – PC³ model and offered as a face-to-face section (with 82 students) as well as an online section (with 87 students) by the same instructor (one of the co-authors). Using the IMODS framework ensured the alignment between various course elements and thereby ensuring high-quality course design.

Table 4: Course Pedagogical activities

Instructional Activities	Domain Category	Knowledge Dimension
Lectures (Face-to-Face, Audio, or Video)	Remember, Understand	Conceptual, Factual
Problem Solving	Understand, Apply, Analyze, Evaluate	Conceptual, Procedural
Partially Guided Programming exercise	Understand, Apply, Analyze, Evaluate	Conceptual, Procedural
Active Reading	Remember, Understand, Apply	Conceptual, Factual, Procedural
Programming Assignment	Understand, Apply, Analyze, Evaluate, Create	Conceptual, Procedural
Guided Lab Exercise	Understand, Apply, Analyze, Evaluate	Conceptual, Procedural
Q&A Forum	Remember, Understand	Factual, Conceptual

Alignment between various course components:

The framework supports the checking of alignment between course assessments and learning objectives. The course assessments are linked to the performance and criteria elements of the learning objective as shown in Figure 1. The framework supports the checking of alignment between course instructional activities and learning objectives. The course pedagogical activities are linked to the performance and content of the learning objective as shown in Figure 1.

Topic Prioritization:

Use of the PC³ model ensured a balanced distribution of the topics under Critical, Important, and Good to know as shown in figure below.



V. FUTURE WORK

Following the high-level design phase of the project, the next step will be software development and testing of IMODS. We will conduct usability testing of the prototype with instructors and solicit feedback using surveys, observation, and user interviews. The feedback will be incorporated into the iterative software development lifecycle model. The scope of this project will also include the evaluation of its novel approach to self-guided web-based professional training in terms of: 1) user satisfaction with the documentation of course designs generated; and 2) impact on users' knowledge of the outcome-based course design process.

ACKNOWLEDGMENT

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Global vs. Local - Experiences from a Distributed Software Project Course Using Agile Methodologies

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Abstract—Global software engineering (GSE) has become common in the software industry. Distributed development work comes with many challenges, especially related to communication and coordination. Thus, it is essential to also teach and prepare the new population of software engineers to be aware of – and familiar with – these hurdles. We addressed this need by arranging a joint (agile) software project course between universities in Finland and Norway. We had three teams – one with students from both countries and two with students from the Norwegian university only. The students were given a teacher mentor, a handbook on agile practices and state-of-the-art tools for project management and software development. Apart from monitoring the teams' progress, we also collected data from emails, questionnaires, student reports and interviews during and after the project. The main lesson learned is that the global and local teams are mostly facing the same challenges - especially when it comes to team building, clear project roles, and communication and management issues. Ultimately, our results show that the challenges were harder to solve by the global team and that not solving challenges in a timely manner had more serious consequences.

Keywords—global software development, agile, student teams

I. INTRODUCTION

Global software engineering (GSE) has become increasingly popular in the industry during the past 15 years [1]. Software components are outsourced to subcontractors around the world, but also the main developer companies have distributed their development to several countries in order to leverage the benefits of a wider pool of skilled resources, lower costs and proximity to the customers. Thus, the development teams themselves have become distributed, with team members working from different locations, having to face temporal, cultural and geographical distances and the challenges they bring on a daily basis [2]. These challenges have significant effects on the project process and outcome, and thus it is necessary to begin preparing the software engineers of the future - the current students at universities - for these challenges in advance and to teach them methodologies that can be used when facing them.

There is a growing trend towards teaching global software engineering in a setup where software projects are developed in distributed teams. Following several experience reports and viewing the increasing need to give students hands-on practice with working in a distributed team, Tampere University of Technology (TUT) (Finland), and Gjøvik University College

(GUC) (Norway) embarked on a joint mission to set up a software engineering project course to reach this objective. TUT had already been running a software engineering project work course for 20 years on the Master's level where the topics came from the industry, while the Master's students in Gjøvik have had their software engineering project in their Bachelor studies.

There were two main drivers for covering global software engineering in a project format rather than in a traditional software engineering course: firstly, and most importantly, we wanted the students to get a hands-on experience in addition to more theoretical introduction to global software engineering. Secondly, we found it easier to organize the teaching activities at the two universities when students worked in projects.

The structure of the paper is as follows: in the next section, we will discuss existing studies on teaching globally distributed software projects. We will then present the setup for our course - the background of the students, the course arrangements (practicalities and implementation of Scrum methodologies), provided tools and description of the assigned project for the students. In section IV, we will describe the project process, and compare the local teams' process to that of the distributed team, especially concentrating on the challenges the distributed team faced. In section V we discuss our findings, backed up by data collected from different sources, and then in Section VI draw our conclusions.

II. RELATED WORK

As is the case for GSE in general, the number of experience reports from teaching GSE have increased significantly in the past decade, since the first experiences from teaching a distributed student project was published already in 1998 [3]. Monasor et al. [4] performed a systematic review on the topic in 2010, and found six types of proposals regarding teaching or educating in global software engineering: learning environments, e-learning approaches, simulators, teaching GSE in the classroom, training GSE in the classroom, and teaching GSE in the company. In this context, a project work in truly distributed teams is considered training in the classroom, so we will focus on existing studies in this category.

The longest running course on GSE seems to be DSD (Distributed software development course), organized by University of Zagreb (Croatia) and University of Mälardalen (Sweden), which has been running since 2003 [5]. The course consists of

introductory lectures (5 weeks) and project work (3 months). During the years, factors affecting student motivation [5], factors to consider when choosing a project for the team [6], and the role of customer have been investigated within the context of the DSD course [7].

The largest GSE course, in turn, appears to be the DOSE course [8]; the 2012 instance of which was organized between 12 universities in 11 countries, each group having members in 2-3 countries [9]. As the previous implementations of the course had revealed that communication, coordination and management roles were challenging for the students, the instructors experimented with a playful competition that would actually act as a pedagogical tool to teach how meaningful the role of project management and working communication methods are in a distributed course.

Recently, Agile methodologies have also been brought to GSE courses. Damian et al. [10] discuss the initial findings of using Scrum in a course distributed between Finland and Canada. These results are further examined by Paasivaara et al. [11]. In the Finnish-Canadian course, the Scrum policies were monitored very strictly, and several practices for supporting GSE were also established. Students reported good outcomes on learning GSE, and showed an innovative spirit to find ways of establishing methods for frequent and fluent communication, which is essential in both GSE and Scrum.

Scharff et al. [12] have also studied the difficulties students have in adhering to Scrum policies in GSE, and have concluded that due to the nature of GSE, there were problems such as unexpected absences of developers, no regularity in doing Scrums, sprint planning was done late, and retrospective and sprint demo were not prepared.

Our work gives a new angle to existing studies by being able to present a realistic comparison between local and distributed teams. Our students had the exact same setup, project descriptions and schedule, and thus we (and the students) are able to analyze the difficulties that were specifically due to the nature of GSE for the distributed team. Additionally, we have used Scrum, and there are still only few experience reports on how distributed Scrum works in student projects. Furthermore, the students were expected to implement a working piece of software from start to finish.

III. SETUP

In the past TUT have been running two project courses. One course has been implemented already since 1991 [13] and the name of the current version is Project Work on Pervasive Systems. During latest years we have also course Demola Project Work that has more innovation and start-up aspects. It was decided to offer the course as a parallel version of the existing project course at TUT, i.e., students could choose if they wanted to participate on the traditional software project course or the GSE project course. For Gjøvik students the project was offered as a separate course by the name "Global Software Development". The Gjøvik semester structure only enabled the course to last for 3 months (beginning of September to beginning of December), while the traditional TUT course lasted for almost five months. To enable same schedule for all students we condensed the GSE version at TUT to last for only three

months. Although the international version took a shorter time, overall effort in terms of working hours was planned to be about the same. The fact that all groups ended up doing the same project made it possible to compare the processes and performances of local teams to the globally distributed team in a systematic way.

A. Student selection

In Tampere University of Technology, 111 students had initially signed up for two project courses called Project Work on Pervasive Systems, and Demola Project Work. We sent an invitation to all those students to consider the international course, and we received 10 initial contacts from students. These students were then asked to provide background information of their experience in different programming languages, software projects in practice, and what kind of studies they had completed. We had to send these questions, because not all of the students had software engineering as a major subject and we wanted to gain insight on the background and motivation of the interested students. Some of the students decided to drop at this phase, while some decided to postpone the project course to next year because they did not have enough background knowledge, yet. Some students also discovered that the more intensive version of the course did not fit to their schedule, and wanted a version where the amount of work is spread to a longer period. After discussing with the teachers a couple of students withdrew themselves because they were in too early a phase in their studies and could not contribute properly. At the end, only two actually joined the course. They were both international students, and had both motivation and skills. Both of them have passed courses on programming and on software engineering processes.

In Gjøvik, the course was made compulsory for students in the Web, Mobile, Games track of the Master of Applied Computer Science program. The course runs in the third semester of the two-year master program and was brand new in the program. The 13 Norwegian students were all registered as full time students on this Master's program track; 7 students having their bachelor degree from GUC, while the remaining students were students from Ukraine, Russia, and China. All students had a Bachelor's degree in computer science (CS) with at least 20 ECTS in SE projects.

Most of the students had some familiarity with Scrum and Agile methodologies prior to the GSE course: 40% of the students reported that they had practical experience in Scrum, 40% reported that they were familiar with the methodology but had never actually used the methodology, and the remaining 20% had no familiarity with Scrum.

B. Course arrangements

1) Practicalities

The course began on September 5th, and lasted until December 5th. The course was divided into 4 sprints, and after each sprint, a 4-hour long seminar was arranged. During the kick-off seminar (before the first sprint), the staff presented the provided tools and the project handbook. The project handbook was prepared for the students to specify explicitly the Scrum practices the students were expected to follow. It also con-

tained information about the tools and the reports required from the students. Other seminars acted as sprint demonstration, review and retrospective events for all the groups, as they presented their progress to the course staff and students and discussed their difficulties and successes. Additionally, relevant topics were presented by the staff.

After the kick-off seminar, the course staff provided the students with an opportunity for team building in a voluntary session. The distributed team chose to have a separate, independently arranged, team building session where they discussed their hobbies and such.

In addition, Gjøvik had invited two senior developers from the industry with extensive experience from working in global teams to share their experiences with the students. These senior developers also participated in the planning of the course to ensure that the project handbook and the chosen tool set were up to date with regard to software development industry practices. Student groups were also assigned mentors to assist them during the project (mentoring is discussed in more detail in a later section).

The students were required to produce three types of deliverables:

- Running software
- Scrum artifacts (backlog, sprint backlog, sprint retrospective, and system documentation)
- Project reports

2) Scrum policies

As discussed above, the students were provided a project handbook explaining Scrum policies, and the groups were thus instructed to familiarize themselves with the contents of the handbook and to make sure that they run the project according to the handbook. The handbook introduced Scrum and included several links to resources on the web describing Scrum in more detail. The handbook further described the mandatory project roles, the required Scrum artifacts, the definition of done, and the required meetings. Finally, the handbook had a short chapter on working in global teams. Groups were required to select a Scrum Master and a Product Owner from the group members. The groups were also encouraged to appoint a Build Master who would be in charge of the development tools. Groups were expected to have meetings at least twice a week.

3) Tools

Gjøvik provided the students with an extensive set of state-of-the-art tools for project management and collaboration. The tools were chosen based on the recommendations given by the two senior developers from the industry, as the tools are common in the corporate world. Atlassian Confluence [14] was used as a wiki for the course, and the teams were given their own spaces for sharing material and discussions. The project groups also used the wiki for the system description they were required to write. In addition, the teams were given access to Atlassian Jira [15], where they were expected to manage the tasks and issues as the development progressed and to log their working hours.

The tool set was to a large degree the same for all projects: A version management server for Git [16] repositories was provided and Apache Maven [17] was chosen as the tool for managing the software build process. The backend parts of the applications were developed as Java applications implementing a RESTful interface [17] and running on Apache Tomcat [19] using MySQL [20] as the database. The teams chose different client side strategies. One team chose to develop a thick Java Swing client. The second team chose to develop a native Android application. The third team chose to develop an application to run inside a web browser.

4) Groups and project description

The students were divided into three groups. Group assignment was based on the students' response to a questionnaire in which they described their programming and management experience and interests respectively. As there were only two TUT students participating, we decided to assign them to the same project group so that all students had also some local team mates. These were the three groups:

1) The members of the (local) Baldr project were three Norwegians, one Chinese, and one Ukrainian student. The group's mentor was one of the senior developers from the industry. In the group members' self-evaluation only one's programming experience was only based on schoolwork, while others also engaged in extra-curricular activities or had professional experience.

2) The members of the (local) Freya project were two Norwegians, one Chinese and one Russian student. The group's mentor was the Norwegian professor. In the group members' self-evaluation three group members' programming experience was only based on schoolwork, while one also engaged in extra-curricular activities and one had professional experience.

3) The members of the (global) Kvasir project were two Norwegians, and a Ukrainian student located in Norway and two Iranian students located in Finland. The group had one of the Finnish professors as mentor in Tampere and one of the senior developers from the industry as a mentor in Gjøvik. In the group members' self-evaluation three group members' programming experience was only based on schoolwork, while one also engaged in extra-curricular activities and two had professional experience.

When reporting experience in Java programming, group members from Baldr and Freya had on average the same level of proficiency, while members from Kvasir group reported slightly lower levels of Java knowledge. In JSP/Servlet technologies Baldr's group members' knowledge was slightly below average, Freya's merely adequate, and Kvasir's the highest of all groups (due to one professional expert).

The students were given a choice of three different topics. All the teams, however, ended up choosing the same topic - an educational trivia game. One team initially chose a different topic, but found it too vague, and then changed to the game topic as well. A two-page project description was given to the students suggesting features for the game play. The document also suggested features for defining questions and answer alternatives and for quiz management. Students were expected to put down at least 275 hours each on the project. The size of the

suggested project was larger than what we expected the students to deliver, thereby challenging the student teams to order features according to perceived importance to the users. The project did not require any special programming skills beyond what an average CS student should have acquired after four years into a CS program.

IV. PROJECT PROGRESS

A. Seminars

The course started in the first week of September. During the course, five seminars were organized in total at intervals varying from two to four weeks apart. The purpose of the seminars was partly to introduce relevant topics (the first four seminars only) and partly to have the students demo their progress and to summarize their sprint retrospectives (the latter four seminars only). Each seminar was held in a room with video conferencing facilities, and both universities were involved in providing content to each seminar. The topics of the first four seminars were:

- Introduction to the project handbook and the project management and the development tool set. The students were also given suggestions for team formation activities.
- Working globally; communication challenges and Conway's law.
- Estimation and (OO) metrics; common issues regarding project startup.
- Beyond school projects: commercial software development projects and open and free software development projects.

Students would be given the floor first to present their progress, after which, the course staff gave presentations on the listed topics. The fifth seminar was reserved solely for review and retrospective.

B. Communication issues and team formation

Not surprisingly, all teams had issues in team formation and communication. As mentioned above, teams were supposed to select the Scrum Master and Product Owner. This process lasted longer for the distributed team than for the collocated teams. It turned out that making such selection is far from obvious if the team members do not know each other and cannot communicate face-to-face. There was a clear difference in how quickly and easily the local teams were able to solve the team formation issues compared to the global team. Earlier projects have shown that physical meetings at the beginning of project are beneficial [1]. Although the course organizers discussed bringing the students of the distributed team together for a physical meeting, it was not implemented due to financial and resource constraints. Our experience confirms the assumption that a distributed project would be more successful if the team can have a physical meeting, too.

The performance of the distributed team was further worsened by the fact that one of the team members refused to install and run Skype on his personal computer. The team there-

fore ended up spending a significant effort deciding whether the team should use Skype or IRC as the chat tool. When choosing the IRC solution, the team also lost a means for seeing each other while communicating.

The third, and maybe the biggest problem, was related to implementation of Scrum practices. All teams would have benefitted from having Scrum ceremonies and well-managed backlog items. The distributed team would have benefitted from those practices most. The implementation of the Scrum practices also took longer time for the distributed team. At the end, it was clear that a simple set of three questions: "What did you do yesterday?", "What will you do today?", and "Are there any impediments in your way?" contributed to trust within the team in addition to improving visibility. However, it took some time and help from the team mentors to learn the value of the Daily Scrum. The distributed team had also difficulties in implementing the daily Scrum meetings due to lack of face-to-face contact and due to mismatching schedules. To overcome these challenges the distributed team decided to use a shared notebook in Confluence tool and set a deadline by which every team member should write an answer to the standard questions. Apparently, this alternative worked and the team members reported that they really checked the content of the shared notebook late in the evening.

C. Mentoring

As already mentioned, each local team had one mentor. The global team, however, had two mentors, one in Tampere and one in Gjøvik to make sure that each both parts of the distributed project had a local mentor. The mentors kept an eye on the group activities and progress. The teams were told that they could invite mentors to their project meetings on demand.

Local teams did not require much help from the mentor, and the teams just reported about the progress. However, the distributed team needed help from mentors several times. Mentors had to help the team in team formation, and explain to the team how important certain Scrum practices are and how they can solve the current issues of the team. Mentors also had to work together in assessing the status of the team. The help from mentors concentrated on teamwork and organization of the work. No help was needed in technical or software development areas.

D. Deliverables

1) Code

The students were asked to deliver running of software. As already mentioned, they were requested to develop a server providing a REST API implemented in Java. The students were free to choose the front-end technology, but selected Java-based application server. Most students were lacking deep Java server experience and were therefore having some problems developing a working server solution. There were no significant differences between the local and the global teams in terms of delivered software.

There was one observable difference between one of the local teams and the global team when it came to adapting to similar challenges in the team organization. Both teams had assigned two team members to work on the server side but expe-

rienced that the server side development was lagging behind. The local team decided to add a third developer to do server side development when they became aware of the problem. The global team, however, had decided to split work so that the Tampere team members worked on the client side while the Gjøvik team members worked on the server side. This way of organizing the project simplified coordination of the server and the client side activities, when both parts were progressing as planned. It turned out, however, that this way of splitting work was not so good when the server side developers, due to unforeseen resource issues and technical complexities, failed in progressing as planned. There was no server side expertise in Tampere that could be used to assist the Gjøvik server team. The Tampere client side team had developed “their part” but could not sign it off completely since it could not be integrated on tested with the server side and was therefore frustrated with the teamwork as a whole.

2) Documents

The students were expected to document their backlog issues and working hours with Jira. They were also expected to document larger discussions in Confluence. In practice, Jira and Confluence were used scarcely. The main reason, according to the students, was that there were several new tools they needed to learn to use and they felt that they had too little time to learn them all. The students claimed that it would take too much time to learn to use two tools properly. The distributed team, however, did use Confluence as a batch-mode tool for sharing notes from daily scrums.

Additionally, students had to submit two reports at the end of the project: A group report (one per group) and an individual report (one per student). In these reports, the students briefly described the project and the product they had developed. In addition, the students were required to reflect on the experiences and learnings. The team report included descriptions of the developed software, project organization, used tools and conclusion. The personal report was more about time spent in various tasks and about personal learnings.

V. RESULTS AND DISCUSSION

In the following, we will discuss issues particularly regarding team formation and project execution based on the data collected from observations, emails and students’ reports. Some participants of the distributed team were also interviewed in Spring 2015. We will also reflect on our own part of how the offered learning experience could have been improved.

A. Team formation

The distributed team clearly had more difficulties in getting organized work started. The team did also recognize this issue and wrote in their final report “Roles within the project should be clearly defined. In the first sprint, our roles were not clear, and each member had slightly different understanding of what he/she supposed to do.” In a later interview, the members also reported that lack of knowing each other’s skills and other background caused problems during first half of the project.

Although we discussed the opportunity to bring the distributed team to the same physical location, that plan was not implemented. The team formation clearly suffered from that

decision, which was also noted in the end-report of the team: “It would be beneficial for distributed teams to meet up in person during the project kickoff. The team could meet up for a two to three day seminar where the project would be outlined and the basic backlog created.”

We proposed that the distributed team should run a networked game to help team formation, but the team did not use this opportunity. In the later interview, we discovered that the students did not understand the need and motivation for such a game session.

B. Project execution

Based on the outcomes of the projects and the data we collected from the teams’ reports, we may evaluate the differences between the local teams and the distributed team.

Firstly, we can compare the used hours on the project. In Table 1, we present the relative percentages of how teams used their time and the total number of hours they put into the project. Note, that not all students provided such detailed estimation of how they spent their working hours, and so estimation is made based on the data at hand.

TABLE 1. GROUPS' WORKING HOURS

	Development and testing	Learning tools and techniques	Project management (incl. meetings)	Other	Total (h)
Baldr (local)	55%	23%	25%	2%	1521
Freya (local)	44%	24%	29%	3%	1485
Kvasir (distr.)	34%	37%	21%	8%	1545

From Table 1 we can see that the distributed team used a significantly larger amount of time learning the tools and techniques. This is partially because several members from the distributed team reported limited experience with Java, so learning that programming language and libraries took them far more time than more experienced teams. Another reason may be that the distributed team was not able to set up a common session for learning the tools and techniques. A third reason may be that everybody tried to learn everything because the team did not have a clear idea of how to divide work in the beginning. For example, the Product Owner from local team Baldr reported spending a day from 9 AM to 10 PM with his teammates, helping them with programming issues, and that overall their pair programming was very efficient. Local team Baldr also stated in their report that “We also helped each other understand the tools“. This kind of collaboration would have been much more difficult for the distributed team.

From the reported hours, we can also see that the distributed team used less time on project management and meetings than the other teams. The Scrum Master of the distributed team states in her final report that “We knew that being distributed will be a very challenging task for us, so we put very many efforts on solving these problems. However, as it could be seen from group presentations, our problems were similar. Miscommunication, cultural differences, language barrier and

TABLE 2. GOOD PRACTICES

	Good practices	Problems	Changed practices during project?	Other observations
Baldr (local)	XP/Pair programming	Initial project selection had to be abandoned. Work distribution.		"If our team had been a distributed team, we expect that most challenging issue would be building communication, and understanding how each member works."
Freya (local)	Face to face kickoff meeting. Regular meetings in person. The idea of using Scrum was good for this project.	Time estimation for tasks. Dependencies between tasks, availability of group members (when needed to ask about the tasks/implementation). Scrum process was difficult to follow due to conflicting timetables.	Technical solutions to support Maven and Jenkins.	Ensure a face-to-face kick off meeting in the start of the project. Ensure the process should be known by each member in time. Be aware of the cultural change.
Kvasir (distr.)	Regular meetings. Clearly defined roles. Agreed and well-defined distribution of work.	Estimating required work effort was difficult. IRC as communication channel did not work, mostly due to communication and cultural differences.	During the 4th sprint communication practices were changed/improved. A shared Notebook was used to collect Scrum meeting notes. More effort put to updating Jira and Confluence. Increasing number of shorter meetings, group members staying online. Sitewise working sessions.	"It would be beneficial for distributed teams to meet up in person during the project kickoff. During the early planning, it is crucial for all members to understand each others' ideas and visions for the project. This can prevent several misunderstandings later on."

different personalities do happen in ordinary teams, but distributed trying harder to solve them, and thus, can be even more effective."

The observations by the mentors and from students' end reports all indicate that communication was the main challenge faced by the distributed team. Due to lack of face-to-face time, the team had to use communication tools. Due to different personal preferences and communication styles, it was hard to find a common set of tools and common ways to use them. In the end, the project chose IRC as the main communication tool, which meant that the team members did not have any means to see the faces of the members from the other location, apart from the video-based seminars.

Overall, it seems that during the first two sprints the distributed team was not able to work efficiently and spent time in learning the needed technologies, and the actual outcome was a result of very hard work during the last two sprints. We suspect that one reason for low percentage of less reported time for management is late team formation since from the reports it can also be seen that the time spent in initial confusion has not been reported anywhere.

In Table we have collected the groups' experiences from their reports. All groups were asked to report what practices worked for them, what did not work (or where they had problems), what changes they made to their practices during the project, and generally what kind of observations and suggestions they would have based on their experience. Notably, the good practices reported in Table 2 by the local teams are such that would have been difficult for the distributed team to adopt.

Nevertheless, the biggest problem encountered for all teams was the same - estimating the time it takes to complete tasks. The second biggest problem for the local teams was work distribution, and more specifically the dependencies between tasks. The distributed team, in turn, reported that their roles distribution (including the roles of developers to back end and front end) worked well, and they did not find as many difficulties between task dependencies.

In Table 3, we have collected individual students' experiences from their final reports. The students were asked to reflect on their learning experiences, what was the best and weakest thing in their project, what they might have done differently, and other aspects they experienced in the course. The students had very different styles for reporting. In Table 3, we have collected those comments that mostly relate to the learning process and to different aspects of a distributed project. From the table we see that all three teams emphasize the importance of communication. It is clear that the lack of an established communication infrastructure for the distributed team was a major hindrance. The team spent time on agreeing on the tools to use and ended up with a solution that did not proved audio/video communication. The teams also seem to share many of the other experiences.

The one issue that is highlighted by the distributed team only is the cultural issue (cultural difference, respect for each other, language differences). None of the other teams mentioned this issue even though they were all multi-cultural teams. It is likely that cultural issues are easier to solve when the team is physically collocated than when it is distributed.

TABLE 3. STUDENTS' EXPERIENCES

	Primary lesson learned	Best part of project	Other comments
Baldr (local)	Working with less experienced developers. Dealing with uncommunicative and unavailable group members. Building a structured workflow. Task distribution. Importance of communication.	Experience, preparing for the future. "letting us figure things out ourselves".	Weakest part was getting to know and using the management tools. Possibility to have face-to-face meetings made the tools less important. "if I had earlier understanding of culture, habits and complexity of some parts of work, I would do proper planning and change development process."
Freya (local)	Team work, agile methodology, tools. Team building takes time. Communication is important. Time must be spent on project management. How distributed development works. Flexibility of Scrum. Completing small tasks is most efficient. Meeting with the team is a great advantage. Need for good communication, good tool stack and project documentation routines key when dealing with cultural difference.	Working in a team. Process. Overall development framework. Producing an actual product using Scrum.	Communication is a necessary part of team work and cannot be overlooked though some people would rather just product code instead of spend time in meetings. Face-to-face meetings and Skype overruled Confluence and Jira due to ease of use. Team members need to know each other well to be effective. Team members' varying background in Scrum effects the Scrum master's workload. "Now, we were a team composed of different cultures, background and experience, and although we weren't distributed, I got a greater sense of what it means to work on a "real world" project."
Kvasir (distr.)	Communication channels. Respect of other cultures and avoidance of stereotypes. Fast response to others. Using Jira as a main tool (Others can keep track of your done, current and future work). Using Confluence as a formal expression of a topic (it can be logged easily in the future). Several problems in distributed teams are similar to problems that appear in regular teams. Misunderstandings are common when not using face-to-face communication. "Miscommunication, cultural differences, language barrier and different personalities do happen in ordinary teams, but distributed trying harder to solve them, and thus, can be even more effective."	Learning how to communicate, respect each other, enhance tolerance, work in a group, learning new things from others and so on. Learning roles in the Scrum methodology. Developing the client part of the application. Division of work.	Live audio and video should be preferred over text only. Overall productivity not too different from local teams. All teams had similar challenges. Deciding roles by ourselves was difficult, too much freedom hindered the project setup. Misunderstandings delayed development. "The weakest part of the project is probably the slow start of communication from the very beginning. If good communication had been in place early, more time could have been spent productively, resulting in a better product. The communication affects all parts of the project planning, which then affects the final product."

C. Reflection

In a normal company environment, the organization guides and helps team formation. The teams are not asked to select critical roles such as product owners. In addition, teams typically have organic growth - which means that teams are not built from solely people that do not share any past experience. In this course set-up, the teams were asked to self-organize and the teams were built from scratch. The distributed team had to adapt to shortcomings in this respect since self-organizing without physical meeting is more difficult and the students from different sites did not know each other in advance.

Although principles of Scrum can be explained in 15 minutes, it cannot be fully learned in such a short time. In addition

to telling the rules of Scrum, therefore, the students should get some "hands-on" experience and learn the reasoning behind the Scrum practices. Thus, the theoretical knowledge about Scrum is best learned by the help of more experienced persons. In our course, all students had about a similar knowledge about Scrum, but the distributed team would have benefitted more from adopting Scrum from the very beginning. Thus, we believe that the first sprint should have been run by the teacher mentor who should play a more active role but still not solve the problems on behalf of the students.

The project was run in autumn 2013 and in retrospect, we recognized a few problems that we wanted to fix for 2014. Those issues and planned solutions were:

Issue: Too few people from Tampere volunteered to international version. We thought that one reason was lack of company contact - local version worked in collaboration with local industry.

Solution: We asked our partner companies to indicate which topics welcome international team. Three topics out of 37 welcomed international teams.

Issue: Students had to learn many tools during the first sprint and create many things "from scratch".

Solution: Having a separate "sprint zero" of two weeks just for learning the tools by the means of an example project.

Unfortunately, for 2014 we got even less volunteers since all Tampere students preferred the traditional local option. Once the traditional project course had ended, we asked students their reasons for not selecting the international version as an additional question in our standard feedback system. The answers we received can be summarized as follows:

Clearly, the biggest reason was the extra complexity and "hassle" the students expected. Twelve (12) responses included a comment on generic complexity of the set-up.

The second area of concern was related to team dynamics. In a few cases, a group of students wanted to work together, or there was at least a wish to work with students that were familiar already. Nine (9) responses included that element.

In addition, five (5) students also expressed concerns of communication explicitly. Tighter schedule was mentioned five (5) times and fear of more work four (4) times. Uninteresting topic was mentioned only five (5) times. Three (3) responses indicated that they had considered but in the end selected differently.

This feedback shows that the students are well aware about the issues of GSE, but did not want to take the challenge as it was seen as extra work or hassle. The summary also shows that the organizing the GSE course as a separate course might work better than having it running as an alternative way to the traditional project course. In the future we should try an option where two local teams collaborate, but are different Scrum teams.

VI. CONCLUSIONS

Our experiments show that if an agile team is distributed, it faces more problems compared to local teams. Our project therefore supports the recommendation that agile teams should be colocated. In addition, we have learned to run a distributed project course that can teach the students valuable lessons in project management and distributed development. We have also discovered that very similar recommendations that literature - like [19] - recommend to actual projects work for project courses, too. The recommendations include:

- Organize face-to-face meetings every now and then, at least in the beginning.
- Pay attention to team formations and provide help for that. Self-organization does not work.

- Provide good and standardized communication tools. For the team it will take long to bootstrap communication tools.

The end reports and the later interview showed that the students have learned well the issues and challenges of global software development.

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A Tree Inclusion Analyzer for Examining Introductory Programming Codes

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Abstract—This paper presents a framework for building mechanisms for automatic analysis of introductory programming exercises. This framework consists of a structure that provides the combination of different types of analysis mechanisms, providing the configuration of various families of analyzers. One of these analyzers is based on a tree inclusion mechanism that verifies whether a particular structure (i.e. combination of language constructs) is contained in a solution. For evaluating our proposal, we conduct a study with 232 submissions from two introductory programming classes. The results indicate the following groups of students: one group that failed on syntactic and functional correctness stages; eight groups that submitted solutions with similar structure. Finally, the results provide evidences that is possible to identify different templates of correct solutions.

Keywords—Computer Science Education, Introductory Programming; Code Analysis.

I. INTRODUCTION

Learning to program, especially in introductory classes, has been defined as a complex task and, therefore, has been the subject of several studies, including being labeled as one of the greatest challenges in computer education [1]. Typically, the introductory classes have a large number of students, and consequently exercises. On that point, provide feedback in a timely manner shown an extremely onerous task, causing overload on the lecturer [2].

In this context, some tools have been used to provide automatic verification of solutions and immediate feedback, reducing the lecturer workload. Usually, the Online Judges verify the syntactic and functional correctness of a solution based on the application of a set of test cases (e.g., [3], [4], [5]). However, this approach takes into account only the performance on these

tests, and does not provide a more detailed information about the solution. Thereby, the traditional tools are not able to identify less suitable solutions and, either, to suggest improvements in student code.

About this aspect, it is possible to highlight a number of initiatives that are beyond the rule and have different analytical perspectives about a programming solution. The work of [6] uses a set of software engineering metrics to analyze the quality of the built program. The work [7] uses metrics of structural similarity and one analyzer to verify the occurrence of certain control structures. The work [8] uses an approach that aims to train students' ability to find errors in a program.

In this work, we present a framework for building code analyzers. This framework consists of a structure that allows the combination of different types of analyzers (e.g., Syntactic, Functional, Similarity, Constructs, among others). We designed this mechanism based on two complementary views: the conceptual view uses a multi-criteria decision-making technique called Valuated State Space [9]; the computational view uses the Decorator Pattern for building different configurations of analyzers (e.g., a syntactic analyzer combined with a functional correctness analyzer and a structural similarity analyzer) [10].

To evaluate our proposal, we present an analysis of solutions from two classes of introductory programming course at Federal University of Alagoas. In this study, we analyze solutions of one activity that correspond to the concepts of variables, inputs, output commands, operators and expressions. We analyze each one of the solutions using a set of structures. Thus, we expect to identify both the least appropriate correct solutions, which uses unusual buildings, as the most appropriate correct solutions, which uses a set of ideal and concise constructs.

The results suggest a set of students who have syntactic and functional correctness errors; a set of students who present structurally redundant solutions; and a group of students who submitted highly concise solutions.

The remainder of this paper is structured as follows: in section 2 we present related work, in particular work that use some kind of approach to analyze codes; in section 3 we present our proposal with the conceptual model and the computational model; in section 4 we present the configuration of our experiment; in section 5 we present and discuss the results of the experiment; finally, in section 6 we present our conclusions.

II. RELATED WORK

For the related of work related we focus on approaches that presents some differential with relation the centered only in verification of inputs and outputs. For those approaches, we aim to evidence its limit and possibility front to framework here proposed.

The work of [6] utilize a set of metrics of software engineering for analyze the quality of the solution. Differently of our approach, the authors do not use other type of analysis. However, the approach based on metrics of quality shows interesting and could be integrated to our framework in order to increase the coverage of mechanism of analysis.

The work of [7] present a mechanism that combine a structural analyzer (i.e., similarity analyzer) and an analyzer of constructs. This approach use the idea of combine different analyzers to provide a more embracing verification. However, one of the differentials of our framework is the conceptual basis defined by the Valuated State Space technique, and the logic architecture that allows easy extension and reconfiguration of analysis mechanisms

The work [8] uses an approach that aims to train students' ability to find errors in a program. The works of [11], [12] use an approach based on peer review to training the students analytical skills. Such work could be further integrated into our framework and thus would provide a wider range of tools for teaching programming.

III. PROPOSAL

Our framework is based on the composition of different types of code analyzers (e.g., syntactic analyzer, functional correctness analyzer, structural analyzer, construct analyzer, among others). This arrangement aims to provide a more

comprehensive analysis, because it allows the verification of different aspects of a code. Thus, we will present three complementary visions to this framework. The conceptual model aims to define the basic concepts of the analysis mechanism, basing its operation on a multi-criteria decision-making technique called Valuated State Space [9]. The tree inclusion model aims to define the basic concepts of the constructs analyzer, basing its analysis on a graph theory approach [13]. The computational model aims to define an architectural foundation for the framework, highlighting its extension points through the use of a set of Software Design Patterns [10].

A. Conceptual Model

Conceptually a programming problem consists of two distinct elements: a set of statements that should provide a clear and objective instruction of the problem to be solved; and a set of constraints, which define the criteria that must be complied in the proposed solution. Such criteria may define a set of allowed programming languages, a set of unit tests, a set mandatory language constructs, a set of reference solutions etc.

In this context, a set of analyzers aims to verify whether a solution violates a restriction of the problem. Each analyzer is defined by a function that determines the level of conformity between a solution and a particular restriction, where the maximum value represents maximum conformity and the minimum value represents minimal conformity.

Definition 1: Let P and S , respectively, a problem and a solution, there is a set of mechanisms that analyzes attributes of this solution. These mechanisms are defined by $A : P \times S \rightarrow \{a : 0 \leq a \leq 1\}$, where each $a \in A$ denotes a particular analysis mechanism.

To quantify the analysis we use a technique known as Valuated State Space [9]. In this technique, a decision maker (e.g., an expert in programming) determines a level of influence for each analyzer (e.g., a gradual scale of 0 to 5). Thus, each analyzer might present different degrees of influence in the resulting score.

Definition 2: Let A a set of mechanisms for analysis, there is a level of influence for each analyzer. The levels of influence are defined by $L : A \rightarrow \{l \in \mathbb{N} : 0 \leq l \leq n\}$, where each $l \in L$ denotes the level of a particular analyzer and the constant n denotes the maximum value of the scale.

The set of levels represents a more intuitive weighting scheme; however, it is necessary to relativize these values, to define a

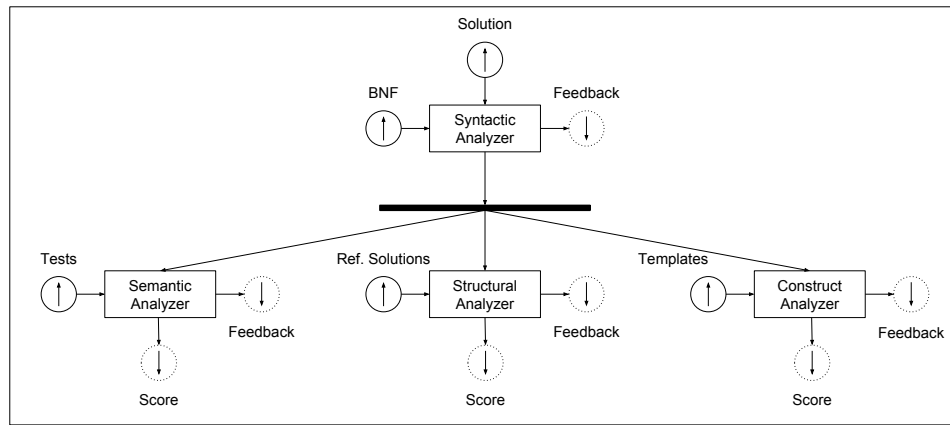


Fig. 1. Conceptual Architecture: the structural analyzer utilizes similarity metrics to compare a proposed solution with a set of reference solutions; the constructs analyzer uses graph theory techniques to determine whether a given solution satisfies a particular combination of constructs of the language; each analysis generates a score and a feedback that can be used by students and lecturers.

resulting score in the range between 0 and 1. Therefore, we define a set of weights to measure this resulting score.

Definition 3: Let L the set of levels, there is a weight for each of its elements. The weights are defined by $W : L \rightarrow \{w \in \mathbb{R} : w = l/\text{sum}(L)\}$, where each $w \in W$ denotes the weight of an analysis mechanism and sum denotes the summation of the elements in L .

To obtain the resulting score, we compute the product of the powers. From this combination we obtain the resulting score, where each of the analyzers present its “contribution” to the final score.

Definition 4: Let P and S , respectively, a problem and a solution, a function $\text{score} : P \times S \rightarrow \{s \in \mathbb{R} : s = \prod a(P, S)^w\}$ aims to assign a score that results of the combination of each mechanism of analysis $a \in A$ and its respective weight $w \in W$.

In short, this mechanism has the function of analyzing a particular solution from different perspectives, providing a more comprehensive view and extracting a score based on criteria defined by a human expert.

B. Computational Model

To build the computational model we used an architectural style based on Pipes and Filters. This architectural style defines a set of elements (filters), and a processing flow (pipes), allowing different configurations of the elements. As illustrated in Figure 1, the analysis mechanism defines the parser as the initial element of the process and, from this, branches the

process through the other analyzers.

To model the structure of analyzers we use the Decorator Pattern, which aims to attach additional responsibilities to an object (see Figure 2). This pattern defines an abstract entity to represent the common features between the various types of analyzers.

To build the Syntactic Analyzer we combine two design patterns: Builder Pattern, which aims to abstract the parsing mechanism and consequently the construction of the Abstract Syntax Tree; Composite Pattern, which aims to compose objects into structures to represent an Abstract Syntax Tree. The combination of these two patterns defines an extension point to abstract the programming language used in the solution.

To build the Filter Analyzer we use the Template Method Pattern, which aims to define the skeleton of an algorithm allowing its subclasses redefine certain steps without changing its structure. In this sense, it defines an extension point that delegates the responsibility of verify the conformity between the solution and the restrictions of the problem.

Finally, we use other Patterns to provide some desired features. The Strategy Pattern encapsulates traversal tree algorithms, which are used in structural analyzers, and constructs analyzers. The Factory Pattern defines a central point for the creation of traversal algorithms. The Collecting Parameter stores the information obtained from the execution of the analyzers in order to provide feedback to the user.

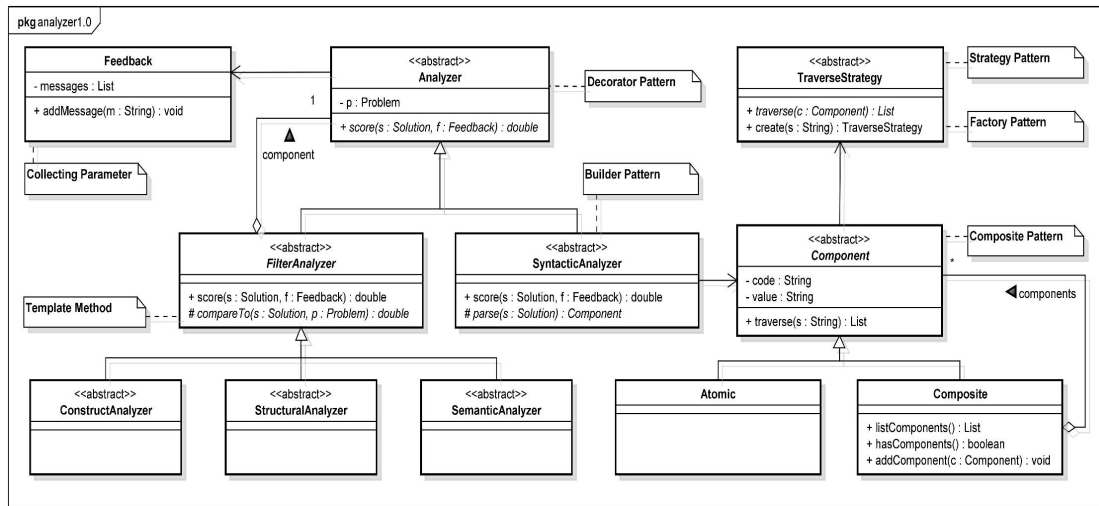


Fig. 2. Logic Architecture: the abstract Analyzer represents the common features between the various types of analyzers; the Syntactic Analyzer defines a specific analyzer, which will be the basis of all the analysis process; the Filter Analyzer defines an extension point for creating filters, which might be attached to the Syntactic Analyzer

IV. EVALUATION

To evaluate the framework we made an initial study with codes submitted by students from 2010 and 2013 classes of Introductory Programming from the Information System course at Federal University of Alagoas, Brazil. Methodologically, we define this study based on the following sections.

A. Planning and Execution

We analyze 232 codes submitted in one homework of the course. In this homework, the students must be able to create a program to calculate the value of an account based on price and quantity of each item consumed. We define each solution as an experimental unit of the study and define the following variables:

I : Submission	(ordinal with $1 \leq x \leq 232$)
D_1 : Syntactic Score	(continuous with $0 \leq x \leq 1$)
D_2 : Correctness Score	(continuous with $0 \leq x \leq 1$)
D_3 : Constructs Score	(continuous with $0 \leq x \leq 1$)
D_4 : Structural Score	(continuous with $0 \leq x \leq 1$)

For the execution of the study we use an instance of the framework that contains the following combination of analyzers: Syntactic Analyzer based on Python 3.x, standard language used in the discipline; Structural Analyzer based on the similarity metric known as Levenshtein Edit Distance

of [14], to analyze the similarity with the reference solution provided by the lecturer; and Constructs Analyzer based on the technique known as Tree Inclusion [13], to analyze compliance with a predefined control structures.

In this study, we do not use the correctness analyzer, considering that the lecturer did not define a standard format for input or output data. Therefore, we perform a manual inspection to establish that score. In addition, we define the constructs analyzer with only one template based on the constructs of the reference solution (i.e., a set of assignments followed by an expression to calculate the total bill). As we are analyzing the programs, we will introduce other templates if necessary.

V. RESULT AND DISCUSSION

The results of the study are summarized in Figure 3, Figure 4, Table I and Table II. Considering these results, we start a discussion in order to highlight the following aspects:

Syntactic Analysis: the results show a low number of students ($7 \leq x \leq 15$) who cannot overcome the syntactic barrier. A manual inspection revealed several types of syntactical problems: solutions described in the algorithmic language; solutions containing the records of the interactive mode of Python; solutions described in older versions of language Python; other more basic syntactic errors, for example, errors in the use of variable identifiers.

Correctness Analysis: the results show a low number of students ($9 \leq x \leq 14$) that cannot overcome the barrier of

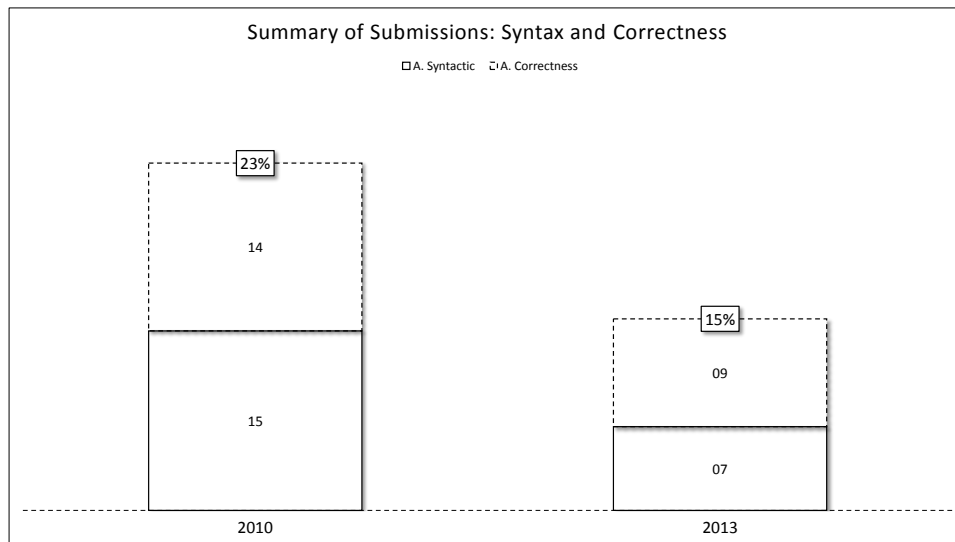


Fig. 3. Analysis of Submissions (Syntactic x Correctness): the lower bars represent the number of solutions that have failed in the parser; the top bars represent the amount of solutions that failed in the correctness analyzer; and the higher rates represent the percentage of solutions which failed in one of the two analyzers.

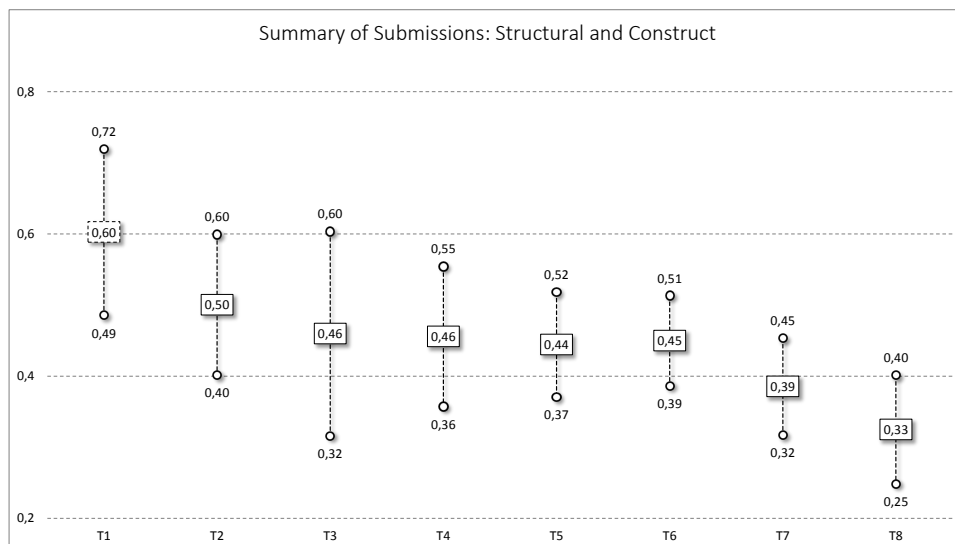


Fig. 4. Analysis of Submissions (Structural x Constructs): the central indices represent the average similarity for submissions of a group; the lower indices represent one standard deviation below the mean; and the lower indices represent one standard deviation above the average.

correctness. A manual inspection revealed several types of errors: misunderstanding of the problem statement; misunderstanding in the use of variables; misunderstanding in the use of expressions.

Constructs Analysis: the results show about eight different types of solutions. The solutions can be summarized from the most concise (Group 1) to the less concise (Group 8). The most concise solutions have only the necessary operations for data entry and only one arithmetic expression to perform the calculation. The solutions least concise solutions have more

input operations than the necessary, more variables than the necessary, and that expression is break in up to four other expressions.

Structural Analysis: the results show an average rate of compliance with the reference solution ($0.3 \leq x \leq 0.6$). These results corroborate the formation of groups of students and show that the solutions of first group are more similar to the expected solution. However, the eighth group present the least similar to the reference solution and have a set of unnecessary structures.

TABLE I. ANALYSIS OF SUBMISSIONS: GROUPS OF SUBMISSIONS

Template	Constructs
01	id = input()
	id = input()
	id = input()
	id * number + id * number + id * number
02	id = number
	id = number
	id = number
	id = input()
	id = input()
	id = input()
	id * id + id * id + id * id
03	id = input()
	id = input()
	id = input()
	id = input()
	id = input()
	id = input()
	id * id + id * id + id * id
04	id = input()
	id = input()
	id = input()
	id = number * id
	id = number * id
	id = number * id
05	id + id + id
	id = input()
	id = id * number
	id = input()
	id = id * number
	id = input()
	id = id * number
	id + id + id

In summary, our study provided evidence that is possible to identify various types of unexpected behavior in the solutions, for example, use of old versions of language, use of non-expected structures, use of redundant constructions, among others. Conventional analyzers might not notice such features, given that they generally perform only syntactic and functional correctness verifications. In addition, our framework allows the configuration of different types of analyzers (e.g., plagiarism analyzer, cyclomatic complexity analyzer, readability analyzer) and new versions of existing analyzers (e.g., new similarity metrics for comparison).

VI. CONCLUSION

We presented the design of a framework for building analysis mechanisms for introductory programming solutions. In this framework, we define a conceptual model based on the Valuated State Space technique, and a computational model based

TABLE II. ANALYSIS OF SUBMISSIONS: GROUPS OF SUBMISSIONS

Template	Constructs
06	id = number
	id = number
	id = number
	id = input()
	id = input()
	id = input()
	id = id * id
	id = id * id
	id = id * id
	id + id + id
07	id = number
	id = number
	id = number
	id = input()
	id = id * id
	id = input()
	id = id * id
	id = input()
	id = id * id
08	id + id + id
	id = number
	id = input()
	id = id * id
	id = number
	id = input()
	id = id * id
	id = number
	id = input()

on Software Design Patterns.

About the results is important to emphasize the identification of different groups of students, among which can be highlighted: students with problems the syntactic and correctness level; students with problems using control structures; and students with problems in building solutions that maintain a minimum level of compliance with the expectations of the subject lecturer.

Finally, we expect present a contribution to the introductory programming area. In this sense, we planning to developed new types of analyzers and perform further studies in order to ensure greater coverage of the approach.

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Analyzing the Impact of Asynchronous Multimedia Feedback on Novice Computer Programmers

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Abstract— For many engineering students, freshman programming represents one of the hardest courses for them to master. Unlike other science fields, few students are routinely exposed to programming in the K12 system. This can make the freshman programming course daunting. However, in the field of software engineering, success in this area is vital, as success in nearly all future courses requires mastery of this skillset.

In the engineering field, we find that many students are visual learners. These students learn best by seeing, and they can perform very well in the classroom with the appropriate usage of teaching styles. However, when it comes to providing feedback to students on submitted assignments, the main method employed is the written comment, which is not conducive to visual learners. From a faculty member's standpoint, this makes sense, as it is the simplest form of feedback. However, written feedback is often ineffective at improving student performance, as many students simply do not read the comments because the students feel they are not relevant to their performance. This can be compounded in the freshman year, as students are still learning what is meant to be an effective college student.

At higher levels, an alternative feedback mechanism, namely asynchronous multimedia feedback, has shown great promise. In lieu of written feedback, students are provided feedback for software engineering exercises through the use of a short video made via video capture. The video captures in multimedia format the instructor's perceptions and actions when grading a given assignment. The video shows, in real time, what the instructor saw, whether it is a program crashing or the successful operation of the program. Furthermore, it provides the instructor the ability to potentially fix simple blatant errors and see the instructor's debugging strategy. The article describes the pedagogical foundation for the technique, specifics of the technique used, student perceptions of the technique, and an assessment of the learning gains from using such a method in an introductory freshman programming course. In general, students are shown to prefer the technique versus traditional grading, and a statistically significant improvement in overall outcomes for the experimental course is shown to exist. A statistically significant correlation between the watching of videos and outcomes is also shown.

Keywords—asynchronous feedback; video feedback; assessment; grading

I. INTRODUCTION

Students receive many forms of feedback throughout their college experience. Feedback has been shown to be the single

most powerful influence on student success [1]. Hounsell states:

"It has long been recognized, by researchers and practitioners alike, that feedback plays a decisive role in learning and development, within and beyond formal educational settings. We learn faster, and much more effectively, when we have a clear sense of how well we are doing and what we might need to do in order to improve." [2]

With appropriate feedback, students are able to master the material. Without appropriate feedback, mastery can be a daunting task. Appropriate feedback must meet many different criteria. First and foremost, it must be applicable to the student [3]. It must be delivered in a timely fashion: taking too long to provide the feedback to students means they have forgotten the purpose for the assignment or have lost interest in the assignment because they have moved on to other things. Feedback must be appropriately engaging to the student as well, for if the feedback is not engaging, then the student may not read the feedback, defeating its purpose. Lastly, the feedback must be relevant to the assignment and the needs of the student [4].

The traditional form of feedback provided to most students is the written comment [5]. Traditionally, faculty marked up hard copy reports, commenting on coding style, algorithms, and other issues. This was then returned to the student at the next meeting. While newer techniques can be employed, for example, marked up pdf files or typed comments in code submissions that are returned electronically, the main feedback is still in the written format. This approach, the traditional written comment, generally is ineffective, as it is a static monologue between the instructor and the student [6]. Research has shown that feedback can be more effective when conveyed in a variety of modes [6].

In past studies, it has been shown that for many problems, other types of feedback can be more effective. In some areas, verbal feedback has become common. Traditionally, verbal feedback has been employed more in a mentorship role. However, modern technology allows it to be used in the more traditional classroom environment. Reference [8] provides details of a program in bioscience whereby feedback was given to students' as mp3 files. Students felt the feedback was of better quality, easier to understand, had more depth, and much more personal than traditional feedback. There also was a greater emphasis on developmental aspects of learning with this method. Reference [9] shows that students overall favor

audio feedback, especially those in the undergraduate population and those with learning disabilities.

In the computing field, the next natural advancement beyond verbal feedback is multimedia feedback. With multimedia feedback, feedback is provided to students through a short video recording the events which transpired during a grading session. In the case of computer programs, this may be program crashes which the students didn't expect, test cases which resulted in unexpected behavior or code that may or may not compile as submitted. The video provides irrefutable evidence to the student of these scenarios, which again leads to more effective feedback [6].

II. PREVIOUS WORK

Previous work on asynchronous multimedia feedback has looked student impressions of the technique as well as provided high level analysis of its effectiveness. Reference [10] provided details on a pilot study of a tool, ASSET, which allowed staff to create video feedback to students, and showed

that the technique was advantageous to both students and staff, as it addressed many of the common problems of feedback. References [11] and [12] again provided a qualitative assessment on the impact on students of video feedback, indicating that students felt that the technique was highly individualized, supportive, and motivating, as well as clearer and more detailed than traditional methods. Reference [13] first looked at the overall process and examined student's thoughts on the process, and showed similar results to [10]. Overall, students were found to like the process, and based upon self-reported data, did watch the videos. References [14], [15], and [16] expanded upon this by with further analysis through short Likert surveys of student sentiment toward the process and also expended the analysis across multiple courses at different institutions. Reference [17] compared lab performance across different years based on whether or not multimedia feedback was employed as a grading technology, and demonstrated that there were gains in lab scores in the year which employed asynchronous multimedia feedback. It also further confirmed that students preferred asynchronous multimedia feedback.

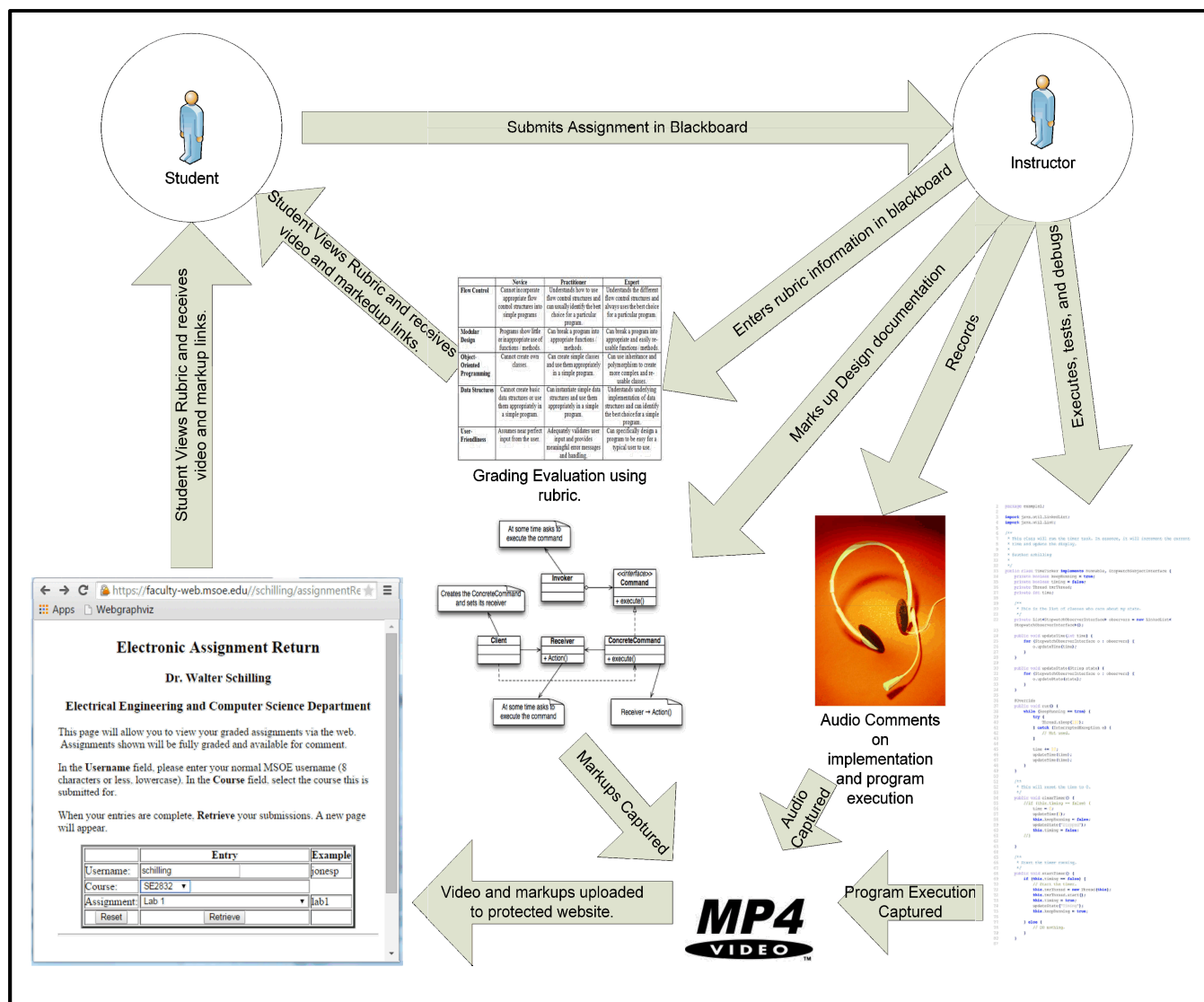


Figure 1: Asynchronous Multimedia Feedback Process

III. AN OVERVIEW OF ASYNCHRONOUS MULTIMEDIA FEEDBACK

Multimedia grading uses many of the same production techniques as the flipped classroom, in that the instructor creates a video during the grading session, excepting that the video is customized to each student or student team based on submitted work, and the focus of the video is to provide targeted meaningful feedback to the student rather than to introduce a new concept. This is, in some manner, more difficult than the traditional usage of videos, as the traditional usage of videos requires the instructor to carefully design the video to maximize all students' learning whereas this approach generates a customized video for each student or team.

The process, shown in Figure 1, begins with a traditional assignment. In this particular case, students uploaded Java implementation code and a lab report to the Blackboard course management system. The instructor then downloads these files and grades them. In grading, the programs were actually compiled and executed on the instructor's machine. While this was occurring, the instructor's screen was captured using a screen capture program (Microsoft Expression in this example). The screen capture program also captured audio narrative of the grading session. This video would capture any program crashes, execution failures, or other problems with program execution in real time. Additionally, the instructor was able to provide a verbal critique of the source code, commenting on code commenting styles, structural issues, and other problems. In certain cases, it was also possible for the instructor to fix simple mistakes in implementation, demonstrating to the student how their submission could be improved with simple corrections.

At the end of the grading session, a grading rubric was filled out which calculated a numeric score for the submission. The videos were post-processed offline and uploaded, along with marked up pdf files of lab reports, to a secure website. When students logged into the course management system, they were provided with both the numeric score for the assignment as well as a link to the files in the secure website.

While this approach may seem to overwhelm the instructor, the overall impact on grading versus traditional approaches was not found to be significant. Reference [14] indicates that there was less than a 5% difference in grading time when compared with traditional approaches.

IV. EXPERIMENTAL OVERVIEW

Previous work has left many questions unanswered. While [6] did show improvements in lab outcomes, data was not available to normalize the cohorts, potentially introducing bias into the results. The other papers mainly focused on student sentiment and included self-reported results of students watching videos. The other papers also focused on upper classmen, and while meaningful, research has shown that retention is highly correlated with the freshman experience. Thus, it would be very useful to have information related to freshman performance, as if the technique increases engagement it is also likely to aid in improved retention.

The goal of this experiment was to attempt to judge the impact of asynchronous multimedia feedback on freshman programming students. The goal was to numerically measure differences in achievement between students who were taught in a "traditional manner" as well as students who received asynchronous multimedia feedback. Additionally, a goal was to directly measure whether the students watched the videos and correlate the performance in class with watching the videos. A final goal was to reaffirm student sentiment that this approach is a worthwhile approach. While the last objective is duplicative of the previous work, the fact that the previous work has focused on upper classman makes the sentiment of freshmen particularly important to understand.

To do this, a cohort of students in the second freshman programming course was studied. This cohort excluded students who had not taken the first programming course in the previous quarter, students who were retaking the second programming course due to poor performance in previous offerings, and students who had received either advanced placement or transfer credit for the first programming course. By defining the cohort in this manner, it was possible to eliminate as many variables related to previous preparation as was possible, as all of the students received the same training going into the second course.

At MSOE, all students enrolled in the freshman programming courses take a common final exam at the end of the quarter. The final, drafted by all instructors teaching the course, is carefully designed to match the daily course outcomes and coverage for the given quarter. Grading is also distributed amongst faculty teaching the course, in that no single faculty member grades an entire student's exam. Rather, faculty members are responsible for grading one or more problems on the exam, and the final exam score is obtained by summing the subscores of individual problems from the faculty members grading those problems. This mechanism, initially intended to improve grading efficiency, also avoids instructors injecting bias into the scoring of the common final exam.

Given that the cohort of students being studied had taken the common final exam the previous quarter, it was possible to use this exam as a normalizing factor for the control and experimental groups. While not perfect as an assessment tool, the exam offers a non-biased mechanism to assess student learning as of the end of the first course, and given the nature of the study, also serves as a pre-requisite assessment for the second course.

To determine whether or not students watched the videos, a secured website was instrumented to provide a log of when students' accessed the feedback videos as well as what items were viewed. This was obtained for all students in the experimental class, and thus allowed student achievement for students to be compared versus the number of videos watched. This data, however, did not include the exact same cohort as the first portion of the experiment. Rather, all students enrolled in the experimental section were compared, not just those who had taken the preceding programming course during the previous quarter. This increase, however, does not introduce bias into the experiment.

Table I: Final Exam Initial Analysis

	All Students			Students in Studied Cohort		
Final Exam Score	Mean Score	Median Score	Standard Deviation	Mean Score	Median Score	Standard Deviation
First Programming Course	78.18%	82.50%	14.90%	82.78%	84.50%	9.38%
Second Programming Course	77.04%	79.00%	12.66%	75.35%	77.00%	12.61%
Delta	-1.14%	-3.5%	2.24%	-7.43%	-7.5%	3.23%

Lastly, to judge student sentiment toward the process, a simple Likert survey was given to all students enrolled in the experimental section. This judged what they felt about the course as well as provided for free-form comments on the technique. From this, student sentiment toward the process was to be assessed.

V. INITIAL PERFORMANCE ANALYSIS

The first aspect to address was to assess the validity of the cohort studied versus all students who had taken the courses. To analyze this, the mean, median, and standard deviations for the exam (shown in Table I) were analyzed. This data showed that there was a small but significant difference between the scores of all students who took the first exam and students who took the first exam and were in the studies cohort. This difference, however, had a logical source. The cohort, by definition, excluded students who did not pass the first programming course, as they were not enrolled in the second course due to a prerequisite issue. Thus, it would be expected that the overall average for all students who took the final would be slightly lower than those in the cohort. On the second exam, there is a small but insignificant difference between the cohort group and all students who took the exam. This small difference is caused by high achieving students who had AP credit and transfer credit who took the second exam but not the first, resulting in a slight bias toward all students versus the experimental cohort.

With the validity of the cohort established, the next aspect to address in the data was the performance of the cohort overall between the first course's final exam and the second course's final exam. In this case, non-normalized scores were used. On the first final exam, the scores were approximately 7.5% higher than on the second final exam. Additionally, there was less

deviation in scores on the first midterm exam.

This difference can be attributed to several factors. First and foremost, by definition, the cohort excluded students who did not pass the first programming course. Thus, the performance on the first exam would be higher because the lowest scores on the first midterm would be excluded from the study cohort. Additionally, some decrease in performance is expected, as the second course is a more difficult course than the first course.

With the cohort group established, the cohort group was broken into two groups, an experimental group and a control group. This division had effectively occurred during registration as students were randomly distributed to the different sections based upon scheduling and registration times. Four sections, deemed the control group, were taught by different faculty members, and a fifth section, the experimental section, was taught by a fifth faculty member. Three of the five instructors had taught the course before, while two of the instructors were new to the course (including the instructor teaching the experimental section.) The courses were taught to the same list of outcomes and used common lab assignments. Faculty members met weekly as a teaching team to discuss course status and impediments to success. Faculty members also shared exam materials for midterms, though exams were not identical outside of the final exam.

The first analysis that was conducted was to determine if there was an initial bias in the scores of the experimental group or the control group on the final exam for the first programming course. The raw data, given in Table 2, was analyzed for the control group and the experimental group. Even though there was a slight difference in the mean score, among the students in the study groups, there was no statistically different performance between the students in the control group ($N=56$, $M=82.10$, $SD=14.64$) and the

Table 2: Final Exam Initial Analysis without normalization

	Raw Control Group Data (n=57)			Raw Experimental Group Data (n=14)		
Final Exam Score	Mean Score	Median Score	Standard Deviation	Mean Score	Median Score	Standard Deviation
First Programming Course	82.10%	83.50%	14.64%	85.50%	86.00%	5.50%
Second Programming Course	73.50	75.00%	12.51%	82.86%	87.00%	9.36%
Delta	-8.60%	-8.50	-2.13%	-2.64%	1.00%	3.86%

experimental group (N=14, M=85.50, SD=5.50), $t(68)=1.21$ $p \geq .05$ CI_{.95}= -2.21 to 9.01. Therefore, we fail to reject the null hypothesis that there is no difference in performance between the experimental and control groups. The control group did exhibit a slightly larger variance in performance versus the experimental group, but it also was a larger group as well.

Being unable to detect any statistical differences between the performance of the control and experimental groups on the final exam from the first course, analysis then moved onto the second exam. This exam, conducted at the end of the second programming course, was also analyzed for performance differences. Among the students in the study groups taking the second exam, there was a statistically different performance between the students in the control group (N=56, M=73.50, SD=12.62) and the experimental group (N=14, M=82.86, SD=9.71), $t(68)=2.52$ $p \geq .05$ CI_{.95}= 1.86 to 16.01. Therefore, we are able to reject the null hypothesis that there is no difference in performance on the second exam between the experimental and control groups.

VI. ANALYSIS OF VIDEO VIEWERSHIP

A second answer that this study desired to answer was whether or not the students actually watched the videos, and what impact this had on their success in the class. References [13] and [14] indicated, through student self-feedback, that a majority of students watched most of the videos. However, this was self-reported data, and the problems with self-reported student data are well known. Subjects tend to report what the researcher would like to see, as well as tend to report positively on their own abilities, knowledge, beliefs, and opinions [17], [18]. Furthermore, since the data regarding video viewership was collected at the end of the quarter, there is a chance that the students did not remember specific details of their viewership. This fallibility of memory is a concern raised by cognitive scientists with self-reported data [18].

To analyze this data, we started by looking at the difference in time between when the assignment was first released to students via the learning management system and when the students first viewed the video feedback. On average, our results found that 65% of the videos were viewed in their entirety an average of 1.35 days after the assignment was graded and returned to the students. This ranged from a high

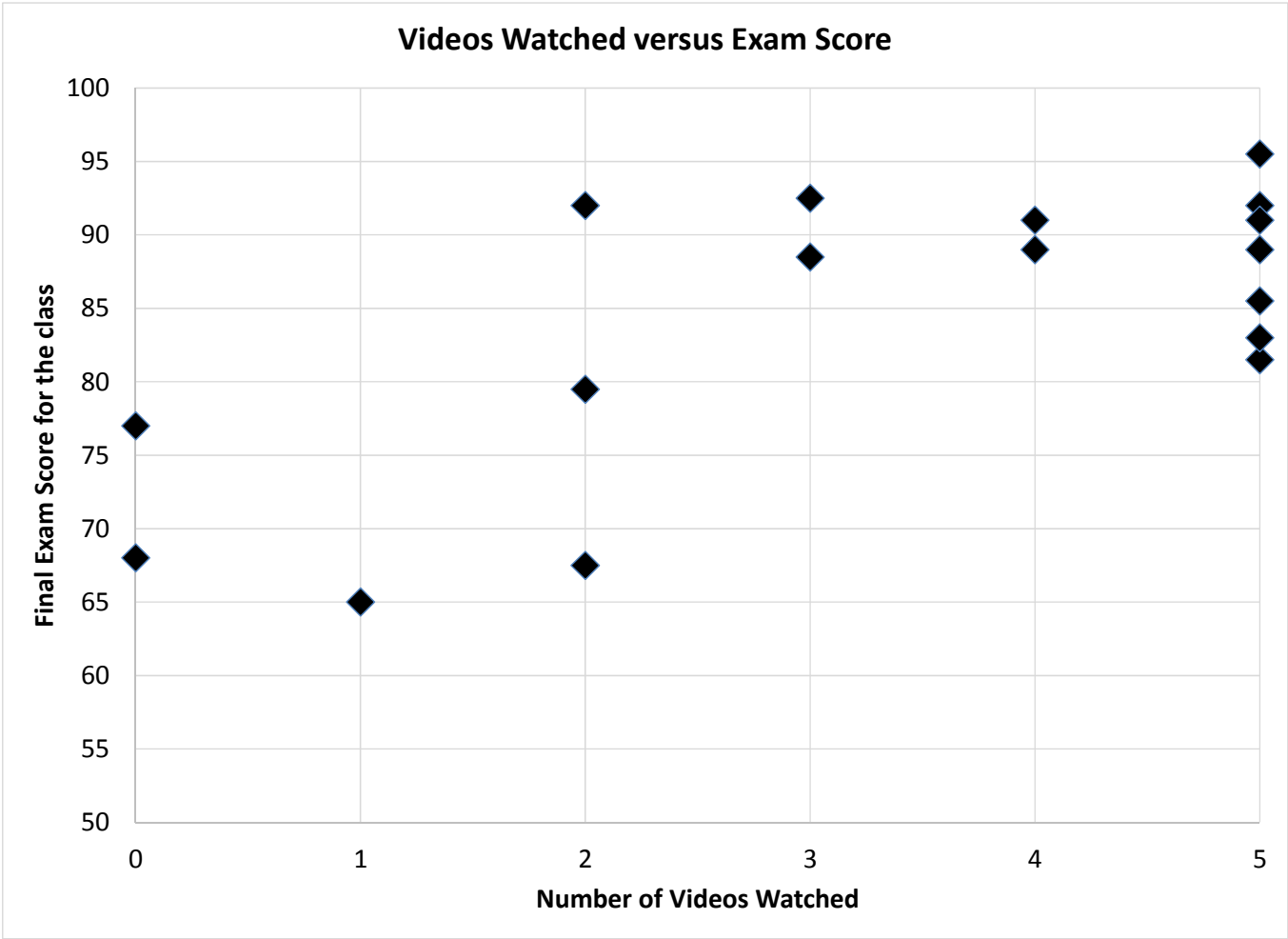


Figure 2: Scatter plot of Videos watched versus exam score

of 76.4% on the first video to a low of 52.9% on the last video. The majority of videos were either watched on the day they were returned or the next day. However, given that most assignments were returned around 18:00, one can safely state that the majority of the videos were watched within 30 hours of being returned. Several students actually watched parts of the video more than once. This second viewing was often found shortly before the next assignment was due, indicating that the students were potentially reviewing feedback before submitting the next assignment.

From this analysis, we believe that we can conclude that the students felt that the feedback was received in a timely fashion. The fact that students believed that feedback was received in a timely fashion was further collaborated by the results of Likert survey, where 90% of students strongly agreed with the statement "The professor provided helpful feedback on student assignments and exams."

This data, in general, appears similar to that which was self-reported by students in the previous works [13] [14].

A second goal of this analysis was to determine if there was a relationship between viewership and performance on the final exam. Figure 2 shows a plot of the number of videos watched versus the performance of students on the common final exam for the course. Due to the small number of videos, the data could not be compared using traditional linear regression approaches. Instead, correlation was analyzed using Spearman's Rank-Order Correlation. The data set was found to have a weak but significant correlation coefficient $\rho(15)=.49$, $P=0.042$.

This relationship, while present, can not necessarily prove causality. From the research, it is not possible to determine if the students did better in the course because they watched the videos or if they watched the videos because they were students who were more concerned about obtaining adequate feedback in the class.

VII. ANALYSIS OF STUDENT SENTIMENT ABOUT ASYNCHRONOUS MULTIMEDIA FEEDBACK

The last analysis attempted to duplicate the results of previous papers in showing that students viewed feedback from the videos in a positive fashion. In [14] and [17], students were asked on a Likert survey if they preferred video feedback to traditional feedback in computer courses. In this paper, for the courses most similar to this course, the majority of students agreed or strongly agreed with this statement. In an Operating Systems Design Course, 92% of students either agreed or strongly agreed with this sentiment. In the Introductory Programming course, 70% of students either agreed or strongly agreed with this sentiment. In the case of the introductory

programming course, even though the technique was only used for one class, it was viewed as successful by students.

For this research, students again were asked to rate their sentiment on a Likert scale whether or not they felt that video grading helped in their understanding of the lab material. The overwhelming response of the students enrolled in the course was positive, as is shown in Table 3. While not asking exactly the same questions as those that were asked on previous surveys, the sentiment expressed by the students is very similar.

Students also expressed strong support for video grading in their comments on the survey. Sample comments received include those shown in Figure 3. As in the previous works, video grading is viewed very positively by students who seem to feel that the feedback is very helpful for them in their academic endeavors.

VIII. CONCLUSIONS AND FUTURE WORK

This paper has analyzed the impact of asynchronous multimedia feedback (video grading) on freshman programming students in the second quarter of programming. Through three different measures, the effectiveness of the technique was investigated.

The first investigation involved establishing if there was a difference in performance between students who were enrolled in a section of programming which used asynchronous multimedia feedback and other sections which did not. Based upon a common final exam from the first programming course, the sections were shown to not have a statistical difference in average scores on the first course's final exam. However, a statistically significant difference was found at the end of the second course. While this does not imply causality with asynchronous multimedia feedback, a correlation is present.

The second investigation involved determining if students watched the videos. Using logs from the secured website, it was found that the majority of students did watch videos in a timely fashion after they were returned. Most videos were watched within less than 30 hours of them being made available to students. More importantly, a weak but statistically significant correlation was found between final exam scores and the number of videos watched by the students. Again, while correlation does not indicate causation, the finding is interesting nevertheless.

The third investigation reaffirmed the findings of previous publications that multimedia feedback is highly valued by students and aids in their understanding of grading. This was shown through both Likert surveys as well as voluntary free form comments from the students.

Table 3: Likert Analysis Video Grading Sentiment expressed by students.

Statement: I felt that video grading helped my understanding of lab assignments and lab grading.				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
83.3%	8.3%	8.3%	0%	0%

- The personal review videos for labs were extremely helpful in seeing what went wrong and what worked when the professor was grading the labs.
- Videos were a great feedback tool for labs
- I like the visual and textual feedback on the labs to know what to improve from lab to lab.
- Video grading is by far one of the best things any professor does, absolutely love it.
- Feedback on labs is excellent. Providing a video is especially helpful.
- The lab grading was amazing
- (Video Grading)Yes, keep doing this. It is awesome.

Figure 3: Sample student comments on Video feedback from student surveys

In terms of future work, there is much that can be done to try and better understand the cognitive aspects of asynchronous multimedia feedback. Certainly the literature indicates that the technique will be successful because it touches on many of the problems of traditional feedback. However, from the work we have done, we do not fully understand why students view the technique so positively. We believe that this technique may show more empathy toward students as well as providing a more dynamic approach. However, this does not explain why it is successful.

We also need to delve further into what makes for successful feedback with this technique. While the video lengths in this work varied, they generally were short, between 4 to 6 minutes each. At some point we know that students will lose interest in the feedback and not watch, but we do not know from our work what really the most effective length is. As it is with the flipped classroom, there may be a significant relation between learning effectiveness and length.

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An Evaluation Method for Panoramic Understanding of Programming by Comparison with Visual Examples

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Abstract—In recent years, professionals in different fields have become able to do programming by using simplified software tools, as a consequence of this they are becoming able to understand programming in a general or “panoramic” way. This understanding is not evaluated by current programming abilities testing methods such as written paper tests or practical programming. This paper proposes a *Programmed Visual Contents Comparison Method* to assess programming ability, and additionally, a testing system based on this method. With this method, by comparing 2 displayed images and interactive animations produced by programming samples (a *question*) a subject must decide which one of the programs is more difficult to build with programming than the other, or, if the difficulty is similar for both of them. The validity of the method is confirmed by comparing the ability reported by programming teachers with the results of an experiment performed with a testing system.

Keywords—Computer science education; Programming Training; Student Assessment; Graphic Design; Software Engineering

I. INTRODUCTION

During the last two decades, software development has changed drastically, more and more people not involved in professional software development have become able to do programming and new resources to make programming easier have been created. For example: several amounts of code samples and tutorials are being uploaded to the web and used through copy-pasting; a large amount of algorithms are constantly being converted into libraries and made widely available, so to find the best-suited function within libraries has become an important task; and several visual software development tools and languages, where the programming code is hidden and it can be applied with “just a click” are being developed.

In addition to those changes on programming development, the background and learning modes of people using programming in their jobs or careers have diversified as well. Software developers are taught to use code samples and libraries to do programming as a complement to the traditional “write code from scratch” perspective, while graphic designers are learning programming through authoring tools and visual-based programming languages; additionally, game designers

are learning the principles of both of the mentioned professions at the same time. As a consequence of these changes, both developers and designers may have changed their way of planning and structuring a programming project and solving programming issues, developing what we think is a *panoramic* way of learning and applying programming.

This paper proposes a Programmed Visual Contents Comparison Method to evaluate programming ability. With this method, from a pair of images produced by programming samples (questions) a student must decide which one of the programs is more difficult to build with programming than the other, or, if the difficulty is similar.

We examined the validity of this method by comparing the ability reported by programming teachers at a technical school with the results of an experiment performed using a web testing system based on the proposed method.

On Section II of this paper, we explain what *Panoramic Understanding of Programming (PUP)* is by taking graphic designers as a particular case. Section III describes the *Programmed Visual Contents Comparison Method*, Section IV introduces and explains the characteristics of the performed experiment, Section V presents the results of our experiment, and, in Section VI we present an analysis of how well this method can evaluate programming ability.

II. BACKGROUND OF THE STUDY

A. Panoramic Understanding of Programming, the Case of Graphic Designers as Programmers

We think is appropriate to explain what *PUP* means by using the specific case of graphic designers since they have started to be more and more involved in programming tasks and have been receiving programming education for the last 10 years approximately, thus acquiring a special, different understanding on programming.

In Graphic Design courses it is becoming usual to include programming classes together with graphic software tools instruction; programming for designers is usually taught by following a basic curriculum summarized from IT courses, but fixing the topics according to the resources available on the

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tools [1], or externally in additional libraries, probably code snippets or extensions.

When a designer deals with a software tool almost always deals with new methods or “tricks” to use a programming language through an interface. Ko et al. consider that, with visualization tools for programming, “*learners [do] not face barriers in understanding data itself, but in trying to act on data (such as how to create or modify it)*” [2].

For example: a popular web authoring tool used by designers to program with HTML (HyperText Markup Language), CSS (Cascade Styling Sheets) and JavaScript among other programming languages is Adobe Dreamweaver [3]; this tool has several snippets and pre-made objects that can be dragged into a visible template of a web page, and supposedly will work at execution time but sometimes they do not. Besides, there are many “tricks” to make appear specific pieces of code or to control diverse processes; these tricks usually require a long sequence of mouse clicks, searching around the tool menus or the interface and dealing with programming code directly.

Considering that a graphic designer is an end-user programmer, or a person who needs to use programming in his projects but is not entirely dedicated to that [4]; by using these tools he will consequently solve programming problems recursively: by trial and error, by pulling in and taking out those code snippets and pre-made objects, by possibly trying out a few lines of code he could have found online; in the end by *sketching* code [4] [5], that he himself has built without having any idea if it is optimal or standard-compliant, not even how many hidden bugs it will have.

Sketching code allows graphic designers to transform the knowledge they acquire on programming, an external matter, into something more related with their visual nature; so they generate a new *panoramic* kind of programming understanding merged with design concepts [1] [4].

A graphic designer expects some of the skills he assumes as fundamental related with the appropriation of objects (for instance: drawing, diagramming, getting to know physical characteristics like: color, form, texture) and scenarios or stages where to explore the relation between objects (things), space, and environmental factors, to be available when programming; but they cannot find any of this in programming code. They lack the understanding of “code” as “objects” because they do not have anything holding up their perception.

Ozenc et al. refer to this as the *immateriality of software* [5]; so through sketching a designer tries to bring materiality to code; regarding this aspect, Ozenc et al. mention that:

“Most designers explore materials in a studio or workshop where they (...) play with a material to develop tacit knowledge (...). However, designers cannot easily play with the material of software making the development of tacit knowledge much more difficult.” [5].

B. A Contrast with Programmers’ Programming Understanding

Programmers on the other hand only get to know and become aware of software graphic elements when they deal with subjects like: User Interface Programming, Web development, or Multimedia (Sound or Video). But unlike designers, they do not do programming by *seeing* but by *reading*; they manage languages so they need to be aware of syntax, coherence and particularly, errors; they focus on code patterns and coding style to “catch the bug”.

Regarding this aspect LaToza and Myers state that:

“In coding activities, developers select among various strategies to answer the questions necessary to complete their tasks (...). When exploring code, developers seek information, make decisions about which structural relationship to traverse to find information.” [6].

Programmers then, make relationships between structures instead of objects, they cannot perceive things like color, or shape but they decipher code and, to do that, they apply *strategies* instead of *sketching*, and their Affordance is on the identification of patterns inside the code. From knowing how an application is supposed to behave (pattern) they can rebuild or modify a program, this only through constant testing of the previous and own (new) code; in this respect LaToza and Myers state that:

“As developers gain expertise in programming, they also gain knowledge about typical code idioms and patterns (...). When developers know how an application is supposed to behave, they can use this knowledge to answer some questions about the code.” [6]

III. PROGRAMMED VISUAL CONTENTS COMPARISON METHOD

A. Basic Concept

This method is based on the comparison of 2 displayed images and interactive animations produced by programming samples that, for our purposes we call a *question*; if a question is showed to the student taking the test, he is requested to decide which one of the samples is more difficult to build with programming than the other, or, if the difficulty is similar for both of them.

The correct answer for a question is defined by a main programming structure we called *programming concept*; basically, the student needs to identify this concept in order to provide an answer, and the most difficult sample of each question is built based on this programming concept.

Considering this approach, we warn the student to answer each question looking at them from a programming point of view, in other words, to think about each question using any experience and knowledge he could have on programming, as little as it could be, regardless of the tools or programming languages he could know. The following question examples will allow us to explain more in detail this aspect:

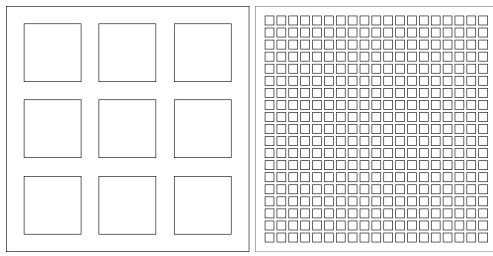


Fig. 1. Question based on the *Nested Iteration* concept

The concept for the question displayed on Fig. 1 is *Nested Iteration*, and the correct answer for this question would be *the difficulty is similar* since both samples were built by using a nested loop changing only the number of squares to be drawn.

We would expect programming experts and programmers with ability in simplified programming languages based on libraries and graphic objects only (e.g. Processing) to answer that *the difficulty is similar*, since *Nested Iteration* is applied in similar ways regardless of the programming language.

Students with an ability limited to graphic tools will surely select one of both samples since they don't necessarily use or know about *Nested Iteration* therefore are most likely unable to identify the concept.

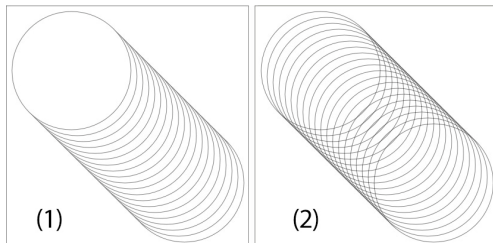


Fig. 2. Question based on the *Hidden Line Removal* concept

The concept for the question shown on Fig. 2 is *Hidden Line Removal* and its correct answer is the sample on the left marked with (1); those students answering correctly would surely know what *Hidden Line Removal* is and how it is applied on the programming sample.

Programmers whose ability is based on simplified programming languages only would answer *the difficulty is similar* since the same image can be obtained easily with languages like Processing by using a single function changing some of its parameters, but, they would probably misunderstand the difficulty of each sample because they certainly wouldn't know what is the content of the function applied, or what kind of algorithm is used to perform the *Hidden Line Removal*.

In the same way, people having an ability limited to graphic software tools, would probably answer based on what is shown on the pictures and could assume that both samples can be performed with the same tool on a specific software.

B. Sample Selection

Several programming concepts were selected from programming books oriented to designers and developers; having as main criteria: its level (beginners to experts), if it is

representative of programming in general and/or if along those books the concept is studied by graphic and game designers, as well as by developers and programmers [7] [8] [9] [10] [11]. The chosen concepts were, respectively: Bezier Line, Nested Iteration, Coordinates Storage and Recalling, Erasing and re-drawing, Boundary detection, Easing, Timer, Area delimitation, New position according to previous position, Change through time, Animation using trigonometry, Picture Pixel Management, Recursion, Lists, Empty Area Recognition and Hidden Line Removal. In total 16 questions were prepared.

C. Questions' Degree of Difficulty

We designed the whole set of questions to have two kinds of difficulty for each one: first, the difficulty of associating images with programs; to surpass this difficulty, we consider that the subject answering the questions probably needs to:

- Understand what is each sample doing (how is it moving? what's happening?).
- Identify what elements each program is using to do what it is doing (if there is a movement on the sample, how is it structured on the program?).
- Understand how the objects the program is using are working together to give that (visual) result (for example how a circle is connected with the movement it is doing).

Second, the difficulty of associating the programs with the programming concept; to surpass this difficulty we think the subject probably needs to:

- Think about, and/or recall from his own knowledge and/or experience:
 - What kind of programming structure or concept can be used to achieve this movement or effect?
 - What is the main effect of each of those structures? (The subject probably asks himself: if we apply that structure to something, what is the result? And, is that result coherent with some of what is currently happening on the pictures?).
 - How many programming structures or concepts he can apply into the objects appearing on the screen, and how many ways of application does they have (alternative uses).
- Identify which is the main concept for each sample (what is the more relevant programming concept?).
- Compare both main concepts, for both samples.

Following this line of thought, we classified the set of 16 questions into three types: first, questions having a difficult image-program association, needing more knowledge on images and/or graphic software tools management (Type A); second, questions having an easily identifiable image-program association but needing a deeper knowledge on programming to perform the comparison between programs and the connection with the concept (Type B); and third, questions with both characteristics, where both kinds of knowledge will be needed (Type C).

D. Programmed Visual Contents Comparison Testing System

Based on the proposed method we built a web testing system where the set of 16 questions was displayed. This system was made by using current web standards; Questions' contents were developed using *Processing.js* and, the interface and database were developed using current programming languages such as: *JavaScript*, *MySQL* and *PHP*.

The answering method was built to be straightforward, having a unique question: "If you were to make any of the previously displayed samples using a programming language, which one do you think is the most difficult?" and four answer options: "sample 1", "sample 2", "Both have the same difficulty" and "I don't know". During the test the student must choose only one answer, then click on a "submit" button to store it on a database and pass to the next question. Fig. 3 shows an example of how a question is seen on screen.

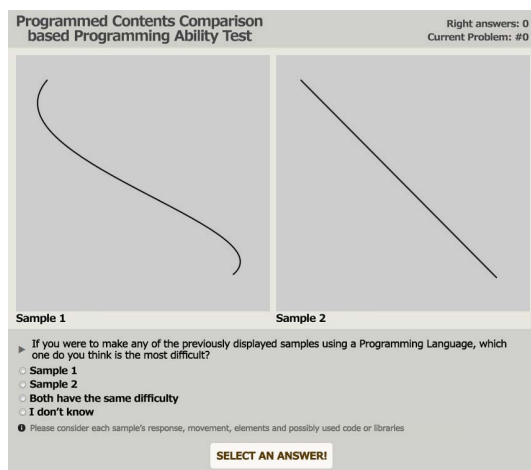


Fig. 3. Example of a question on the Web Testing System

The test is thought to be carried on sequentially (one question after another) and in one try, the time needed to answer one question is considered to be 30 sec. to 1 min. Table I shows the displaying order of the test questions, and the programming concept of each numbered question.

TABLE I. DISPLAYING ORDER OF TEST QUESTIONS INCLUDING THEIR PROGRAMMING CONCEPT AND TYPE

Question Number	Type	Programming Concept
#1	A	Bezier Line
#2	B	Nested Iteration
#3	A	Coordinates Storage and Recalling
#4	A	Erasing and re-drawing
#5	C	Boundary detection
#6	C	Easing
#7	B	Timer
#8	C	Area delimitation
#9	B	New position according to previous position
#10	C	Change through time
#11	C	Animation using trigonometry
#12	A	Picture Pixel Management
#13	C	Recursion
#14	B	Lists
#15	B	Empty Area Recognition
#16	B	Hidden Line Removal

In addition, at the end of the test, a report with user's answers per question compared with their respective correct answers is displayed; and following this, the test subject has the opportunity to answer a brief questionnaire about the whole test experience.

IV. EXPERIMENT

We wanted to know if the programming ability of students of different fields and level could be evaluated with this method; for this purpose we performed an experiment with 4 groups of students whose ability in programming was already known. This experiment mainly consisted of: doing the test using the Testing System and answering the final questionnaire.

The programming ability of these student groups was reported by their programming teachers who we gathered together to share their results and to make them know in detail what the experiment consists of and how their report was to be utilized.

The ability reported by these programming teachers (from now: *the report*) was compared with the results of our experiment; in this sense three kinds of results are the outcome of this comparison: *Questions matching our assumption*, *Questions mismatching our assumption but having a significant difference*, and *Questions mismatching our assumption and having a small or no significant difference*.

A. Student Groups Characteristics

According to the report, the students groups differentiated each other by their field of study and curriculum related with programming and/or graphic software tools in the following way:

The first group: Graphic Design (GD) has a curriculum that includes classes where Graphic Software Tools for Photo Edition, Illustration, Desktop Publishing and 3D Modeling are taught together with Web Coding and Web Design. This group studies only programming languages oriented to Web (HTML, CSS, JavaScript).

The second group: Game Software (GS) studies several programming languages such as: C (and its derivatives: C++ and C#) and Java besides of Game Design related subjects such as: Graphic Design Principles, Character Design, 3D Modeling and Animation. Additionally, their curriculum includes subjects on Application Programming Interfaces such as DirectX and OpenGL, Web related languages, Algorithm Theory and Mathematics. Graphic Software Tools are used mostly on Game Design classes.

The third group: IT and Software (IT) has a curriculum including subjects on programming languages such as: C, Java and Assembler, that are studied together with Algorithm Theory and Web back-end programming and networking. It does not include classes about graphic software tools or visual/graphic related programming languages.

This report indicated also a subdivision in levels of knowledge for IT. The group was divided into two sub-groups: IT-1 and IT-2. It also pointed out that IT-2 had more

knowledge on programming than IT-1, since they have received preparation for IT tests such as the JITEE (Japan Information Technology Engineers Examination).

B. Assumption Based on the Reported Programming Ability

Based on the report, and using the questions types we specified previously for the method on section V, our assumption on the results for our experiment is summarized in Table II.

TABLE II. ASSUMPTION ON ANSWERS TO THE TEST QUESTIONS PER GROUP PER TYPE ACCORDING TO THE PROGRAMMING ABILITY REPORTED

	Type A	Type B	Type C
GD	●	×	×
GS	●	●	●
IT-1 and IT-2	×	●	×

Conventions

●	Group with high score
×	Group with low score

According to the report, Type A questions are to be best answered by GD and GS, due probably to GD's knowledge on Images Management and/or Graphic Software tools; IT's knowledge on this area is little to none.

Type B questions are to be best answered by IT and GS, due to their deeper foundations on programming; they are capable of managing programming concepts from their base while GD manage those concepts only through Graphic Tools, possibly without having a conceptual base of what kind of programming structure is.

Finally, Type C questions are to be best answered by GS, because this is the only group who learn both Programming and Graphic Tools at the same time.

For IT-1 and IT-2, even when both are supposed to answer better the same type of questions (Type B), the report mentions that IT-2 has a higher knowledge in programming than IT-1 so we expected IT-2 to have a better correct answers average than IT-1.

V. RESULTS AND COMPARISON TO FIND SIGNIFICANT QUESTIONS

Here we describe how significant questions were found by comparing the difference on correct answers' percentage between groups. The amount of answers per option per question were compared with the correct answer for each question to obtain the amount of correct answers per group for each question and for the whole test per student. Being unequal groups, we had to establish the percentage of correct answers per question for each one of the groups, Table III shows the percentage of the total of correct answers and average for each question per group, highlighting questions with high and low scores.

TABLE III. PERCENTAGE OF CORRECT ANSWERS PER QUESTION HIGHLIGHTING THOSE WITH HIGH AND LOW SCORES PER GROUP

	Type A				Type B						Type C						Avg
	#1	#3	#4	#12	#2	#7	#9	#14	#15	#16	#5	#6	#8	#10	#11	#13	
GD	88	72	44	66	31	44	72	63	41	25	88	81	34	19	16	53	52
GS	90	64	31	69	74	54	67	72	44	51	62	85	41	5	26	84	57
IT - 1	63	56	37	39	66	41	66	49	27	41	71	80	37	20	20	63	48
IT - 2	76	56	56	36	80	28	72	68	60	40	64	80	48	20	24	84	56

Conventions

High Score

Low Score

By using the correct answers percentages, we could establish difference per questions between the four groups by comparing: GD with IT-1 and IT-2; GD with GS, GS with IT-1 and IT-2 and the two IT subgroups.

Having the differences on the correct answers for each group we could see which questions had a significant difference; considering these as representative we performed an F-test of equality of variances and a two tailed T-test to confirm the validity of the difference for each representative question.

Table IV shows the difference on correct answers' percentage between the groups highlighting the questions having a significant difference for, at least one of the performed comparisons, those are our representative questions.

TABLE IV. SIGNIFICANT DIFFERENCE ON PERCENTAGE OF CORRECT ANSWERS VERIFIED THROUGH T-TEST PER GROUP COMPARISON PER QUESTION, HIGHLIGHTING REPRESENTATIVE QUESTIONS

	Type A				Type B						Type C					
	#1	#3	#4	#12	#2	#7	#9	#14	#15	#16	#5	#6	#8	#10	#11	#13
Difference GD vs IT-1	⊙	×	×	⊙	⊙	×	×	×	×	⊙	⊙	×	×	×	×	×
Difference GS vs IT-1	⊙	×	×	⊙	×	×	×	⊙	×	×	×	×	×	⊙	×	⊙
Difference GD vs GS	×	×	×	×	⊙	×	×	×	×	⊙	⊙	×	×	⊙	×	⊙
Difference GD vs IT-2	×	×	×	⊙	⊙	×	×	×	×	×	⊙	×	×	×	×	⊙
Difference GS vs IT-2	×	×	⊙	⊙	×	⊙	×	×	×	×	×	×	×	×	×	×
Difference IT-1 vs IT-2	×	×	×	×	×	×	×	×	⊙	×	×	×	×	×	×	×

Conventions

⊙

Questions with Significant Difference on one comparison

⊙

Questions with Significant Difference on many comparisons

×

Questions without Significant Difference

The result for each representative question belonging to each one of the types previously determined, was compared with our assumption; Table V shows which questions' result matched our assumption and which ones had other outcomes. Each question has its own particularities regarding measurability and optimization that will be discussed in the following section.

TABLE V. REPRESENTATIVE QUESTIONS MATCHING AND MISMATCHING OUR ASSUMPTION

	Type A			Type B					Type C		
	#1	#4	#12	#2	#7	#14	#15	#16	#5	#10	#13
GD	●	●	●	×	●	●	●	×	●	●	×
GS	●	×	●	●	●	●	●	●	×	×	●
IT-1	×	×	×	●	●	×	×	●	●	×	×
IT-2	×	●	×	●	×	●	●	●	×	●	●

●

 Group with high score

×

 Group with low score

Conventions

●

×

 Result mismatching the assumption

VI. ANALYSIS AND DISCUSSION ON THE METHOD'S APPLICABILITY

A. How Well Can This Method Evaluate Programming Ability?

In this section, three types of representative questions (see Table V) will be discussed: those whose results matched our assumption, those not matching our assumption but considered useful to assess programming ability and those having only one significant difference and whose results mismatched our assumption; additionally, we consider necessary to do some remarks about non-representative questions.

1) Representative Questions whose Results Matched our Assumption

As shown on Table V, results for representative questions #1, #2, #12 and #16 matched our assumption, these questions are considered valid to assess programming ability. To this respect we want to quote questions #2 and #16, used as an example in section III-A.

TABLE VI. NESTED ITERATION (#2) QUESTION - ANSWERS FOR EACH GROUP (PERCENTAGE)

	Sample 1	Similar	Sample 2
GD	25	31	44
GS	3	74	23
IT-1	12	66	22
IT-2	12	80	8

Table VI shows the percentage of answers that students from the four groups gave to question #2, which concept is: *Nested Iteration* (see Fig. 2) and belongs to Type B.

As we stated in section III-A the correct answer for this question is *the difficulty is similar*, which was selected by a 31% of GD, a 74% of GS, a 66% of IT-1 and an 80% of IT-2. These students found out that, using *Nested Iteration* both the first and the second sample can be performed with the same difficulty while GD didn't perceived this issue, seemingly, their programming ability doesn't reach this level.

We consider worth mentioning that a 44% of GD a 23% of GS and a 22% of IT-1 selected *sample #2* as the right answer, while a 25% on GD and a 12% on both IT-1 and IT-2 selected *sample #1*. These students probably considered the difficulty of both samples based more on screen presentation issues (scale, distance between objects, visual impression) than on how they were programmed. For instance: some GD students could have thought the second sample was the most difficult because it had more squares than the first one, then involving more steps if performed using a software tool; or, for the first sample's case, some students probably thought that the squares' size or scale needed to be calculated.

TABLE VII. HIDDEN LINE REMOVAL (#16) QUESTION - ANSWERS FOR EACH GROUP (PERCENTAGE)

	Sample 1	Similar	Sample 2
GD	25	22	53
GS	51	15	34
IT-1	41	25	34
IT-2	40	24	36

Table VII shows the percentage of answers that the four groups gave to question #16 which concept is *Hidden Line Removal* (See Fig. 1) and belongs to Type B.

As we said in section III the correct answer for this question is *Sample #1* and a 25% of GD, a 51% of GS, a 41% of IT-1 and a 40% of IT-2 selected this answer. These students found out that the first sample contained the *Hidden Line Removal* concept. The programming ability of GD almost certainly wasn't enough to figure out the difference between the two samples, neither to identify the concept.

We may assume that those students who answered *the difficulty is similar*, namely, a 22% of GD, a 15% of GS, a 22% of IT-1 and a 24% of IT-2, probably have a programming ability limited only to simplified programming languages, therefore not familiar with the *Hidden Line Removal* algorithm; they were able to associate both samples only to the simplified functions used to do these samples on those languages. For example: by using *Processing*, through a *for* loop and the *ellipse* and *fill* functions both samples can be done and modified in their size, color and filling.

2) Representative Questions whose Results mismatch our Assumption but Useful to Evaluate Programming Ability

By looking at Tables IV and V we can see that questions #5, #10 and #13 have more than one significant differences on the comparisons between groups, but they didn't match our assumption.

We discussed and analyzed the results for questions #5 and #13 together with the group of teachers in charge of the four groups to establish to what point they could be useful. Since question #10 was one of the three questions obtaining the lowest score (see Table III) we thought more appropriate to include it in the group of non-representative questions instead.

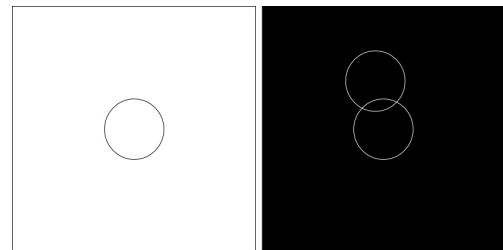


Fig. 4. Appearance of: *Boundary Detection* (#5) question

Question #5, *Boundary Detection* (See Fig. 4) belongs to Type C. For the first sample, if the mouse pointer hovers over the circle, the background turns black; for the second sample, if the moving circle (replacing the mouse pointer) touches the border of the static circle the background turns black.

TABLE VIII. BOUNDARY DETECTION (#5) QUESTION - ANSWERS FOR EACH GROUP (PERCENTAGE)

	Sample 1	Similar	Sample 2
GD	4	8	88
GS	9	29	62
IT-1	12	17	71
IT-2	12	24	64

We initially considered the correct answer for this question to be *Sample 2* and an 88% of GD, a 62% of GS, a 71% of IT-1 and a 64% of IT-2 guessed our assumption, but in fact, the second sample has other ways to be programmed. For example: and the answer would change to become *the difficulty is similar* if the second sample changes to contain a bigger invisible circle placed around the centered one, so when the moving circle intersects it, the background turns black just when the borders of the visible circles apparently touch each other.

This issue makes the question not valid to measure *PUP* related with the *Boundary detection* concept but, looking at the results from students answering *the difficulty is similar*, namely: 8% of GD, 29% of GS, 17% of IT-1 and 24% of IT-2 we can see that a significant percentage of GS and IT-2 students somehow perceived the similarity between the two samples; this aspect led us to think that they probably went deeper to think about the difficulty of the algorithm of both samples to compare them.

Having this into account, even when this sample resulted inappropriate to measure *PUP* related with *Boundary Detection*, we considered it useful to identify student's potential algorithmic skills.

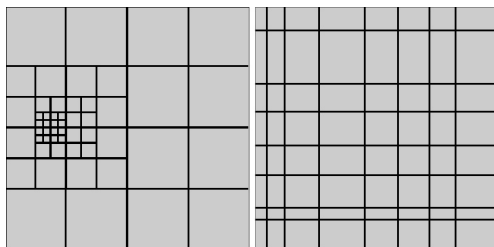


Fig. 5. Appearance of: *Recursion and Repetition* (#13) question

Question #13, *Recursion and Repetition* (see Fig. 5) belongs to Type C, the first sample changes according to a recursive algorithm when the user clicks over; the second sample draws two crossing lines in the position where the click is performed.

TABLE IX. *RECURSION AND REPETITION* (#13) QUESTION - ANSWERS FOR EACH GROUP (PERCENTAGE)

	Sample 1	Similar	Sample 2
GD	53	16	31
GS	84	5	11
IT-1	63	10	27
IT-2	84	6	10

The correct answer for this question was *Sample #1*, GS and IT-2 obtained a comparatively high score of 84% both, while IT-1 obtained a 63% and GD had a 53%.

IT-1 and GD had almost the same percentage of people selecting *sample #2*, and little difference between the percentage of those selecting *the difficulty is similar*; while for GD this kind of results can be supposed, for IT-1 this could be a sign of their ability level difference with IT-2, some students on IT-1 are probably lacking the ability to identify the common pattern of a recursive algorithm or haven't studied it yet.

Furthermore, each time the student clicks a mouse on any of the samples, the picture changes; in other words the number and position of clicks affects the visual impression of each sample, this could have affected his answer too.

3) Questions whose Results Mismatched our Assumption Useless to Evaluate Programming Ability

Questions #4, #7, #14 and #15 had only one significant difference and their results didn't match our assumption; these questions are not useful to evaluate programming ability.

Within this set, questions #7, #14 and #15 were *interactive* (affected by clicks or mouse movement); this interactivity was programmed together with the code containing the concepts to be evaluated, and in some cases it was more difficult that those concepts; additionally, these questions were lacking enough instructions or guidance about how to operate them. The following example will provide details regarding this issue.

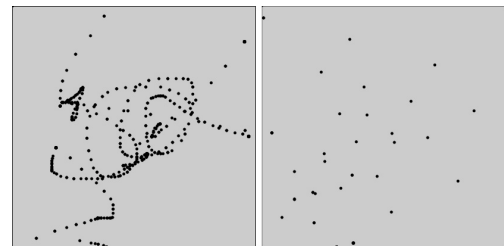


Fig. 6. Appearance of: *Timer* (#7) question

Question #7, *Timer* (See Fig. 6) belongs to Type B, the first sample draws a point on mouse coordinates every frame; the second sample draws a point each 400 milliseconds only when the mouse almost stops or is really slow.

TABLE X. *TIMER* (#7) QUESTION - ANSWERS FOR EACH GROUP (PERCENTAGE)

	Sample 1	Similar	Sample 2
GD	20	36	44
GS	15	31	54
IT-1	39	20	41
IT-2	18	54	28

The correct answer for this question was *Sample #2*, and even when the 44% of GD, the 54% of GS and the 41% of IT-1 guessed this answer, but the difference in the percentage of answers between the groups is minimal. Probably the lack of appropriate instructions and the fact that the response of this sample depends on the slow movement of the mouse, made some students think the answer was different.

An additional issue to have into account with this question is that, even when we implemented the second sample to have a timer (and to be the most difficult), the first one also has a timer: the frame rate, and the mouse makes evident from the moment that it enters the sample's area that this frame rate works as a timer, so that could have been confusing as well.

4) Non-representative Questions

Table IV indicates that questions #3, #6, #8, #9 and #11 didn't have any significant difference on the comparison of correct answers between the four groups, these questions are not valid to evaluate programming ability. Additionally, as it

was mentioned in the previous subsection A-2), question #10 belongs to this group too.

For questions #3, #6, #9 the four groups had high percentages of correct answers (see Table III); we think these questions compared samples containing difficult concepts (see Table I) with samples evidently easier or too basic; in other words, the difficulty level difference of the compared samples for these questions was too obvious; probably, even students without *PUP* could have answered right.

On the other hand, questions #8, #10 and #11 had low percentages of correct answers (see Table III); these questions were ill-made, most likely because they contained additional concepts on the same level or more difficult than those evaluated, or the programming samples were too similar.

B. Questions' Programming Level and Difficulty

One of the main aspects that affected the results for all groups is the definition of *difficulty*. Even when in section III-C: *Questions' degree of difficulty* we defined it, in many cases students couldn't identify what was the main difficulty for each one of questions; this lead us to think that this definition is not complete, however those students having the ability to perceive the difficulty for the valid questions answered correctly. For future tests and questions we need to find a way to make clear each question's *difficulty*.

In the aforementioned section III-C we also established that the level of the programming concepts is the main selection criteria, having as a reference a somewhat wide range going from concepts studied on a programming beginner level to expert level concepts. We originally thought that the correct answer for each one of the questions could be one and only one, but we omitted the possibility of each one of these questions to be answered by people with different knowledge levels, thus having different ideas of programs that can be harder or easier for each one of the samples, this could lead them to think different correct answers. In this sense, our criteria for choosing the right answer is still weak, we need to define what kind of answers per level can emerge for different (future) questions.

In the same way, those questions whose results matched our assumption are a reference of the necessary level to answer a specific question with a specific concept; having this in mind, we can consider to test other concepts, of other levels with other difficulty with the same question, to measure other abilities on a later stage.

CONCLUSION

In this paper we propose and describe a *Programmed Visual Contents Comparison Method*. Through the use of this method in an experiment we were able to evaluate the programming ability of four groups of students from different fields and levels of knowledge.

We could understand as well that the assessed programming ability is related with *PUP*, and the level of the person who answers, the definition of difficulty and how the programming samples are built and paired to form a question define how well this method can evaluate programming ability.

In the same way we were able to find other kinds of programming abilities used by the students to answer the questions of our method; those abilities, even different to the ones we wanted to assess, are also related with a Panoramic Programming Understanding.

This method can be used in the future with other kinds of samples and other kinds of programming concepts to obtain more results regarding abilities related with *PUP*.

Additionally, results from the questionnaire performed at the end of the test showed a positive feedback regarding the test system. The majority of the students from the four groups recognized that this test allowed them to evaluate their own ability on programming, and that this test was more enjoyable than a paper based ability test. This feedback will be used in future stages of this research as criteria to modify questions and the testing system in general.

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Identifying Learning-Inductive Content in Programming Discussion Forums

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Abstract— Online programming discussion forums are popular trouble-shooting and problem-solving sites for programmers and learners to reach out for help. The massive volumes of forum threads harbor tremendous amounts of information, but at the same time increase the complexity of search and navigation. In this work, we make use of programming discussions' syntactic, semantic and social features to model content associated with learning activities based on the ICAP learning framework. Our main goal is to detect *useful* content for learning programming in a large scale of questions and answers, while at the same time experiment with an artificial intelligence approach to detect learning-inductive content. We build regression models based on the defined constructive learning activities. Results reveal a *passive-proactive* learning behavior in an online programming discussion forum. The findings also reconfirm the value of programming discussion content, disregarding the crowds' approval. The automatic detection of constructive learning activities from programming discussions can be a helpful classifier in identifying relevant educational resources. Overall, this project contributes to our understanding on analyzing and utilizing mass programming discussion content for online programming language learning.

Keywords— *learning activity; engagement activity; discourse analysis; programming language learning; constructive learning; discussion forum; programming; semantic modelling; learning assessment.*

I. INTRODUCTION

Online programming discussion forums are popular trouble-shooting and problem-solving sites for programmers and learners to reach out for help. For instance, StackOverflow¹ harbors large amounts of social and gamified Question and Answers (Q&A). This and similar kinds of programming discussion forums provoke the engagement and response rate of knowledge providers, resulting in vast popularity and tremendous amount of valuable information [1]. Just in the span of two years since its foundation in 2008, more than one million questions and 2.5 million answers have been posted [2]. As this amount of information continues to grow, the complexity of navigation has also increased. The scale and types of content are often very diverse in terms of user background, coverage of topics, post volumes, post-response turnaround rates, etc. It becomes a typical "open corpus"

challenge, where content sources are diverse and usually unbounded; therefore, it is challenging to estimate learners' knowledge and further provide personalized support. To tap into this reservoir of knowledge, it is increasingly important to innovate automatic methods to discern the quality and *usefulness* of content to facilitate programming learning in cyberspace.

Learning programming is a challenging task and involves a variety of cognitive skills. Discussion technologies have been successfully applied with Intelligent Tutors and have demonstrated that students can learn from a wide range of dialogue-based instructional settings, such as dialogic-based tutors, asynchronous discussion forums, etc. [3-8]. However, it is not yet clear how people learn programming from such free, open and fast-growing online communities (homework-help sites, discussion forums for MOOCs courses etc.). Recently, studies from Learning Science/Computer Supported Collaborative Learning (LS/CSCL) show an alternative instructional context by *learning from observing others learn* [3] and is considered a promising learning paradigm [4]. It suggests that passive participants (such as lurkers who consume content without contributions) can still learn by reading the postings-and-replies exchanges from others due to the constructive responses in the content [9]. Such a *learning-from-observing* paradigm addresses a major limitation on development time in ITSs & liberates the domains from procedural skills to less structured fields. Nevertheless, verifying students' learning activities usually relies on qualitative human-coded methods (i.e. domain expert judges), which is typically difficult to scale. Furthermore, it is challenging to keep persistent traces of current knowledge prediction. Thus, the challenge motivates us to investigate automatic methods for identifying learning activities and associated content from large scale programming discussions.

In this project, we aim to study automatic methods for identifying *useful* content to learn programming from a discussion forum. Our assumption is that online programming learning activities in discussion forums are quantifiable. We hypothesize that identifying learning-inductive content in large scale programming discussions will prevent learners from searching for a needle in the haystack and reading a mess of new detail. In the context of programming learning, can we successfully model users' learning activities in such a large-scaled open corpus environment? To what extent can we

¹ <http://stackoverflow.com>

capitalize the learning activity: reading others' constructive dialogues voluntarily and engage in some sort of learning activity afterwards? The rest of the paper is structured toward answering these research questions. We begin with reviewing two streams of related work: online support for programming learning and learning from discussion forums. We then present the methodology, detail features extraction exploring, and describe how we model learning activities in an online programming discussion forum. Finally, we discuss the findings and summarize the study.

II. LITERATURE

A. Online Support for Programming Language Learning

There is a great deal of research addressing the issue of developers switching between activities like searching for relevant code and collecting code and other information [10]. These tools are designed mainly to extract relevant information from the web to assist in current coding tasks and save time spent navigating through codes when gathering information. Some examples include navigational shortcuts to the code in IDE [11] leveraging version history data in predicting code changes [12], better use of API [13] and integration of web search or recommend source code examples in the developing environment [13-15]. Additionally, with the rise of web 2.0, we also see a variety of technologies (blogs, tags, wikis, recommenders etc.) emerging, such as online collaborative programming (social coding in GitHub), Q&A websites, crowdsourcing suggestions, etc. [1, 16, 17]. However, almost all of these tools are targeted at problem-solving augmentation, reducing coding cognitive overhead when coding. Utility features enhancement (i.e. collaboration) and supporting learning activities are less emphasized.

Using code examples is not only a common practice for programmers to reduce development efforts in solving task-specific problems, but they are also frequently used in teaching or offered in programming textbooks as problem-solving practices and strategies [14, 18]. Worked examples have been extensively studied since the early 90's and frequently adopted in math, physics, computer programming etc. up until today [19, 20]. We believe that large scaled online discussion forums should go beyond the merits of traditional discussion technology offers: collaboration and communication. We argue that the fragments of code in online discussions and various code solutions in Q&A provide monumental learning opportunities. For instance, similar or different solutions are constantly exposed to learners for comparing and contrasting, which help students identify what is important in a problem, identify different features of code, and paint a road-map to the problem [21, 22]. Multiple pieces of code can allow a novice construct patterns and schema [23], while even erroneous worked examples may assist learning in various levels [24].

B. Learning from Discussion Forums

Over the decades, discourse analysis on discussion forums has been carried out through various formats, network analyses, topical analyses, interactive explorers, knowledge extraction, etc. [25-29]. Due to calculation complexities (since linguistic features rely on computer processing power), most

of these in-depth analyses were performed offline [30]. As a result, the lesson learned could only be applied in the next iteration of system development. Recently, however, we have begun to see some studies that focus on dynamic support for users [31]. Yet, there has been no conclusive or comprehensive technological support, nor systematic studies to date on large-scale discussion forums that associate with students' learning. With the rapid growth of free, open, and large user-based online discussion forums, it is essential, therefore, for education researchers to pay more attention to emerging technologies that facilitate learning in cyberspace. For instance, Wise, Speer, Marbouti, and Hsiao [32] studied an invisible behavior (listening behavior) in online discussions, where the participants are students in a classroom instructed to discuss tasks on the platform; van de Sande [33] and Sande & Leinhard [34] investigated online tutoring forums for homework help, making observations on participation patterns and the pedagogical quality of the content; Hanrahan, Convertino & Nelson [35] and Posnett, Warburg, Devanbu, & Filkov [36] studied expertise modeling in a similar sort of discussion environment; Goda & Mine [37] quantify online forum comments by time series (Previous, Current & Next) to infer the corresponding learning behaviors.

III. METHODOLOGY

In order to research automatic methods for identifying *useful* content to learn programming from a discussion forum, we select a single programming language domain, Java, based on our expertise and interests. We experiment and study the content corpus from StackOverflow site due to the openness, popularity, and availability. There are three types of posts: question, accepted answer, and answers. Often times, there is more than one "correct" answer, especially for code review questions [2]. Even though quality indicators (votes, acceptance, favorite) point to the correctness of a possible solution, readers have differing backgrounds and varying degrees of previous knowledge which influence which answer is the best for that particular individual. Therefore, these quality indicators may not be universally applied to all users. For example, an accepted answer may be too dense for a novice to grasp. Therefore, this project is set out to research artificial intelligent methods to evaluate content quality that provokes learning in large scale programming discussions.

According to ICAP (Interactive, Constructive, Active, Passive) learning activity framework, "learning activities" are a broader and larger collection of instructional or learning tasks, which allow educational researchers to explain subtle engagement activities (invisible learning behaviors) [4, 9]. The framework examines comparable learning involvement, where *Interactive* modes of engagement achieve the greatest level of learning, followed by the *Constructive* mode, the *Active* mode, and finally, at the lowest level of learning, the *Passive* mode. This will allow us to predict learning outcomes and estimate knowledge transformation. In our project context, "replying to a post based on co-constructed content" is an interactive activity; constructing meaningful posts that require cognitive thinking is a constructive activity; shallow posts content or interactions are active activities; search, browse and read

content without contributing to the content are passive activities.

Our goal is to be able to identify useful content that provokes learning. We aim to detect all the constructive content to encapsulate users' learning. Thus, we focus on identifying the constructive activities in this project. Based on the framework, constructive learning activities include the following possible underlying cognitive processes: *inferring, creating, integrating new information with prior knowledge, elaborating, comparing, contrasting, analogizing, generalizing, including, reflecting on conditions, explaining why something works*. According to these cognitive processes, we build a constructive lexicon library to capture comparing & contrasting words, explanation, and justification & elaboration words. We then adopt a comparative opinions mining technique and extend the constructive lexicon, which was originally used in sentiment analysis for detecting and comparing product features in reviews [38]. For example, comparative or superlative adjectives and adverbs, such as *versus, unlike, most etc.*, are included in our lexicon. We then modify an arguing lexicon to extract explanation, justification & elaboration words [39]. We focus on the *assessment, emphasis, causation, generalization, and conditionals* sentence patterns and include WH-type and punctuation features in generating associated constructive lexicons. For instance, "in my understanding...", "all I'm saying is..." (*assessment*), "...this is why...(emphasis)", "...as a result...(causation)", "...everything...(generalization)" and "...it would be...(conditionals)" are merely a few examples.

To automatically identify useful content that might elicit learning, we construct a model to capture quality of the content that signals constructive behavior. We define the value to provoke learning as *constructiveness* based on the constructive lexicons mentioned above. We then analyze forum content and extract features. We consider three dimensions of features that cover the knowledge sphere for an online programming learning: 1) Syntactic features, 2) Semantic features, and 3) Social aspects features. Table 1 presents an overview of the features categories.

Table 1: Generic Feature Groups

Features Groups	Descriptions
Syntactic features	Statistics based on text readability, post length, code length, the amount of information the post carries, overall post readability.
Semantic features	Semantics of an answer and its similarity or coherence to the semantics of its corresponding question post and polarity.
User and social features	User characteristics (reputation and number of badges ²); social features include the user interactions with the posts, such as votes and favorites.

Programming discussion forums include a mixture of natural languages and programming languages. To represent both languages' complexities, we focus on extracting generic

features, instead of specific linguistic components. For instance, we leverage a modern opinion mining technique to analyze post polarities, which is commonly used in analyzing product reviews (i.e. amazon product reviews, restaurant reviews, movie critiques, news, etc.) or detecting spams. The polarity analysis is usually used to detect good or bad quality of the content. For a product, the majority of extreme opinions may be representative on product quality. In a discussion forum, a *negative-opinionated post* may not necessarily mean that it is a bad post. It can indicate the dis-association between question and answer; it can also suggest emphasis on contrary cases, instead of pinpointing on correct solutions (trial and error; learning from mistakes; erroneous example).

IV. FEATURE ENGINEERING

Our features collection specializes features, which are usually generally applied to social media platforms, to specifically detect useful content in not only programming, but also other discussion forums. We provide both the generic applications of these features in Table 1 and describe each feature in detail and how we made them domain specific.

A. Syntactic Features and Readability Metrics

Syntactic features capture the surface level, exterior characteristics of the text and any accompanying code that may provide insight into identifying constructive content. The following features are included:

- *Post length*, counts the number of words in the text. We hypothesize that answers with higher post length include more constructive learning behavior.
- *Code length*, counts the number of lines of code. We hypothesize code examples will increase constructive learning since more explanation is likely to follow, which is a constructive learning activity.
- *Informativeness*, measures the novelty of terms in a post compared to another post. Not only did we measure the informativeness of an answer compared to other answers of the same question, but also the informativeness of an answer compared to its corresponding question. We assume informativeness to be an indicator of constructive learning since it detects posts which are more informative. To ensure that domain-specific informativeness is detected, each post (p) is parsed to only contain words (w) found in the index or glossary of domain related textbooks or websites and is calculated as follows:

$$\Sigma_{w \in p} tfidf(w, p) \quad (1)$$

- *Readability metrics*, measure the difficulty in the understandability of text using various characteristics of the text, such as the Gunning Fog³ index, which uses syllables and the Coleman Liau⁴, which considers the number of characters. We assume a lower readability index indicates a post is easier to understand and thus easier to learn from.

² Stack Overflow utilizes gamification mechanism, which allows community members to vote and gain badges in reflecting community status (i.e. gold, silver, bronze, etc.)

³ http://en.wikipedia.org/wiki/Gunning_fog_index

⁴ http://en.wikipedia.org/wiki/Coleman-Liau_index

B. Semantic and topical features

Semantic and topical features measure characteristics of a post beyond the surface level and text structure by taking the meaning of the text into consideration. Concepts from both the text and code are also derived to gain insight on the actual topical features of the post.

- *Code concept count*, counts the number of concepts in the code accompanying an answer using a programming language parser [40]. We assume that a higher concept count indicates more learning conducive content.
- *Code concept entropy*, measures community code concept focus through code topic distribution. The program code parser [40] is used to obtain semantics from the code accompanying a post. We assume code concept entropy to be an indicator of learning since people often seek code solutions in programming discussion forums. We define entropy as the following where u is the user who authored the post, t is a topic, and n is the number of topics.

$$Entropy(\hat{u}) = -\sum_{j=1}^n p(t_{i,j}) \log_e p(t_{i,j}) \quad (2)$$

- *Post entropy*, measures community topic focus through post topic distribution. These topics are extracted by Topic Facet Modelling (TFM) algorithm from the post texts into corresponding sets of topics [41]. TFM is a modified Latent Dirichlet Allocation (LDA) probabilistic model, capable of automatically detecting content semantics in conversational and relatively short texts. We assume topical focus has an effect on the constructiveness of a post's content, since a low topic focus indicates high focus. Post entropy is calculated in the same manner as code concept entropy as described above.
- *Overall Sentiment*, subtracts the number of words that express negative sentiment from words that express positive sentiment. It is based on a list of positive and negative sentiment words in English [42]. In order to make the lexicon domain specific, words from Oracle's Java glossary were removed. We assumed overall sentiment may influence whether or not an answer is accepted. We further break down overall sentiment by considering positive and negative sentiment as separate features, since a more comprehensive sentiment analysis may give further insight into effects of sentiment on learning.

$$Sentiment = \#(PosTerms) - \#(NegTerms) \quad (3)$$

- *UMass Coherence*, measures the coherence between an answer and its question. It is measured as a pairwise score to represent how much a word in a post triggers the corresponding concept [43]. In order to make coherence domain-specific, we parse each post to only contain words from a lexicon of stemmed words from domain-specific glossaries and indexes. We assumed that a more coherent answer would most likely be accepted.

$$score_{UMass}(w_t, w_p) = \log \frac{P(w_t, w_p)}{P(w_p)} \quad (4)$$

C. User characteristics and Social Features

Social features include all the user and system interactions, which can also promote forum participation through gamification.

- *Votes*, are used to evaluate the quality of post content using up or down votes by community democracy.
- *Reputation*, measures community trust of a user based on prior activities on the site as well as up-voted posts.
- *Status*, of a user is measured through the number of badges earned. The score represents the amount of contribution and work done in the site community. i.e. Gold indicates important contributions; silver indicates strategic questions or answers; bronze shows rewards for participation.
- *Favorite*, is the number of bookmarks by the community. We assume that this may indicate learning inductive content in post and may even aid in filtering poor questions.

Table 2: Features Overview

Feature	Description
Syntactic Features and Readability Metrics	
Post length	Number of words in the post
Code length	Number of lines of code
Informativeness	Novelty of words in a post compared to another post
Readability Metrics	Understandability of text
Semantic and Topical Features	
Code concept count	Number of code concepts
Code Concept entropy	Code topic distribution among all codes to measure community code topic focus
Post entropy	Post topic distribution
Overall Sentiment	Positive and negative sentiments of the content
UMass coherence	Coherence score between the text of a post with another
User Characteristics and Social Features	
Vote	Community democracy evaluation of content quality
Reputation	Community trust measurement
Status	The accumulated scores on user profile to symbolize the amount of work done in the community.
Favorite	Number of saved bookmarks by the community
Dependent Variable	
Constructiveness	The number of constructive word counts based on the constructive lexicon described above

V. EVALUATION

According to the engagement activity framework reviewed above, we constructed the learning activity model based on the features identified. We then further analyzed the forum content to examine the validity of the findings from the results discovered from the model.

A. Data Collection

We sampled one year (year 2013) of forum posts under topic Java from StackOverflow site through the StackExchange API. Stack Exchange

(<http://stackexchange.com>) is a question and answer website network for various fields. The data pool was selected from the top 9 frequently tagged questions due to the fact that most of the posts in this section contained at least one accepted answer. It allowed us to build a baseline on the answer quality according to crowdsourced votes. There is a total of 16,739 posts, which includes 3,725 questions and 13,014 answers, 3,718 of which are accepted answers.

B. Model Learning Activity Analysis

To capture whether the observed assumptions on the features would account for the variation in user engagement prediction, we performed a logistic regression analysis. The full model was able to successfully predict *constructiveness* at 0.001 level, *adjusted-R*² = 0.6514. We tested the goodness of the models reserving 20% of the observations for testing with 10-fold cross validation and selected a final model. The full model is reported in Table 3.

Table 3: The logistic regression model on Constructiveness

Feature	Coefficient
Sy-code_length	-2.135
Sy-post_length	3.758***
Sy-informativeness	2.797***
Sy-GunningFox	2.030***
Sy-ColemanLiau	-8.608**
Sy-ComplexWords	1.245
Se-concept	-1.619***
Se-code_entropy	3.341***
Se-post_entropy	1.560
Se-positive	1.682***
Se-negative	-4.226**
Se-coherence	9.748
So-vote	2.583
So-reputation	4.441
So-gold	-1.912
So-silver	-3.834
So-bronze	3.615
So-favorite	9.344
constant	-2.555(*)

Significance codes: 0***, 0.001**, 0.01*, 0.05(.)

We found that there are significantly more constructive words within Accepted Answers ($M = 0.827$, $SE = 1.334$) than Answers ($M = 0.583$, $SE = 1.005$), $p < 0.01$. This result confirmed that the answers accepted by the crowd not only agreed as correct solutions among the best available answers, but also contained higher constructive information. Accepted Answers also showed a positive correlation between user favorites and the amount of constructive words ($r = 0.0781$, $p < 0.01$), but we did not see such correlation between Questions/Answers and the amount of constructive words. This result is not surprising. This indicates that the community tends to bookmark useful Accepted Answers, but not Questions nor Answers. However, we found the community provided as many votes to Answers and Accepted Answers, no matter how constructive the content was. This observation was very interesting and revealed that the community may not bookmark the Answers as frequently as they do to Accepted Answers, but it did show the effort to screen the Answers and

provide votes to them. Table 4 summarizes all the significant differences between Accepted Answers and Answers.

C. Deeper Content Analysis

From the learning activity model analysis, we learn that there are learning opportunities in utilizing discussion forum content that is not limited to the crowd accepted content only. To further understand why and how people can benefit from the content (not just the Accepted Answers, but also the Answers), we analyzed the forum content. We further divided the content into two categories, Easy & Difficult (based on whether the topic is covered in CS1 or CS2 courses). Easy topics include *Classes*, *Objects*, *Loops*, *ArrayLists* etc.; difficult topics contain *Inheritance*, *Recursion*, *Multithreading*, *User Interfaces* etc. We found that easier content had slightly higher constructive words than difficult content, but the difference was not significant. It is understandable that simpler problems may be easier to provide examples and tougher problems may require more effort to justify the answers. However, we found that among Answers, users bookmarked and up voted more in difficult content when the content also had more constructive words. But we saw no such pattern in Accepted Answers or in Questions. This again shows important evidence that the users in the community spend effort in locating relevant information to themselves, even if the answers are not accepted by the crowd. These results suggest that there is a *passive-proactive* learning behavior, in which users did not simply read the Accepted Answers, but also read the Answers and further performed some sort of action (up voted, bookmarked etc.) These findings also suggest that detecting constructive content can be a helpful classifier in discerning relevant information to the users, and in turn provide learning opportunities.

Table 4: Mean and standard deviation of all features. Significance is highlighted in bold.

	Question	Accepted Answer	Answer
Syntactic Features			
Post length	89.02±67.11	84.47±76.61	58.86±61.3
Code length	45.29±88.46	39.49±81.37	15.8±43.2
Informativeness	-	0.777±0.828	0.672±0.706
Gunning Fog	13.94±6.94	13.98±7.13	13.84±7.45
Coleman Liau	8.697±2.75	8.895±3.446	9.244±4.366
Complex Words	9.746±8.773	9.904±10.356	7.708±8.856
Semantic Features			
Code concept Count	4.944±7.573	4.58±7.189	2.576±5.119
Code Entropy	2.316±2.165	2.386±2.139	1.759±2.085
Post Entropy	4.302±0.251	4.241±0.437	4.109±0.71
Overall Sentiment	0.507±2.831	0.585±2.717	0.479±1.871
UMass Coherence	-	4361±13746	1709±6938
Social Features			
Votes	8.807±32.79	10.547±38.03	3.16±10.92
Reputation	4337±15812	38467±97657	33793±78433
Status – Gold	21.34±81.25	19.706±66.59	10.485±28.76
Status – Silver	31.48±59.81	112.97±492.7	77.42±349.49
Status – Bronze	46.83±75.78	162.57±644.1	116.07±461.1
Favorite	5.92±19.72	-	-

D. Topic Difficulty and Content Type across Constructiveness Predictors Analysis

Based on the topic difficulty distinctions described in the previous subsection, the pairwise comparisons of content types across all constructiveness predictors are reported in Table 5.

1) The effects of topic difficulty levels with syntactic features:

a) *Accepted Answers have an overall higher informativeness:* this confirms that they have more novel terms compared to the question. Since domain-related novelty was measured, it can be assumed that more domain-related constructive learning occurs. However, the average informativeness values of Answers are not too far behind, confirming their importance in also delivering novel information.

b) *Accepted Answers consist of more complex words:* The readability metrics of Gunning Fog and Coleman Liau are very similar between Accepted Answer and Answers, however there are more complex words in Accepted Answers than Answers, which may indicate that accepted ones were more composed and phrased formally with more complex words.

c) *Syntactic features differ between Accepted Answers and Answers on different topic difficulties:* Both post length and the length of the accompanying code are significantly higher in Accepted Answers than Answers. Accepted Answers delve into more detail and may provide various alternative solutions to a question, leveraging constructive learning. It is not surprising that post length, code length, and readability scores are lower for easier topics than more difficult topics since easier topics do not require as much explanation and depth as harder ones.

2) The impacts of topic difficulty levels with semantic features:

a) *Accepted Answers cover more concepts:* Code concept count and code entropy for Accepted Answers are significantly higher than Answer values. This can be due to the reason that people often turn toward programming discussion forums in search of code solutions; relevant code solutions are then more likely to be accepted. This also relates to the fact that Accepted Answers have a higher code length, which can increase the probability of more concepts being covered.

b) *Accepted Answers are more coherent with Questions:* Code concept count, code entropy, and domain-related UMass coherence are also significantly higher in Accepted Answers, which is not surprising, since the answer most coherent to the question is most likely going to be accepted. However, this does not discredit other answers, since they can also present learning inductive material not entirely coherent to the question.

3) The impacts of topic difficulty levels on social features:

Easier topics tend to have more votes and favourites than difficult ones. This indicates that using system interactive features (vote or favourites) may reach a limit in identifying useful content when the topics get tougher. This supports the

assumption that programming discussion forums may attract novice programmers more and reinforces the importance of intelligent content filtering assistance.

Table 5: Pairwise comparisons of topic difficulty and all constructiveness predictors

Easy/Difficult Question			Accepted Answer	Answer
Syntactic Features				
Post length	E	73.07±51.71	71.45±65.3	50.76±55.53
	D	96.54±72.04	90.59±80.66	63.56±63.93
Code length	E	43.81±94.89	36.05±75.05	13.99±29.5
	D	45.99±85.26	41.1±84.13	16.86±49.41
Informativeness	E	-	0.759±0.61	0.68±0.58
	D	-	0.785±0.912	0.667±0.77
Gunning-Fog	E	13.68±6.63	13.52±6.67	13.14±6.83
	D	14.06±7.08	14.19±7.32	14.24±7.75
Coleman-Liau	E	7.99±2.49	8.29±3.45	8.67±4.59
	D	9.03±2.80	9.18±3.41	9.57±4.2
Complex Words	E	7.53±6.65	8.11±8.92	6.74±8.3
	D	10.79±9.43	10.75±10.86	8.26±9.12
Semantic Features				
Code Concept Count	E	4.95±7.46	4.56±6.7	2.73±4.74
	D	4.94±7.63	4.59±7.41	2.49±5.33
Code Concept Entropy	E	2.37±2.16	2.46±2.14	1.94±2.12
	D	2.29±2.17	2.35±2.14	1.66±2.06
Post Entropy	E	4.29±0.23	4.21±0.487	4.05±0.77
	D	4.31±0.26	4.26±0.411	4.14±0.669
Overall Sentiment	E	0.46±3.05	0.556±2.7	0.476±1.63
	D	0.53±2.73	0.598±2.72	0.481±1.99
UMass Coherence	E	-	3124±15555	1090±5534
	D	-	4939±12772	2069±7612
Social Features				
Votes	E	11.45±50.59	14.38±58.39	3.81±15.5
	D	7.56±19.27	8.75±22.68	2.78±7.00
Reputation	E	3223±14678	38408±98306	33190±8153
	D	4858±16289	38494±97351	34148±7655
Status - Gold	E	18.11±70.36	18.12±59.18	10.42±27.7
	D	22.85±85.83	20.45±69.78	10.53±29.37
Status - Silver	E	27.8±52.31	113.04±478.4	81.57±376.7
	D	33.21±62.95	112.94±499.2	74.98±332.4
Status - Bronze	E	41.94±75.31	162.4±625.82	120±495.77
	D	49.12±75.89	162.65±652.5	113.7±439.4
Favorite	E	7.14±25.94	-	-
	D	5.41±16.39	-	-

VI. DISCUSSIONS

In this paper, we modeled constructive engagement activities in an online programming discussion. In order to identify learning-inductive material from such platforms, we built a constructive word lexicon based on constructive learning activities underlining cognitive processes described in the ICAP learning activity framework. We then performed logistic analysis and selected a model, which was able to explain 65.14 % of users' engagement activities. Deeper analysis confirmed that the crowd perceived Accepted Answers as more likely to contain more constructive words. Moreover, users had more up vote interactions with Answers and Accepted Answers disregarding the quantity of constructive words. Furthermore, they especially bookmarked and up voted more in difficult Answers when the content also

had more constructive words. In addition, in the semantic content analysis, we found higher topical focus of the program codes in Answers in the discussion forum. This again demonstrated the value of discussion forum content, no matter whether or not the crowd approves the content.

All these findings combined together supported the existence of *passive-proactive* learning in large-scaled online discussion forums and confirmed that content of discussion forums is a valuable asset for learning, disregarding the acceptance by the crowd. They also suggested that detecting constructive content could be a helpful classifier in discerning relevant information to the users, and in turn providing learning opportunities. For instance, we can optimize learning opportunities in the open corpus large-scaled discussion forum by identifying and ordering content based on the quality and constructiveness, which may result in better efficiency for mass *passive-proactive* users (as opposed to the traditional layout of the content, which is ordered by content quality and reversed chronological order). Similarly, the value of the Answers in the massive amount of discussion forums should be harnessed and better utilized. For example, relevant Answers can be recommended to learners, instead of Accepted Answers.

VII. LIMITATIONS & FUTURE WORK

We recognized two major limitations during the exploratory modeling process. 1) We currently only considered the constructive learning activity, while neglecting other activities, such as *Interactive* learning. Learning is complex. Therefore, all sorts of learning activities can be intertwined among the same context. 2) The current model considered limited social features to capture users' profiles. We believe that a learning-inductive post should also take into account the content poster's expertise, rather than just the amount of activities in the community. Therefore, in the future, we plan to integrate other learning activities associated with constructive ones and conduct more rigorous evaluation in modeling forum posters' expertise. Moreover, we are currently testing innovative learning analytics interfaces, which present personalized views, sequencing, and summaries to assist users to make better use of the massive content from discussion forums. More exhaustive user studies have been planned to evaluate the effectiveness of this predictive model.

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Gauging Influence in Software Development Teams

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Abstract— Agile software development teams are generally small, focused groups that require highly motivated members operating in a high-trust environment. Through interactive communication and collaborative work, team members can influence project outcomes both directly and indirectly. One method to examine influence is in terms of communication and control flow among team members when sharing a communication medium and artifact development tools. There currently exist several approaches for characterizing team communication using social network analysis. However, these approaches require modification to be applicable for measuring control flow influence in small teams. In this paper, we discuss the methodology and results of an influence study in which we analyze data generated by student teams in a capstone Software Engineering course. We develop three metrics to measure direct and indirect influence among team members, taking into account the temporal order of interactions and the small size of the teams studied. We correlate the influence metrics with grades, existing participation metrics, and team evaluation scores. The results suggest that our influence metrics correlate to a team member's perceived role on the team, measures of team communication and levels of task performance. This suggests that instructors can recognize the levels of influence exerted by team members by examining team communication and control flow, allowing for mediation prior to product development milestones.

Keywords—Computer science education; agile software development; collaborative work; social network analysis; centrality

I. INTRODUCTION

The role of influence in team dynamics has been studied from multiple perspectives, such as the response to leadership [1], the allowance of diversity in problem solving approaches [2-3], and the impact of perceived status and likeability on individual performance [4]. In a classroom setting, understanding how influence is manifested and perceived by team members can allow for early mediation. If negative influence from a team member is evident, individual and team meetings can help bring awareness and correction. If a member exerts positive influence and is perceived as a leader or role model for the team, then watchfulness may be needed to ensure adequate participation by all members.

The objective of the research is to devise an influence measure that can serve as a predictor of team performance characteristics. We use communication and control flow as an influence indicator among team members as they share a dedicated communication medium and multiple artifact

development tools. The resulting sociometrics developed in this study are based on the concepts of centrality and centralization from social network analysis [5]. *Centrality* is a number that quantifies some type of "importance" of a node in a social network. *Centralization* is a numerical measure of how evenly centrality is distributed over the nodes in a network. If a social network has a high centralization, this means that most of the centrality is concentrated in a relatively small group of nodes.

The main research question we seek to answer is: *Can social network analysis algorithms be applied in small team assessment to accurately quantify influence and predict aspects of product outcomes, individual performance, and peer assessments?* Section II overviews studies in influence, provides an overview of centrality and centralization, and briefly describes the communication medium used by the teams in this study. Section III describes our methodology, including the processes used to build and analyze influence network graphs based on each team's recorded actions. Section IV describes the study parameters and correlation results. Section V provides discussion and conclusion.

II. RELATED WORK

A. Influence Studies

Status and sentiments are two major factors that have been researched with respect to determining the expectations to task ability among collaborative team members. This expectation can translate into one team member influencing the behavior of another in a positive or negative way. Status is defined as the prestige a person has because of a valued social distinction. Sentiments involve the relationship of liking or disliking a team member. They may be expressed in the form of expressive patterns or gestures that are manifested in social settings. Research in understanding the interplay between sentiments and status can provide reasons for team interventions to reduce any negative effects on group behavior. Bianchi [4] crafts a set of actor-partner studies to examine the interplay between advisor-decision maker and neutral-negative sentiment. Each study participant was informed that they could not directly view their partner and did not know that their partner was a computer program. With respect to influence, the results indicate that the partner's approval is more important when an actor is fully responsible for the outcome of the team and less important if there is dislike.

Goh and Wasko [3] explore the roles of leadership as a form of influence on how resources are allocated to members on a virtual world team. Abstractly these resources may include expertise, task load balancing, or planning aid. Using a massive, multiplayer online game, they found that there is a leader-member relationship that impacts performance. Notably, the higher the quality of the relationship, the better the resource allocation. However, they also found only partial support for a relationship between the level of quality and the level of trust and performance. The possibility exists that virtual world teams may not have the same social connection to other team members as teams that can meet face to face.

Santos, et al. [6] examine organizational strategy and communication flow and channels as influencing factors for knowledge sharing. Their goal was to study these factors in terms of how the companies used agile methods. Using survey data, they showed that extensive communication with multiple channels fostered knowledge sharing across teams, which also had a significant association with a company's experience using agile methods.

B. Centrality and Centralization

There are many metrics used to compute centrality and centralization. Two existing centrality metrics which are relevant to our study are *degree centrality* [5] and *Katz centrality* [7]. Degree centrality is a metric in which each node's centrality is equal to the number of direct connections it has with other nodes. In a directed graph, degree centrality might consider only incoming or outgoing connections, depending on what the graph models. Katz centrality is a metric that considers all paths that exist in a network (including those that follow the same edge multiple times), and assigns each path a weight which degrades exponentially with path length. If we let $L(p)$ denote the number of edge traversals in a path p , the weight of p is

$$w_{\text{Katz}}(p) = b^{-L(p)}$$

where $b \geq 1$ is a parameter. The centrality of a node is then the sum of the weights of all paths that start at that node. If we let V denote the set of nodes and P_{ij} denote the set of all paths from node i to node j , then the Katz centrality for node i is given by

$$\sum_{j \in V} \sum_{p \in P_{ij}} w_{\text{Katz}}(p)$$

Since the number of paths in a network is often infinite, this sum may not converge if b is too small.

In this study, we use slightly modified versions of two existing centralization metrics. One simple centralization metric is the population variance of the observed centrality values [5]. If we let $C(i)$ denote the value of some centrality metric for node i and let \bar{C} denote the mean observed centrality, the variance is

$$\left(\sum_{i \in V} (C(i) - \bar{C})^2 \right) / \|V\|$$

Another centralization metric is *Freeman's centralization index* [5]. This metric is computed by finding a sum of differences representing the amounts by which the most central node's centrality exceeds each other node's, and dividing the sum by its theoretical maximum. If we let C^* denote the maximum observed centrality, the value of Freeman's centralization index is

$$\left(\sum_{i \in V} (C^* - C(i)) \right) / S$$

where S is the maximum possible value of the numerator sum

$$\sum_{i \in V} (C^* - C(i))$$

Note that Freeman's centralization index is always in the range from 0 to 1.

C. Communication Medium

In prior studies, we have examined learning indicators [9] and performance metrics [10] using a collaborative project management tool, SEREBRO [11]. We developed SEREBRO in 2008 as part of an NSF Creative IT program [12] and have used it as courseware in Software Engineering classes since 2009. It was used in Introduction to Psychology classes for further studies on self-regulation from 2011-2013.

Fig. 1 shows the interface of SEREBRO as it relates to a forum post. The forum is structured as a set of trees where each root (circle) is a brainstorm node to start a conversation and the triangles are agree (point up) or disagree nodes (point down, not shown). The lightbulbs mark posts the user has not yet viewed. Hovering over a node on the graph displays the post, and clicking on it allows the user to agree, disagree, or comment to add a child post. The tabs at the top of Fig. 1 show that the user is in the Sprint 1 milestone under the topic Meeting 6. To the left of the interface is the listing of project management modules. These include a wiki and an SVN version control repository.

SEREBRO has an embedded event tracking system that assigns events to users whenever they post, change the wiki, upload files, or commit to the SVN. We use the SEREBRO forum and wiki data, along with other event logs from Git (for version control), Google Drive (drive.google.com), and Lucidchart (www.lucidchart.com), to build our influence networks, as described in Section III.B. In the Software Engineering courses used in this study, team members are required to use these tools for all electronic communications. Thus, untracked interactions such as email and text messages are discouraged.

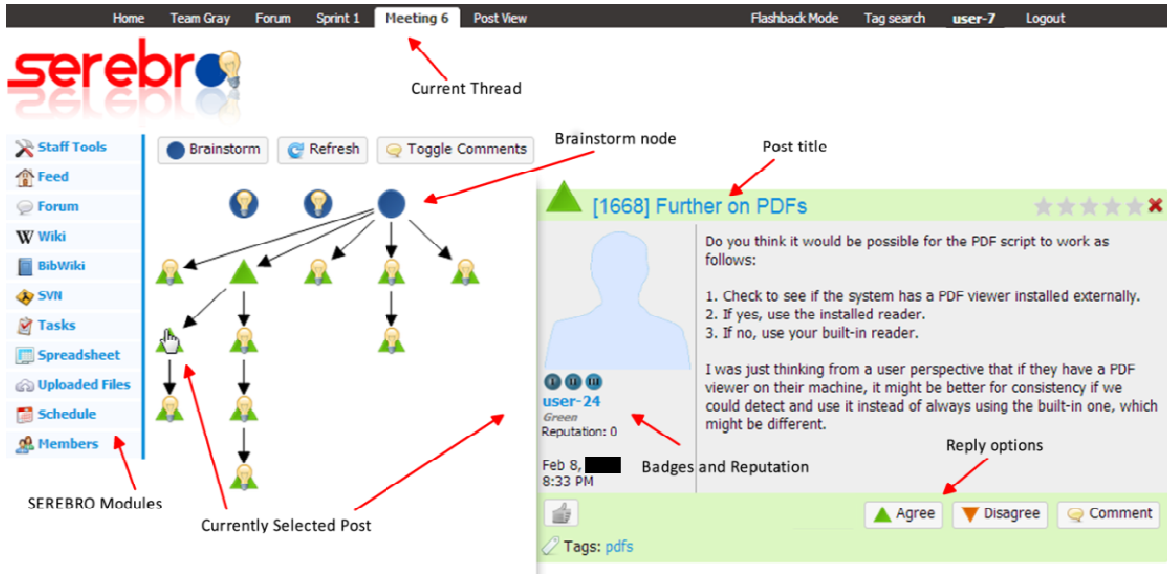


Fig. 1. SEREBRO Forum Interface

III. METHODOLOGY

When reviewing existing social network analysis techniques, we generally found that these techniques model the network as a simple graph, where an edge between two nodes indicates that a connection or interaction was observed between those nodes (e.g., [1], [5], [8]). Since our study focuses on small teams, in which any given pair of members will likely share a direct interaction at some point, this type of model would tend to produce a clique very often. Without some way of modeling the number and type of interactions, this leaves little potential for differentiating the influence levels of different team members.

Another limitation of a standard graph-based model is that it does not provide information about the timing of interactions. The lack of timing information could be problematic for our purposes. For example, if person *A* interacts with person *B*, who then interacts with person *C*, it seems reasonable to suspect that *A* may have exerted some indirect influence on *C* through *B*. However, if the interaction between *A* and *B* had taken place after the interaction between *B* and *C*, no indirect influence from *A* to *C* would be possible. Since one of our goals is to develop sociometrics that take indirect influence into account, it is desirable to use a model that can distinguish between the above two scenarios. To this end, we developed a modified graph model, described as follows.

A. Network Model and Metrics

In our model, the influence network contains *member nodes* representing the human team members, as well as *artifact nodes* representing shared documents and code repositories. The graph contains an edge for each influence event tuple that we recorded (as described in Section III.B.). Each edge is directed from the node responsible for the influence to the one receiving the influence, and edges are marked with time stamps indicating the time of the influence event. Since there can, of course, be many observed influence events between two nodes, our graph can include multiple edges from one node to another.

We developed three centrality metrics to use in this study. One

metric is similar to Katz centrality [7], but with a few modifications. First, since the network can contain multiple edges from one node to another, there can be multiple paths following the same sequence of nodes. Paths that visit the same node sequence but use different edge sequences are considered distinct. Second, our metric only considers paths that are monotonically increasing in time. This ensures that indirect influence will not be considered when the ordering of events makes it impossible. It also ensures that only finitely many paths will be considered, which means centralities will be defined even when *b* is small. Third, we include an optional *path length limit* parameter L_{max} ; paths containing more than L_{max} edges are assigned zero weight and thus ignored. Fourth, our metric ignores paths that start and end at the same node. This is because we are primarily interested in the influence a node has on other nodes, rather than any indirect influence a node may have on itself. Fifth, our metric includes *normalization* of centrality values so that the centralities of all member nodes sum to 1.

To express this metric formally, let V_M denote the set of member nodes, and let PT_{ij} denote the set of monotonically temporally increasing paths from node *i* to node *j*. Furthermore, let

$$w_{Exp}(p) = \begin{cases} 0, & \text{if } L(p) > L_{max} \\ b^{-L(p)}, & \text{otherwise} \end{cases}$$

for each path *p*, and let

$$I_{Exp}(i) = \sum_{j \in V_M - \{i\}} \sum_{p \in PT_{ij}} w_{Exp}(p)$$

for each node *i*. w_{Exp} is a weighing function giving the weight of each path, and I_{Exp} gives the centrality values before normalization. The normalized centrality is then

$$C_{Exp}(i) = \frac{I_{Exp}(i)}{\sum_{j \in V_M} I_{Exp}(j)}$$

We developed another metric C_{poly} in which path weights degrade at a polynomial-like rate rather than an exponential rate. The metric is

the same as above, except that the weighing function w_{Exp} is replaced with

$$w_{\text{Poly}}(p) = \begin{cases} 0, & \text{if } L(p) > L_{\max} \\ (L(p))^{-a}, & \text{otherwise} \end{cases}$$

where $a \geq 1$ is a parameter.

The third centrality metric we used is C_{Direct} , a form of degree centrality based on outdegree. This metric can be defined the same way as C_{Exp} , with w_{Exp} replaced by

$$w_{\text{Direct}}(p) = \begin{cases} 0, & \text{if } L(p) > 1 \\ 1, & \text{otherwise} \end{cases}$$

Note that the use of C_{Direct} is practically equivalent to assigning influence values by simply counting the number of direct influence events from a given team member. As such, this metric is not novel; it was included as a baseline to determine whether our other metrics gain any advantage by considering indirect influence.

Since we are primarily interested in the influence of human team members, we also modified existing centralization metrics to consider only the set V_M of member nodes. Note that, despite being ignored in the centralization computations, artifact nodes do have a meaningful impact on centralization due to their use in computing the centralities of member nodes. The modified variance centralization metric is

$$\left(\sum_{i \in V_M} (C(i) - \bar{C}_M)^2 \right) / \|V_M\|$$

where \bar{C}_M is the average centrality over all member nodes. The modified Freeman centralization index is

$$\left(\sum_{i \in V_M} (C^* - C(i)) \right) / S_M$$

where S_M is the maximum possible value of the sum in the numerator. For all three of our centrality metrics, the most centralized scenario possible is one in which one team member has centrality 1 while the others have centrality 0. In that case, the sum in the numerator reaches its maximum value:

$$S_M = \|V_M\| - 1$$

In addition to trying the above centrality and centralization metrics with various values for the parameters, we experimented with different ways of building the influence network. In our first approach, we included edges for all the influence event tuples that we had recorded (see Section III.B.). In another approach, we omitted all direct communication edges between team members, so that only influence events involving artifacts were considered. In a third approach, we omitted all edges starting or ending at artifact nodes, so that only influence arising from interpersonal interactions was considered.

B. Constructing the Networks

Because the teams were formed with a common goal and had approximately the same foundational training, we hypothesized that those team members that would assert themselves as leaders would

also influence the team through their collaborative actions. To construct our influence networks, we compile a set of influence events based on the communication among team members and the control they exert over artifacts. Each event was encoded as a 3-tuple corresponding to an edge in the network. The tuple set is described below.

Direct naming. If user A names user B in a SEREBRO forum post with a request to perform a task or a suggestion as to how to perform a task, then A influences B at the time, t , of the direct naming of B in the forum post, resulting in tuple (A, B, t) .

Direct use. If user A names user B in a post at time t in reference to evaluating or using something B produced, then B influences A , resulting in tuple $(B, A, t - \varepsilon)$, where $t - \varepsilon$ is a time that precedes t by a small amount, such that no tuples will have timestamps between $t - \varepsilon$ and t . The subtraction of ε is done so that, if a single post involves both direct naming and direct use, the direct use will appear first in the temporal order. We believe this is appropriate, as the actual influence implied by direct use presumably occurs before the associated forum post.

Deliberate response. As shown in Fig. 1, the forum is structured in a manner such that a conversation is held by a tree within a larger topic. If user A posts and user B responds in any way that reflects the content of A 's post and is within the same forum topic, then A influences B , resulting in a tuple $(A, B, t - \varepsilon)$, where t is the time of B 's post.

User/wiki interaction. If user A edits a SEREBRO wiki page at time t , then a tuple (A, W, t) is produced, where W is the wiki's artifact node. Furthermore, if the previous person to edit the wiki was someone other than A , then a tuple $(W, A, t - \varepsilon)$ is produced. The rationale for recording influence from W to A is that A presumably would have to read the wiki page before editing it if A was not the previous editor.

User/codebase interaction. In this study, each team used one or more Git repositories hosted through either GitLab (gitlab.com) or Bitbucket (bitbucket.org). If a Git repository G contains a commit with author A and commit time t , and that commit is an ancestor of G 's master branch at the end of the associated 3-sprint project, then a tuple (A, G, t) is produced. For each parent of A 's commit that does not have A as its author, a tuple $(G, A, t - \varepsilon)$ is produced. Multiple identical tuples may thus be generated when a commit has multiple parents; these are treated as distinct.

Google Drive and Lucidchart interaction. In addition to SEREBRO and hosted Git repositories, each team used one or more shared Google Drive and/or Lucidchart documents. Due to the nature of the Google Drive and Lucidchart Web interfaces (which upload changes frequently and automatically even when the changes are minimal), we suspected that recording a tuple for each uploaded change would result in a disproportionately large number of tuples associated with these artifacts. To avoid this, we generated tuples based on small intervals of time in which users actively edited documents. These *activity blocks* were estimated as follows. Wherever a document's event log indicates that a user A made two edits less than 30 minutes apart, user A is assumed to have been editing the document in the time between those edits. User A is also assumed to have been active at the single point in time corresponding to each recorded edit (possibly producing some single-point editing

intervals). Each contiguous interval of active time, including any single-point intervals, is split into 5-minute activity blocks. (The interval's last block may be less than 5 minutes long. Any active interval shorter than 5 minutes becomes a single block.) Then, if user A has an activity block for document D that starts at time t , a tuple (A, D, t) is generated. Additionally, if one or more other users were active with respect to D between the current block's starting time and the starting time of A 's previous block for D , one tuple $(D, A, t - \epsilon)$ is generated.

IV. ASSESSING INFLUENCE

A. Study Parameters

The preliminary study reported here involved 19 students separated into 5 teams with 3 to 4 people per team. Each team's work was separated into 3 sprints, each having its own milestones, grades, and peer evaluations. Considering each sprint and student separately, our data covers a total of 57 evaluation points. The teams are in a realistic setting, with a product customer, and work collaboratively both face-to-face and asynchronously through SEREBRO. Teams collaborate on code development through shared Git repositories that replace SEREBRO's SVN repositories used in previous years. While they have consented to the study of their data, they are not acting primarily as study participants, but as actual team members with a common product goal. Sprints last an average of 5 weeks.

For each team, we generated 3 sets of influence tuples corresponding to the 3 development sprints. This allows us to compute centralities separately for each sprint, resulting in 57 data points for each centrality metric and 15 data points for each centralization metric. For each sprint, we also calculated some of the performance metrics assessed in [10]. We believe the Influence metric from this previous study was too narrowly based on event counts. We re-term this metric as *Event Proportion* here to avoid confusion. The performance metrics for Contribution and Impression from [10] are repeated below.

Contribution. *Contribution* measures quality of meeting check-ins on the SEREBRO forum for each sprint according to Subject Matter Expert content evaluation and rating [10]. The meeting check-ins simulate a daily Scrum meeting with modifications for an educational setting. Users are expected to (1) state what they did since the last check-in, (2) state what they are doing for the next check-in, (3) state what impediments they have or evaluations of other team members they have performed, and (4) be on time for posting. A sprint averages 12 meeting check-ins with each check-in worth 15 points. There are sometimes bonus points awarded if an individual completes all requirements for all check-ins during the sprint.

Impression. *Impression* measures the average evaluation rating for 20 qualities in a team survey regarding each individual's perceived performance during a sprint [10]. The general qualities are the same for each sprint, but some of the questions are presented differently given the goals of the sprint. The survey requires individuals to report on the performance of each team member (including themselves) with a rating from 0 (no performance) to 10 (exceedingly high performance) for each quality. The questions common to all sprints are listed below.

- Q1. Participated in online and face-to-face meetings
- Q2. Responded to team activity in a timely manner

- Q3. Contributed project ideas that were implemented
- Q4. Contributed to document artifacts creation and/or review
- Q5. Set the standard for team performance
- Q6. Completed all tasks assigned at agreed upon timeline
- Q7. Organized the requirements, user stories, and Sprint Backlog
- Q8. Communicated project and instructor expectations well
- Q9. Performed design based tasks effectively
- Q10. Initiated and maintained required documents
- Q11. Worked with team to create overall product vision
- Q12. Delegated tasks appropriately

Qualities that relate to status or sentiment among team members in terms of perceived reputation and follow-through, and embody project and team influence, are included in questions 2, 3, 5, 6, 11, and 12. We target these questions in the correlation results presented in Section IV.B. For each question and sprint, we assigned each team member an *Evaluation Question score* equal to the average of all scores assigned to that user (for the given question) in surveys from the given sprint.

Event Proportion. *Event Proportion* measures the number of events an individual performs relative to the number of team events for a given sprint. The events we counted for this metric consist of SEREBRO events, Git commits, and activity blocks for Google Drive and Lucidchart documents.

Sprint Grade. A team grade is assigned for each sprint based on the timely hand-in of the team work products which generally include design documents, code, project documentation, artifacts such as images created for a web application, and presentations. All team members received the same team grade as an initial score. Individual grades are produced by incorporating participation in meeting check-ins, attending mandatory team meetings, and the team evaluation. If the team evaluation goes below certain levels and there is general agreement among the team, the individual affected receives a percentage of the team grade. The individual grade is recorded as the Sprint Grade for the study.

For purposes of statistical analysis, the Contribution, Impression, Sprint Grade, and Evaluation Question scores were normalized for each sprint/team. That is, for each sprint/team, each of these metrics was multiplied by a normalization factor so that the metric's values across team members sum to 1. This was done to compensate for any overall performance differences among teams. Without normalization, we believe these differences would negatively impact the meaningfulness of our correlation analysis, since our centrality metrics only attempt to measure a team member's influence relative to other members of the same team.

B. Results of Correlation

As mentioned in Section III.A., influence networks were constructed three ways: (1) *All* – using event tuples from forum posts and artifacts, (2) *Artifacts* – using only artifact tuples (thus ignoring direct communication within teams), and (3) *Forum* – using only forum tuples (thus considering only direct communication within teams).

We examine the linear dependence among our influence centrality metrics and the normalized Sprint Grades, Evaluation Question scores, Impression scores, Event Proportions, and Contribution scores. We use the Pearson correlation coefficient (Pearson's r) to determine

what correlations exist between influence centrality metrics and other performance measures. Correlation values are calculated using sum of squares. Critical values are chosen based on a two-tailed test with 55 degrees of freedom, corresponding to the 57 evaluations examined.

We experimented with a broad range of metric parameters. In Tables I, II, and III, we show the results obtained using C_{Direct} , C_{Poly} with $a = 2$; and C_{Exp} with $b = 2$, $b = 5$, and $b = 10$. In all cases shown, L_{max} is set to infinity. These tables show the obtained correlation values for *All*, *Artifacts*, and *Forum*, respectively, as defined above. Cells in the tables are highlighted to show significant results as follows.

- $p > 0.05$ (low confidence), $|r| < 0.261$; white cells
- $p \leq 0.05$ (95% confidence), $|r| \geq 0.261$; blue cells
- $p \leq 0.01$ (99% confidence), $|r| \geq 0.339$; tan cells

1) Correlation Results – All Event Tuples

Reviewing Table I, the degree centrality metric, C_{Direct} , strongly correlated with several performance measures. The correlation with event proportion is particularly strong. This is to be expected, since C_{Direct} is equivalent to a normalized event count. The correlations with peer evaluation questions 1-5 and 10-11, as well as with Impression and Sprint Grade (both of which depend on evaluation scores), suggest that team members were able to accurately assess the direct work occurring within their teams.

The polynomial decay metric, C_{Poly} , had no correlation with sprint grade, but did correlate with 3 of the 6 targeted questions. C_{Poly} had a slightly higher correlation with question 11 than the other sociometrics.

Of most interest for our research is the exponential decay metric, C_{Exp} , which correlates well with our target questions (particularly with $b = 10$) while taking the possibility of indirect influence into account. This metric's correlations with evaluation questions are fairly similar to those of C_{Direct} , with the exceptions of questions 4, 6, and 10. Notably, questions 4 and 10 are both closely related to documents. This may indicate that indirect influence is less important in document creation than in other aspects of team functioning, or that our methodology for deriving document editing events, primarily the timings set for the activity blocks in Google Drive and Lucidchart documents, needs further refinement. C_{Exp} appears to be the best predictor for question 6, which measures team members' reputations for completing assigned tasks on time.

The overall lack of correlation with questions 8 and 12 indicates that, when all events are used, the communication authority exhibited by team members is not captured well by the influence centrality values.

2) Correlation Results – Artifact Event Tuples

For the most part, Table II exhibits the same patterns as Table I, although the correlations are generally weaker. The similarity of the *All* and *Artifacts* cases suggests that, in the *All* case, artifact event tuples may have had excessive impact on the sociometric values, overwhelming the effects of the discussion-based tuples. This is further supported by the strong contrast with Table III (in which only the forum was considered), and indicates a possible need for modifications to the way artifacts are incorporated in the *All* case.

TABLE I. CORRELATION RESULTS – ALL EVENT TUPLES

	C_{Direct}	C_{Poly} (a=2)	C_{Exp} (b=2)	C_{Exp} (b=5)	C_{Exp} (b=10)
Sprint Grade	0.393	0.236	0.265	0.301	0.330
Q1	0.412	0.232	0.288	0.334	0.347
Q2	0.438	0.206	0.264	0.324	0.357
Q3	0.427	0.280	0.356	0.411	0.440
Q4	0.363	0.082	0.034	0.020	0.058
Q5	0.495	0.345	0.401	0.440	0.471
Q6	0.247	0.207	0.270	0.312	0.319
Q7	0.231	0.043	0.029	0.013	0.009
Q8	0.242	-0.027	-0.091	-0.160	-0.142
Q9	0.156	0.097	0.033	0.000	0.008
Q10	0.278	0.021	0.0431	-0.073	-0.048
Q11	0.316	0.327	0.3241	0.301	0.289
Q12	0.179	0.071	0.079	0.051	0.049
Impression	0.400	0.284	0.320	0.336	0.352
Event Proportion	0.902	0.294	0.380	0.556	0.659
Contribution	0.397	0.277	0.245	0.225	0.252

A few differences between Tables I and II are notable, particularly with respect to C_{Poly} with $a = 2$ and C_{Exp} with $b = 2$. C_{Poly} no longer correlates significantly with Contribution or question 3 but now correlates with question 1. C_{Exp} with $b = 2$ no longer correlates significantly with Sprint Grade or question 2. We do not have a satisfactory explanation for these changes, but we note that the associated changes in r seem fairly small. In all cases where significant correlations are lost or gained between Tables I and II, the insignificant correlation is within 90% confidence ($p \leq 0.1$, $|r| \geq 0.220$). Therefore, we hypothesize that these differences are due to coincidence. Further experiments with more teams would be needed to test this hypothesis.

3) Correlation Results – Forum Event Tuples

Table III has the most interesting results. When artifact tuples are omitted, all of the sociometrics shown have highly significant correlations with questions 1-3 and 5, as well as Sprint Grade and Impression. Significant correlations with questions 6 and 11, as well as Contribution and Event Proportion, are also present for all metrics. Higher correlation with Contribution is to be expected, as Contribution scores are heavily dependent on forum activity.

Notably, C_{Exp} with $b = 10$ has larger r values than C_{Direct} for *all* of the performance measures. This provides support for our hypothesis that influence metrics can gain predictive power through the consideration of indirect influence. Admittedly, some of the differences in r values are quite small, suggesting a need for further study of how indirect influence may be gauged.

TABLE II. CORRELATION RESULTS – ARTIFACT EVENT TUPLES

	C _{Direct}	C _{Poly} (a=2)	C _{Exp} (b=2)	C _{Exp} (b=5)	C _{Exp} (b=10)
Sprint Grade	0.364	0.219	0.240	0.264	0.289
Q1	0.383	0.264	0.307	0.311	0.309
Q2	0.408	0.211	0.260	0.2900	0.312
Q3	0.384	0.260	0.321	0.367	0.396
Q4	0.361	0.073	0.031	0.001	0.036
Q5	0.465	0.356	0.398	0.409	0.430
Q6	0.191	0.242	0.282	0.280	0.270
Q7	0.245	0.034	0.032	0.009	-0.004
Q8	0.247	0.005	-0.063	-0.143	-0.135
Q9	0.160	0.071	-0.002	-0.031	-0.019
Q10	0.306	-0.015	-0.071	-0.096	-0.067
Q11	0.288	0.351	0.347	0.299	0.270
Q12	0.160	0.049	0.066	0.032	0.024
Impression	0.369	0.284	0.303	0.302	0.311
Event Proportion	0.879	0.311	0.383	0.543	0.643
Contribution	0.375	0.259	0.230	0.205	0.220

C_{Exp} with $b = 5$ and $b = 10$ correlate with question 12, while Tables I and II show no significant correlation with question 12 for any metrics. This is understandable, as question 12 relates to task delegation, which is more likely to occur through discussion than to be recorded in artifacts. C_{Exp} has also gained significant correlations to question 4, where in Tables I and II the r values were extremely low. This is difficult to explain, since the correlation between C_{Direct} and question 4 is much *smaller* in Table III compared to the other two tables.

Also note that for questions 4 and 12, C_{Exp} with $b = 5$ and $b = 10$ have stronger correlations than C_{Direct} (which gives the least consideration to indirect influence) as well as C_{Poly} with $a = 2$ and C_{Exp} with $b = 2$ (which have the slowest path weight degradation and thus give the most consideration to indirect influence). This indicates that, for some predictive purposes, it may be important to avoid both underestimating and overestimating the amount of indirect influence. Further research is needed to determine how one might choose the best parameters for sociometrics given an intended application.

It should also be mentioned that our correlation analysis remained consistent with results presented in [10]. Given the data from the current study, which uses multiple teams, semesters, and instructors, Impression strongly correlated with both Event Proportion ($r = 0.429$) and Contribution ($r = 0.764$), and Event Proportion strongly correlated with Contribution ($r = 0.429$).

We also performed analysis of correlation between our centralization metrics and other measures relating to teams as a whole, such as team size and overall team grade. The goals of this analysis were to determine whether team size affects a team's level of

centralization and whether more centralized teams tend to have higher or lower performance than less centralized teams. We found very few significant correlations, so the numerical results are omitted here. However, it is worth noting that, in the *All* and *Artifacts* cases, both the Freeman and variance centralization metrics correlated negatively with team size (with at least 95% confidence) for C_{Exp} with $b = 10$. It is possible that the lack of meaningful results is due to the small sample size; since these metrics apply to teams rather than individuals, only 15 data points were available for the analysis.

TABLE III. CORRELATION RESULTS – SEREBRO FORUM EVENT TUPLES

	C _{Direct}	C _{Poly} (a=2)	C _{Exp} (b=2)	C _{Exp} (b=5)	C _{Exp} (b=10)
Sprint Grade	0.370	0.366	0.375	0.409	0.401
Q1	0.386	0.345	0.362	0.409	0.408
Q2	0.393	0.355	0.378	0.431	0.426
Q3	0.421	0.388	0.409	0.433	0.433
Q4	0.253	0.200	0.212	0.270	0.273
Q5	0.480	0.480	0.523	0.551	0.529
Q6	0.380	0.324	0.318	0.369	0.380
Q7	0.165	0.221	0.219	0.229	0.211
Q8	0.149	0.185	0.204	0.195	0.176
Q9	0.162	0.153	0.160	0.201	0.192
Q10	0.055	0.038	0.058	0.107	0.095
Q11	0.333	0.357	0.356	0.355	0.348
Q12	0.261	0.230	0.244	0.280	0.277
Impression	0.445	0.433	0.450	0.483	0.475
Event Proportion	0.416	0.322	0.326	0.409	0.422
Contribution	0.337	0.346	0.352	0.375	0.367

V. DISCUSSION AND CONCLUSION

A. Potential Threats to Validity

As our data were gathered in a real class setting and students were not enrolled primarily as research subjects, some anomalous situations occurred which we had to work around. In one case, there was a 4-member team in which one member stopped working and attending meetings early in Sprint 1, and later withdrew from the class. We chose to exclude this team member from analysis to reduce the risk of producing a statistical outlier. The team was treated as a 3-member team, and the small amount of activity by the omitted member was ignored as if it were influence from outside the team.

We also encountered a situation in which a team member moved from one team to another between Sprints 2 and 3, but later made a small commit to the previous team's Git repository. This commit had one child and one parent. In tuple generation, the child commit was treated as if it were a direct child of the anomalous commit's parent, and the anomalous commit was ignored.

Another potential issue is the complex dependency of events in different sprints, due to the fact that most teams keep the same members across sprints. Students are evaluated and graded separately for each sprint, but the separation is likely imperfect. For instance, a poor grade in one sprint might motivate higher performance in the next, and team members might develop status and sentiments in one sprint that could affect their interactions and peer evaluations in later sprints. It is possible that influence may manifest itself differently in different sprints based on how long team members have worked together. However, we believe that there was significant independence in the communication and collaborative activities during each sprint, as well as evaluations of team members, to justify the use of the data.

B. Conclusion and Future Work

The correlation results from this study support the hypothesis that social network analysis can be applied in small teams to make predictions about the likely performance of individuals. Thus, social network analysis may provide a useful way for instructors, supervisors, or team members to monitor the performance of individuals in an agile software development team, and detect potential problems.

One key result from the study shows the benefits of assessing the frequency and content of communication among team members. Given Table III's correlation values, influence appears to be manifested most among forum posts. While an instructor needs artifact-based events to track and grade a student's project engagement and outcome, having access to team communication provides a clear mechanism to assess who is exerting influence on the team. Self-reporting team evaluations provides additional insights into a student's perception of a team member and their own role on the team. Table III also provides some evidence that the consideration of indirect influence based on the timing of interactions may improve predictions.

One goal for our future work is to repeat our analysis with a larger data set having at least 200 samples. A larger sample may provide more detailed information about the behavior of our sociometrics.

Other important directions for future research include seeking ways to automate the construction of influence networks (thus making our metrics much easier to apply in practice) and determining how artifacts can be more effectively incorporated into our analysis.

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Adaptive systems as enablers of feedback in English language learning game-based environments

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Abstract — This paper presents perspectives on adaptive web-based learning environments, their tasks, functions, techniques and methods. The main categories, types and layers of adaptive learning systems as well as different forms of feedback used in these environments were examined. The significance of feedback becomes emphasized in learning environments because it helps to plan the student's learning path, provide information about their progress, note the important information and guide the student along the learning process. This work introduces an evaluation framework for the analysis of game-based learning environments by the main criteria used in adaptive learning games. The analysis is focused on various learning environments, specifically applications and games for English language learning. The analysis results in an evaluation of 23 game-based learning environments and applications that are developed for the purposes of English learning. The relationship between the feedback types and areas of English learning is presented.

Keywords — *adaptive learning system; game-based learning environment; feedback system; English-learning games*

I. INTRODUCTION

In recent years, there has been a growing interest towards utilizing adaptive intelligent technologies in creating learning environments for enhancing more personalized education. The use of these technologies contributes to improving the quality of education, as well as reducing the time required for mastering learning content. Learning environments that adjust themselves according to the needs and abilities of individual users or groups of users are called adaptive learning systems.

Adaptive learning systems allow organizing content, identifying the way to learn according to learner's knowledge and use assessment results to provide personalized feedback to each learner [1]. Adaptation of the learning process implies a change in the sequence of the studied topics and visual representation of each viewing page. The quality of the educational process in web-based learning systems depends on the use of adaptive technology, methods and built-in mechanisms.

This paper provides a short review on existing adaptive game-based learning systems, specifically concentrating on English language learning. The use of game-based learning in English language learning has spread on a wide area including games and applications that may be used, for instance, for vocabulary and grammar learning, pronunciation and listening comprehension, and it has been proved to improve learning [2], [3], [4]. However, as the previous studies reveal, research in the area of feedback in applications and games has not yet been conducted to a large extent and at the same time the amount of students hoping to improve their language skills by

using e-learning tools is increasing. As Belotti F. et al. [5] point out, technology and various tools can be used to provide a learner with assessment and feedback without the presence of an instructor or a teacher.

The problem of assessing the quality of adaptive learning system, the problem of choosing technologies and methods for constructing such adaptive systems, as well as determination of the causes of low efficiency of learning are relevant for the development of such systems.

Despite the fact that significant results have been achieved in the area of adaptive learning systems, including practical ones, there are not any defined evaluation criteria and optimal components for these systems, nor are there any specific requirements for the construction of logical and structural models for these systems. In order to build a good quality adaptive game-based learning system, developers have to understand the main criteria for the evaluation of these systems.

This paper consists of five sections. Section 2 presents general information about adaptive learning systems and their division according to types, methods, technologies, features and levels. Section 3 opens a discussion about the meaning of feedback in game-based learning environments, especially focusing on English learning. Section 4 presents a design of evaluation framework for adaptive English learning game-based environments and criteria for this evaluation. Section 5 concludes the paper by presenting results in 23 evaluated game-based learning environments according to feedback types. It presents feedback types used in different English learning areas, addressed in selected game-based learning environments, and the relationship of English learning areas to the types of feedback.

II. CONTEXT OF THE ADAPTIVE LEARNING SYSTEM

A. Adaptive Learning and Adaptive Learning Systems

According to Gifford T. [6] adaptive learning is a method that is centered on "creating a learning experience that is unique" for every individual learner through the intervention of computer software. Adaptation in learning can be viewed from several different aspects: adaptation to the current needs of particular learner; adaptation to a particular learner's state; adaptation to a chosen specific field for studying and adaptation to a specific task.

According to Sonwalkar N. [1], adaptive learning systems are technological systems that are capable of adapting and learning depending on received input signals. Intelligent adaptive learning observes each decision a student makes and

adapts the student's learning pathway (or produces many personalized learning paths, which are specifically designed to a student's unique needs).

The goal of an adaptive learning system is to individualize learning so it becomes possible to improve or stimulate student's performance gain. According to Weber G. [7] the system is able to "enhance the individual learning process with respect to speed, accuracy, quality and quantity of learning". Adaptive learning systems are intended to identify what a student does and does not understand, identify and provide content that will help the student learn it, assess again, help again, etc., until a defined learning goal is achieved [8].

Adaptive distance learning systems have a number of advantages, the main ones being: providing opportunities to choose student's own path of learning; differential approach to learning based on the fact that each learning experience and knowledge in one area that determines the degree of understanding of the new material is different; increasing objectivity and knowledge control efficiency of the student; individualization of learning activities; and increasing motivation and activation of cognitive activity of students.

B. Types, Technologies, Methods, Levels and Features of Adaptive Learning Systems

Earlier research has indicated that adaptive systems can be defined according to their types [8], utilized technologies [9], [10] methods for building these systems [11], [12], [13], [14], levels [8] and features [15], [16].

The main types of adaptive learning systems are simpler adaptive systems and those that are algorithm-based [8]. Simpler adaptive systems are based on rules and are more content-oriented. They are easier to understand in terms of functionality; however they are less adaptive to individual needs of students. Here is an example of a system flow: the system asks the user a question, and if the answer is correct, it continues to the next one. If the given answer is incorrect, the system helps the user by displaying additional information, e.g. a hint, same learning material repeated, additional learning material, explaining the matter in a different way, etc. Algorithm-based systems are based on advanced mathematical formulas and machine learning concepts. These systems are more complex. Such systems may make use of educational data mining and advanced analytics to deal with big data, and employ complex algorithms for predicting probabilities of a particular student being successful in learning particular content.

There are two main technologies utilized in the design of adaptive systems: Adaptive Hypermedia Systems and Intelligent Tutoring Systems [10]. Adaptive Hypermedia Systems include adaptive presentation and adaptive navigation support. Intelligent Tutoring Systems include curriculum sequencing, intelligent solution analysis and problem solving support.

Adaptive and intelligent technologies can significantly improve the quality of distance education systems. Adaptive presentation can improve the usability of course material. Adaptive navigation support and adaptive curriculum sequencing can be used for full control over the course and to aid in selecting the most appropriate information and regulations. Problem solving support and intelligent solution analysis can significantly improve the quality of software requirements, and make teachers' work easier.

Many techniques and methods have been utilized in the development of adaptive learning systems [11], [12], [13], [14]. The main methods include the data-based inference method (case-based reasoning, machine learning, collaboration filtering), theory-based inference method (Bayesian networks, Naive Bayes analysis, fuzzy logic, Dempster-Shafer theory of evidence) and decision-making methods (influence diagrams, decision theoretic planning). Some of the techniques are using learning style (MBTI, Kolb's, Felder-Silverman, and The Vark) and some are using technologies based on Semantics (ontologies, agent-based, etc.).

The levels of adaptivity are determined according to the complexity of a system. Verdugo D. and Belmonte I. [4] present five levels, which differ in regard of complexity and features.

Level 1: Students complete a quiz after reading the material and the system provides feedback informing the student on whether or not the given answer was correct.

Level 2: Same as in Level 1. In addition, the system provides some explanations detailing why some answers were incorrect, as well as presenting a link to the material for a review.

Level 3: Same as in Level 1. Furthermore, the system gives a recommendation about the material to read. In the next quiz, the system will add the questions that have been answered incorrectly in the previous section to see if the student has mastered the material. Students can track their progress on the dashboard.

Level 4: The student studies learning material and then completes quizzes on it. Based on the results, the system provides an individualized learning plan that aims to fill any possible gaps in the student's knowledge. After completing the plan, the student completes another quiz to see whether he or she has made progress.

Level 5: A student is given a problem, and asked to fill in the gaps for each step along the way to a solution. Feedback is given right after each step or after the whole quiz. The feedback is based on the analysis of the steps the student has taken, compared to the most effective methods for solving such a problem. The system then selects the next question based on student's readiness.

The features of adaptive systems describe and provide relevant content and support, and guide the learner through the adaptive learning system and the accompanying courses [15]. The author divides such features into the following five categories according to the functions that a system can have.

- Pre-test: when the system begins with an assessment of current knowledge and skills. This assessment gathers information about personal learner characteristics, which include prior knowledge on the subject domain.
- Pacing and control: when a learner has control over certain aspects of the system, such as controlling the speed with which the content is presented, or the order in which the content is presented, among others.
- Feedback and assessment: when the system evaluates learner's progress and gives feedback according to his/her performance. Feedback can be presented as correct/incorrect responses, or the system can recommend material, resources and suggest some possibilities for additional practice.

- Progress tracking and reports: when the system can save the user's profile with his/her progress, and the user has a possibility to start from where he/she left off. System can also generate some periodic progress tracking according to individual progress.
- Motivation and reward: when the system includes gamification elements to motivate its users. This can involve rewards (points, stars, badges) for passing levels, and its aim is to advance the users' performance and achievement.

According to Paramythis A. and Loidl-Reisinger [16], there is one extra feature that could be used for defining adaptive learning systems. This feature is about understanding the student's requirements and preferences.

III. THE MEANING OF FEEDBACK IN GAME-BASED LEARNING ENVIRONMENTS

A. Feedback Types and Formes Used in Game-based Learning Environments

The significance of feedback becomes emphasized in learning environments and games because it helps to plan the student's learning path, provides information about his/her progress, notes the important information and guides a the learner through the learning process [17], [18]. In games and learning platforms, feedback can improve learning and help the learner to make decisions about his/her learning strategy, while also increasing the learner's motivation [19]. Breuer and Bente [20] (as quoted by Bellotti et al., 2013) state that incorporating the elements of assessment into games makes assessment more invisible and enables a more thorough use of the medium itself.

In the definition of Mory E. [21], feedback is any message that is generated in response to a learner's action, usually after the learner has completed a particular task or function. It implies that there is an "interactive flow between the learner and the system, coming from some information collected or generated by the learner and coming back to him as an output after some processing".

There are many existing studies based on categorization of feedback. Table 1 presents the number of feedback types [22], [23], [24], [25], [26] and their description.

According to the provided descriptions of each feedback type in Table 1, it could be argued that informative and conformational feedbacks are closely related to each other. These types of feedback only provide information on whether the answer is correct or not. Likewise, instructive and corrective feedbacks are also closely related, because they provide corrections and instructions on how to get the correct answer. Explanatory and elaborative feedbacks are also concentrated on similar things, providing explanations of why the answer provided by the user is wrong. Information-based and point-based feedbacks are closely related, because they provide the accuracy and quality of answers in levels of mastery, progress bars, cumulative points, etc.

Taking into account that some of the feedback types have the same functions, this study used a combination of feedback types, specifically informative, corrective, explanatory, diagnostic, point-based, consequence-based and interactional feedbacks provided by Kinzer C. et al. [22], McNamara et al. [23], Kapp K. [24] and Mackey A. [25]. These types are related to the features used in adaptive learning games and applications in area of English learning.

TABLE I. FEEDBACK TYPES

Author	Type	Description
Kinzer C. et.al. [22]	informative	provides information on results, does not explain why the results are right or wrong.
Mory E. [21]	informative	is focused on self-regulation, related to the context where learning takes place.
McNamara et. al [23]	information-based	is concentrated on providing the accuracy and quality of answers and actions including immediate corrections, delayed corrections, level of mastery achieved on specific content.
McNamara et. al. [23]	point-based	can be conveyed in the form of cumulative points, progress bars, and levels.
Kapp K.[24]	conformational	indicates the degree of "rightness" or "wrongness" of a response, action, or activity. Feedback immediately informs the learner if he or she did the right thing, the wrong thing, or if it was somewhere in the middle. This feedback doesn't tell the learner how to correct the action.
Mory E. [21]	instructive	is related to the knowledge domain. It provides instructions on how to get right answer.
Kapp K. [24]	corrective	guides a learner with instructions. If the learner did the wrong thing, he or she will be prompted, guided, or pointed toward a more appropriate action. Corrective feedback informs the learner that their response was incorrect and provides knowledge of the correct or desired response.
Kapp K.[24]	diagnostic	provides diagnosis about incorrect answers. It defines why the incorrect response was chosen, corrects those common mistakes through the feedback.
McNamara et. al [23]	consequence-based	is a type where the system reacts to the user's responses or actions by changing the system path (paths of actions taken by the system).
Kinzer et.al. [22]	elaborative	provides more information about why an answer was wrong and what has to be done to correct an error.
Kapp K. [24]	explanatory	works as corrective feedback but it also includes relevant information about why an answer is correct or incorrect. It provides a rich explanation to a learner for effective encryption of knowledge.
Mackey A. [25]	interactional	provides the receiver of the feedback with corrective feedback based on learner's utterances, for instance, on pronunciation or articles. Used frequently in language learning applications and games

B. Game-based learning in English Learning and the Significance of Feedback

In order to analyze various English learning applications and games, it is important to understand the underlying processes normally associated with language learning. As we think about language learning as a process, we normally associate certain features to it: listening, reading, speaking and writing. Of these four, the first two are receptive skills, which

normally precede the following two productive skills, speaking and writing. Johnson K. [26] notes, however, that these skills are frequently intertwined, e.g. a learner working on a writing exercise can benefit from previous speaking exercises. Learning grammar and vocabulary are also frequently connected to mastering a foreign language.

There are, however, more thorough ways of categorizing the skills involved in foreign language learning and acquisition. Johnson K. [26] has divided the process of learning a language, basing the division on an earlier model by Canale, M. and Swain, M. [27], into three various parts: systemic competence, sociolinguistic competence and strategic competence. In order for a person to master a language properly, he/she has to be familiar with the various sounds in the target language, the rules that apply to that specific grammar and the lexis, that is, the vocabulary or words of the language. These components form an important ground for further knowledge of language learning. The sociolinguistic competence, on the other hand, entails the cultural norms that one has to take into account when speaking a certain language. This area of language includes, for instance, the codes of being polite in a specific culture language wise. The last one, strategic competence, and covers a language user's ability to handle situations where the right type of vocabulary, for instance, is not found.

At this point it is important to mention that the focus of the present study is on foreign language learning and acquisition which diverges itself from the process of the natural first language acquisition [26]. As explained by Krashen S. and Terrel T. [28] language learning follows certain paths and learners typically acquire certain language features in a certain order. According to the natural order hypothesis, grammatical morphemes, for instance, are acquired in a highly organized manner by children and adults with progressive from preceding articles, irregular past forms and possessive forms [28].

Many studies conducted in the field of English learning with games and applications give proof that they improve learning outcomes for students. Aghlara L. and Tamjid N. in [29] discovered in their study aimed at Iranian, six- to seven-year-old girls that vocabulary of animals, family members, numbers and colors was acquired more efficiently with a software game than with traditional teaching tools, such as blackboards and flash cards, which was explained by the increased motivation of children playing the game. Verdugo D. and Belmonte I. in [4] also share the same result with children's listening comprehension. They studied six-year-old Spanish learners and concluded that the children learning with digital stories improved their skills in listening comprehension more compared to those learning with traditional methods. Verdugo D. and Belmonte I. in [4] mention the more focused way of learning and individual learning pace as key elements that favor the use of digital stories as a form of developing learners' listening comprehension. Vocabulary acquisition and learning with applications and games has been examined in many studies. Cobb T. and Horst M. in [3] studied the word acquisition process with a vocabulary training system and they concluded that with the use of the system in language learning, significant results were achieved. During a two-month period, participants learned the amount of vocabulary that in a normal classroom setting is achieved in one to two years. Aghlara and Tamjid [29] share this result and they further state that vocabulary, in addition to the increased speed of learning, is also retained longer in the memory of a learner with online games compared to the traditional classroom environment. Yip F. and Kwan A. in [30] imply that the enhanced learning experience created by a mobile English vocabulary learning

system is explained by a more personal and flexible learning method.

Games and applications for learning may include various elements for signaling how a player has succeeded in it. The most common, and perhaps the most simple, form of receiving feedback in educational English learning games is to signal the right and wrong answers, for instance, by giving awards for correct answers. Aghlara L. and Tamjid N. in [29] studied a game for English vocabulary learning which offers confetti for every right answer whereas a wrong answer will be delivered in the form of a squashed tomato. Scoring is another popular method of providing feedback for learners [31]. With scoring, learners are able to see how others have succeeded in the game but most importantly they are being informed of which aspects are the most significant in the learning process. Michael D. and Chen S. in [32] have studied the effect of an automatic scoring system in an application for rehearsing English pronunciation. The benefit of such system is that a teacher is not required to provide a learner with corrections but the feedback is provided automatically by the system. This type of a feedback mechanism is able to provide the learner with feedback, for instance, on mispronounced phones. This type of a mechanism is able to tackle areas such as spectral match, phone duration, word duration and speech rate in foreign language learner's pronunciation [33]. Chen C. and Chung C. in [31] studied vocabulary learning with a personalized mobile English vocabulary learning system that uses the collected information to improve the learning process. The idea of the system is to first to determine the learner's vocabulary skills with a pre-test after which the learner is able to proceed to the actual learning process based on the test results. A learner is first provided with a rehearsing mode of the targeted vocabulary, which is followed by a test mode. The learning process is stored in a personal portfolio showing the learner the progress with the vocabulary. The improved learning with the system is connected to the system's ability to recommend a learner with appropriate vocabulary.

As language learning is a complex process, the feedback and assessment techniques utilized in the games and applications should support a learner to acquire and master areas in language learning, such as vocabulary, grammar and pronunciation. Sandberg J. et al. [34] summarize that such support could be provided to a learner by offering more difficult content (such as words) more often, providing feedback that goes deeper than just pointing out the correct and wrong answers (e.g. explanations), taking in the information and knowledge a learner already possesses on the subject, and offering a learner with formative targets and assigning new study objects based on the results.

IV. RESEARCH METHODS AND DESIGN

A. Procedure

Previous studies used criteria for the evaluation of learning systems mostly from the perspectives of technology and education. Yip and Kwan [35] used two criteria for the evaluation of educational websites: an educational perspective and a technical perspective. Educational perspective concentrated mostly on information quality, and technical perspective concentrated on navigation, consistent look of the websites and the use of multimedia-like enhancement. Wood [36] discussed in his work desirable criteria related to technical features of vocabulary websites, such as animations, sound components, hints or clues, multimodal presentation of information, and online definitions for the words. Cowan [37]

suggested to use criteria such as relevance, peer interaction, continuous motivation and minimum equipment.

As for the evaluation of adaptive learning systems, the criteria that has been used [38], [39], [40] has been based on evaluation of input data, inference, adaptive decision, total interaction, predictability, privacy, controllability, breadth of experience, unobtrusiveness, timeliness, aesthetics, necessity, consistency, etc.

In order to make an evaluation framework for the adaptive learning applications and games in English learning, we used criteria that is based on defining adaptive learning systems and feedback types in those systems. In this study, we concentrated on various areas of English learning, age level, adaptive system features which were based on combining features discussed in Section B of Chapter 2 with features of feedback, types of feedback, levels of adaptivity and types of adaptive learning systems. The analysis is not based on the techniques and methods of adaptive learning systems, but mostly on the features of these systems for defining types of feedback and levels of adaptivity.

B. Description of Evaluated Game-based Applications for English learning.

In order to reach a sufficient amount of games and learning solutions for the evaluation process, many searchers were executed through Google. Searching in Google was considered to provide us with the broadest selection of English games. The following search terms were used: "games for English learners", "best apps for English learning", "best apps for learning English grammar", "best apps for learning English vocabulary", "applications for English language learners" "online games for English language learner", "best applications for language learning", as well as "adaptive learning in English language teaching", "adaptive games for English learning", "intelligent learning games for English learning", "smart games for English learning", and "intelligent learning applications for English learning".

Games and learning solutions were also selected based on their availability, namely whether they were free of charge for users. There were many web-based applications; some of which could be used on tablets or mobile phones. The applications that clearly did not include gaming aspects or that did not give learners the opportunity to exercise their language skills were excluded from the evaluation. Various sites were then browsed through in order to discover whether there were games that frequently surfaced after which they were included in the study.

In the following phase, 23 games were selected for the evaluation process. Both applications and games were included in the study, in order to construct as comprehensive a picture of the various feedback features as possible. Applications and games were selected in a way that they represent different aspects to language learning, covering areas from systemic and sociolinguistic competence, as explained by Canale M. and Swain M. [27] to the four significant skills of language learning, those of reading, writing, listening and speaking. The analysis included altogether 23 English learning applications or games ranging from colorful vocabulary games for preschool children to more comprehensive individualized learning paths for adult learners. Many of the applications and games could be used for several educational levels; three were targeting preschool children, nine primary school students, 17 junior high school students, 15 high school students and 16 adult learners. The applications and games were also selected to cover the

various language proficiency levels from beginner levels to the more advanced proficiencies. 15 of the applications and games included the beginner level, 18 the intermediate level and 15 the advanced level.

C. Criteria for the Evaluation Framework

For the analysis of the selected English learning games and applications, a table was created, in which evaluation criteria such as application name, area of English learning, grade, level of knowledge, learning system features, types of feedback in those systems, levels of adaptivity and types of adaptive systems was used.

Areas for English learning, such as grammar, vocabulary, reading, writing, listening, speaking and culture, were listed. Preschool, primary school, junior high school, high school and adult learners were used in the analysis of grade/age. Such levels as beginner, intermediate and advanced were used in the analysis of level of knowledge.

For the analysis of adaptive system features we used a list of features according to our research in Section 2:

- 1) *Checking the right or wrong answer:* the system simply tells the user if the given answer is correct or not.
 - 2) *Providing hints:* the system gives hints if a user is struggling.
 - 3) *Providing explanation:* in the case of an incorrect answer, the system explains why the answer is incorrect.
 - 4) *Understanding the users' requirements and preferences:* the system asks questions about the user's hobbies, preferences and goals.
 - 5) *Progress tracking and reports:* the system can track the user's progress and the user can see it on his/her dashboard.
 - 6) *Updating information according to user's actions:* the system changes the material to be learned according to the user's progress.
 - 7) *Diagnosis of the users' mistakes:* the system detects why the answer were answered as wrong.
 - 8) *Having a live discussion with a tutor:* this could be with a native speaker or with a tutor.
 - 9) *Pre-test:* the system conducts a pre-test to detect the user's level of knowledge and to provide recommendations.
 - 10) *Pacing and control:* the option to control speed, select a level, change courses, etc.
 - 11) *Providing recommendations:* when the system recommends what material to study.
 - 12) *Motivation and rewards:* the system provides rewards for the user, which can be used to move to next levels or when competing with other users.
 - 13) *Creation of learning path:* the system creates an individualized learning plan.
- The first eight features are related to feedback type recognition. In our study, we used seven types of feedback:
- 1) *Informative feedback:* includes feature 1.
 - 2) *Corrective feedback:* includes feature 1 and feature 2.
 - 3) *Explanatory feedback:* includes feature 1 and feature 3.
 - 4) *Diagnostic feedback:* includes feature 1 and feature 7.

- 5) *Point-based feedback*: includes feature 1 and feature 5.
- 6) *Consequence-based feedback*: includes feature 1 and feature 6, also not obligatory is feature 4.
- 7) *Interactional feedback*: includes feature 8.

Rule-based and algorithm-based systems were used as types of adaptive systems. Five different levels were used for adaptive systems according to our research in Section 2.

Level 1 includes feature 1 (checking right or wrong answer).

Level 2 includes feature 1 (checking right or wrong answer) and feature 3 (providing explanation).

Level 3 includes feature 1 (checking right or wrong answer), feature 11 (providing recommendations), feature 5 (progress tracking and reports) and feature 6 (updating information according to users actions).

Level 4 includes feature 1 (checking right or wrong answer) and feature 13 (creation of learning path).

Level 5 includes feature 1 (checking right or wrong answer) and feature 7 (diagnosis of users' mistakes).

V. RESULTS AND DISCUSSION

23 game-based environments and applications that included different types of feedback were analyzed in the paper.

After the analysis of the selected applications, we also found other criteria which could be taken into account, such as: collaboration (ability to learn together with someone), mobility (users could use applications on tablets, not only on computers), having how-to videos with explanations, having a discussion area, etc.

The applications and games in the present study can be categorized into four sections: applications and games for grammar (5 out of 23), vocabulary (8 out of 23), speaking (pronunciation) (2 out of 23) and applications that include multiple language learning goals (8 out of 23).

In addition, a deviation of main and second areas of English language learning was applied. Main area has number "1" for the analysis. Secondary areas have number "2". If a system does not include a specific area, it is signaled with a "0". According to Table 2, there are 12 applications that have grammar as one of the main areas of English learning. 16 applications have vocabulary as one of the main areas of English learning. Ten applications have reading as one of the main areas of English learning. Seven applications have writing as one of the main areas of English learning. Nine applications have listening as one of the main areas of English learning. Seven applications have speaking as one of the main areas of English learning. Zero applications have culture as one of the main areas of English learning, but seven applications have culture as secondary area of English language learning.

According to the number of features in applications (discussed in Section 4), we detected the types of feedback that each system uses and the level of adaptivity in these systems. The level of adaptivity 1 is more common (appears 12 times out of 23) because it is a more simple one. Level of adaptivity 2 appears 8 times out of 23 and level of adaptivity 3 appears 3 times out of 23.

Other levels need to have more features. The most common feedback types are informative feedback and point-based feedback. Diagnostic feedback does not appear in the list of

analyzed applications. This type of feedback appears more in high-level adaptive learning systems.

TABLE II. SURVEY OF THE ENGLISH LEARNING AREAS AND THE FEEDBACK TYPES USED IN THOSE AREAS

Application (game-based environment)	Grammar	Vocabulary	Culture	Reading	Writing	Listening	Speaking	Type of feedback
Grammar up	1	2	0	2	0	0	0	3,5
Practice English Grammar	1	2	0	2	2	0	0	3,5
Grammaropolis	1	2	0	2	0	2	0	3,5
British council's learn English grammar	1	2	0	1	2	0	0	1,5
IKnow!	0	1	2	2	2	2	1	2,5
PowerVocab Word Game	0	1	0	1	0	2	0	2, 5
Knowji	0	1	0	2	2	2	2	1,5,6
Bitsboard	0	1	0	2	2	2	0	2,5
Arcademics	2	1	0	2	0	0	0	2,5
Quizlet	2	1	0	2	2	0	0	1
Speaking pal	0	2	2	2	0	2	1	1,5
Hawina	0	1	2	2	0	2	1	1,5
Duolingo	1	1	2	2	1	1	1	3,5,6
Busuu	0	2	0	1	2	1	0	1
The interactive grammar of English	1	2	0	2	0	0	0	3,5
Rosetta Stone	1	1	2	2	1	1	1	1,5,7
LinguaLeo	1	1	2	1	1	1	0	1,6
SHAIEEx	0	1	0	1	0	1	0	1,6
Agnitus Personal Learning Program	0	1	0	1	2	2	0	1,5,6
Scootpad	1	1	0	1	1	1	1	2,5,6
Voxy	1	1	2	1	1	1	2	1,5,6,7
Babbel	1	1	0	2	1	1	2	2,3,5
Livemocha	1	1	2	1	1	1	2	3,7

As an experiment, we analyzed the relationship of English learning areas to the types of feedback. As shown in Table 2, one game or application can have several areas of English learning and several feedback types.

In Table 3, the relationship between the English learning area and the feedback types is presented in percentages, knowing the total amount of applications and the frequency of feedback type in a selected area.

We discovered that there are similar features in applications targeting the same types of language skills. In English learning areas like grammar, vocabulary and reading, the most common type of feedback is informative and point-based. Vocabulary also has corrective feedback. In the English learning areas such as writing, listening and speaking all feedback types are almost equally presented (but with the frequency under 6) except of diagnostic feedback. As culture is not a very popular area of English learning, it has a low frequency of informative, explanatory and point-based feedback in secondary area of English language learning.

TABLE III. RELATIONSHIP BETWEEN THE ENGLISH LEARNING AREA AND THE FEEDBACK TYPES, %

Area	Type of feedback						
	informative	corrective	explanatory	diagnostic	point-based	consequence-based	interactional
Grammar	17,4	9	30	0	44	17,4	13
Vocabulary	35	26	13	0	12	30	13
Reading	26	9	4,3	0	21,7	21,7	8,7
Writing	13	8,7	13	0	21,7	17	13
Listening	21,7	8,7	8,7	0	21,7	21,7	13
Speaking	17,4	4,3	8,7	0	26	13	13
Culture (only for secondary area)	4,3	0	4,3	0	4,3	0	0

Informative feedback is basically incorporated into each application and game that we examined in our analysis, and it typically takes the form of simply signaling a learner with either a correct or an incorrect answer. Corrective feedback is almost identical with informative feedback also entailing the part of informing a learner about the correctness of the answer (explicit correction). There are examples where the right answer is simply explicitly stated to a learner. Alternatively, the system briefly shows the correct answer after which a learner corrects the answer accordingly. Metalinguistic feedback, also a part of corrective feedback, on the other hand, is in one application interpreted to represent a situation that points out the incorrect parts for a learner without actually stating how to correct it. One application we analyzed included a clarification request that was a part of a speaking exercise. Examples of explanatory feedback typically include a brief explanation following the wrong (sometimes also the correct) answer. Some of the grammar specific applications and games analyzed have explanations about grammar rules that are not necessarily connected to exercises or games. Each of the applications and analyzed games incorporated at least some elements of point-based feedback in the form of cumulative points, progress bars or levels or a combination of the three. Interactional feedback is rather difficult to analyze

since it can be interpreted in many ways. Naturally all of the applications and analyzed games include some interactional elements such as instant information about the correctness of the answer. There are, however, some applications that allow a learner to discuss the learning process with other users therefore making the learning experience even more interactional.

Most of the English learning applications have multiple learning goals; therefore, it is difficult to separate the various language areas from each other. Furthermore, in many cases, the applications are not targeted for a specific group but they offer a creation of a personalized learning path.

CONCLUSION

In this article, we presented a short review on adaptive web-based learning environments and applications according to their tasks, functions, techniques, methods and levels. We examined feedback, which is an important feature of all adaptive learning systems. According to the selected adaptive game-based environments and applications based on English learning, we found some similarities in feedback types according to a specific English learning area.

The main problem in analyzing the contents and various feedback features of English learning applications and games is that at most times they are complex systems targeting multiple language learning goals simultaneously. Therefore, it is rather difficult to divide the applications based on any one area of language learning, e.g. grammar or vocabulary. Instead, the trend in the applications for English learning at present time seems to be the aim to provide a language learner with a personalized learning path that leads a learner from the beginning steps of language to the more advanced levels.

According to our results, we can say that the more complex feedback types the system has, the more adaptive it will be. Therefore, it is very important to know which types of feedback to use while creating adaptive learning systems with high level of adaptivity. Feedback is an important feature of the adaptive learning systems since it can help to guide users. They can see how they are progressing and what needs to be improved. If there are any problems with answering questions and a learner is struggling, embedded feedback should provide hints and explanations to support the learning process. When a learner has some incorrect answers, the system should include the same questions in the next lessons to see if a learner can solve the task according to provided instructions and learned material.

The findings from the present study function as important guidelines for the developers of various applications and games for English language learning. The users of the applications and games will also get some ideas to select the best tools to guide them in the language learning process.

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Game-Based Assessment for Radiofrequency Circuits courses in Engineering

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Abstract—In addition to a high technical level and performance in their discipline, engineers of the 21st century require a high level of general or transferable skills that allow them to excel in their work environment. Engineers at the University of Antioquia in Colombia are no strangers to this situation, which is why the University has decided to face this new condition through the inclusion of activities in courses that support the development of these skills. Part of these activities includes the transformation of the traditional evaluation scheme for Radiofrequency Circuits course in Electrical and Telecommunication Engineering programs. This transformation has been performed taking advantage of the LMS (Learning Management Systems) platforms, web and mobile application and game-based learning techniques. The development of innovative practices that can leverage information and communication technologies is one of the major challenges in education. This paper shows the design of an online game-based assessment and training strategy. The new assessment and training tests were designed to help students improve their learning outcomes on the course topics; meanwhile, they promote development of general or transferable skills such as the ability to solve problems in complex situations and working under pressure.

Keywords—Assessment strategies; Game-based learning; LMS; Mobile applications; Professional performance; Transferable skills; Web applications

I. INTRODUCTION

Engineers at the University of Antioquia, Medellín, Colombia, have been characterized by a high technical standard. However, due to high professional competition and they work for society, engineers must not only be people with great disciplinary knowledge, but also be integral professionals. Since 2005, the University of Antioquia has been developing several investigations about the lack of comprehensiveness on professionals, which has led to the restructuring of undergraduate engineering curriculums. With the curricular changes, the program added the use of virtual platforms in some courses, and also has promoted the development of student transferable skills that improve their professional and personal performance [1, 2, 3].

The Radiofrequency Circuits course, which is taught at the undergraduate level in Electrical engineering and Telecommunications Engineering programs at the University of Antioquia [4], is a deepening course in wireless

communications area and is offered when the student has completed 70% of the courses on his career. The course is divided into two parts, one part is theoretical and the other one is a laboratory. Traditionally, the theoretical component assessment has been evaluated through 6 tests, using traditional strategies such as paper based tests and writing home works.

The University has been using during the last 10 years virtual platforms to support the student learning process, including assessment modules of these platforms, which simulate the behavior of paper based tests made in the classroom. Since 2014, the program, has been designed a strategy to develop new assessments schemes, changing some of the traditional assessments to game-based training and assessment schemes that not only assess knowledge of the course topics but also allowed improving transferable skills of students.

This article presents the design of a training and assessment tool, and is organized as follows: Section II presents an overview of Game-Based Assessment Scheme and transferable skills; the Section III shows the new approach of evaluation schemes in Radiofrequency Circuits course assessment; and Section IV presents the proposal study and finally the conclusions are stated.

II. TRANSFERABLE SKILLS AND GAME-BASED ASSESSMENT SCHEME

Since the late 20th century, society has professionals with technical or disciplinary skills, and also skills that include values and attitudes that enable them to confront and solve important new century problems [2]. The transferable skills are those skills that are transversal to many activities, common to different professions and related to aptitude, knowledge and values of people [5]. These transferable skills are part of the 21 century skills [6, 7].

Studies have found a relationship between the transferable skills development in people and their subsequent educational and labor outcomes. People, who develop transferable skills on their education, has better academic results and better attitudes and behavior in several situations [6, 8], and are more effective when use this abilities in a specific contexts [9].

These competences could be developed using new assessments schemes. There are various techniques with which one student can learn about a topic and at the same time

develop transferable skills. According to several studies, traditional tests formats such as multiple choice, essay or short answers are not completely appropriate to evaluate academic concepts and to improve transferable skills. Therefore the use of alternative assessments schemes becomes necessary [10].

For students, the assessment is important because it allows them to follow their progress and it also provides valuable information to teachers to give feedback to student, this information could be used to motivate them to keep learning. The assessment can relate the skills that the teacher hopes to teach with student expectations. Thus, a good assessment reflects good teaching [11]. A good assessment allows the teacher to know what students have understood, so the teachers can modify the way to reach the learning objectives based on this information [12, 13, 14].

Good assessment methods have to include the following characteristics: evaluate what is intended to measure, predictive validity of future behaviors and should motivate the student to work hardy in challenging scenarios [12, 13]. Assessment should be an engagement for the learner, help to improve persistence and 21th century skills, relevant for students and teacher, and provide a personalized learning environment [15].

However generally the real life problems are different from the ones students solve in their classes. This may be because real life problems do not have a standardized solving method; it needs collaborative systems, experience, diverse knowledge and especially transferable skills [16].

For that reason the teacher has the responsibility to change the traditional class assessment into one that reduces the gap between the traditional education and the real-world challenges. Alternative assessments methods involve real-world applications and ask students to create, produce, solve problems and develop their critical thinking. These assessments involve new strategies to accomplish learning outcomes [11, 14, 17].

Game-based assessment can help students to construct knowledge through trial and error, solving challenging problems that motivates students to learn intrinsically. Student can work or observe real life situations, motivating the need to reach the goals and improve their persistence [18, 19]. Digital learning environments can provide a meaningful assessment to students, where they can learn and play in scenarios where they have to improve several competences, like academic, social and personal. The really important point is to develop assessments that lead students to use their knowledge and combine it with other skills to solve different problems [12, 13].

With the Game-based assessment it is possible to transform a boring or stressing assessment into one that evaluates the knowledge and also can be enjoyable. Assessment with games, is a strategic option, because students have an inherent attraction to games, are part of their lives and “win the game” is one of the most valuable rewards. Shute and Ventura, Zapata Rivera and Bauer and DiCerbo [12, 14, 19] presents cases of success in game-based learning, where students develop class activities simulating games and finally acquire specific academic knowledge and transferable skills.

Bokyeong, Hyungsung and Youngkyun [20], present three strategies for learning with games that allows the students improve transferable skills: The self-recording which includes writing, modeling, thinking aloud, listening and speaking activities. Osman and Bakar [21] describe a method where the student is not only a player but also becomes in a playmaker. This is known as collaborative game making. Its importance lies in that students can make part of creating a game, where they can learn the class subject, inventing meaningful games and allows them to develop transferable skills, as critical thinking, creativity, innovation, problem solving and team work.

III. PROPOSAL ASSESSMENT SCHEME IN RADIOFREQUENCY CIRCUITS COURSE

Being in a technological age, it is necessary to potentiate and take advantage of information and communication technologies ICT. There are several Learning Management Systems LMS like Moodle, Canvas, Sakai, Blackboard, Desire to Learn [22, 23, 24, 25, 26] among others, all of them includes modules that allows interoperability and flexibility for assessment and training process [27].

The technological architecture includes the integration of services through standards such as LTI (Learning Tools Interoperability), Tin Can API (XAPI), XML- Moodle [28, 29, 30] and using the LMS and mobile apps as interfaces of interaction for students. The figure 1, shows the interaction between users and modules of the system.

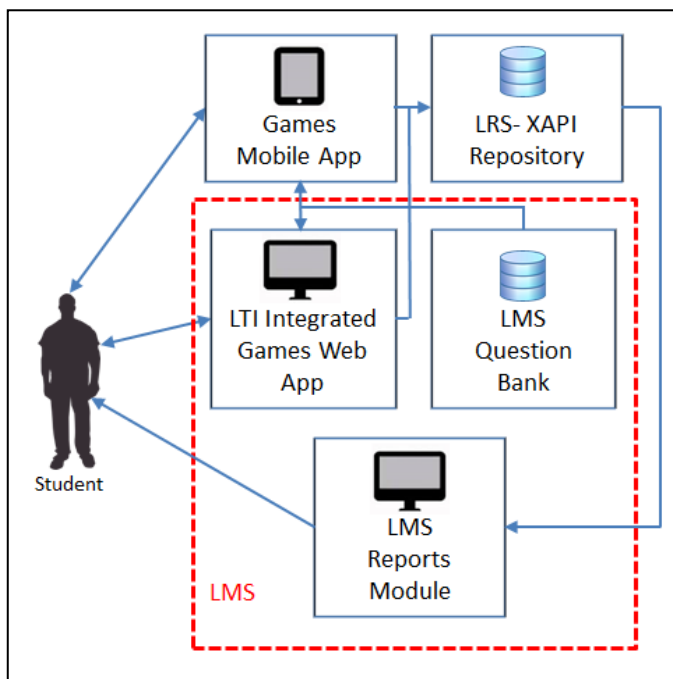


Fig. 1. User interaction with system modules.

The games for Radiofrequency circuits course are being developed in a web and mobile application versions. The web application could be integrated to LMS platform via LTI standard or could be used directly in Android devices like cell phones or tablets. These applications use the LMS question

banks as inputs for all games. In both cases (LMS integrated web and mobile application) the interactions will be stored in the LRS (learner record store) and the results of interactions could be included into student LMS reports. Figure 2 and 3, shows mobile app Mockup.

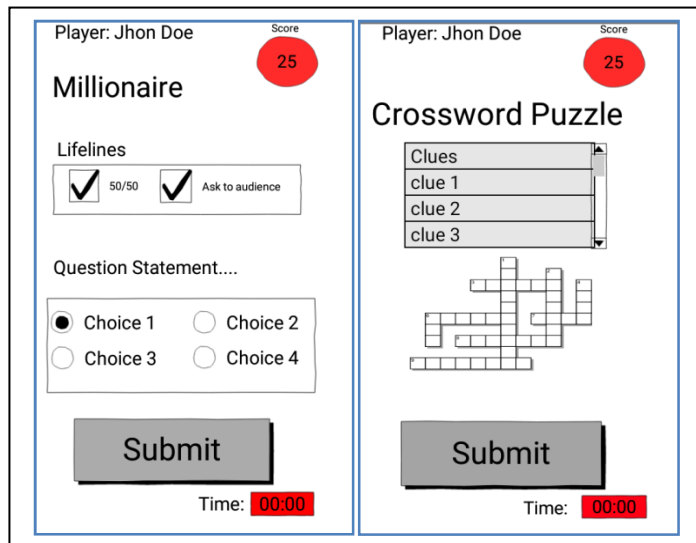


Fig. 2. Mobile app Mockup of Millionaire And Crossword Puzzle



Fig. 3. Mobile app Mockup of What happens if? and Cause-effect problems

The games were divided into four groups: Trivia Games, Word Games, Prediction and Decision making. The style of question planned for different games includes multiple-choice questions, short answer and essay. Games are different each other according to particular intentions, some of them are focused in development of solving problem skills, while others have the goal of improve the agility of giving solution to a complex situation when time is a limited resource. The difficulty level of each interactive game has direct correspondence with the skills level defined in the course topics. These games are aligned with transferable skills like: decision making, working under pressure, problem solving, willingness to learn, self-motivation and analytical thinking.

Descriptions of each game, type of question used for develop them and an example of real question that will be used in the Mobile app Mockup (see figure 2 and 3) are:

- Trivia game: Millionaire. The aim of the activity is answer a series of questions, where each new level of questions increases difficulty. If the student answer correctly, (s)he goes to the next question. The student has 1 minute to answer each question. The activity has two types of lifelines: 50-50 where the platform deletes 2 wrong answers and ask the public, where the student can go to an internet page using hyperlink and consult the question during 30 seconds. The type of questions used to develop the game was: Multiple choice questions. The student can decide not continue with the game on any moment, but (s)he cannot answer the question before leaving. Example:

If you have a circuit with $R_S = 10 \text{ ohm}$ and $R_L = 50 \text{ ohm}$, which coupler do you use?:

- Resonant Coupler
- Coupler type T
- Coupler type L
- Coupler type π

Helps:

- 50 – 50
- Ask the audience (consult internet)

- Word games: Crossword Puzzle: the activity presents a track to student and (s)he should interpret it and write the concept that is reference. The student has 30 minutes to develop the activity. On this game, short answer questions were used. Example:

5. (Across) RF output power and DC power ratio.

- Prediction of future events: “What happens if?”. In this activity, a real life or laboratory situation is presented to the student, then (s)he have to predict what happens later. On this game, the student has 5 minutes to write the answer. Multiple choice questions, short answer question and essay were used. Example:

What happened if you are in a laboratory with a BJT mixer circuit and you change the transistor for another with higher transconductance. If the initial mixer has a low amplitude output, what would you think is the amplitude of the mixer with the new transistor?

- Decision making game: Cause – effect problems. The activity presents a series of real life situations, where the student should make a decision. These decisions affect subsequent situations, and then the activity has multiple ways of solve it. The student has 2 minutes to take each decision. If the student does not choose any answer, the game will end. Type of questions used: multiple choice or short answer questions, according to the previous response. Example:

You have a video transmitter with 3 blocks: an oscillator, a low signal amplifier and a power amplifier. If the central frequency should be 56.92 MHz and the output amplitude 1.92V, but the oscilloscope shows 51.87 MHz and 1V and you use T band-pass couplers, you can:

- a. Change the output T type coupler of the power amplifier.
- b. Change the T type coupler between the low signal amplifier and the power amplifier.
- c. Change the value of the mechanical capacitor of the oscillator.
- d. Change the T type coupler of the low signal amplifier.

Currently, there are platforms that offer the possibility of bring training and evaluation processes through trivia games in different areas of knowledge. Kahoot and Duolingo [31, 32] are examples of mobile applications where questions can be created and solved through a playful interaction. One of the important contribution of the proposed scheme is that allows to link the gaming environment used by students and the formal on-line environment used for learning, commonly LMS platforms. This integration favors the monitoring and reporting processes in terms of time investment and student results on their gaming sessions. And also it helps to take advantage of the 70% of informal learning or experience learning that occurs outside the classroom, that when is mixed with 10% of formal learning, best results are expected to achieve in the course [33, 34].

Moreover, there are two reasons for using this evaluation scheme based on games. The first reason is based on the investment of time of students in interaction with course concepts involved along levels or stages of games. The second reason is to propose an additional learning challenge to student, because traditional methods of education generate some level of challenge, but games generate the additional addictive and engaging component. This motivates the player to achieve progress and increasing their score of previous attempts; this is commonly known as persistence. The evaluation scheme can transform an assessment moment in a learning process based on training and experimentation, allowing the existence of formative assessment and feedback schemes and even more, a development of transferable skills.

IV. STUDY PROPOSAL

The system will be used in the second semester of 2015 in the radiofrequency course to probe if the use of the new scheme of training and assessment can improve the student's motivation and scores on the course, and moreover if can help to develop some transferable skills. The course will use the game-based assessment system in each test, and a training session will be done before every quiz and laboratory practice. The periods of training with the system correspond to the periods in which each topic is taught. The students assessment

scores will be measured according to the number of clear levels, scores obtained on the games and time required.

At the end of the semester the student scores will be compared with the scores of the past courses that have used traditional assessments methods. And also a survey will be applied to know the perception of the students about the proposed scheme and transferable skills improvement. Some questions of the survey are:

1. If you compare the training and assessment games proposed with the traditional training and assessment, you would say proposed games are:
 - a. More entertaining but does not allow me to acquire knowledge
 - b. More entertaining and allow me to acquire knowledge
 - c. Equally entertaining and acquire the same knowledge
 - d. Less entertaining but allow me to acquire knowledge
 - e. Less entertaining and not allow me to acquire knowledge
 2. Will you consider investing more time training with the games proposed that in traditional homework?
 3. Do you think that using the training and assessment games helps you to acquire transferable skills?
 - a. True
 - b. False
- Which? _____

V. CONCLUSIONS

Implementation process imply high technical skills like: design and implementation of web and mobile applications, integration of web services through educational standards and LMS management, which requires a multidisciplinary work.

The game-based training and assessment strategy proposed have the potential to be implemented in other undergraduate courses.

The development of more games and activities could help to mapping other transferable skills like: team work, communication skills, co-operation among other, that are not included on this version of the system.

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Teaching K-12 students STEM-C related topics through playing and conducting research

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Abstract—Living in the world that is rapidly changing and is strongly interconnected with digital technologies puts a lot of pressure on K-12 students' teachers. Although, today's K-12 students are surrounded by technology and computers from the day they are born, they also must learn the basic principles of computer science in order to be adequately equip for their future jobs. However, Science, Technology, Engineering, Mathematics and Computer Science (STEM-C) fields are too wide and too complex for only K-12 schools to participate in the teaching process. In this paper we thus present how high education institutions can cooperate with elementary and secondary schools in STEM-C education process of K-12 students. We will share two good practices for allowing K-12 students to learn STEM-C related topics that have been implemented in Puerto Rico and Croatia. The objective of both projects is to establish a pipeline for K-12 students to go to colleges, and from colleges to graduate schools. The paper will present the impact of the program on the pre-college and university community of Puerto Rico, as well as the results of outreach activities conducted in Croatia.

Keywords—K-12 students, early research experiences, STEM-C fields, learning programming through "playing" computer games

I. INTRODUCTION

According the U.S. National Academy of Engineering and National Research Council the Science, Technology, Engineering, Mathematics and Computer Science (STEM-C) fields are too wide and too complex for one single educational institution to cover all areas [1]. It is thus of vital importance to combine the strength and knowledge of various institutions in order to achieve successful education of students in STEM-C fields. The academia and other high educational science institutions, as well as research laboratories, have the knowledge and resources that elementary and secondary schools lack of. In this paper we will show how K-12 students can benefit from simultaneously combining both "sides" of education.

As opposed to elementary and secondary schools that have very firm schedules and clear learning outcomes, after-/out-of-school STEM-C settings (i.e., informal education) can contribute towards K-12 students' development of interest and identity in STEM-C fields. In that way, already jam-packed elementary and secondary school curricula do not have to be extended or reorganized, and students can have a boost they need to consider STEM-C fields as an important part of their lives. Here we do not only want to make an impact on K-12 students that will work in STEM-C fields in future, but also on

every K-12 student as this knowledge will help them to cope with the challenges that will await them in their everyday lives.

Informal STEM-C education can be either a long term or a short term one. Both approaches have its advantages and disadvantages. For example, when K-12 students are involve in a long term after-/out-of-school STEM-C program then they get better understanding of how things work in this particular case and gain more extensive knowledge. However, they can experience only a limited number of opportunities as this approach is time consuming. Moreover, time constraints also affect educators who can provide these opportunities to only a limited number of K-12 students. On the contrary, when K-12 students are involved in short term programs then they can explore different types of programs and since they are short, more students can benefit from participating in them.

In this paper we will present both approaches and compare them in cases of K-12 students involved in programs run in Puerto Rico and Croatia. Namely, in Puerto Rico K 10-12 students are mostly involved in STEM-C long term research projects: (1) 16 weeks out-of-school program on Saturdays, (2) research mentoring process by undergraduates, (3) pre-college research symposium, and (4) 7 weeks summer research program at the US mainland research institutions. In Croatia K-12 students and their teachers are involved in shorter term programs: (1) K-8 students visit our research groups and departments where they play and learn how to code, (2) K 9-12 students do their own specific mini projects with their school teachers during a school year and then present them at our university, and (3) K-12 school teachers learn how to improve their approach to teach STEM-C concepts in a fun way.

The rest of the paper is organized as follows. In Section II we present related work and Section III describes two frameworks that are used to carry out STEM-C outreach activities: "SUZA - from school to science and the academic community" in Croatia and the Student Research Development Center (SRDC) in Puerto Rico. The SUZA program started in 2012, while SRDC has served as STEM-C outreach activity center in Puerto Rico for almost 15 years now. Furthermore, Section IV present short term out-of-school STEM-C activities, while Section V emphasizes our efforts made in long term outreach programs. Finally, Section VI comments on results that are obtained from our STEM-C outreach activities and Section VII concludes the paper.

II. RELATED WORK

Changes in STEM-C formal education are a "hot topic" across different countries in the world, although discussed differently by nations. Differences can be mostly seen in a case of level of integration of STEM-C and other fields. Some scholars are more keen on STEM-C taught using an integrative subjects approach, other consider STEM-C education to be the improved teaching of the separate subjects of STEM-C and many believe that it should be a combination of both of these approaches [2]. There are also some efforts made towards understanding challenges in developing a global curriculum [3]. However, no matter what their opinion on the level of integration is, it is widely accepted that STEM-C formal education needs to be complemented with the education activities conducted in informal STEM-C settings.

There is an extensive body of related work how universities and other research institutions can contribute to K-12 student's STEM-C education. Recently Steinmeyer has shown how to increase the reach of STEM-C exposure and education programs for high school students through the use of online environments [4] and Granchelli and Agbasi-Porter showed how intensive classroom lectures and hands-on activities can be used in their experiential STEM-C programs also for K 10-12 students [5]. Moreover, it has been shown that research is not only important on undergraduate level [6], but also on the high school level [7]. However, most of the studies are only concentrated on one STEM-C outreach activity (e.g., Kinect sensor [8], robots [9] or Arduino [10]) and are rarely focused on building pipelines [11].

In that sense, the contribution of this paper is threefold: 1) we propose a pre-college pipeline in which K-12 students participate at different stages of their pre-college education, 2) we introduce case studies of our STEM-C outreach activities in which we compare long and short term out-of-school STEM-C programs and 3) we distinguish among different goals for informal STEM-C education depending on student group ages.

III. FRAMEWORKS FOR STEM-C OUTREACH ACTIVITIES

All activities that are organized in Croatia are a part of a program called "SUZA - from school to science and the academic community" [12]. This program is the official popularization program of the University of Zagreb Faculty of Electrical Engineering and Computing in Zagreb, Croatia. We partner with the Institute of Electrical and Electronics Engineers (IEEE) Croatia Section and the student organization eSTUDENT with the support of two Croatian agencies: Education and Teacher Training Agency (AZOO) [13] and Agency for Vocational Education and Training and Adult Education (ASOO) [14]. The aim of SUZA is to increase interests of K-12 students and their school teachers in STEM-C fields by organizing different educational and popular science talks, presentations, workshops and organized tours.

All activities organized in Puerto Rico are grouped within Student Research Development Center (SRDC), which is a part of Ana G. Mendez University System (AGMUS) in San Juan, Puerto Rico. AGMUS became the model institution for excellence institution when received the first National Science Foundation (NSF) grant in 1985, following by others grants totaling over 30 million USD. One of the main objectives of

these grants was to establish a pipeline for pre-college from high school to college, and from college to graduate school for young economically disadvantage minority students from Metropolitan San Juan, Puerto Rico, interested STEM-C fields.

IV. SHORT TERM OUT-OF-SCHOOL STEM-C PROGRAMS

This section presents three short term out-of-school STEM-C activities, two of which were organized in Croatia and one in Puerto Rico. As mentioned earlier, activities organized in Puerto Rico are mostly, although not exclusively, a longer term and aimed to K 10-12 students, while activities in Croatia are mostly a shorter term ones and aimed mostly to K-8 students. Namely, as the vision of SUZA program is to ensure the feasibility of the mutually entangled priorities of high science and industrial leadership defined by the Horizon 2020 program through ensuring quality learning outcomes and professional guidance for the top students [15], in SUZA we want to (1) start early (i.e., include K-8 students), and (2) reach out to as many students as we can (i.e., in form of short term outreach activities). On the contrary, STEM-C outreach activities in Puerto Rico are more oriented towards pre-college students (i.e., K 10-12 students) helping them with their transition from a high school setting to a university life.

A. Scientific visits for K-8 students

K-8 students should be first introduced to the basic concepts in STEM-C fields in order to understand that this is an important part of our everyday lives [16]. Applying the described concepts, we organize K-8 student short visits to our research groups and departments followed by a programming class similar to the Hour of Code [17]. These short term visits are usually 2-3 hours long and follow the same format: K-8 students are first introduced to simple theory concepts that are behind things they are going to see (see Fig. 1) and then they can even try simple examples by themselves (see Fig. 2). Finally, they participate in a short programming workshop where they write their first codes (see Fig. 3).



Fig. 1. Our volunteers explaining basic theoretical concepts before showing the real-world examples of their research.

At our university in Zagreb, Croatia in total we have 12 departments where each department has different focuses and things to explain and show to K-8 students. For example at Department of Electroacoustic K-8 students learn about physical phenomenon related to sound propagation, visit so-called "deaf chamber" and experience a professional audio equipment in a controlled environment. They also learn about how dangerous it is to hear music very loudly and can "play" with some sound equipment.



Fig. 2. Experiencing "deaf chamber" and playing with sound equipment.

Last part of the visit is a programming workshop where K-8 students do a pair-programming with help of our volunteers and learn basic concepts of computer science with drag and drop programming [17]. Using this game-like approach, they learn repeat-loops, conditionals and basic algorithms.



Fig. 3. Learning basic programming concepts in pairs with help of our volunteers and earning certificates for successfully finishing the workshop.

B. Science fairs for K 9-12 students

K 9-12 students should have a basic knowledge about: (1) STEM-C in the modern world, (2) STEM-C concepts and practices, and (3) specific topics in STEM-C. They should first learn how to appreciate the breadth of computing and its influence in almost every aspect of modern life and should be aware of social and ethical impacts of their choices when using computing technology, both in their work and personal lives. Then, they should also learn how to clearly understand the application of computational thinking for tackling the real-world problems and how to work collaboratively to solve various problems using modern collaboration tools. Finally, K 9-12 students should be involved in projects-based work focusing on a single problem [16].

In contrast to short term programs that we organize for K-8 students where we want to make a first impact on student lives, by organizing short term programs for K 9-12 students we hope to help students to continue their interest in STEM-C fields. With that goal we help K 9-12 students to present outcomes of their work at a scientific fair. Fig. 4 shows

a student fair that was organized at our university for two years in a row and where more than 60 students and teams from almost 30 technical and vocational secondary schools in Croatia presented their work in front of their future professors and colleagues. Their work was judged by external team of university professors and research assistants and the best of them got awards for their achievements.



Fig. 4. Defending their work in front of judges.

C. Research symposiums for K 10-12 students

In Puerto Rico twice a year (i.e., in December and May) we organize AGMUS pre-college research symposium with the goal of emphasizing the importance of conducting research work starting already in pre-college years. Namely, at this event K 10-12 students present their research results in forms of professional posters or oral presentations. By doing so, K 10-12 students gain experience of communicating their scientific results using PowerPoint presentations and computer-generated posters (see Fig. 5).

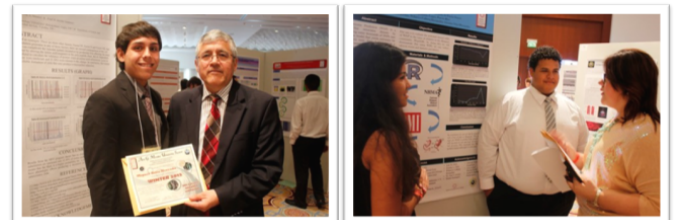


Fig. 5. K 10-12 students at the poster session.

A typical structure of AGMUS pre-college research symposium includes: a poster session set up, breakfast, registration followed by an opening ceremony with a keynote speaker presenting motivational and state-of-the-art talk every time with a different topic (e.g., topics from robotics, computational chemistry, computational biology, modeling and simulation, software development, visualization and astronomy). Moreover, during the symposium K 10-12 students have opportunities to attend workshops for example in ethics, English and STEM-C fields.

The efforts of the students that showed the most outstanding performance are recognized at the end of the symposium during the closing ceremony when they are awarded the certificates (see Fig. 6). By presetting in this research symposium, pre-college students not only gain knowledge and practice how to present their work in front of others, but also do get feedback on their presentation performance as they are evaluated by professional judges (e.g., faculty members and/or specialists within the area).



Fig. 6. The awarded K 10-12 students.

All posters and oral presentations are in English, which is not their mother tongue, so they practice to present in a foreign language as well. Finally, in addition to the pre-college students who present their research work, other K 10-12 students who do not have any prior research experience are also invited to attend the symposium. By just attending, these students have the opportunity to see posters and presentations done by their peers that can give them a push to try the same in the following years.

Once when AGMUS pre-college research symposium finishes, we publish a special post symposium proceedings in which we include all presented posters and given presentations. Although this event can be seen as a short term one, it has long term positive effects on lives of students who participated in it as we encourage them to continue with their research activities and to participate in national and international research conferences. We also support them in their future years as young scientists by providing them with more information about the process of publishing in peer-reviewed journals [18].

D. Short term programs for K-12 school teachers

Within SUZA program we also offer K-12 school teachers in STEM-C fields educational workshops where they can learn how to present STEM-C topics in such a way that is understandable, interesting and attractive to "ordinary" people, especially youth (see Fig. 7). Namely, during their studies, future K-12 school teachers usually learn how to present the required content in a traditional ex-cathedra way. However, times have been changed and nowadays K-12 students want and expect more out of their education.



Fig. 7. Teachers listening to presentations.

This is also recognized by AZOO and ASOO agencies that are encouraging K-12 teachers in their life-long learning process. Not only school teachers are encourage to take additional "classes", but attending certain programs is even mandatory. That is why the aforementioned workshops entered the calendar of professional teacher conferences and are now

a part of the lifelong learning education and professional education offerings for K-12 school teachers in Croatia.

V. LONG TERM OUT-OF-SCHOOL STEM-C PROGRAMS

In this section we will present two types of longer term outreach activities designed for pre-college students. Both activities are organized in Puerto Rico. The first one is a pre-college research program organized in a partnership with institutions in Puerto Rico and US Virgin Islands during the school year, while the second one is a summer research program for pre-college students, undergraduates, and graduates organized in collaboration with some of the best universities and research institutions from US mainland and abroad (e.g., MIT, UCLA, UC Berkeley, University of Texas-El Paso, Carnegie Mellon University, Spanish Research Council).

A. K 10-12 student research program on Saturdays

The AGMUS pre-college research program is developed with NSF support who awarded us with the three grants: Modeling Institutions for Excellence, AGMUS Institute of Mathematics and Caribbean Computing Center for Excellence [19]–[21]. The main objective of the program is that K 10-12 students by attending Saturday research-oriented activities become more interested in STEM-C fields and afterwards enroll more easily to universities in the same fields. This is a longer term program that is run twice a year (i.e., during both fall and spring semesters) with total load of on average 64 hours per semester (see Fig. 8).



Fig. 8. Students involved in research programs run on Saturdays.

Students, while participating in research activities in STEM-C fields, are guided by their research mentors who are mainly undergraduate and graduate students. Research mentors provide students with knowledge and skills that they need to conduct their research. Namely, training that they get comprises of basic steps how to do research starting with how to make a literature review, format research hypotheses, what methods to use, how to get results and finally how to draw conclusions from their research.

They also learn about research protocols and safety, how to make a good plan for dissemination activities and the most importantly what the "real world" application of their research/science can be. Some of the examples of the previous projects are: (1) extrapolation of stock market data using MATLAB, (2) a study of Newton's law using Maple, (3) simulation of the Lorenz equation using an RK4 algorithm in C++, and (4) gamma ray burst associated with Supernova: a highly correlated physical sample.

B. Summer pre-college research program

Every summer for the last five years we have been organizing 7 weeks summer research program in which our partners were institutions in the US mainland and abroad (see Fig. 9). The list of partner institutions includes: MIT-Haystack, University of Vermont, University of Texas, El Paso, National Center for Atmospheric Research, North Carolina State University-Raleigh, Vanderbilt University, UCLA, UC Berkeley, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, and Jagiellonian Observatory in Krakow, Poland.



Fig. 9. Summer pre-college research program flyers for 2012, 2013 & 2014.

The participants for this program are selected among the best performing students who attended our research programs on Saturdays during the given school year. The selected participants travel in groups of five, supervised by a chaperone, to one of the partner institutions where their mentors provide them education in the following core areas: (1) hands-on laboratory research, (2) computer-based research, (3) mentor/modeling, (4) career counseling and orientation, (5) professional growth, and (6) English language enhancement. A list of previous projects includes:

- Leg design for a praying mantis robot
- Visualization of molecular-dynamics simulations

- Tekkotsu support for the calliope platform
- An ontology on algorithms for high spatial resolution image interpretation
- Graphical display of search trees for transparent robot programming
- Teaching robotics in a three-dimensional visualization environment
- Development of educational data mining environment for the analyses of Moodle data
- Robot for support teaching parabolic trajectories
- Dog simulation behavior through the game of "catch"
- Effectiveness of a sensor-based video game system in the therapy of students with special needs.

During the program students spend on average eight hours per day, five days per week doing research-related activities under their mentor supervision. On weekends and holidays a chaperone, who is usually an undergraduate student, organizes cultural and social activities for them. Selected students are prepared and trained during a spring or fall semester prior to the summer one participating in research methodology seminars, English courses, and other professional development activities. Moreover, we help them with their travel and housing arrangements. Finally, as they move forward with their research we monitor their progress either via e-mail either by having weekly meetings on Skype or by telephone.

At the end of the summer experience, students have to make their posters and prepare oral presentations that they present both at their research sites while still there, and later one during a local research symposium held in Puerto Rico early in fall of the same year (see Fig. 10). The AGMUS research symposium is a two days event organized with the goal of bringing together pre-college, undergraduate and graduate students presenting their research projects in STEM-C fields [22], [23]. In addition to student research presentations, future participants can get an insight into summer research internship opportunities offered by major US research institutions such like MIT, UC Irving, Carnegie Mellon, University of Vermont, Princeton, University of Colorado, Boulder, UCLA, Washington University, St. Louis. The AGMUS research symposium finishes with an award ceremony where the best students are recognized for their posters and oral presentations and where they receive prizes from local industries and commerce.

VI. RESULTS OF OUT-OF-SCHOOL STEM-C PROGRAMS

We achieved great results both in short and long term outreach activities in STEM-C fields. Activities that we have organized in Croatia during the last two years made impacts on more than 500 K-8 and K 9-12 students all together. Our university was visited by K-8 students from 4 different elementary schools in Croatia: (1) more than 60 students visiting from elementary school "Kralj Tomislav", (2) more than 20 students from elementary school "Pavel Miskin", (3) more than 20 students from elementary school "Tin Ujevic", and (4) more than 10 students from elementary school "Stenjevec". On top of that we had more than 100 K-8 students participating in Hour of code workshops.

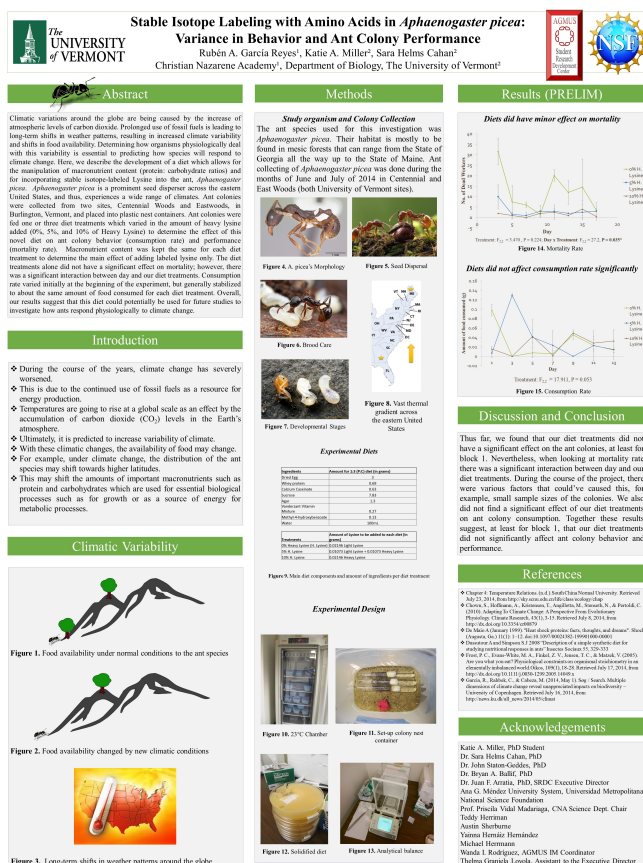


Fig. 10. An example of a scientific poster made by a pre-college student.

In addition to K-8 students, we also supported different activities for K 9-12 students. By organizing student scientific fairs and mini hands-on workshops, in total we hosted more than 210 K 9-12 students, where the full statistic is as follows: (1) more than 20 Swedish secondary school students, (2) more than 90 students participating at Student fairs 2013 and 2014, (3) more than 30 students visiting from Technical school "Ruder Boskovic", (4) more than 40 students participating in Scientific Saturday, and (5) more than 10 students visiting from Electrotechnical school. Finally, in collaboration with other popularization groups, initiatives and organizations in Croatia, we made impact on more than 540 not only students, but also other individuals interested in STEM-C fields.

In order to improve our program after each event that we organize we collect students' feedback. We rarely give to them specialized questioners, but rather support their creativity to express their opinion in a nonstructural and for them the most preferable way. In that sense, K-8 students expressed their opinions through their paintings (see Fig. 11), while K 9-12 students provided us with their feedback in form of a short written summary of their visit along with things that they liked or did not like. We took their feedback very serious and tried to improve our further activities based on the things that they did not like as much. Although our main goal is not only to promote our university, we are proud when students before leaving say: "See you in ten years!".



Fig. 11. A K-8 student giving us her feedback.

In partnership with public and private high schools across Puerto Rico and the US Virgin Islands for the last fifteen years we have impacted more than 4,550 K 10-12 students from 225 schools. The partnership with the Department of Education of Puerto Rico, and the Municipalities of the major cities and town of Puerto Rico and US Virgin Islands helped with the recruitment and selection of pre-college students for the research agenda. The model has a very successful track record of transferring almost 100% of the participants into college, and a rate of 85% of them into STEM-C fields. Fig. 12 shows outcomes of our activities that we organized for the last fifteen years. The blue colored bar denotes the number of project per year, while the orange one denotes the number of students participating in those projects.

The most important outcome of our long term project in Puerto Rico is the establishment of a pipeline from pre-college to college and from college to graduate school for STEM-C minority students from Puerto Rico and the Caribbean. During the last fifteen years we have witnessed to numerous successful examples of students who were involved in our projects. It can be either a short term success when for example technical papers that students write as a part of their summer pre-college research program are published in scientific journals or a longer term success when our students finish good universities and build a successful scientific career. In the rest of this section, due to the lack of space, we are going to mention only a few of them.

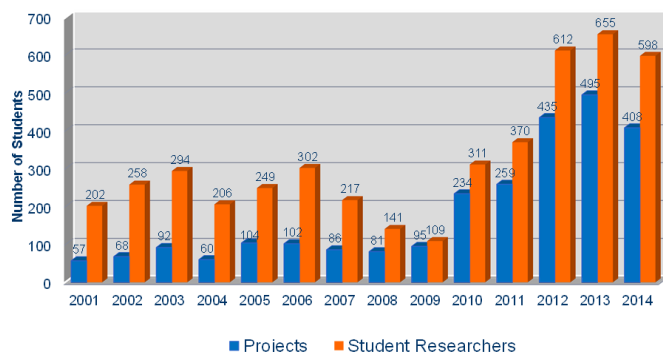


Fig. 12. Outcomes of outreach activities organized in Puerto Rico.

One of the successful short term outcomes was when the technical paper written by a student Andrea Boria who worked in the research project "Gamma Ray Burst Associated with Supernova: A Highly Correlated Physical Sample" under the mentorship of Dr. Maria Dianotti from the Jagiellonian Observatory in Krakow, Poland was published as a journal paper. Other longer term successful stories are in cases of Dr. Dalvin Mndez and Dr. Joshua Martnez, who are both from Puerto Rico. Namely, Dr. Dalvin Mndez, who entered our program as a 10-K student, finished an undergraduate program in Chemistry, Ph.D. in Computational Chemistry at Arizona State University and now is a Postdoc at Yale University. Dr. Joshua Martnez, who also joined our program in grade 10, finished his undergraduate program in Material Sciences at MIT, Ph.D. in Bio-Materials at Johns Hopkins University and now is a Postdoc at Oxford University, UK.

The list of universities where we successfully implemented our pre-college pipeline includes: the University of Puerto Rico-Mayaguez, MIT, the University of Texas-El Paso, Universidad Metropolitana, Universidad del Turabo, the University of Puerto Rico-Ro Piedras, the University of Puerto Rico-Humacao, Polytechnic University of Puerto Rico, Universidad del Sagrado Corazn, UC Irvine, UC Berkeley, the University of Virginia, Charlottesville, Howard University, Universidad Central del Caribe, Universidad Interamericana, the University of Vermont, Syracuse University, Tuft University, Cleveland State University, Boston University, Ohio State University, Georgia Tech University, the University of Maryland, Johns Hopkins University, the University of Kentucky, Pontificia Universidad Catlica de Puerto Rico, the University of Puerto Rico-Cayey, and the University of Puerto Rico-Bayamn.

To gather information about the outcomes of our activities, our students are always asked to complete an anonymous evaluation questionnaire. The evaluation questionnaire is usually a modified version of the Student Assessment of their Learning Gains instrument [24]. Due to lack of space, we are going to show only results from research program run on Saturdays in 2014. Of 65 participants who participated and completed the online survey, 24 (38%) were males, and 39 (62%) were females. In relation to education level, 21 (33%) were high school seniors, 18 (29%) were juniors, 8 (13%) were sophomores, and 12 (19%) were freshmen, and 3 were college students (5%). Most participants, 56 (90%) were Puerto Rican, 2 (3%) were White, 1 (2%) were African American, 3 (4%) reported "Other" race/ethnicity and one student did not report his/her race/ethnicity.

After finishing our program, participants reported substantial knowledge in relation to numerous scientific research-related variables. As illustrated in Fig. 13, over 70% of participants reported "great deal of knowledge/a lot of knowledge" in relation to all of the scientific research related-variables.

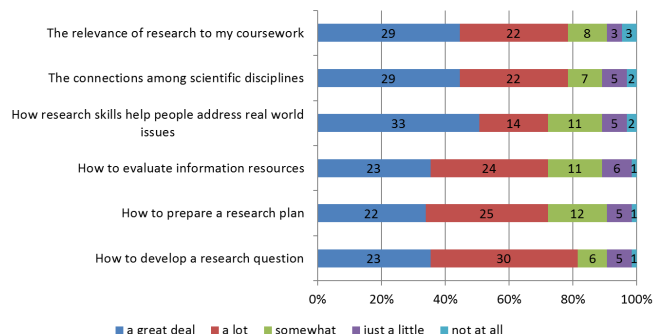


Fig. 13. Students' scientific knowledge and understanding of research.

Moreover, as expected, most participants (about 70%) reported "great/a lot" of skills in relation to many research/scientific related skills as shown in Fig. 14.

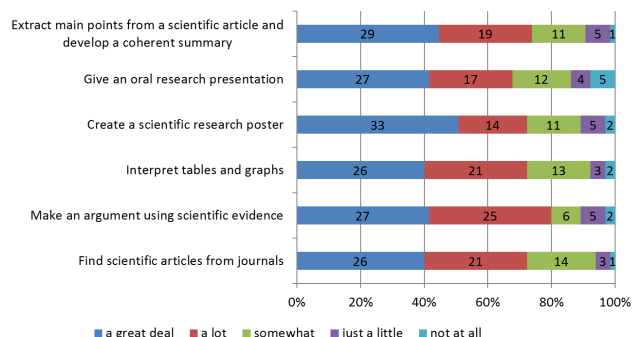


Fig. 14. Students' skills related to higher learning and scientific research.

Finally, as displayed in Fig. 15, over 80% of participants reported "great/a lot of interest" in relation to educational opportunities in STEM-C and over 80% of students reported interest in majoring in STEM-C and enthusiasm for research.

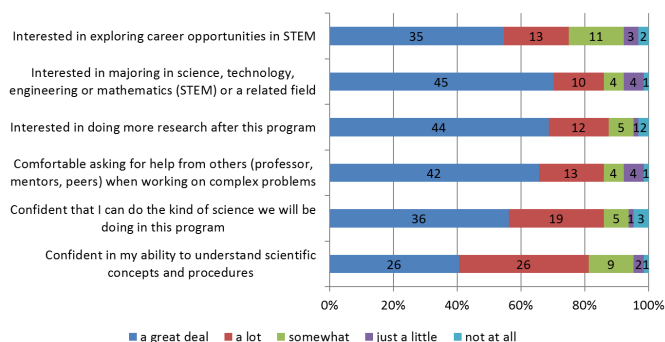


Fig. 15. Students' attitudes and interests in higher learning (Ph.D. in STEM-C), science, and research.

VII. CONCLUSION

As today we are facing very rapid changes in the way we are living (e.g., crowd-sourcing, crowd-owning), it is very hard to predict what future is going to look like. However, the thing that is very obvious is that jobs people (i.e., today's K-12 students) will have in 10-20 years are going to be more and more connected with digital technologies. In that sense, it is of vital importance to prepare today's students for the future challenges in the best way we can, i.e., by teaching them basic concepts of STEM-C fields. Without any doubt, this knowledge is going to be needed not only for people working in those fields, but also for other professions.

In this paper we presented two ways of introducing K-12 students to STEM-C fields: by involving them into short and long term programs. With the goal of promoting STEM-C fields, we have been organizing different scientific events both in Croatia and Puerto Rico. We showed that both approaches have their own advantages and disadvantages. Unlike the longer term activities, in cases of short term activities, we are able to include more students. However, with longer term activities we are able to establish a pre-college pipeline through which we are able to achieve more concrete results.

In our future work, we will try to benefit from both approaches by combining them together and by merging our two programs into the one. Namely, in two settings that we have today in Croatia and Puerto Rico we have either a pipeline that starts at a pre-college level or disconnected activities at lower levels (i.e., for K-8 students). In order to get better results, we would need to establish a pipeline that starts in elementary school and continues until the college level. However, to successfully implement this model, we would need every entity in the pipeline supporting lower levels. That would for example mean that high schools would need to be involved in outreach activities for elementary schools, and elementary schools would need to participate in STEM-C popularization activities for kindergarten students. Once when fully established, students who enter this pipeline will have a lower level risk of dropping along the way. Consequently, this would mean that we would have more students educated in STEM-C fields. Finally, by having more people educated in STEM-C fields, in future we will hopefully live in a more advanced and safe world.

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Using Simulation Games to Teach Global Software Engineering Courses

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Abstract— Global software engineering is a growing field of research. The ability to develop software at remote sites provides means to utilize talents and skills in different parts of the world. Organizations and companies benefit from such diverse pool of developers. Recently, global software engineering courses started to be popular in academic settings to prepare generations of developers who can function in a professional way in such distributed setting. Courses are normally offered as part of computer science or software engineering degrees. There are different challenges pertaining to team members, environment and the interlacing factors like time zones, cultural diversity of team members, location barriers and gender issues. Simulation games have been used to teach classical software engineering courses. Simulation games can be used to illustrate and experiment with concepts like team management, performance and tool selection. SimSE is an educational simulation tool that provides graphical simulation environment to help students to practice anticipated challenges during software development. In this paper, we propose a model for distributed global software development simulation games. The model includes factors like time zones, cultural diversity of users (mainly Hofstede's culture dimensions are used), location barriers and gender issues. These factors will result in game triggers that may affect the development of the virtual project. The model is then implemented using the SimSE model builder. The game will be illustrated showing how it can be used in teaching global software engineering courses. The results will be verified using existing models.

Index Terms—Global Software Engineering education.

I. INTRODUCTION

Research in collaborative global software development (GSD) is mainly concerned with studying methodologies, tools, infrastructures, and other factors that influence distributed software development by culturally diverse teams. The main classifications of collaborative software development are: context, support, tasks interaction, teams, individuals and overreaching factors [1]. Typical problems in teaching global software engineering (GSE) courses include grading and aligning learning outcomes, securing proper communication and overcoming cultural barriers, different time zones and university calendars [2].

In the past 30 years, a considerable amount of literature has examined the definition and characteristics of culture, mostly from a person-task perspective. The most referenced research

of all literature on cultural dimensions in the context of global software engineering is that of Greet Hofstede, Project GLOBE, Trompenaars and Hampden-Turner and Hall [3]. Hofstede identified four major dimensions on which cultures may vary: Power Distance, Individualism, Uncertainty Avoidance and Masculinity. In subsequent years, Hofstede and his partners add two more cultural dimensions (Long-term versus short-term orientation (LTO) and Indulgence versus Restraint (IVR)) [4].

The general framework of our research aims to provide a longitudinal observation and documentation of distributed software development projects within an educational context. Over the period of 3 years, student teams at three sites (Kuwait, Poland and USA) will be assigned to collaborate in developing software projects. The projects and the student teams will change on an annual basis. The model simulates outsourcing in software development context. Many issues will be studied as the project progresses. Typically, the teams are enrolled in advanced software engineering courses (offered simultaneously at participating sites). The associated tools, risks and best practices will be investigated. We will choose a client from Kuwait for all experiments. We plan to run the experiments for 3 years (following similar previously reported experiments) to allow enough time for the evaluation of outcomes between the different phases.

The proposed simulation game is part of our research project. It can be used to teach and prepare students located at different sites about expected challenges in global software development. The simulations produced by the game should lead to improve the overall experience and minimize the risks and overheads. According to theories of diversity management, understanding the challenges associated with cultural differences at an early stage may help the workgroups to manage more effectively their cross-cultural communication and conflict management techniques. Based on the newly gained cultural understanding, the workgroups can come up with rules of interaction and reach a harmonization stage in which all groups are satisfied [5]. The main idea of the simulation game is to have three teams at different sites (one in Kuwait, one in USA and one in Poland) collaborate in developing software projects. The three sites belong to different cultures which may result in challenges. The goal of the simulation game is to help students understand

real challenges in global software development by trying different scenarios in the game.

The rest of this paper is organized as follows:

- Section 2 includes research background and literature survey.
- Section 3 includes related important issues to be included in the model.
- Section 4 discusses the simulation model and its components.
- Section 5 discusses how the model can be used in classroom.
- Section 6 concludes the paper and points to plans to future enhancements.

II. BACKGROUND AND LITERATURE SURVEY

SimSE model builder was used to implement the model. SimSE is an educational software engineering simulation environment that aims to bridge the gap between the large amount of conceptual software engineering knowledge given to students in lectures and the comparably small amount of this they actually get to put into practice [6]. SimSE provides a graphical simulation environment that helps students to practice and appreciate anticipated software development problems. Figure-1 shows a snapshot of the game [6]. The tool includes a model builder that can be used to construct games for different software development paradigms.

There are some other software engineering simulation games: SESAM [7], SimVBSE [8] and OSS [9]. Up to our knowledge, they do not simulate distributed software development using cultural models as a reference.

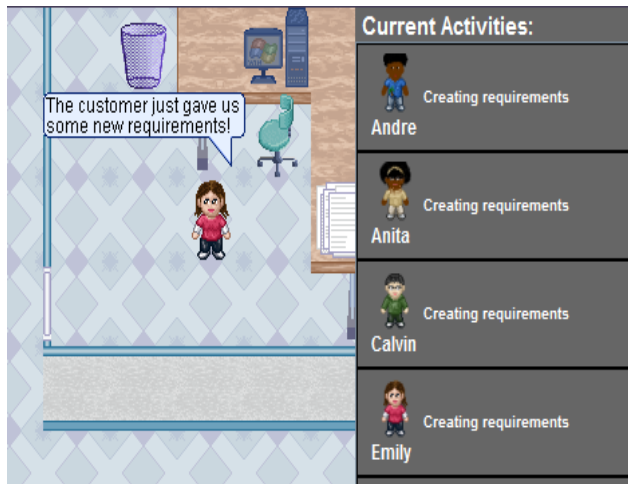


Fig. 1. Screen-Shot of SimSE tool.

A. Cultural Dimensions

Geert Hofstede conducted one of the well-known and most widely used studies about defining cultural dimensions. According to Hofstede, culture can be measured by six dimensions [10]. The following three dimensions are the most relevant measures to global software engineering [11]:

- Power Distance (PDI): This dimension expresses the degree to which people and society accept that power is not equally distributed. In societies with low power distance, people strive to equalize the distribution of power and demand justification for inequalities of power [10].
- Individualism versus collectivism (IDV): the degree to which people are attached to the group/tribe/family [10]. A society's position on this dimension is reflected in whether people's self-image is defined in terms of "I" or "we."
- Uncertainty avoidance (UAI): The degree to which people accept ambiguous and unknown future [10]. The fundamental issue here is how a society deals with the fact that the future can never be known: should we try to control the future or just let it happen? Weak UAI societies maintain a more relaxed attitude in which practice counts more than principles.

There are other cultural dimensions that will not be considered in our initial study. The remaining dimensions are [10]:

- Masculinity versus femininity (MAS): The masculinity side of this dimension represents a preference in society for achievement, heroism, assertiveness and material reward for success.
- Long-term versus short-term orientation (LTO): The long-term orientation dimension can be interpreted as dealing with society's search for virtue.
- Indulgence versus Restraint (IVR): Indulgence stands for a society that allows relatively free gratification of basic and natural human drives related to enjoying life and having fun.

Other efforts to define culture were reported. Examples include: Trompenaar's dimensions and Hall's dimensions [12]. The decision to base this discussion on Hofstede's dimensions is due to the fact that it is the most widely used cultural benchmark in the context of software industry since it was originally conducted at IBM. In next phases of research, other models and dimensions will be considered.

B. Global Software Development

Many empirical studies and literature reviews focus on the identification of challenges in collaborative work [13]. In the context of GSD in academia, there were similar projects that investigated possible challenges through experiments. The first project had two sites of software development (in multiple countries): one in Turkey and one in USA, while another experiment was done between USA and Sweden [14]. The clients in both experiments were from industry. During the first study, students from the US visited Turkey twice during the semester, once at the beginning of the project and once at the end. It was reported that time difference and language were among the major obstacles in performing the experiments [14]. The research group of Global Software Engineering at University of Victoria, Canada carried out several related research projects. One of the projects

investigated whether geographical distance continues to affect developers' collaboration in large teams that use development environments specifically designed to support collaborative distributed teams. Communication and response time were analyzed [15]. Another project at the same university developed an improvement to the original socio-technical congruence calculation in the literature. A metric that measures the strength of relationships between people and tasks, interdependent tasks and between project members was used [16].

Many efforts aimed at applying Hofstede cultural dimensions on global software engineering. Borchers suggested using three of Hofstede's cultural dimensions in the context of global software development [11]. Other research efforts argue that applying Hofstede's dimensions is not sufficient to study cultural factors in GSD [12]. Shah et al proposed using different cultural models instead of the dimensions of Hofstede [12].

C. Using Simulation in Global Software Development

The idea of using simulation to evaluate global software development projects was examined by Setamanit [17]. A hybrid simulation model was introduced [17]. The model includes fundamental factors, strategic factors and organizational factors. Fundamental factors include communication and coordination problems, cultural and time-zone differences. Strategic factors include development site, product architecture, task allocation and distribution overhead. Organizational factors include team formulation and team dynamics. The model has been verified and validated [17]. The model has been tested against ideal situation and real world cases [17]. In this paper, we will follow similar approach but we will add more details about the cultural differences using Hofstede dimensions. Our developed game simulation is verified using the simulation model of Setamanit [17].

III. ISSUES TO BE CONSIDERED IN THE MODEL

Learning outcomes of using the game partially cover the learning outcomes of the global software engineering course. In each category, the learning outcomes will be mentioned followed by a discussion of relevant issues to be considered in the model.

A. Fundamental Factors

1) Related Learning outcomes

The learning outcomes related to fundamental factors are (after playing the game):

- Students should be able to choose proper communication tools.
- Students should appreciate that cultural differences may affect the productivity of global software development teams.

2) Communication and coordination problems

The following two methods of communications can be considered: synchronous and asynchronous methods. Synchronous methods include video conferencing and chatting, while asynchronous methods include email and document sharing.

It has been argued that informal communication is important in enhancing distributed software development [17]. Distance may hinder informal communication. This may result in longer development time [17]. Coordination is affected by distance and time-zone differences as well [17].

A combination of both methods (synchronous and asynchronous) should be investigated in the game. Clear meeting agendas and minutes have to be written and disseminated early enough to give people with high UAI chance to read and prepare for meetings. Local meetings will provide an opportunity for low IDV teams to prepare and discuss in a more relaxed way before the actual formal meetings. A superior moderator for the meetings will be needed to accommodate teams with high PDI (Kuwait), while the moderator role could rotate in groups with low PDI (USA).

3) Cultural Differences

We conducted preliminary research adopting cultural measures in global software engineering [2]. The following table includes the three proposed cultural dimensions for the three proposed sites [4].

TABLE-1 CULTURAL DIMENSIONS IN KUWAIT, POLAND AND USA

	PDI	IDV	UAI
Kuwait	90	25	80
Poland	68	60	93
USA	40	91	46

It can be noticed from Table-1 that:

- Kuwait has the highest PDI, followed by Poland then USA.
- Poland has the highest UAI, followed by Kuwait then USA.
- USA had the highest IDV, followed by Poland then Kuwait.

A. PDI

- Kuwait has the highest PDI (90) which means that people accept an extreme hierarchical order which needs no further justification. Hierarchy in an organization is seen as reflecting inherent inequalities, centralization is popular, subordinates expect to be told what to do and the ideal boss is a generous autocrat.
- Poland (PDI 68) is a hierarchical society. This means that people accept a hierarchical order which needs minor justification.
- The United States score low on PDI (40) which is evidenced by the focus on equal rights in all aspects of American society and government. Within

American organizations, hierarchy is established for convenience, superiors are always accessible and managers rely on individual employees and teams for their expertise [4].

B. IDV

- USA has the highest IDV which means that it is a very highly individualistic culture. This translates into a loosely-knit society in which the expectation is that people look after themselves and their immediate families. There is also a high degree of geographical mobility in the United States and most Americans are accustomed to doing business with, or interacting, with strangers. Consequently, Americans are not shy about approaching their prospective counterparts in order to obtain or seek information. In the business world, employees are expected to be self-reliant and display initiative. Also, within the exchange-based world of work, hiring and promotion decisions are based on merit or evidence of what one has done or can do.
- Poland, with a score of IDV 60 is an Individualistic society. This means there is a high preference for a loosely-knit social framework in which individuals are expected to take care of themselves and their immediate families only.
- Kuwait, with a score of 25 in IDV is considered a collectivistic society. This results in a close long-term commitment to the 'group', be that a family, extended family, or extended relationships. Loyalty to the group in a collectivist culture is essential [4].

C. UAI

- Poland and Kuwait have high UAI thus they have a very high preference for avoiding uncertainty. Countries exhibiting high uncertainty avoidance maintain rigid codes of belief and behavior and are intolerant of unorthodox behavior and ideas. In these cultures, there is an emotional need for rules (even if the rules never seem to work). Time is money, people have an inner urge to be busy and work hard. Precision and punctuality are the norm, innovation may be resisted. Security is an important element in individual motivation.
- USA scores 46 on this dimension and therefore, the American society is what one would describe as "uncertainty accepting." Consequently, there is a larger degree of acceptance for new ideas, innovative products and a willingness to try something new or different, whether it pertains to technology or business practices [4].

4) Language Differences

Non-native English speakers tend to prefer asynchronous communication methods to have more time to understand and plan their answers [17]. However, using asynchronous communication methods may lead to delays due to difference in calendars and working hours.

5) Time-Zone Difference

Difference in time zones is a factor that will affect communication methods. Kuwait is UTC+3:00, Poland is UTC+01:00 (one hour behind Kuwait during daylight saving, two hours otherwise) while the American site follows EST (7 hours behind Kuwait during daylight saving, 8 hours otherwise). It is also worth mentioning that both Poland and USA follow daylight saving while Kuwait does not.

B. Strategic Factors

1) Related learning outcomes

The learning outcomes related to strategic factors are (after playing the game):

- Students should be able to choose proper development strategy taking into consideration distribution overheads and differences in infrastructure.

2) Development Site

Different development sites may have different infrastructures which affect communication. Employees in different regions may have different levels of education which may affect productivity [17].

3) Development Strategy

Development strategy will affect the operations since it affects working hours in participating sites. The three proposed strategies by [17] are: module-based, phase-based and follow-the-sun strategies. Follow-the-Sun (FTS) approach means handing-off work daily from one site to the next time zone site to optimize productivity [18]. In our case, the sequence will be: Kuwait-Poland-USA. FTS approach has many challenges when it comes to coordination, especially in the context of global software development [18].

4) Distribution overhead and effort loss

It has been found that distributed work will take around two and half longer time to complete that identical projects there the project activities are located at the same place [17].

C. Organizational Factors

1) Related Learning Outcomes

The learning outcomes related to organizational factors are (after playing the game):

- Students should properly assign tasks to virtual teams to optimize performance.
- Students should experiment with different team structures and to evaluate the productivity and quality of the outcome in the different cases
- Students should identify the best techniques to manage and avoid risks in the context of global software engineering
- Students should identify techniques to build trust among team members.

2) Team formulation and Structure

Building trust among team members that never met face to face is challenging. It has been argued that face to face kick off meetings improve productivity [14] [17]. It is essential that trust is established as early as possible. Without proper

personal interaction and synchronous communication, the level of trust may decrease over time [17].

Research has shown that team homogeneity is positively correlated with high performance, satisfaction, and better communication. However, overtime, an organization which manages to create a common identity or organizational culture among its diverse team can benefit from a wider pool of talents, backgrounds, and skills. Depending on the context in which they are introduced, training programs could help bridge communication gaps between culturally diverse groups. Hybrid team cultures infuse a sense of common identity that aids team interactions and performance. Earley & Mosakowski's [19] study is particularly important because it captures interactions among transnational and globally distributed work teams, a practice that has been recently growing especially in fields like software development. Although this type of studies involves cost, time, and difficulty in isolating factors, it still holds a lot of research opportunities that are worth investing in [20].

Three different settings for the teams can be investigated using the game and the outcomes can be compared [2]:

- Option-1 a typical team structure with team leader in each participating academic site. Each team has three different types of roles: analyst, designer and developer. In this setup, each team will implement a subsystem of the project then integration will take place.
- Option-2: each site is specialized in a certain activity (requirements, design and development) that better suits the culture and nature of participants in that site. Culture dimensions can be used as guidelines to assign roles. However, timing and coordination will be a challenge.
- Option-3: In this model, each team leader leads a team of a mix of cultures. In this setting, the members of each team are distributed. The role of each member is based on his/her qualifications. Leaders have to be aware of different cultures, otherwise delays and misunderstandings are probable.

3) Learning New Technologies

From the cultural interpretation, cultures with low UAI have larger degree of acceptance for new ideas, innovations and willingness to try something different. Depending on the team structure and culture mix, students will investigate which teams are faster in grasping and learning new technologies in such setting.

4) Documentation and Risk Management

Various risks related to GSD were reported in literature. Lack of understanding of requirements, selecting a wrong project, product quality and poor documentation are among the anticipated risks [21] [22]. Risks in academic environment may vary from the ones related to industry.

Using UAI as a guiding measure, it can be predicted that teams/members with high UAI can be more suitable for carrying out risk analysis and taking care of documentation along the way.

5) Gender and Trust Issues

Percentage of females studying computer science and engineering in Kuwait (around 50%) is high compared to USA and most of Europe [23]. In reality, teams will definitely have unbalanced gender distribution. While gender-segregation is a dimension of culture in Kuwait [23], it is not applicable in the other two sites. In previous research in Kuwait, it was found that gender-segregated students perform better than mixed-gender students [23].

IV. PROPOSED MODEL, IMPLEMENTATION AND VALIDATION

The proposed model is illustrated in figure 2. It includes the main classes of the simulation according to Navarro [6]. The main purpose of the simulation is to fully implement a virtual project within time and budget using the available resources (employees and tools) in the most efficient way. The score is calculated accordingly. The initial model supports a typical waterfall model. The following are the main components of the simulation model. The proposed model is implemented using SimSE model builder. The tool also provides a facility to generate a graphical representation for the developed model. The model builder provides a framework to implement models with the following components:

- Employees: team members with their attributes. Attributes can be added according to proposed model.
- Actions: possible actions to be taken by team members.
- Triggers will cause actions to begin in the simulation.
- Rules will connect actions to triggers.
- Tools: to be bought by team members to help developing the project. Tools should increase productivity.
- Artifacts are the proposed submissions by the teams.

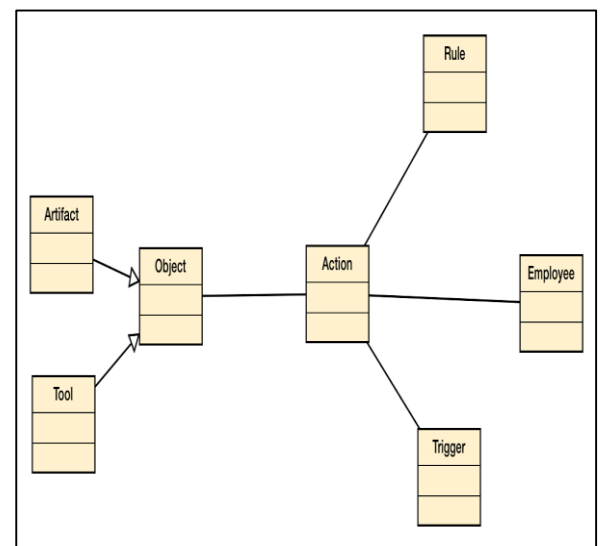


Fig. 2. Class diagram for the model components.

A. Employee

Employees are mainly team members that can be used in the simulation. Each employee can work in one or more activities at the same time. Figure 3 shows a snapshot of the model builder while adding the attributes of employees. The following are the attributes of the employees:

- Language of communication: important to help discussions and communication. Team members who can communicate in more than one language have an advantage over others with limited capabilities.
- Gender
- Location: indicates where the team member is located.
- PDI, UAI and IDV based on Hofstede cultural measures.
- Skills in requirements
- Skills in Design
- Skills in implementation
- Skills in testing
- Leadership skills and knowledge of other cultures.
- Hourly pay rate
- Energy level/productivity

B. Actions

The actions in a SimSE model represent the set of activities in which the objects in the simulation can participate in [6]. The following are samples of the possible actions participants can do:

- Learn about other cultures: can be done at any time, preferably done before the simulation begins to improve communication.
- Create team: only done once at the beginning of simulation.
- Buy tools: can be done at any time of the simulation.
- Change team leader: can be done at any time during the project.
- Change communication method: either use synchronous or asynchronous communication methods.
- Change development strategy: users can either follow-the-sun or phase-based strategies
- Call for a meeting
- Give bonus or salary increase
- Fire
- Build requirements
- Build design
- Implement code
- Implement test plan
- Integrate code
- Submit final product

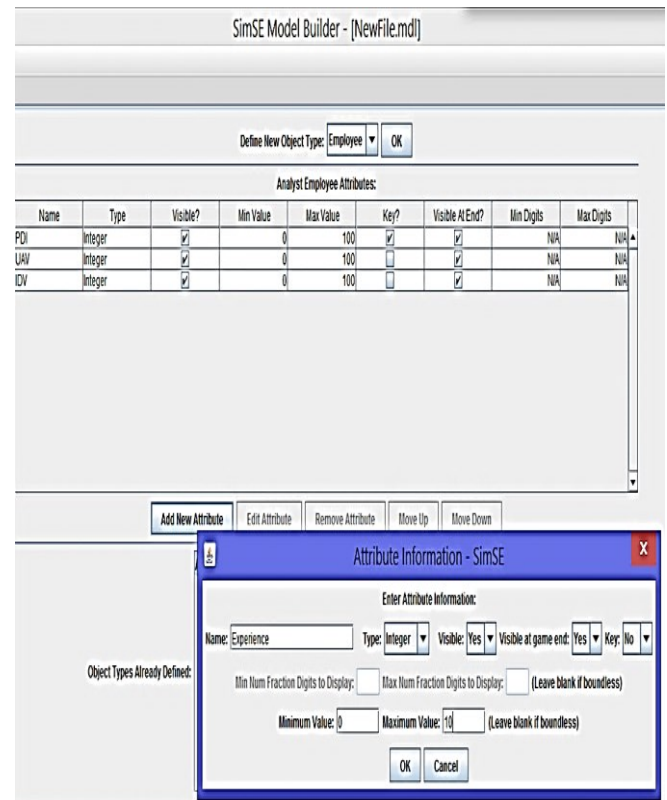


Fig. 3. Model Builder with Employee creation.

C. Triggers

Triggers are what cause the action to begin to occur in the simulation. Three distinct classes of triggers exist: autonomous, user-initiated, and random [6]. Autonomous triggers specify a set of conditions (based on the attributes of the participants in the action) that cause the action to automatically begin, with no user intervention. For instance, an Employee may automatically take a break when his or her energy level drops below a certain threshold. User-initiated triggers also specify a set of conditions, but include a menu item text string, which will appear on the right-click menu for an Employee when these conditions are met [6]. Random triggers introduce some chance into the model, specifying both a set of conditions and a frequency that indicates the likelihood of the action occurring whenever the specified conditions are met [6]. The following are some of the triggers:

- Communication lost
- New Requirements by customer
- Requirements is finished
- Design is finished
- Test plan is finished
- Risk analysis is finished
- Implementation is done
- Integration is done

D. Rules

After all of the action types have been defined, the next task in building a SimSE model is to attach rules to each action

type. A rule defines an effect of an action (if the simulation is affected when that action is active [6])

- Difference in time zone
- Language difference
- Difference in PDI
- Difference in UAI
- Difference in IDV

E. Artifacts

The initial model includes the following components that have to be developed by the virtual teams:

- Requirements document
- Design document
- Test plan
- Risk analysis document
- Final integrated product

F. Tools

Players can buy the following tools to help developing the project:

- Communication tools: Synchronous tools include video conferencing and chatting, while asynchronous tools include email and document sharing.
- Social media to communicate with other team members informally
- Requirements and design tools
- Implementation tools

G. Graphics and Map

Graphical representation for each component is included in the simulation game. The following components have icons: employees, tools, artifacts and project. In addition, each site is represented by a separate room.

H. Validation of the model

Previous research proposed to have two validation models. One of the models shows that distributed software development will reduce the time and cost of software development. In this scenario, it was argued that there are no problems associated to cultural and communication barriers. It was also argued that follow the sun approach increased productivity [17]. The other real life validation model includes the overheads distributed work introduce like language, culture and time differences. Follow the sun approach took 37% longer than single site development [17]. Our developed model and game are validated by the results of the study of Setamnit [17]. Our developed model will be tested by control groups to further validate the results of the game.

V. EXERCISE

The main learning outcomes of playing the simulation game are emphasized in the following exercise. Students have to be familiar with software process models. Process models are mainly introduced in the prerequisite course (Software Engineering). Students are given a set of handouts about cultural dimensions and their interpretations. In

addition, the Global Software Engineering course will include other topics like: risk management and effort estimation in distributed development setting. After that they play the game and answer the following questions:

A. Describe in detail the process

The students should list the steps they followed from the beginning of the game till they submitted the virtual project.

B. What is the effect of having people from diverse cultures work in the same team?

Successful diversity management and training will lead to more productivity. Earley & Mosakowski [19] suggest that successful diversity management training could help diverse teams create a hybrid team culture, “an emergent and simplified set of rules, norms, expectations, and roles that team members share and enact”.

C. What is the effect of having multiple sites developing projects?

Multi-site development will take two and half longer time [17]. Players can try to develop the same project once with one site, and then experiment with two and three sites to appreciate the overheads resulted from distributed development.

D. What are the best communication tools?

The diversity of cultures may affect the choice of the communication tools. Asynchronous tools will be the most appropriate if there is language differences. Synchronous tools would improve the communication and trust if the participants can overcome time-zone differences.

E. How is the outcome of the game affected if you change the team leader in the middle of the project?

Changing the team leader will lead to delays in the development of the project. The attributes of the new leader will affect the overall process. If he has prior knowledge about other participating cultures, this will make up for the delays.

F. Does it pay off to learn about other team members' culture?

Yes, the productivity level will improve if the participants take time at the beginning to know more about other teams' culture. Also, the productivity will be better if participants' use social media to improve informal communication.

G. What is the effect of adopting follow-the-sun approach?

It has been reported that using follow-the-sun development strategy in ideal cases may reduce development time by as much as 50% [20]. On the other hand, if not properly supported with coordination, it may result in delays of approximate 37% [17]. If the player chooses this approach, he has to follow with coordination to avoid delays.

In addition to the game, students are asked to fill a survey after the end of the semester about the experience of playing the game and how it contributed to solving some of the

problems they faced in the real global software development. The outcome is used to improve and fine-tune the model.

VI. CONCLUSION

There is a thirst among scholars and students for practice-oriented studies charting cross-cultural interactions. There have been some attempts in the US and Europe to discuss workforce diversity and its associated challenges. However, very limited research has been conducted outside of these two regions. In addition, the majority of existing literature address the topic from a management perspective, and very few deal with the social, psychological, or anthropological perspectives [24].

In this paper, we presented a model for a simulation game to be used in teaching global software engineering. The model is implemented using SimSE tool. We showed the main elements of the model and how it can include cultural factors and other challenges that affect software development in a distributed environment. The game can be used in global software engineering courses. Control groups from different cultures and backgrounds will be used to test the game. We introduced the simulation using team members from three different cultures. The model can be extended for other cultures. The model can also be extended to include other cultural dimensions. The uniqueness of this paper is in applying using simulation games in global software engineering education.

In addition to helping students to grasp the expected challenges in global software development, the proposed game can be used to explore the following ideas:

- Success factors for global software development projects.
- The benefits of distributing software development vs the overheads.
- The benefits of dividing work between development sites in an efficient way.

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On Combining Gamification Theory and ABET Criteria for Teaching and Learning Engineering

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Abstract— The main contribution of this paper is the introduction of a continuous improvement cycle for devising teaching scenarios and conducting learning experiences in engineering. The proposed cycle consists of seven steps on which gamification theory and ABET criteria are combined. It arose from the adaptation of a gamification design framework, commonly used in industry, into the specific context of high quality education in engineering. It is formulated at high level. Consequently, it should be useful for practitioners having different requirements and expectations. A developed practice, following the proposed cycle, is presented, discussed and evaluated. In particular, the proposal is applied and exemplified, in a scenario for teaching introductory concepts of computer programming in a first-year course. A digital game was used within a gamified learning experience, as a teaching tool. However, the learning process does not rely solely on the use of the game by itself. Moreover, the devised scenario has a purpose beyond edutainment: contributing to achievement of student outcomes, under a continuous improvement approach, according to ABET. A quantitative and qualitative evaluation of the developed practice was performed. A positive impact on students' emotional engagement and behavior was observed as a result of the evaluation process.

Keywords—gamification; ABET criteria; teaching; learning; continuous improvement; student outcomes.

I. INTRODUCTION

Improving the quality on engineering education by incorporating international standards and criteria, such as those considered by ABET, implies not only advantages but also challenges, for both students and faculty members. In particular, an increasing expectation about student outcomes may lead to a complex learning experience. In this paper, a first attempt for combining ABET criteria and gamification theory is discussed. These concepts are briefly introduced as follows.

A. Gamification

The term gamification was coined in 2004 to propose that electronic devices can be profitably turned into games [1]. Nevertheless, the term and its practice took off by a software based approach. It is defined in [2] as the use of game design elements in non-game contexts. Gamification can be understood as an implementation and use of game elements (i.e. design, mechanics, and thinking, among others) in a

process or service, in order to improve user experience, engagement and productivity beyond a pure entertainment area [3]. It has been widely adopted in industry as an engagement strategy for business [4] [5], [6]. Moreover, it is expected that industry will demand a significant number of well trained and highly educated specialist on gamification from professional areas such as business management, design and engineering [7]. In [1], gamification is defined within a learning context, as simple game play to support productive interaction for expected types of learners and instructors. In fact, the use of gamification for educational purposes is on the rise [8], [9], [10]. It is motivated by its potential to engage students in learning activities [8]. Such engagement is positively correlated to the achievement of student outcomes [11], [12].

B. ABET Criteria

ABET is the acronym for Accreditation Board for Engineering and Technology [13]. ABET origins dates back to 1932, when the Engineer's Council for Professional Development (ECPD) was founded by seven engineering societies. The ECPD was conceived as a professional body dedicated to the education, accreditation, regulation and professional development of the engineering professionals and students in the United States. It was renamed to ABET, in 1980, in order to accurately describe its emphasis on accreditation. ABET is a nonprofit organization that accredits college and university programs in the disciplines of applied science, computing, engineering, and engineering technology. Currently, ABET accredits over three thousand engineering programs worldwide [13]. ABET accreditation is voluntarily submitted, and attained by a peer review process. It aims to provide assurance that a college or university program meets the quality standards of the profession for which that program prepares graduates. ABET considers a set of general criteria, as well as program criteria for accreditation purposes [14]. Among the general criteria, student outcomes and continuous improvement are fundamental and inherently related [15]. Student outcomes describe what students are expected to know and be able to do by the time of graduation. The extent on which such student outcomes are being attained should be assessed and evaluated in order to systematically be used as input for the continuous improvement of the program. However, specifying ways or approaches on which assessment and continuous improvement processes should be conducted, is

beyond the spirit of ABET. Consequently, each program has to devise and conduct strategies, not only for accomplish the fulfillment of such goals, but also on generating evidence in this regard [16].

II. PROBLEM STATEMENT & PROPOSAL SUMMARY

There are some proposals on gamification frameworks to be applied on education [17], [18]. However, how to properly and successfully apply gamification mechanisms into education remains as an open question. Moreover, most of previous works reporting a successful use of gamification for educational purposes may exhibit some, or a combination, of the following weaknesses:

- Ignore high quality education international standards.
- Lack of a continuous improvement approach.
- Ignore the inherently cyclical nature of learning, on which an advanced knowledge or a highly developed skill (e.g. analyze, evaluate, create) is constructed upon, or requires, more basic skills (e.g. remember, understand, apply) [19].
- Be mainly focused on applying gamification mechanisms such as badges, bonus points, and gaming elements, among others.
- Require the use of a complex or a specifically tailored gamification platform.

In this paper, a teaching and learning cycle composed of seven steps is introduced. The proposed cycle adapts the Werbach's gamification design framework [4] into the specific context of high quality engineering education. It contextualizes the first four ABET criteria (i.e. students, program educational objectives, student outcomes, and continuous improvement) within a gamified teaching-learning experience. In this way, the former four weaknesses mentioned above are explicitly tackled by the proposal, whilst the latter should be considered by practitioners following the proposal. Additionally, a concise model for estimating students' emotional engagement during the experience is proposed. The model allows obtaining feedback on the way the teaching-learning unit was gamified and conducted.

The remainder of the paper is organized as follows. Required background and related works are briefly discussed in section III. The introduced cycle and the proposed emotional model are presented in section IV. An application of the proposed cycle is exemplified and evaluated in section V. Final remarks are stated in section VI.

III. BACKGROUND & RELATED WORKS

A. Student Engagement

Engagement is defined in [20] as student's psychological investment in and effort directed toward learning, understanding, or mastering the knowledge, skills, or crafts that academic work is intended to promote. It is defined in [21] as a meta-construct including behavioral, emotional and cognitive engagement.

- Behavioral engagement: a positive conduct, absence of disruptive behavior, participation and involvement on learning-related activities, expressed by effort, persistence and attention.
- Emotional engagement: student's willingness to do work, interest in learning activities, enjoyment, and positive attitudes about learning.
- Cognitive engagement: student's investment on learning to achieve deep understanding and expertise.

Engagement is commonly measured by self-report surveys, on which students identify those aspects that best describe them [21]. Among these constructs, behavioral and cognitive engagements are discussed most frequently on literature [22]. Nevertheless, the emotional engagement should not be overlooked, since there is an interplay between emotions and learning, and consequently, a range of emotions occur inherently in a learning process [23], [24]. A model relating phases of learning to emotions is presented in [23]. Such model considers three axes: Learning, Emotional and Knowledge. Additionally, an emotion set for learning, (i.e. associated to the Learning axis), is proposed.

B. Gamification Elements

According to [18], gamification elements are classified into self-elements or social-elements. On the one hand, self-elements engage students for competing against themselves toward recognition of self-achievement. Elements such as points, levels, badges and quests are considered as self-elements.

- Points: a player obtains a reward in the form of a point on the achievement of a certain behavior or the completion of a task.
- Levels: a player has a level that increases as he/she reaches a certain number of points.
- Badges: represent certain achievements of a player.
- Quests: represent tasks that a player has to complete.

On the other hand, social-elements engage students for an interactive competition or cooperation with others towards a public recognition, or a collaborative achievement. Ranking and voting are two commonly used social-elements.

- Ranking: a leader board is presented to all players to increase competitiveness.
- Voting: players can vote on another player's behavior.

C. Gamification in Education

The gamification of a software engineering curriculum is proposed in [7]. This proposal is based on several strategies such as an implementation of gamification-related-topics into traditional courses, an active use of gamification mechanisms in course activities, and an active involvement of students into research projects on gamification and serious games on industry, among others. Nevertheless, presented discussion is focused on incorporating gamification concepts and theory into course syllabus, whilst insights in how to successfully achieve

and implement others aspects of the proposal are not addressed. Moreover, some of the final recommendations, such as including experienced software designers and programmers into project teams, could be difficult to accomplish in a daily basis.

A five step process for applying gamification in education is proposed in [18]. In particular, the process is aimed to gamify an entire learning program. The involved steps are outlined below.

1) *Understanding the target audience and the context:* A good understanding of who the student is, as well as of the context on which the program is being delivered, are required in order to designing a program that empowers the student to achieve the expected objectives.

2) *Defining learning objectives:* Every instructor should state an objective or objectives to be achieved by the students at the end of the learning program.

3) *Structuring the experience:* The program has to be broken down into stages or milestones. Instructors should quantify what the students need to learn and achieve by the end of each stage or milestone.

4) *Identifying resources:* Once the stages or the milestones have been identified, the instructor can more easily judge which stages, if any, can be gamified and how.

5) *Applying gamification elements:* Select and apply game mechanics within the learning process.

Although some of the steps identified in [18] are indeed fundamental for applying gamification in education, this proposal ignores high quality standards and lacks of a continuous improvement approach.

An exploration of the impact of applying gamification mechanisms on students' cognitive engagement and learning about the C-programming language is presented in [8]. To this end, a gamified learning platform was designed and deployed, following the user-centered theoretical framework for meaningful gamification proposed in [17]. They concluded on the positive effects on cognitive engagement by the gamified learning activity employed. Such cognitive engagement was expressed as a desire to go beyond requirements and measured by performing work after having accomplished learning goals. Besides of interesting and encouraging conclusions in [8], this work exemplifies the weakness of requiring a tailored platform for applying gamification in education.

D. Werbach's Gamification Design Framework

The gamification design framework proposed by Werbach [4] is commonly used in industry. It comprises six steps which are outlined below. The purpose of each step is exemplified by questions [25].

1) *Define business objectives:* Why the gamification process is taking place? What are the specific results that will be generated into the organization by the gamification process?

2) *Deliniate target behaviors:* What are the behaviors that will lead to the fulfilment of stated objectives? What metrics will be used to measure them?

3) *Describe your players:* Who are the participants in the gamified activity? What are they like?

4) *Devise your activity loops:* What kind of feedback the system will offer to the players in order to encourage further action? How such feedback will work to motivate players?

5) *Don't forget the fun:* How the gamified system would function without any extrinsic rewards? It is fun?

6) *Deploy the appropriate tools:* How the system would look like? How it is going to be experienced?

E. Engineering Accreditation Commission Criteria

Among the several commissions of ABET, the discussion presented in this document does emphasis on the criteria stipulated by the Engineering Accreditation Commission (EAC). Such commission accredits engineering programs of bachelor's or master's degree levels [15]. A program seeking accreditation from the EAC must demonstrate that it satisfies all the following criteria: students, program educational objectives, student outcomes, continuous improvement, curriculum, faculty, facilities, and institutional support. Among these, closely related criteria to the presented proposal are summarized below.

1) *Students:* Student performance must be evaluated. Student progress must be monitored to foster success in attaining student outcomes, thereby enabling graduates to attain program educational objectives.

2) *Program educational objectives:* The program must have published program educational objectives that are consistent with the mission of the institution, the needs of the program's various constituents, and ABET criteria.

3) *Student outcomes:* The program must have documented student outcomes that prepare graduates to attain the program educational objectives. Student outcomes are outcomes (a) through (k), plus any additional outcome articulated by the program.

a) An ability to apply knowledge of mathematics, science and engineering.

b) An ability to design and conduct experiments, as well as to analyze and interpret data

c) An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

d) An ability to function on multidisciplinary teams.

e) An ability to identify, formulate and solve engineering problems.

f) An understanding of professional and ethical responsibility.

g) An ability to communicate effectively.

h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

i) A recognition of the need for, and an ability to engage life-long learning.

j) A knowledge of contemporary issues.

k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

4) *Continuous improvement*: The program must regularly use appropriate, documented processes for assessing and evaluating the extent to which the student outcomes are being attained. The results of these evaluations must be systematically utilized as input for the continuous improvement of the program.

F. Assessment and Evaluation

The EAC makes a distinction between assessment and evaluation [15]. On the one hand, assessment is defined as one or more processes that identify, collect and prepare data to evaluate the attainment of student outcomes. On the other hand, evaluation is defined as one or more processes for interpreting the data and evidence accumulated through assessment process, in order to determine the extent to which student outcomes are being attained.

In a classic approach [26], there are two types of assessment: formative and summative. The formative assessment takes place during the instructional process, while learning is occurring. It refers to an interactive monitoring and feedback of student progress in order to properly understand and identify learning needs, as well as to adjust teaching. Typically, it is not graded. In this way, a primary focus of the formative assessment is to identify areas that may need improvement,—regarding the both roles—, by gauging student learning progress and determining teaching effectiveness. The summative assessment is used to promote students, by measuring what they have learnt. It allows ensuring students has met required standards on the way to earning certification for studying completion [19].

IV. PROPOSAL FOR AN INNOVATIVE PRACTICE

A cycle aimed to teaching and learning engineering, under a continuous improvement approach, is introduced in this section. The goal of the proposed cycle is to serve as a basis for devise high quality teaching scenarios, in order to provide engaging teaching-learning experiences. Additionally, a concise emotional model is presented. It allows estimating the emotional engagement by students during the teaching-learning experience.

A. A Continuous Improvement Cycle for Teaching and Learning Engineering

The proposed cycle is illustrated in Fig 1. It is composed by seven steps: (1) define educational goals, (2) document impacted student outcomes, (3) characterize target students, (4) select tools and gamification mechanisms, (5) plan assessment and evaluation processes, (6) develop the teaching-learning scenario and gather data, (7) analyze data and provide feedback.

scenario and gather data, and (7) analyze data and provide feedback.

Each one of these steps is discussed below.

1) *Define educational goals*: What is expected from the students to learn? Which are the subjects on which the learning unit will be focused on? Which are the subjects that students may require in order to successfully approach and take benefit of the learning activity? Why an specific subject should be gamified? This step considers the specific knowledge or skills that it is expected students will acquire or attain. In this regard, well known curricula recommendations [27] and bodies of knowledge [28] should be taken into account. As a guideline, a *keep it simple* approach may be convenient (i.e. although it is indeed possible to teach elaborate and complex engineering concepts, probably it is not adequate try to teach more than once at the same time).

2) *Document impacted student outcomes*: Which are the student outcomes that students will develop or enhance during the teaching-learning experience? What are the abilities that will take benefit from the learning activity? What is the justification for the specific selection? This step articulates the educational goals, with the impacted students outcomes by the teaching-learning experience. In this step, student outcomes can be selected among a list of previously considered outcomes for the specific course according to the program educational objectives, or in concordance with the defined educational goals in the previous step. As a guideline, it may be convenient to select only a few student outcomes to be considered, and even just a single or a pair of them.

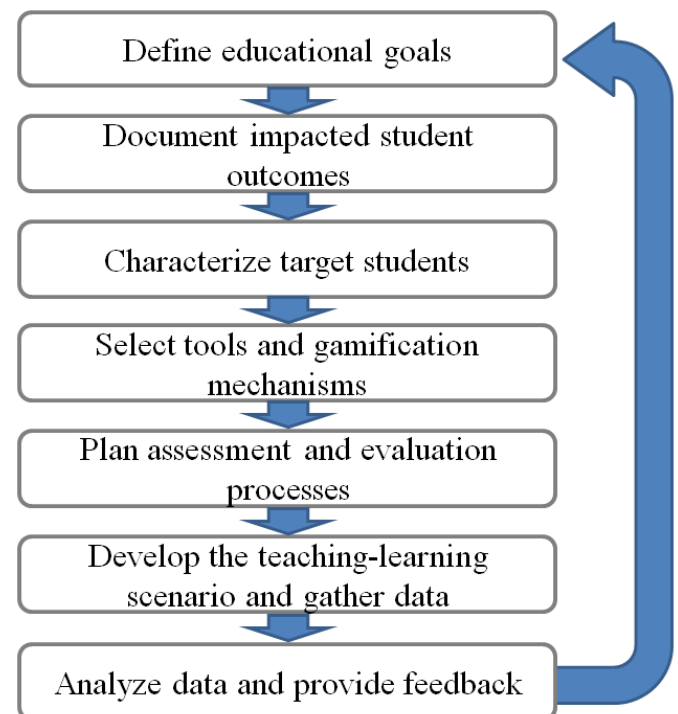


Fig. 1. Proposed teaching-learning cycle.

3) *Characterize target students*: Who are the target students? How are they (e.g. demographically, psychologically)? What strengths or weaknesses, regarding the previous steps, may they already have? Can they be considered as homogenous or what kind of disparities among them should be taken into account? This step highlights the relevance of being aware of the nature of the students in order to properly teach them. As a suggestion, as one of the first activities in a course, some demographic data about the students may be gathered by anonymous self reports. Moreover, an exercise on which students introduce themselves and explicit their expectations on the course could contribute to the development of the student outcome (g), as well as to allow the teacher (and faculty members in general) to get an idea about who they are.

4) *Select tools and gamification mechanisms*: Which are the gamification elements that can be incorporated into the teaching-learning experience? Why the experience may take benefit of such elements? Among the already available tools (e.g. digital games, non-electronic ludic activities, role playing games, among others) [29] which ones incorporate the desired gamification elements? Are such tools adequate to the target students? Why the selected tool it is suited to be used according to all the previous steps? The main guideline in this step is to reuse or adapt available resources.

5) *Plan assessment and evaluation processes*: In the first place, performance indicators should be devised according to the previously considered student outcomes. In this regard, a rubric should be designed or selected accordingly [30],[31]. Moreover, multiple *specific and single point in time* rubrics can be used in conjunction with a single *general and developmental over time* rubric. For each designed rubric, the way on which it will be gathered should be documented. In the second place, ways on how the designed indicators are going to be analyzed and interpreted should be delineated. Such interpretation can be considered as an stop criterion over the proposed cycle. In the third place, an evaluation of how the teaching-learning experience was perceived by the students should be conducted. As a guideline, a formative assessment should be firstly conducted, whilst a summative assessment could take place as a second iteration. Besides, a summative assessment can be approached by some of the gamification mechanisms (i.e. social-elements) considered in the previous step. Additionally it is also important to consider or evaluate, not only the final product the learning unit may have, but also the process followed by students during its development [32].

6) *Develop the teaching-learning scenario and gather data*: When and where the teaching-learning unit will take place? It is the place suited? How data about the students emotional engagement will be gathered, without strong interferences? What to do if any inconvenience arises? What activities should perform the teacher, before, during and after the teaching-learning unit? What are the rules and the constraints for the interaction among participants? As a guideline, the teacher should construct a bitacora about the

development of the teaching-learning unit, and share it with other faculty members.

7) *Analyze data and provide feedback*: Students should be informed by the teacher about how well they performed. Additionally, the teacher must bring a clear indication of what they need to accomplish in the future in order to improve their performance. Moreover, the teacher also requires feedback on his/her own performance. Such feedback process is based on performance rubric, as well as on the emotional engagement estimation by the students' self-report survey. Taking this information into account, an informed decision about the requirements and expectations of the next iteration of the cycle, can be addressed in an proper way.

B. An Emotional Engagement Model for Gamified Teaching-Learning Experiences

The author holds that emotional engagement is not trivial at all to be measured, since such attempt itself may impact on students' emotions. However, in the context of the proposed cycle, the goal is to obtain a fast and reliable feedback about how was perceived the teaching learning experience (instead of obtain an emotional profile of the students). This is quite relevant due to the gamified nature of the proposed cycle. During the innovative practice presented in this paper, an intuitive tool for estimating the emotional engagement was developed. To this end, a variation of the model presented in [23] was conceived. The proposed model, illustrated in Fig 2, is focused on emotions, and consequently involves only two axes, since other dimensions of a teaching-learning experience are considered by rubrics. Such two axes generate the following quadrants: self-engaging, self-pushing, self-reward, and self-punishment. These quadrants are associated to emotional states. In the proposed model, the student navigates through the quadrants during the teaching-learning experience. Thus, in a successfully gamified learning experience, the emotional state of a student may begin in the self-engaging quadrant, and moves around self-pushing and self-reward quadrants. In contrast to, in an unsuccessfully gamified experience, the emotional state of the student may end in the self-punishment quadrant, and consequently the learning process will cease.

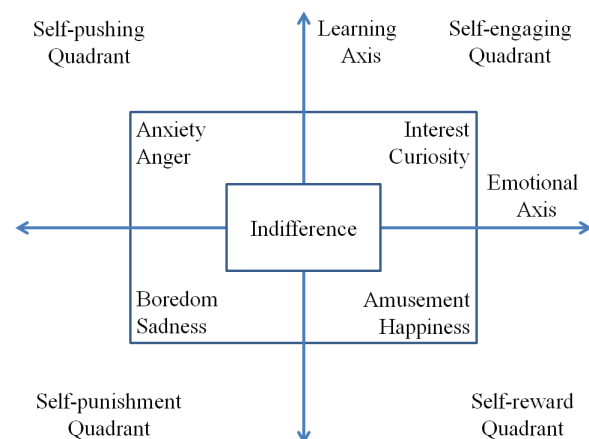


Fig. 2. Proposed emotional model for estimating students' emotional engagement during a gamified teaching-learning experience.

Such cases could be associated to gamified activities, too difficult, or too easy, or even to activities perceived as irrelevant by the learner. Additionally, since in practice the emotional state of the student is commonly estimated by a survey, a very basic set of emotions is required. In contrast to the emotion set proposed in [23], the emotional axis presented in Fig. 3 includes just nine elements: four positive, four negative and one of neutral character. Moreover, the presence of a neutral element is a distinctive characteristic. Although, it contains two more elements than the emotions set considered in [24], it is properly balanced. In particular, the set presented in [24] contains four negative elements and three positive elements. Thus, there is a bias on the probability of selecting a negative element.

In order to implement the model in a survey, the elements of the emotional axis may be presented in disorder to the learner, who should select the subset which describes best his/her own perceived state. Additionally, control questions aiming to determine the coherence in answers could be introduced into the survey.

V. DEVELOPED PRACTICE AND EVALUATION

An innovative practice was developed following the proposed cycle. It is presented in this section, and motivated by answering some of the stated questions.

1) *Define educational goals:* The Software Development Fundamentals knowledge area of the Computer Science Curricula 2013 –CS2013 [28]– generalizes introductory programming to focus on more of the software development process, identifying concepts and skills that should be mastered in the first year of a computer-science program, and similarly named engineering programs. It includes Algorithms and Design as a knowledge unit. This unit considers the role of algorithms in the problem-solving process as a topic. Consequently, a first year student belonging to such engineering programs should be able to create algorithms for solving simple problems. It was the educational goal defined for the conducted teaching-learning unit. Apply algorithms on problem solving was considered as suited for gamification, due to its inherent abstraction, since in practice, a problem may be splitted into subproblems in order to be properly tackled.

2) *Document impacted student outcomes:* The (d) and (e) student outcomes were selected for the conducted learning-unit experience. Such selection makes tottally sense, since, by the time of graduation students should be able to perform an algorithmic approach for problem solving, whithin a multidisciplinary workteam.

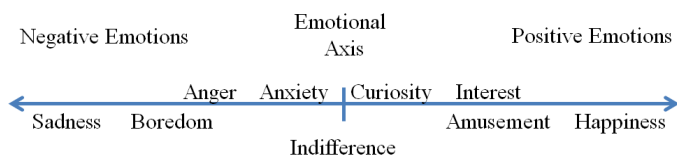


Fig. 3. Proposed emotional learning axis.

3) *Characterize target students:* Target students were enrolled in two groups of the Introduction to Programming first-year course, during the second semester of the 2014. A total of 45 students composed these two groups. The morning classes group had a population of 21 students (90.5% male) with an average age of 18.8 years (std: 1.9), whilst the afternoon classes group had a population of 24 students (83.3% male) with an average age of 19.3 years (std: 2.1). Most of them were not yet properly familiarized with ABET student outcomes (neither related terminology), but they were aware of concepts related to a competence based educational system. They belong to the following programs: Systems Engineering, Electronical Engineering, and Multimedia Engineering, at the Engineering Faculty of the Universidad de San Buenaventura, in Cali, Colombia. These programs are not certified by ABET.

4) *Select tools and gamification mechanisms:* Lightbot™ is a programming puzzle game associated to the Hour of Code initiative [33], [34]. Such initiative is dedicated to inspiring K-12 students to take interest in computer science. Lightbot™ was developed by D. Yaroslavski, and a free web-based version is available at [35]. This version is composed by three levels –Basics, Procedures and Loops–, for a total of twenty different scenarios. The goal of the game is to guide a robot to light up all the blue tiles in each scenario, by a set of instructions introduced by the user. This puzzle game was selected as the gamification tool. The teacher played the game in order to determine if it was suitable to be used within the teaching-learning experience. He concludes that the difficulty of the three game levels was appropriate. Additionally, the following gamification elements were identified:

- **Quests:** each different scenario implies a new task.
- **Badges:** a certificate of completion is granted to the user when he/she fishes the three game levels. The website allows sharing it on social networks.

Other factors such as having a gender neutral game character, and absence of a puerile context were also taken into account. Finally he introduced an additional gamification element:

- **Points:** a player who completes all the scenarios will obtain a reward.

5) *Plan assessment and evaluation processes:* Two holistic rubrics, with a single dimension each, were developed in order to allow an individual formative assessment. The rubric related to student outcome (d) it is shown in Table 1, whilst the rubric related to student outcome (e) it is shown in Table 2. The latter rubric was used for calculating rewarding points, following the previously introduced gamification mechanism. Points were added later to another grade.

6) *Develop the teaching-learning scenario and gather data:* The Introduction to Programming course has two weekly sessions of two hours each. The devised teaching-learning unit was conducted on the second week of the semester. The concepts of programming, algorithms,

computational problems and subproblems were briefly introduced, intuitively defined, and motivated by examples on the two previous sessions. The web based version of Lightbot™ was presented in class, just before the end of the previous session. Its first level was cooperatively played by the entire class, not only in order to familiarize students with the interface and game goals, but also for allowing the teacher to graphically illustrate and reinforce the previously introduced concepts. The session on which the teaching-learning unit was conducted was divided into three segments. The first segment was used for explaining the activity, its goals and deliverable. The template for reporting developed solutions was posted on the Moodle platform of the University, and used to illustrate the procedure concept in Lightbot™, required to solving levels two and three. This first segment was about fifteen-minutes long. The middle segment was about one hour and half long. It was used by the students in order to accomplish the activity goals, construct the report, and uploaded it in to the Moodle platform. During this segment, the teacher provided some guidance, when required, but only in aspects related to the work report. He gathered data related to the teamwork dimension considered in the rubric, in a non intrusive way, by a passive observation approach. To this end, each team was observed multiple times, considering factors such as who was on the keyboard at a single time, if the team were using more than one computer, the interaction between the team members, and the strategy adopted by the team, among others. Additionally, he wrote some notes about how the students did use the provided template, or regarding the experience as a whole. The last segment was devoted to individually and anonymously answering the survey on the activity and its affective perception. Nevertheless, participating in the survey was optional. The paper survey was filled out in the morning classes group by the 86% of the students, and by the 84% in the afternoon classes group.

TABLE I. TEAMWORK RUBRIC

	Teamwork			
	Exemplary	Satisfactory	Developing	Unsatisfactory
Attitude & Participation	Shows willingness to cooperate by expressing own ideas, and paying attention to others	Exhibits positive attitude and leadership	Exhibits a passive attitude	There is not evidence of willingness for work team

TABLE II. PROBLEM SOLVING RUBRIC

	Problem Solving		
	5	3	0
Task Achievement & Technical Report	All problems were solved, and solutions were properly reported	There are unsolved problems or reported solutions are inadequate	No attempt

7) *Analyze data and provide feedback*: Gathered data by rubrics, were processed and summarized. Each student was informed about his/her own performance. Classroom data were published through the Moodle platform. Further teaching directions were guided based on such summarized data. The obtained teamwork assessment, summarized by classrooms, is shown in Fig. 4.

Additionally, surveys were analyzed in order to obtain an estimation of the emotional engagement perceived by students. The students were asked about to identify on the survey up to three emotions associated to their own experience. The most frequently reported emotions were, in its order: amusement, interest, curiosity, anxiety, happiness, and anger. The emotions of sadness, boredom, and indifference, were not reported at all (or filtered out by the control questions on the survey). The emotional profile of the teaching-learning experience, associated to the proposed emotional model is shown in Fig. 5. It can be observed that there is a trend to the positive side of the axis. Consequently, the emotional engagement of target students during the developed practice can be described as positive.

Moreover, the survey also allowed measuring the combinations types of emotions occurring during the learning process. In this sort of ideas, Fig. 6 illustrates the percentage of students that reported only positive emotions (Totally Positive, 54.8%), more positive than negative emotions (Predominantly Positive, 35.5%), just indifferent or a single positive in conjunction with a single negative emotion (Indifferent, 6.5%), more negative than positive emotions (Predominantly Negative, 3.2), and only negative emotions (Totally Negative, 0%). Thus, a change in the emotional state of students among the quadrants of the proposed model can be observed from data. This observation is congruent with the range of emotions that according to [23] arose naturally during a learning process. In the context of this paper, such observation can be understood as a successful gamification process of the teaching-learning experience. Thus, the teacher has now information about students as learners, regarding their emotional engagement during the conducted activity. Such information, combined with the results obtained by devised rubrics will allow him/her to define which should be the educational goals on the next iteration of the teaching-learning cycle.

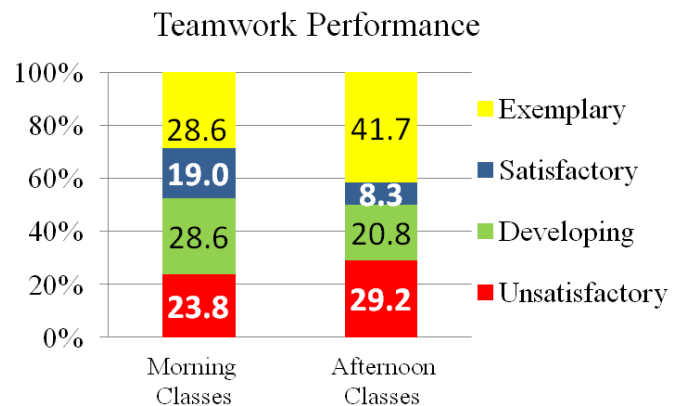


Fig. 4. Teamwork performance assessment on the gamified the activity.

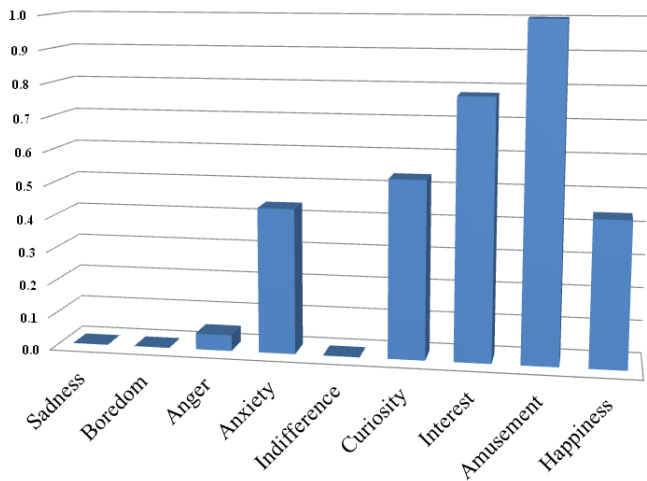


Fig. 5. Emotional profile of the conducted teaching-learning experience.

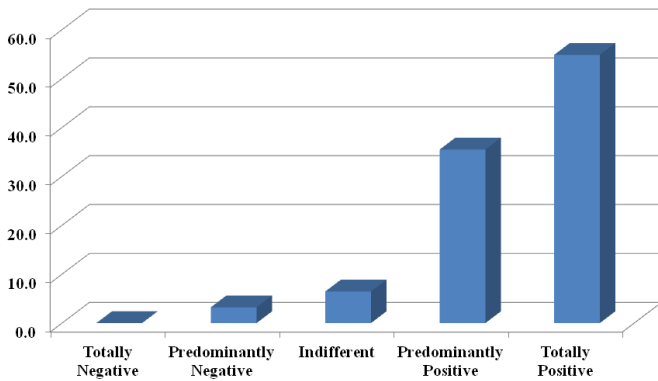


Fig. 6. Percentages of combined emotions reported by students regarding the teaching-learning experience.

An analysis on the variation of the teamwork behavior was possible based on gathered data later on the class's final project. The teamwork performance assessment on the class's final project, according to the rubric shown in Table 1, is illustrated in Fig. 7. Although such project was not gamified, the aspect to highlight is how the data gathering, considered by the proposed cycle, allows analyzing students' behavior on different time moments.

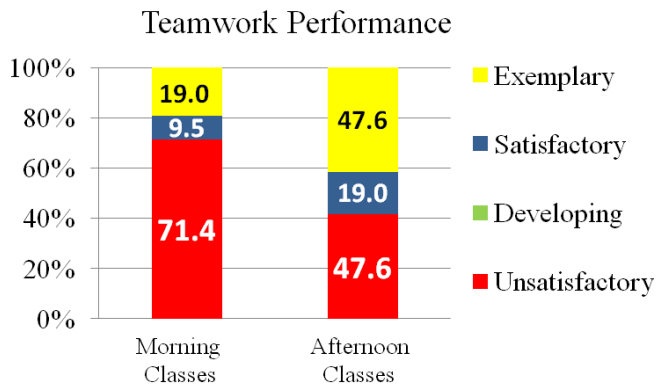


Fig. 7. Teamwork performance assessment on the class's final project.

As can be seen in Fig. 7, there is an increase on the percentage of students with an unsatisfactory teamwork performance. This is due mainly to a high dropout ratio on the course. Simultaneously, there is no evidence of students assessed with a *Developing* teamwork performance. This can be associated to an improvement on this regard by remaining students on the course.

VI. FINAL REMARKS

A plenty of universities and educational institutions in the United States, and many others in well developed countries around the globe, have a long tradition in ABET accreditation process. In contrast, universities in underdeveloped regions are struggling in order to properly incorporate such high quality standards and documented processes in a daily basis. Moreover, such universities are facing another challenges related to a low number of applicants for engineering programs, as well as a high dropout. In the context of such endeavor, the engineering faculty of the Universidad San Buenaventura in Cali, has already started to explore alternatives to fulfill with the guidelines of the EAC. A success in this effort will require a large investment as well as an considerable learning curve by faculty members, and students. The proposed cycle arose motivated for tackling the challenges above mentioned. The main contribution of the proposed cycle is to combine elements from gamification theory with the first four ABET criteria, aiming to make possible a continuous improvement process. Moreover, it considers the most relevant weaknesses commonly found in approaches for applying gamification in education. A detailed description of the proposal was provided in order to facilitate its application by a wide audience of practitioners looking for a concise way to incorporate ABET criteria in the teaching exercise, and also gamification elements into learning activities. In fact, the proposed cycle can be used not only by faculty members starting in an ABET accreditation process, but also by faculty members expecting to promote students emotional engagement. In this sort of ideas, the proposed cycle is a useful tool in order to devising and conduct gamified teaching-learning experiences, under the ABET criteria.

ACKNOWLEDGMENT

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Is there a gender difference in Maths competencies achievement between Aerospace Engineering students in Spain?

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Abstract—The NSF has recently issued the report on “Women, Minorities, and Persons with Disabilities in Science and Engineering” which provides statistical information about the participation of these three groups in science, engineering education and employment. The percentages in Spain, and particularly in the Technical University of Valencia where almost all degrees are technologically related, are not very different even though there is a general feeling in Spanish society to consider engineering studies to be appealing and with high employability possibilities. In this paper we analyze how they perform inside the university in a highly technological degree as Aerospace Engineering. We present their results corresponding to competencies achievement in each gender group and each topic of these Mathematics subjects.

Keywords—*Mathematics in Engineering Education; Assessment and Evaluation Strategies/Approaches Laboratory Experiences; Teaching & Learning Experiences in Engineering Education; First and Second Year Program*

I. INTRODUCTION

Gender inequity in academic Science, Technology, Engineering, and Mathematics (STEM) has been a topic of growing interest and intense debates [1,2]. In many countries, including those belonging to the European Union and in the United States, women are still underrepresented in STEM [3]. For decades this low rate of women has been a concern in the U.S., and more recently in Europe. In the late twentieth century many national committees and professional organizations initiated a number of programs with the aim of increasing female presence in science and engineering (e.g., American Council on Education 1988; National Research Council 1991 [4]). These programs were created to promote the talent pool and mainly worked at school education level changing the attitudes of female students. Despite that the long term interventions led to a progressively increasing number of women in some STEM disciplines, a proportional increase of women faculty members did not take place as expected.

According to a recent NSF report [5] roughly above 20 percent of Engineering students are female, percentage that becomes multiplied by 2 when it comes to Mathematics, thus

making clear the difference appeal in gender towards STEM. This same proportion is also found in Spain [6]. Despite the fact that engineering studies in Spain are considered and accepted as attractive by their employability [7], same gender ratio is maintained in the different engineering schools in the Technical University of Valencia (UPV). The fact is that traditionally there are more female students in careers related to Health Sciences, Social, Law, Humanities and Arts (Nursing, Medicine, Psychology, Teaching, Fine Arts...) [8,9,10]. Many people have attempted to give reasons of the relatively low numbers of women in STEM fields, leading to the rise of a number of biological, structural, and social-psychological explanations [11,12,13]. In fact, Bachelor's Degree in Aerospace Engineering, delivered at the UPV, is one of the degrees in which the enrollment of female students is lower than male students, roughly above 20 percent as in the US and in their first year they have to perform the following compulsory subjects: Business Studies, Chemistry, Computer Science, Materials Science, Mathematics I, Physics and Technical Drawing. In this paper we analyze gender performance of Mathematics I in each of the different blocks: Algebra, Calculus and laboratory practice during 2013-14 and also of Mathematics II of Second Year during 2014-15. We present their competencies achievement results in each gender group and topic of these Mathematics subjects.

II. THE LOCAL SETTING

BEng Aerospace Engineering is a 4 year degree whose strongly motivated students have achieved the highest scores in their pre-university studies. As in most engineering careers, there is a greater male demand (circa 80%).

The first and second course of BEng Aerospace Engineering comprise basic subjects from different areas including Mathematics I and Mathematics II, on which we will focus in this paper.

Mathematics I has 120 contact hours (12 ECTS), 75% of them correspond to Theory/Problems (TP) sessions and the remaining 25% to Lab practice (LP) sessions and covers as topics Calculus of one and several variables and Linear Algebra. Mathematics II with 60 contact hours (6 ECTS) is

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devoted to ODEs, Analytic Solutions of ODEs, Laplace transforms and PDEs. In both of these subjects all students should achieve basic competencies and skills. In these two subjects of Mathematics we use methodologies that encourage our students to an active learning in line of [14]. Now, we describe briefly the methodology used in TP and LP sessions.

TP sessions are standard and at the end of each topic, the instructors propose students a collection of problems to be solved. If the student has some difficulty on how to solve them, he should meet the instructor during office hours. Students have to perform three exams along the academic year related to Calculus topics and one related to Algebra in Mathematics I. In Mathematics II there are also three exams: the first one, DE1, concerning ODEs; the second one, DE2, to Analytic Solutions and Laplace Transforms; and the last one, DE3, to PDEs. In addition, before each exam the student must perform an assignment.

LP methodology used is based in flipped classroom [15]. The process can be divided into 3 stages: pre-class, in-class and post-class:

- Pre-class: Instructors provide a guide in PoliformaT, an educational platform developed by UPV based upon the Sakai project [16], with topics and exercises that student work autonomously prior the Lab session.
- In-class: In the first part students discuss about the difficulties encountered. Next, they are evaluated by solving a set of exercises by means of PoliformaT.
- Post-class: Students can check their answers and scoring through PoliformaT. In addition, instructors will provide the correct answers.

Instructors assist students in all stages of this process. With this methodology, students follow the subject and do not just prepare it for TP exams.

III. GENDER PERFORMANCE

A. Gender performance at mathematics first year

In this section we present the results performed during the academic year 2013/2014. In that academic year Mathematics I got 126 students enrolled with 102 males and 24 females. We will focus in the following aspects of the subject: Weekly Lab sessions, Lab exam, Calculus, Algebra

The ratings presented in this paper have been divided according to the Spanish system. If x denotes the mark in a 0-10 scale, the grade is considered to be Excellent (if $9 \leq x \leq 10$), Very Good (if $7 \leq x < 9$), Good/Pass (if $5 \leq x < 7$), Fail ((if $x < 5$) or Not taken (if the student has dropped this topic).

Fig. 1 represents the grades obtained by male and female students in the weekly Lab sessions. We can observe that female students obtained grades slightly better, most of them with a grade of Excellent or Very Good and without dropouts. A 90% of female students and a 70% of male students obtained Excellent. In general marks obtained in Lab sessions are significantly good, because students are encouraged to prepare

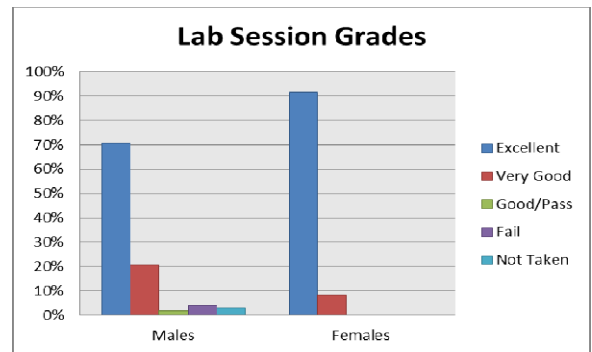


Fig. 1. Lab sessions grades from Mathematics I. Academic course 2013-14.

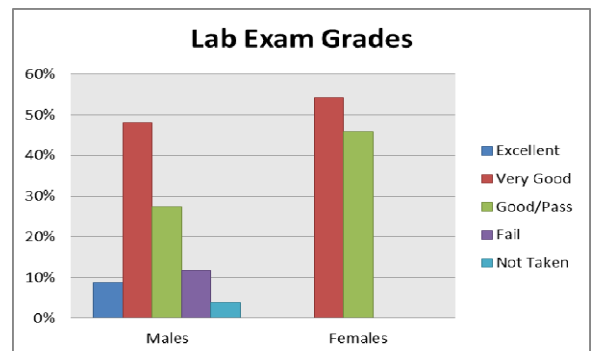


Fig. 2. Lab exam grades from Mathematics I. Academic course 2013-14.

the lab sessions in advance and they are able to solve doubts asking the instructor or a partner during the in-class evaluation.

The grades concerning LP exams are represented in Fig. 2. The contents covered in these LP exams are Calculus, Algebra with the CAS Mathematica. Males obtained more disperse marks than females. About a 10% of the males have obtained the Excellent grade whereas no girl has attained such grade. However, all the females obtained a mark greater or equal to 5, while approximately a 12% of the males fail to pass.

The grades obtained in the exams involving Calculus topics are gathered in Fig. 3. We observe that the percentage of male and female students obtaining a mark greater than 5 is similar. However, female students obtained better marks than males since 71% of females obtained a score greater or equal to 7, while only 52% of males obtained these values.

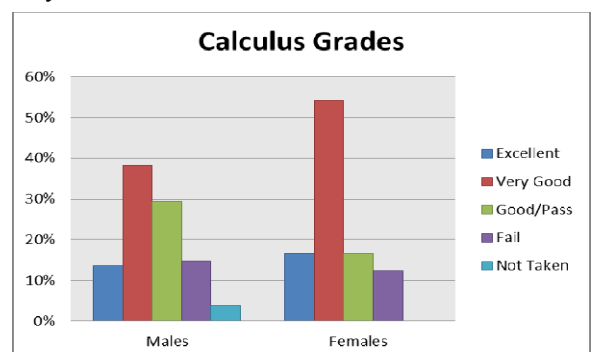


Fig. 3. Calculus grades from Mathematics I. Academic course 2013-14.

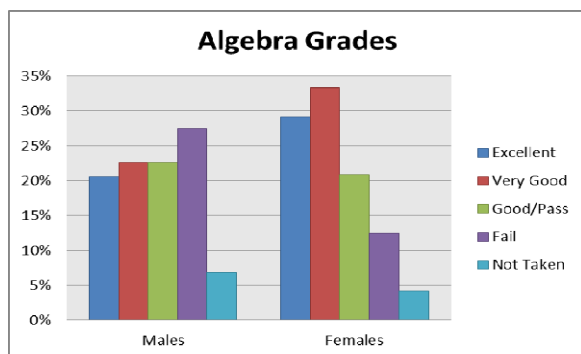


Fig. 4. Grades from Mathematics I. Academic course 2013-14.

The proportion of males and females not passing the exam is comparable, being the females the ones with a lower rate of about 12%). Also, the percentages of students achieving Excellent grades are significantly similar, with the females having the higher rate (almost 18%).

Fig. 4 represents the grades obtained by male and female students in the Algebra exam. We can observe that male students failed this exam in a significant higher percentage than female students. In general, females obtained better marks in this exam, achieving a bell-shaped distribution with the weight to the left.

It is noteworthy to mention that 3 male students dropped Mathematics I out. None of the females dropped out.

B. Gender performance at mathematics second year

In this section we describe the students' performance at Mathematics II. Fig. 5 shows the grades obtained by students in the weekly Lab sessions. It can be observed that females still performed better, most of them with a grade of Excellent. An 80% of females and a 62% of males obtained Excellent.

Fig. 6 represents the grades of LP exams. ODEs, Analytic Solutions of ODEs, Laplace transforms with the CAS Mathematica are the contents covered in these LP exams. As seen in the figure, males have obtained a more rectangular-shape distribution than females, with a higher rate of Excellent grades (about 9%). It is noteworthy that the males have obtained a similar rate for Fail, Pass and Very Good grades, meanwhile females show a more bell-shaped distribution with more weight on the right side. The most significant difference occurs in the interval from 5 to 7, in which we find almost 60% of females versus the 28% of the males.

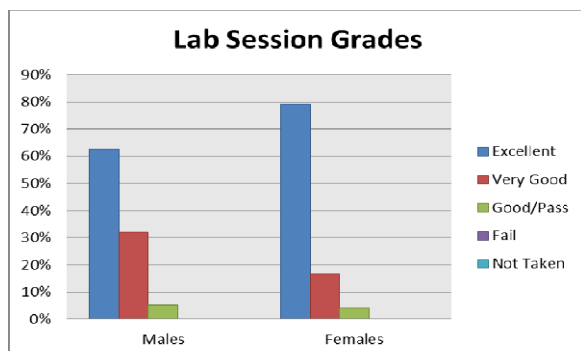


Fig. 5. Lab sessions grades from Mathematics II. Academic course 2014-15.

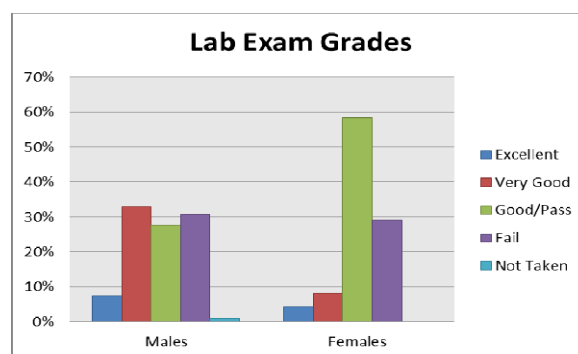


Fig. 6. Lab exam grades from Mathematics II. Academic course 2014-15.

Fig. 7 contains the grades in the first exam covering ordinary differential equations. It can be observed that, despite the fact that 37% of females fail the exam, the marks are still better for female students, except in the number of students obtaining Excellent grades.

Concerning the second exam, which covers Laplace Transforms and its applications and analytical solutions of ordinary differential equations, Fig. 8 shows that fewer students fail the exam, and that there is a significant increase in the Very Good marks for females (from 32% in the first exam to 42% in the second) and Excellent marks for both genders.

Next, Fig. 9 includes the marks attained by the students in the third exam, covering Partial Differential Equations. Here female students reduce the number of Very Good marks, increasing the number of females passing the exam. The number of females not passing the exam keeps decreasing, as opposed to what happens with the males.

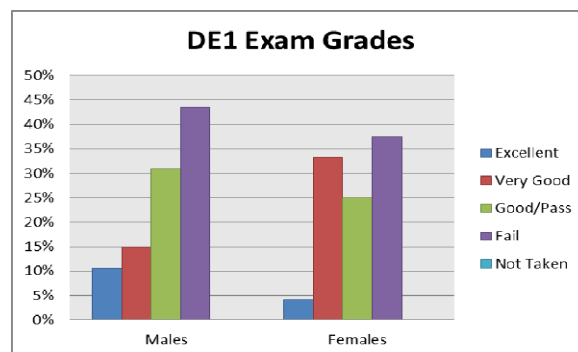


Fig. 7. ODE exam (DE1) grades in Maths II. Academic course 2014-15.

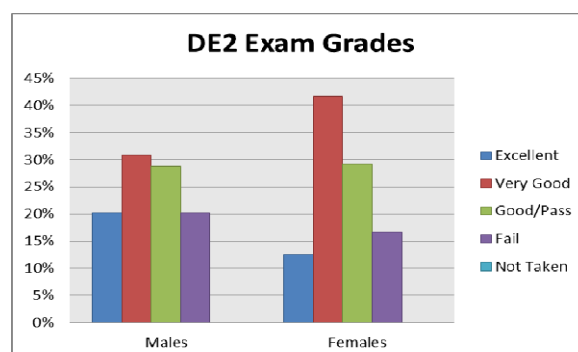


Fig. 8. Laplace Transforms and analytical solutions of ODEs (DE2) exam grades in Maths II. Academic course 2014-15.

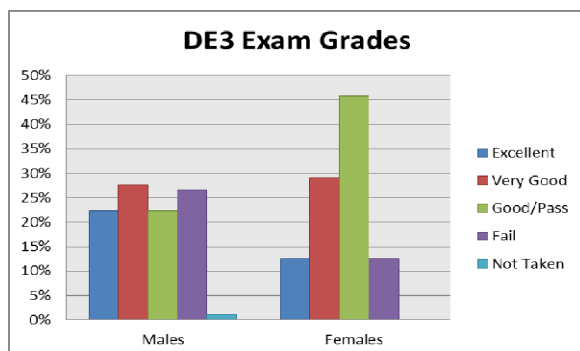


Fig. 9. PDEs (DE3) exam grades in Maths II. Academic course 2014-15.

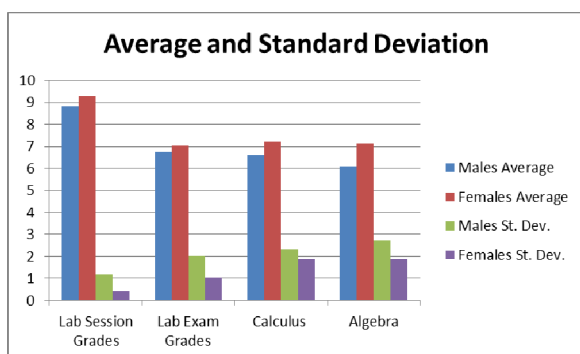


Fig. 10. Comparative study of the averages and standard deviations in Mathematics I. Similar results can be obtained from Mathematics II.

IV. SUMMARY

Underrepresentation of STEM female students in Spain is similar to other western countries. The interest of studying this participation lies in the fact that its increase would likely enhance diversity and innovation and having a positive impact on future generations.

We have focused our study on Aerospace Engineering at UPV where around 20% of students are female analyzing their performance compared to male students. In general results are good as Aerospace Engineering students are highly motivated. The only slight variations observed are that, for very a small difference, in a 0-10 scale, female students get better results in the range 7-10, showing a more stable behavior in the middle zone.

When it comes to the average grades, females perform better than males in all cases and with a significantly lower standard deviation (Fig. 10). Dropout rates are rare in both cases, being more common between male students. On the other hand, male students obtained better marks in LP exams which were done by using Mathematica as CAS.

Further analysis with wider perspective might be needed but from this analysis it seems that there is no significant difference between the performance of both groups of students, male and female when we consider the global numbers and the distribution of grades.

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CodePlus – Designing an After School Computing Programme for Girls

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Abstract—Women are underrepresented in the field of Computer Science. This project aims to help Secondary School girls develop an insight into the role computers play in society and to learn some of the key skills in computing including computer programming. Exposure to Computer Science, in home or school environments, and encouragement from family and peers are leading factors that influence girls’ decisions to pursue careers in Computer Science. Other factors include the girls’ perception of their own problem solving ability, an understanding of the diverse applications of Computer Science and related career paths and the potential for positive social impact. This paper describes the design of an after school computing programme, CodePlus, which uses a novel 21st Century learning model. Pre and post questionnaire are being used to explore girls intentions to study CS, their confidence to study CS, perception of CS as a career, gender perception of CS and IT profession and self-efficacy following participation in the CodePlus programme. Preliminary results comparing pre questionnaire results with a male control group highlight differences in how girls see themselves in terms of CS capabilities and their future potential. Initial post questionnaire findings show a significant increase in the participants’ perceived programming ability.

Keywords— *Computing; 21C Learning; Programming; Scratch; Computational thinking; Collaborative learning*

I. INTRODUCTION

Women are traditionally underrepresented in the field of Computer Science. The aim of this project was to help Secondary School girls develop an appreciation of the role computers play in society and to learn some of the key skills in computing with particular emphasis on computer programming. Existing research points to several factors which influence an adolescent girls’ decision to pursue a career in, or to study, Computer Science. Exposure to Computer Science, in home or school environments, and encouragement from family and peers are leading factors. Other factors include the girls perception of their own problem solving ability, an understanding of the diverse applications of Computer Science and related career paths and the potential for positive social impact.

A distinctive feature of the education system in Ireland is the number of girls only secondary schools which offer an interesting context in which to address some of the issues outlined in the previous paragraph.

Bridge21 is a model of 21C teaching & learning developed in Trinity College Dublin which has been used to deliver a variety of curriculum topics including mathematics [1] and computer programming [2].

This study examines CodePlus, a programming club based on the Bridge21 model, which was set up in three female-only schools. In two schools, a self-selecting sample (~70 girls, age 12 to 17) took part in weekly, two hour workshops. In the third school, one class (~17 girls, age 15-16), took part in a 4 day programme during school time. The Bridge21 learning model was used throughout the workshops and there was a two to one ratio of students to computers. Students worked together on activities including computational thinking, computers in society and programming using Scratch. Pre and post questionnaires were designed to measure the students’ prior exposure to Computer Science and their attitudes to Computer Science in terms of future study and career choices.

The findings will explore the students’ attitudes towards Computer Science via a pre - post workshop questionnaire instrument, and their technical competence based on the work they completed during the workshop and their self-reporting via the questionnaires. This research helps informs whether the Bridge21 approach to Computer Science can both encourage Computer Science career aspirations and develop comprehension of basic programming concepts.

II. LITERATURE

A. Girls in CS: Problems and Solutions

The under-representation of women in computer science is well-documented. Much work has been done both in an attempt to uncover the reasons for this lack of participation and to look for strategies to rectify the situation but, despite this, the discrepancy between the numbers of women and men studying and working in computing continues to exist. In 2012 the US women received just 18% of Computer and Information Sciences undergraduate degrees down from 37% in 1984 [3]. In Ireland only 15 per cent of new-entry students into 3rd level Computer Science courses in 2013 were female [4].

Research suggests a range of explanatory factors that contribute to this inequality. Ceci et al. [5] looked at both possible biological as well as social factors in their review of over 400 articles exploring the causes of women’s

underrepresentation in STEM fields. They found that the research on gender differences in brain structure and hormones is inconclusive. The evidence instead points to sociocultural factors, particularly the power of culturally prescribed gender roles, to explain the gender gap. Spertus [6] suggests that these "factors include the different ways in which boys and girls are raised, the stereotypes of female engineers, subtle biases that females face, problems resulting from working in predominantly male environments, and sexual biases in language."

These sociocultural factors seem to have a particularly strong negative impact on women's self-confidence. Numerous studies have found that women have lower levels of self-efficacy than boys when it comes to stereotypical male dominated subjects such as mathematics, engineering and computers [7, 8], and that it is this lack of self-confidence, not ability, that is the most significant difference between male and female science students [9].

Whatever the causes, and clearly they are manifold and complex, one common finding is that girls are just not that interested in pursuing a career in computing. This manifests itself at a young age and increases through 2nd and 3rd level education with the result that, from early adolescence, girls express less interest in STEM careers than boys do [10, 11]. Consequently it is crucial to introduce computer science to girls before the negative stereotypes have set in [12].

If multiple factors contribute to the underrepresentation of women and girls in STEM, multiple solutions are needed to correct the imbalance. Notable successful interventions include that of Carnegie Mellon University where they increased the percentage of female students enrolled in Computer Science from 7% to 42% between 1995 and 2000 [9]. Factors behind this success included widening the admissions policy and making the culture of the department more female-friendly by implementing policies designed to change stereotypical attitudes and behaviours. These included the addition of greater social context to entry-level computer science courses in response to women being more likely than men to prefer work with a clear social purpose [13-16].

Such work done in the areas of recruitment and retention at 3rd level has clearly shown that attempts to remedy the imbalance can be effective. However, the research clearly points to the importance of earlier interventions. A lot of work in this area has tended to focus on providing early exposure in a more welcoming environment for girls. The establishment of all-girl coding clubs (Girls Who Code, Black Girls Code, CoderDojoGirls) and attempts to provide positive female computer science role-models (e.g. Google's madewithcode.com mentors) fall into this category. Others have tried to making computing less abstract by integrating it into activities and communities that girls and women are already engaged in, such as storytelling [17] or e-textiles [18]. There has been less work done into the effect of pedagogy or *how* we teach computer science as opposed to *who* we teach or *what* we teach. However, research into how pair programming can help female computer science students shows the potential

of collaborative learning to break down the negative stereotype of the solitary nature of computer science [19].

B. 21st Century Learning

Both industry leaders and policy-makers concur that the social and economic trends of the 21st century, promoted by advances in information and communications technology (ICT), have altered the global economy and work practices, from one of material goods and services, to one of information and knowledge [20-22]. These changes require the 21st century workforce to have a higher level of learning capacities and cognitive skills [23]. Despite these shifts in required skills, many argue that the education systems have been slow to adapt to this changing environment and still promote information transfer over the skills development. They also suggest that, pedagogy, curricula, school organisation and assessment remain largely the same as they were in the industrial era of the 20th century [21, 24].

Contemporary pedagogical approaches suggest moving away from developing the simple ability to reproduce received information in subject-specific classes towards learning that focuses more on meta-cognitive skills, problem-solving and the development of the whole person [25]. Rather viewing learners as 'Knowers' who absorb and reproduce received information the aim is to develop 'Learners' with positive transferable learning dispositions [20]. In order to move from the old 20th century industrial paradigm to the new, 21st century information society and economy, requires fresh pedagogical approaches. Voogt and Pelgrum [24] suggest a view that learning should be activities determined by the learners themselves working in small groups, rather than prescribed in a didactic fashion by the teacher during whole class instruction. In order to develop creativity, we need to move away from situations where students apply known solutions to known problems and promote a more productive learning, where students are encouraged to develop new solutions to new problems [24].

III. BRIDGE21

A. The Bridge21 Model of 21st Century Learning

Bridge21 is a practical, pedagogical model of 21st century teaching and learning, that focuses on team-based, project orientated and technology-mediated activities [26]. The essential elements of the Bridge21 learning model are: (1) project based activities, (2) technology-mediated learning, (3) structured team-based pedagogy, (4) recognition of the social context of learning and (5) facilitation, guiding and mentoring, with teachers orchestrating these activities [27].

The Bridge21 Activity Model outlines how Bridge21 activities are designed and consists of seven consecutive steps which form the basis of each lesson. Sessions typically start with an optional (1) 'set up phase' in which introductions are made and teams are formed. This is followed by a (2) 'warm up' activity designed to encourage divergent thinking and get the teams thinking creatively and working together. Next is the (3) 'investigation' stage which promotes convergent thinking and sets the context of the workshop. Teams define a problem and research the context in preparation for planning and

creating some digital artefact. The (4) 'planning phase' has teams discuss and assign tasks and roles and agree a schedule for the delivery of work to be completed. The creation phase is a cyclical process in which teams (5) 'implement' and iterate on their design. Finally teams are invited to (6) 'present' their work to their peers and share what they have learned. A final (7) 'reflection' phase is used to consolidate the learning.

B. Bridge21 CodePlus Programme

The Bridge21 CodePlus workshops were designed to explore a number of issues. These include early exposure to programming; delivery in the distinctive environment of girl only secondary schools and focus on a structured 21C pedagogy. Four instances of the programme were run, following one of two formats. With 3 groups, the programme involved weekly two-hour sessions over a 10 week period. This was a voluntary after-school programme with students aged between 12 and 17 years of age. For the fourth group, the programme took place over a 4 day block, during school time. All students in the class were required to participate. In both cases, the students spent up to 20 hours working on, and learning from, various computing projects.

The programme was based on a set of existing tried and tested CS activities [2] which was extended in a number of ways in light of the literature on girls and programming discussed above. The CodePlus programme covered three broad areas.

1) Computers in Society

In the early sessions, the students, working in teams of four, looked at how they use technology in their daily lives and did online research about how technology is currently used in areas such as medicine, fashion, education and entertainment. They also came up with ideas for new pieces of technology that could solve problems in the same areas. The aim here was to help the students understand the influence technology has on our lives and to see the broad range of potential career paths that computing might involve.

2) Computational Thinking

Throughout the sessions, the students worked on several small problems designed to introduce them to procedural thinking or "thinking like a computer". These included online games such as Blockly, pen and paper activities including several from CS-Unplugged [28] and other games and activities where the students must write instructions or algorithms which their peers will follow to achieve different tasks, such as, walk to a particular location in the building or to draw some simple pictures. These activities often served as warm-up activities at the start of the sessions.

3) Computer Programming

The students used the Scratch programming language to create their first computer programmes. Working in pairs, they created simple animations and then moved on to creating interactive computer games. Through this process, they were introduced to concepts such as initialisation, looping, variables, conditional statements, events and concurrency. Some of the students also used Kinect2Scratch and AppInventor to create more advanced games and simple smart-phone apps. The

students presented their work to their peers at several points during the workshops.

IV. RESEARCH METHODOLOGY

A. Participants

The pre survey was conducted in the first Bridge21 CodePlus workshop with each group. A group of comparison mixed-gender control participants were recruited from a transition year program run in the Bridge21 learning centre. (a programme known as CS-TY) [2] The total sample was 164 students, 110 girls, aged 12 – 17 years old ($M = 15.23$, $SD = 1.18$) 70 on the CodePlus programme, 40 on the CS-TY, and 54 boys from the CS-TY programmes aged 12-17 years old ($M = 15.25$, $SD = 1.54$). At the time of publication the post survey was still on-going, the analysis of pre and post results was undertaken on the smaller sample which had completed both pre and post surveys. This was 38 girls on the CodePlus programme.

B. Instrument

The questionnaire consisted of 6 groups of questions.

1. **Demographic.** Consisted of biographical information, including age, school grades and general access to technology.

2. **Studying CS.** This section examined students understanding of, and confidence and motivation to study CS at third level. It asked students how likely it is that they will attend university to study CS, answers were a 5-point scale (very likely to very unlikely) and how confident that they would be to study CS in university, on a 5-point scale (very confident to not confident at all). They were asked to identify which university subjects they were considering through a closed ended question with 3 responses (yes, no and not sure at this time).

3. **Perceptions of CS & IT.** Questions that explored students' perceptions of CS and the IT profession were adapted from work by Papastergiou [29]. These presented 10 specific areas of CS¹ to the students and asked them to rate on a 5-point scale (1: not at all, 5: to a very large degree) the extent to which they believed that CS involved the specific area. It also asked them to rate on the same 5-point scale the extent to which they believed that the IT profession involved each of 8 aspects².

¹ 'computer architecture', 'human-computer interaction', 'study of algorithms and information', 'use of algorithms and information for everyday life problem resolution', 'telecommunications systems design', 'artificial intelligence', 'business computing', 'development of applications for social benefit', 'computer programming', 'computer systems security'

² 'is creative', 'is competitive', 'is interesting', 'is difficult', 'is well-paid', 'is prestigious', 'offers one the opportunity to engage in a variety of fields', 'demands that one engages in computer programming'

4. **Self-efficacy with CS.** This is a modified version of Papastergiou's self-efficacy scale. Participants were asked to state their level of agreement on a 5-point scale (from "strongly disagree" to "strongly agree") with the 10 statements.

5. **Mathematics.** Students were asked about their current or expected performance in mathematics³ in the Junior Certificate (the state examination taken at the end of the junior cycle of secondary education, age ~15) and about their intentions and ambitions with regard to taking mathematics the Leaving Certificate (the state examination at the end of secondary education, age ~18).

6. **Gender perceptions.** Students were asked to express their perceptions regarding the suitability of CS and the IT profession for men and women, through indicating their level of agreement with statements on a 5-point (strongly disagree to strongly agree).

V. FINDINGS

A. Pre Questionnaires

Analysis of baseline gender comparisons revealed some interesting trends in terms of girl/boy differences in demographics, self-efficacy and likelihood of and confidence to study CS at university. The most pertinent results were as follows. Independent sample t-tests revealed

- No gender difference in expected and actual math grades for both junior and leaving certificate.
- Boys played computer games for significantly more time than girls (on average 1-5 hours per week) $t(159) = 5.59, p < .001$
- Girls spend more time using computers for homework purposes ($t(159) = -3.207, p = .002$), while boys spend more time using computers for general information seeking not related to school ($t(159) = 2.206, p = .044$)
- Interestingly, boys demonstrated significantly higher levels of self-efficacy with CS than girls, $t(159) = 2.85, p = .005$
- Boys were also more likely to study CS at university than girls ($t(159) = 2.53, p = .012$) and they were more confident to get accepted into a CS degree ($t(159) = 2.83, p = .005$)

Baseline comparisons demonstrate clear differences in how girls see themselves in terms of capability with CS and future potential.

B. Post Questionnaires

1) Computer Programming

A paired-sample t-test was conducted to examine changes to the CodePlus student's perceived ability to program a computer following participation in the CodePlus programme. This revealed a significant increase; $t(34) = 2.03, p = .049$, whereby the students perceived their ability to have improved

from time 1 ($M = 2.6, SD = 1.1$) to time 2 ($M = 3.0, SD = 1.2$). See figure 1

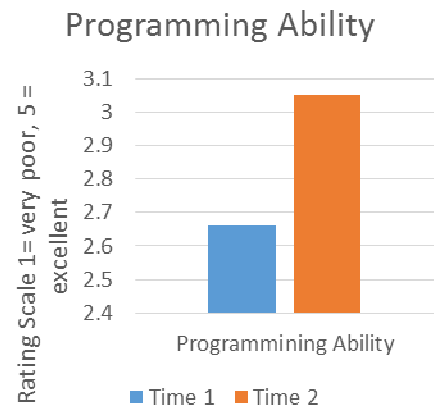


Figure 1: Demonstrates an increase in student's perceived ability to program computers following participation in CodePlus

A paired sample t-test also revealed significant increase in computer self-efficacy from time 1 ($M = 2.8, SD = .32$) to time 2 ($M = 3.4, SD = .20$); $t(37) = -9.8, p = .001$.

2) Studying Computer Science

There was no effect on student's perceived likelihood to study computer science or their confidence to study computer science following participation in the programme. This may be due to the fact that it was a self-selecting group with an existing interest in computer science.

However, students were more informed about career options. Paired sample t-tests revealed they were more aware from time 1 ($M = 1.38, SD = .54$) to time 2 ($M = 1.63, SD = .59$) that a CS career involved learning programming language from; $t(35) = -2.65, p = .012$, and that from time 1 ($M = 1.52, SD = .60$) to time 2 ($M = 1.88, SD = .94$) a CS career involves team work; $t(35) = -2.25, p = .030$

There was also a change in how they perceived a CS degree following participation. They were less likely to agree at time 2 ($M = 1.88, SD = 1.07$) than time 1 ($M = 2.22, SD = 1.30$) that Computer Science was a degree for geeks; $t(34) = 2.24, p = .032$

These findings represent positive outcomes which address some of the key factors which affect girls' decisions to pursue careers in CS. Further research will be undertaken as the CodePlus programme continues.

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³ Mathematical ability as this is a fundamental for entry to engineering and computer science degrees in many third-level institutions in Ireland and the U.K.

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Insights from a First-Year Learning Community to Achieve Gender Balance

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Abstract—Engineering remains challenged with regard to underrepresentation by gender and ethnicity. Lack of gender parity in engineering has been a problem since the very start of engineering but conversations about and efforts to address the lack of women in engineering has grown in momentum over the past 30 years. The problem is not only that gender disparity exists, but also an inability to make significant progress in closing the gap over time on a national level. This lack of change suggests that new approaches to understanding the complex problem of underrepresentation of women are needed. Research has advanced our understanding of what can attract women to engineering and retain them within the field. This paper presents data from a service-learning program that aligns pedagogically with the literature on gender and diversity more broadly. Specifically a first-year learning community of 120 students that was 54% female is examined to provide the student perspective. 77% percent of the women cited gaining experience in engineering as a motivation for selecting the learning community. 55% of the women cited the opportunity to impact others with 42% combining the two. Sample comments and quotes from the male and female students are presented and discussed.

Keywords—Service-learning, first-year, diversity, gender

I. INTRODUCTION

For more than two decades, engineering has sought to address the issues of underrepresentation of women and students of color within engineering. This past year ASEE made diversity an area of emphasis with its “Year of Action on Diversity”. There has been a great deal of research on the issues of diversity and underrepresentation in engineering science and computing[1-8]. One of the leaders in the area of women in science and engineering is Dr. Sue Rosser who was the distinguished ERM lecturer at the 2002 ASEE Annual Conference. After her lecture, ERM hosted a follow-on session with Dr. Rosser where she was asked about service-learning as it aligns with her work and the other literature on gender in science, engineering and computing. She said that service-learning embodied the characteristics of a gender-friendly curriculum. She discussed this alignment in her address at the National Academy of Engineering at a Symposium on Engineering and Computing Service-Learning in 2004. Dr. Elaine Seymour, another distinguished researcher in this area, visited the campus of Purdue University in 2013 and shared similar views on the pedagogy of service-learning as it aligns with her research and that of others.

Research on service-learning approaches, also called Learning to Serve (LTS) has shown benefits including improved retention [9,10] and increase in attracting and retaining a greater diversity of students in engineering [4,11,12]. EWB-USA currently has more than 12,400 members, of which more than 7,000 are students and forty percent (40%) are female.

The EPICS Program founded at Purdue University (www.purdue.edu/epics) is an example of an engineering and computing-centered service-learning approach. In EPICS, teams of undergraduates earn academic credit by partnering with local or global not-for-profit community organizations to define, design, build, test, deploy, and support engineering-centered projects that significantly improve their ability to serve the community[13]. With its focus on engineering and computing in a context of addressing human and community needs, EPICS has proven to be a very effective vehicle for encouraging women and under-represented groups in engineering. EPICS has grown at Purdue to over 400 students each semester. In the spring of 2014, 29.9% of the participants were female, while 46.7% of the participants were non-Caucasian. Over a 20 semester period, female participation from Electrical and Computer Engineering in EPICS was on average 77% higher than the overall school enrollment [4].

In the fall of 2014, 120 first-year students participated in EPICS through the EPICS Learning Community. This cohort was 54% female compared to the overall college enrollment of 23% female for that year. This class offers an opportunity to examine why such a high percentage of women chose the EPICS Learning Community option and potentially explore the findings for applications to other programs across engineering and computing.

II. EPICS PROGRAM

EPICS is an engineering and computing-centered, multidisciplinary, service-learning design program where students earn academic credit for partnering with not-for-profit organizations to develop and deliver designs to meet community needs. The program began at Purdue University in 1995 with 40 students and has substantially grown since its inception. In 2014-15, over 800 students were engaged in over 90 projects distributed across 33 sections. The program is explicitly multidisciplinary with over 70 majors participating, and it encompasses students from their first-year to senior year. The curricular structure is designed to allow students to participate over multiple semesters and supports long-term,

reciprocal community partnerships. The long-term student participation allows projects to be developed over multiple semesters or years and allows projects to address complex and compelling needs. The project timelines are completely decoupled from the semester schedule allowing projects to span multiple semesters or even years allowing projects of significant scope to be developed. Once a project is delivered, a new project is then identified by students under the guidance of their faculty mentor(s) and community partner(s). The students and teams are mentored by advisors (faculty, professional staff and local industry). EPICS teams, or course sections, consist of 8-24 students and are student led with a faculty or industry mentor (called an advisor), and a graduate teaching assistant (TA). Each team comprises multiple sub-teams, each one of which supports a single design project.

EPICS has been recognized for its curricular innovation by the NAE with the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education (2004), as an NSF exemplar of programs "Infusing Real World Experiences into Engineering Education (2012), by NSF's Corporate Foundation Alliance as an Exemplar Program (2002), by the Chester Carlson Award for Innovation in Engineering Education (ASEE) (1997 and 2012), and as a signature program by the IEEE Foundation (2013).

III. LEARNING COMMUNITY STRUCTURE AND OVERVIEW

The EPICS courses can be used to count as an alternative for many different courses within the engineering curricula and vary by discipline. It is most commonly used as a technical elective. Seniors can count their EPICS courses as capstone with departmental approval in Electrical, Computer, Environmental and Ecological and Multidisciplinary Engineering. EPICS can also fulfill university requirements as part of the University's core curriculum as a Science, Technology and Society requirement as well as part of the Entrepreneurship certificate.

Purdue University has a common first-year engineering program. Students enter the First-Year Engineering Program and complete a common set of courses that includes two required engineering courses before being admitted to their engineering major. The EPICS courses were approved as an alternate path through the first year as part of the university's learning community initiative.

Assessment data from earlier inclusion of first-year students showed that students who were involved in EPICS early in their academic careers reported an increase motivation to remain in engineering. The challenge of engaging students as early as their first year is that students can become intimidated on a team with older students. While the experience can be very positive, when students are adjusting to college life and course loads, the additional variable of an experiential learning environment can be foreign and sometimes overwhelming. In addition, while the vertical integration allows mentoring of younger students, older students do not always embrace the mentoring roles. The results have been bimodal with first-year students in the program having either very positive or negative experiences. To increase the number of first-year students and to insure a

more consistently positive experience, scaffolding and support are needed through their experience.

The learning community structure provides this kind of support and offers the opportunity to impact the recruitment and retention of students from groups traditionally underrepresented in engineering and computing [14]. The EPICS Learning Community structure includes placement into three linked courses. Students were all placed into one introduction to engineering course (ENGR 133) that covered required material including MATLAB computing and an introduction to the engineering majors required of all first-year engineering students. This course brought the entire cohort together for common instruction, community building and peer support.

The second course was the EPICS courses. Students were placed into EPICS teams along with sophomores, juniors and seniors. EPICS students learn design, which is also a required topic for all first-year engineering students. EPICS project teams are typically 4-5 students and the individual divisions are 8-24 students. The small class sizes provided opportunities for mentoring by the faculty or industry advisors and upper division students.

The third course was either an introduction to composition (English) or speech (Communication) in sizes of 20 or 28 respectively. These courses provided another smaller community with only first-year students from the learning community.

Students were given the option to live on the same floor with others in the learning community. Approximately 70% chose to live on the floors. The female floors are the same floors where a residential women in engineering program is housed so that female students did not have to choose between the EPICS Learning Community and the Women In Engineering residential experience. They could participate in both.

Learning community applications and placements are made through a central university office. A holistic placement process is used to place students into the learning communities. The process takes many factors into account to provide as equitable placement as possible. In the first two years of the EPICS Learning Community over 300 students applied for the 120 seats. In both early years, the percent of women was about 30%. The learning community office seeks to have similar demographic profiles across all of the learning communities. For the class entering Purdue in the fall of 2014, a high percentage of the female applicants only selected the EPICS Learning Community as a curricular option. As a result, the central office could not distribute them to a second or third choice as they has in the earlier years. The results was a class that was 54% female (65/120). Of those enrolled, 95% had selected EPICS as their only curricular learning community option. The following sections summarize the results of assessment data from this cohort. The data includes a survey distributed through Qualtrix that probed student motivation for electing to the in the learning community and their expectations, an end of semester survey asking students to reflect on their experience and the end of semester reflections that were assigned across the EPICS course. The beginning of

the semester data included a question on gender but the end of semester data did not include gender. The final reflections were an assignment with names included and could therefore be identified by gender for analysis.

IV. ASSESSMENT RESULTS

At the beginning of the semester, students were asked why they selected the EPICS Learning Community. Figure 1 shows the responses by gender. The open ended responses were analyzed by gender and five codes emerged. They were “Experience (in engineering, hands-on, design), “Community” (making a difference, community engagement, etc.); a blended category “Experience and Community” when they described making a difference while gaining engineering experience; “Learning Community” when they described the benefits of the learning community; and “Particular Learning Community (LC)” when they described wanting EPICS to specifically avoid the traditional first-year sequence. The last code was only explicitly present in the male responses although three women alluded to avoiding the traditional courses as part of their answer but added additional information that aligned with another code.

The results show that the majority of both male and female students were seeking experience in engineering. The women described the connection to the community or helping others while they gained that experience at a higher rate. 77% of the female students cited gaining engineering experience either by itself or connected to the community.

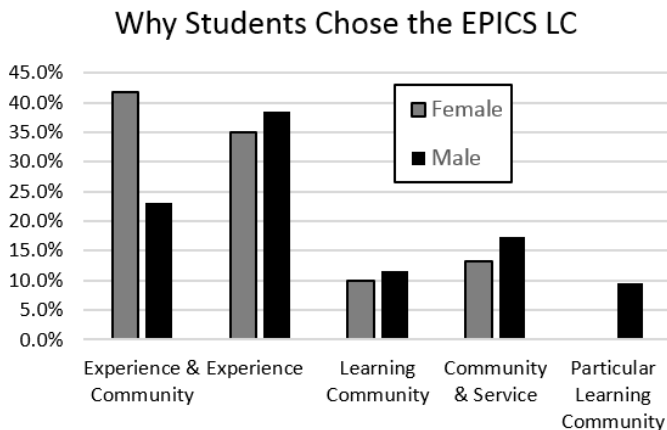


Fig. 1. Why students Chose the EPICS Learning Community

Among the comments for the female students who cited experience as the primary reason for choosing EPICS were the following:

I wanted real world engineering experience and to learn by solving real world problems.

I wanted to work on a project that I was interested in involving characteristics of the discipline of engineering I'd like to study along with wanting hands-on experience, to work with a project partner, work with others, and take on roles for success as a team.

1. Real world experience: unlike most other alternatives for EPICS, I will be able to execute the entire design process; 2. Team work: While working to meet the stakeholder's requirements and needs, I will gain the experience of working in a team with people with different ideas and viewpoints.

These data consistent with prior research on women participating in EPICS [15] where women reported enrolling in EPICS to seek engineering experience. In that study, the women described EPICS as working with the community, implying that this was also a factor. For the Learning Community students, the community and helping others clearly played a role. A majority of the female students (55%) mentioned the community or helping others as part of their reason for enrolling. 42% combined gaining experience and impacting the community, world or the environment. Sample comments of this combination included:

I want to be an engineer so that I can use what I learn to give back to my community and EPICS allows me to start with that before I even get a degree

Community service was an important part of my life in high school, and EPICS was the perfect way to help continue that while learning Engineering skills at the same time

I chose to enroll in the EPICS learning community because I can actually experience and learn how engineers work in real problem-solving situation and also participate in a community work at the same time.

I thought it would be fun to design and build devices for community use, and it will be good experience for when I need to find a job or internship.

Real world experience-getting the chance to create something that could be potentially beneficial to at least one person or a community. Team practice-having the ability to function on a team and learning to cope with any problem that can pop up.

Comments that cited just the opportunity to impact the community as a reason included:

I enrolled in EPICS because I love volunteering to help the community!

I really love the idea of helping out others, and the ability to combine my passion and future career with service is such an incredible opportunity. I also love being connected with people with similar passions and ambitions as me.

During a visit to Purdue for a Women in Engineering event I heard about an EPICS project that worked with Riley Hospital for Children, which is a very important organization to me as I have been a patient there almost my entire life. I wanted to be a part of a program that helped many organizations improving lives like Riley's patients'.

most importantly I wanted a chance to make a difference.

The male students responded more heavily to gaining experience with a rate nearly 40%. It is interesting to note that a similar percentage cited the community involvement as a motivation for selecting the EPICS Learning Community by itself or in combination with the experience. The distributions by gender are similar for the males and females.

As part of the same survey, students were asked “what they hoped to do with their engineering degree?” The female responses were coded and 40% responded that they wanted to help others or make the world or environment a better place. Example quotes include:

I hope to not only make a difference in this world by helping in technological advancements but I also want to inspire others especially women that anything is possible and attainable as long as one works hard.

I hope to make a difference in the world. I want to be able to do something in my life as an engineer that will impact someone else's life for the better

Create things, and make things which will be able to help people.

41% stated that they hoped to obtain a job, either in general or in a specific field such as aerospace, medicine and companies such as Disney.

Summative evaluations were collected at the end of the semester but they did not include gender identifiers. However, the data on the student experience was overwhelmingly positive with all students agreeing or strongly agreeing to recommend the EPICS Learning Community to other students as shown in Figure 2. This is consistent with the earlier two years. In those three years of data, three students have been neutral but none have disagreed with the statement, male or female.

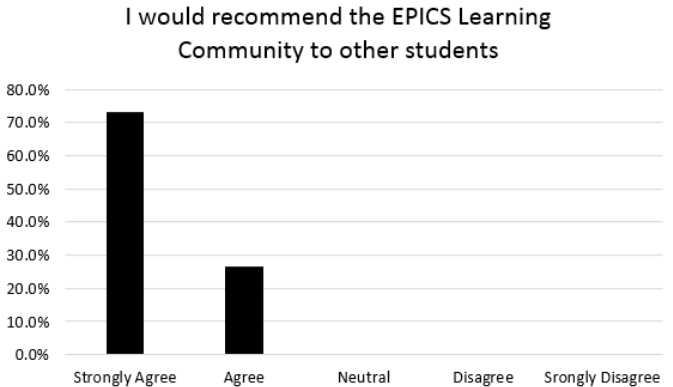


Fig. 2. Responses to “I would recommend the EPICS Learning Community to other students”

The summative evaluations also asked what impact their participation had on their motivation to pursue engineering. One student reported a decrease in motivation. 70% indicated a positive impact on their motivation as seen in Figure 3.

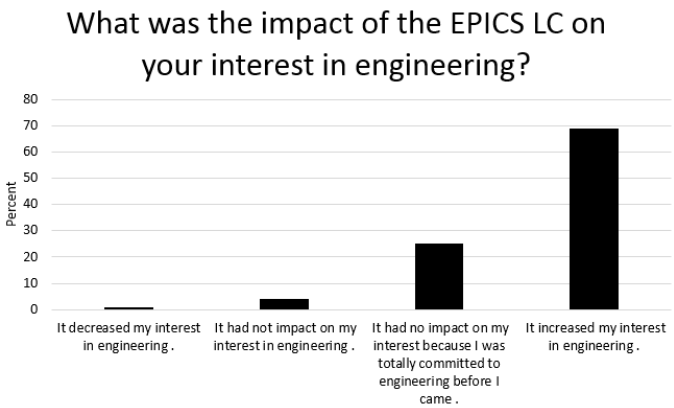


Fig. 3. Responses to “What impact did the EPICS Learning Community have on your interst in Engineering?”

Students were asked if the EPICS Learning Community met their expectations? Figure 4 shows the strong positive response. Students we asked to explain why and their answers were coded positive, negative and neutral. About a fifth of the students used terms that explicitly stated that the experience exceeded their expectations and the “exceeded” code as added as shown below.

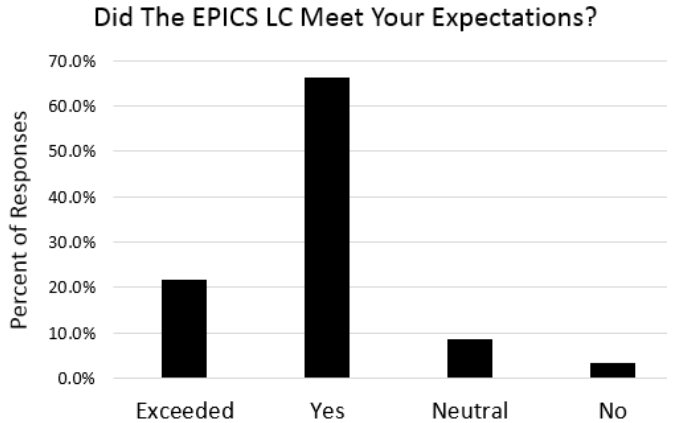


Figure 4. Did the EPICS Learning Community Meet Your Expectations?

Positive comments that were coded as “Yes” included

The EPICS learning community met my expectations. It helped me to learn about a specific concept within engineering. It was also helpful for me to learn more about the ethics of working as an engineering team, a concept that can only be learned from being in a team environment.

Yes because I expected to be working on a real world project and learning the process of engineering and EPICS fulfilled my expectations and more.

The EPICS learning community met my expectations and more. When I joined this learning community, I did not know exactly what to expect. I knew I would be living with girls who were also in engineering, and that we could do our homework together, but I had no clue how much fun I would have.

I expected a more diverse group of people and I am very happy with how the learning community worked out. Most of my friends are from the learning community and it had greatly helped me academically. One of the best things that had helped me in college was being able to ask for help from the people on my floor. I am very pleased with how EPICS turned out and I have made my best friends through the learning community.

Comments that were coded as “Exceeded” included:

Yes it did, in fact it exceeded them. I wasn't expecting everything to be so professional, but it was, and I am glad I am a part of EPICS.

It was completely different than what I expected. It was far more involved, and taught me much more than I expected. I didn't think I would be doing much real engineering, and EPICS provided an opportunity to try what I would actually do in our field.

The EPICS Learning Community has exceeded my expectations. I learned a lot in both the classroom and the lab. In the classroom, I learned a lot about Excel and Matlab. I also gained a better understanding of what EPICS is through the group project. In the lab, I was able to become a more vocal teammate, who is able to express his opinions and ideas. I was also able to look at problems from different points of view because of the influence that my teammates have had on me.

Comments that were coded as “Neutral” included

I didn't really know what to expect from the LC, just some vague idea that it would be something like Key Club from high school. However, I found that the learning community was much more than that. It actually allows us to use our engineering for real-life problems and create a solution.

I had no expectations for the EPICS learning community when I applied to be a part of it. I didn't really know what I was signing up for, just that the projects in the community seemed like a good program.

Open ended comments were solicited in the summative evaluations. While the data was collected without gender identifiers, there were comments where the gender could be deduced. These comments were almost exclusively from

female students who commented on the environment being mostly female. These included:

The EPICS learning community met my expectations and more. When I joined this learning community, I did not know exactly what to expect. I knew I would be living with girls who were also in engineering, and that we could do our homework together, but I had no clue how much fun I would have.

As a girl the diversity has caused me to not really see the gender gap so this has definitely made me more comfortable in my studies this first semester. I think this will cause me to be more surprised regarding the gender gap in the future.

I was always told it was a rarity to be a girl in engineering. EPICS isn't like this. Everyone is either a different culture or gender and no one judges each other based on their background.

As a girl, I really liked it. I was surrounded by other girls, something that I wasn't expecting in engineering. I think that I would have done well in a less diverse class too, but I did appreciate how diverse ENGR133 was.

Being a girl in engineering, I felt normal and equal to any and everyone else. I can't necessarily attest to another engineering setting though because I didn't have that experience. Because I felt equal, I had no problem sharing my ideas and putting myself out there.

This impacted me because I got to work with a lot of different types of people and it was especially different because I went to an all-girls school before so I had never had to work with boys on school projects. I think this is a lot different from my high school because it seems like boys and girls have a different type of work ethic.

I have developed a friend and peer group that is so crazy and different but I wouldn't have it any other way. I have really enjoyed having the opportunity to get to know a smaller group really well rather than being just a number among many, many students. I also really enjoy having some a large group of girls in engineering because I feel like the ratio would be much different in the other group. I feel like I understand more points of view than others do. I have had a more rewarding first-year so far because of all the diversity in ENGR 133.

I think I benefited from it because I know that engineering is usually mostly males, but our class was actually more females, and we had people from several other countries. It all added up to an interesting dynamic between the groups because everyone had a different viewpoint and I think it promoted learning. I definitely thought I learned very well and worked with others a lot in this class.

EPICS allows me to meet many new people, and as a women in engineering, I am, for once, in a class that has a greater amount of females than males.

One of the evaluation comments could be identified as coming from a male student who said *“Working with women in my engineering group was a good experience. We had a slightly different perspective on our projects, and they changed the dynamics of how and when work was done, as they motivated us away from procrastination.”*

End of Semester Reflections

All students in EPICS write regular reflections. At the end of the semester, they write a summative reflection where they are given a list of question prompts to choose from. The reflections were examined from the female learning community students and two themes emerged when commenting about their experience. The first was

All students in EPICS write regular reflections during each semester as part of the coursework. At the end of the semester, they write a longer summative reflection where they choose from a list of question prompts. The final reflections were examined for the female learning community students who wrote about their overall experience. Two major themes emerged. The first was about gaining experience. Clearly the student valued the engineering experience they gained. Example comments from these reflections included the following.

EPICS has taught me how much I value the hands on side of working. Writing papers and doing homework while sitting at a desk is not something that I could do as a job (or for the rest of my school career). It is neat to me to be able to do things for myself – solving problems and making things better. I like getting to see how things work first-hand, and, being able to design and build it myself, adds to how fun it is. I definitely have a strength for design. I can visualize things in my head well and love trying to communicate ideas to other team member. Specifically, designing what the solar rig would look like was really neat. We got to draw out and explain concepts for designs on the white board in the lab, and I found that debating which idea would work the best was really fun.

I have learned how to work in ethnically diverse teams as that was not an experience I have had before. It wasn't difficult as it was simply interesting. Other than a language barrier, different viewpoints are brought up because everyone develops different understandings of the situation and different ideas for how a problem could and should be solved. This sort of thinking is important because not all problems only have one answer. It is critical that students are taught to think outside of the box and cover all aspects of a problem. I have learned that problems with multiple issues that need to be addressed are most interesting to me. This mirrors real-world engineering as not everything can be solved all the time, and sometimes the best solution is the simplest one that will leave things out while other times all of the needs absolutely have to be met. I can definitely use

this sort of problem solving in future engineering endeavors.

A second theme emerged where the women talked about learning about themselves and gaining confidence. These included comments that discussed learning to take more initiative and having the confidence to speak up in design groups now and in the future in internships and eventually in permanent jobs. They described examples of where their experience nurtured their ability and their success gave them confidence that they will carry forward into their career. Comments included the following:

From participating in EPICS, I've not only developed many useful lifelong skills that I'll incorporate in the workforce but I also got to learn more about who I am. From all the workload, big projects, and responsibilities, and EPICS deadlines thrown at me this semester, it was crucial for me to get adjusted to this new college life, and there was no other better way to learn more about myself. From struggling and trying new things until getting to the point of my satisfaction taught that I am more persistent and diligent than I already know. I think that is my main strength that puts me far apart from others professionally. Once I set the goal, I'll do or give up anything to achieve that goal.

Taking part of the Camp Riley team and EPICS as a whole has taught me a lot, especially about my individual self. It also helped me decide in a clearer light who I want to be and what I need to change and keep the same to become that person. During this semester I learned a lot about my strengths and weaknesses that I was not aware of before. I learned that I may not know a lot about details about a certain topic, like this semester drainage solutions, but if I try to my fullest potential to understand the situation as a whole that I can contribute a lot to my group.

Being in EPICS, I was taught many things about myself, and who I was becoming as an engineer. I found my strengths, weaknesses, and how to work with others by being in EPICS. By working in teams, I was shown how to work with a group: the pros, the cons, and the in between. I found that working with groups builds self-awareness of what is going on, and teaches you how to do things when it turns out to not go along as planned. Working in groups allows for different input, and in turn a better product to come out of all the hard work. As for myself, I learned that I work best when working together with others. I originally was always a person who enjoyed working independently; however, when we started the project for the West Lafayette Jr./Sr. High School, I realized how much more difficult everything would be if working alone. Teamwork showed me a new sense of leadership, which I had never had before, and working with others also brought out a more outspoken side of me. When working with others I noticed I wasn't afraid to put in my two senses and speak up about ideas that could improve our project.

Through this experience in the beginning of the semester, I realized one of my greatest weaknesses is speaking up. In the beginning of any teaming situation, I tend to remain quiet as I become comfortable with the new team. This is an area I can continue to work on improving in, especially as I look ahead to professional careers. As in EPICS, I will partake in various (design) groups in future jobs. In these teaming situations, in order to be an active participant, I need to be able to voice my ideas and opinions. Otherwise, I may appear as an incompetent co-worker.

Based on the work I accomplished this semester, I determined one of my greatest strengths is helping people to divide up work so it's accomplished in a timely manner. For example, when our team was trying to decide what type of garden plots to implement (community, individual, guerilla), I had the idea to compile all of our research into a shared Google document. Also, when creating the final design of our garden, I recommended we each come to the final design meeting with a general sketch of our ideas. This way, our team could figure how to best incorporate the different aspects of our designs and the survey feedback into the final design. I know in my professional career I will want to remain well organized since it is a valuable skill to employers, and it will help me to be successful in my job.

This semester I learned not to make assumptions about team members' skill levels and let your assumptions about their skill level affect your confidence in your ideas. At the beginning of the semester I felt like I took a little bit of a step back from fighting for some of my ideas for the project because I felt like, as a freshman, I didn't really have the technical knowledge to form fully comprehensive ideas. However, this didn't prove to be the case, and some of my team members made comments about it in my peer evaluations. They encouraged me to fight for my ideas and the direction that I wanted to see the project go, rather than worry about not having as much experience. In reality, no one on the team really had experience with our specific project and specifications, so anyone's input, no matter their background, was equally valid. It's important in any team, especially when brainstorming, to be as open as possible when it comes to coming up with ideas. Everyone should provide input, no matter their perceived knowledge, to try and generate as many ideas as possible. If proper brainstorming is done using strategies like 'piling on', etc, then the range of ideas will be greater and a better solution to a problem may be reached. It is important for freshman, or really anyone working with other people they are not familiar with, to never undervalue their perspective. What I learned this semester is something that I will carry with me into my first internship this summer. Even though I may be working with professionals in their field, it is still very important that I speak up and voice my ideas. Even though they may have more experience or knowledge than me, I

still have a different perspective unique to myself that could introduce something that they've never thought of.

V. DISCUSSION

Decades of research on underrepresentation and gender point to the need to link engineering and computing with people, communities and/or the environment as a relevant context. Humanizing the image of engineering is one of the characteristics of the National Academy of Engineering's report on *Changing the Conversation* [16]. The pedagogy of service-learning aligns with these goals and the EPICS Learning Community was evidence of the impact. A majority female first-year engineering course is unprecedented in the core first-year engineering program at Purdue. The high percentage of women in the EPICS Learning Community was a result in the high demand among women and their choice of only one learning community. The attraction of a higher percentage of women is consistent with the history of EPICS [4] but the 2014 class was significantly higher. It is not clear why a sudden increase occurred. One possible reason is that the EPICS Learning Community operated under temporary experimental course numbers in prior years with 2014 being the first year with permanent course numbers. This may have made it more visible or to feel safer for students to select. Another possibility is that in its third year, former participants in the program have been integrated into the student recruitment volunteer pool and have become advocates for the learning community. Many students reported hearing about the EPICS Learning Community on campus from other students.

While it is not clear why the increase occurred, it is clear why the female students selected the EPICS Learning Community. They seek relevant work experience that will prepare them as engineers and are attracted to gaining that experience within a context that is relevant. They are not just seeking to do service, they want real engineering experience. Being able gain such experience within in the community context became very appealing. They do not want to simply "help people" but to develop as professionals. The male students also responded in a similar way. While more males only listed gaining experience, several also listed the community context as a compelling reason to join.

The female students reported that being in the majority in the Learning Community class was a benefit. Their descriptions of the benefits including the building of community, friendships and support systems. They also reflected on future courses and noted that they expected to be in the minority. Their first-year experience provided a base to build upon to handle what they saw ahead. Their reflections on their first semester included descriptions about gaining experience and self confidence that would carry into the workplace through internships and eventual permanent employment. A strong majority indicated that the experience reinforced their desire to complete an engineering degree.

The data suggests that students, especially the female students seek experience within a context. Such experiences can be as part of a more traditional courses in the form of

content or projects. The nature of the community-based projects provided this naturally. These attributes can be integrated into more traditional courses to impact the image of engineering and computing. There are many ways to put decades of research into practice within the engineering and computing curricula to address the issues of underrepresentation.

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Effects of Gender and Abstract Thinking Factors on Adolescents' Computer Program Learning

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Abstract—Computational thinking ability is important in computer science education. It emphasizes abstraction and automation. For automation, programming has become a key ability in digital society recently. As a result, the increase in the importance of coding education in many countries has brought various educational methods to improve teenagers' programming abilities. Among programming abilities, reading ability is important especially to programming novices. This paper focuses on the effects of gender and abstract thinking abilities of adolescents on understanding computer programs. Also, we examine if there is any difference in teaching between adolescents and college students. In order to achieve our research goals, we surveyed on the abstract thinking level, and then measured program understanding ability for 300 academic high school students who had learned C language. From this research, we found that the abstract thinking affects more complex program understanding positively. Also, we found that the language experience before learning brought the difference in program understanding. However, we could not find statistical differences in program understanding between two genders. From this research, we can provide a new point of view to improve adolescents' programming ability with abstract thinking and gender factors.

Keywords—computer science education; computer programming understanding; abstract thinking; gender difference; software metric;

I. INTRODUCTION

Traditionally, programming behavior was classified into 5 activities: composition (writing a program), comprehension (understanding a given program), debugging (finding errors in a given program), modification (altering a given program), and learning (acquiring a new skill) [1]. However, during the programming class in secondary schools, after students learn about how to use a set of keywords and grammar, they key in a few programs their teacher prepared. And then, due to the programming typos, they spend a lot of time on correcting their typos. So far, many researchers continue to find an appropriate way for computer programming learning. Among various programming abilities, this paper focuses on programming understanding ability. This ability is essential to programming novices because they do not have knowledge so much. Thus, before they learn how to write and debug programs, they should have a change to read and to understand

other people's programs. In fact, many of adolescents are programming novices at this moment. Shneiderman and Richard mentioned that programming novices focused more on specific code than the structure of a given program [1]. It seems that the novices tried to understand a program at a low abstract thinking level. In addition, they mentioned that using mnemonic names, comments, and modularity helped to understand a given computer program [1].

Besides, many research works examined the relationships between cognitive personal factors and learning ability of computer programming [2][3][4]. According to the previous literature, motivation and skill are the keys to success in computer programming [2][3]. Self-efficacy is also an important mean of measuring people's performance and it affects computer programming ability[4]. On the other hand, Kramer described his teaching experience for about 30 years that abstract thinking ability helps students' academic achievement in his paper [5].

Recently, due to the advent of the concept of computational thinking ability, abstraction and automation became keys in computer science education [6]. However, the previous literature rarely analyzed how the abstraction or the abstract thinking worked with program understanding. In particular, the researchers did not pay attention to how the adolescents felt and what the problems were when they read computer programming component such as if-statement, while statement, and functions. Also, there rarely exists a measurement to assess the students' abstract thinking ability from the programming point of view.

Thus, in this research, we firstly show how adolescents' abstraction thinking level affects their computer program understanding based on their programming language experience. Next, we examine if there exists gender difference in program understanding ability. In addition, we examined if the traditional metric for measuring software complexity is consistent with the difficulty level the adolescents feel when they solve program understanding problems.

In order to achieve our research, we adopt the Behavioral Identification Form (BIF) [7] as our measure for abstract thinking. According to action identification theory, the identities for an action can be classified into two groups hierarchically. One is low in level and the other is high in level.

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The low level identity usually concerns about *how* an action is performed, whereas the high level identify usually concerns about *why* the act is performed. Vallacher and Wegner developed 25 items to measure action identification, which have two alternatives; one is abstract and the other is concrete [7][8]. Many researchers have referred the behavioral identification form, and Trope et al. adopted the BIF in their construal level theory [9]. In the theory, the low-level action identification is related to concrete thinking, *how*, whereas the high-level action identification is related to abstract thinking, *why* [9].

Next, we adopted the program examples from the research [10], which are the basic structure, the selection structure (if-else), and the iteration structure (do-while). All the problems were covered in the class of the high school we chose. We assumed that the basic structured programs are lower level in abstraction, whereas the selection and the iteration structured programs are higher level in abstraction. However, we did not know the exact difference in abstraction level among the programs.

The rest of our paper is organized as follows. In section 2, we review the previous literature related to the Behavioral Identification Form and software metric that is a quantitative measure of a degree to which software possesses a set of properties [11]. In section 3, we firstly describe the problems we chose for this study. And then, we describe the experimental process and methods for this research. In section 4, we perform a t-test and ANOVA to examine if there exists any difference due to gender and abstract thinking level. And then, we analyze the relationships among abstract thinking ability, language experience, and program understanding ability in order to see if there exists a moderating effect among the factors. Finally, we conclude our paper in section 5.

II. EASE OF USE

A. The Behavioral Identification Form for Abstract Thinking

The action identification theory insists that any action done by a person can be identified from the person's thinking styles [7]. The thinking style can be divided into two: thinking globally (abstract) or locally (concrete) [7]. Sometimes it can affect adolescents' academic achievement. There are many methods to measure thinking level. One of them is the Behavioral Identification Form (BIF) [7][8]. Vallacher and Wegner developed items to measure the action identification, which have two alternatives; one is abstract and the other is concrete [10]. In the theory, we can calculate an abstraction thinking value by giving 0 score for concrete alternative and giving 1 score for abstract alternative. The BIF is linked with measuring people's spatial distance and mental construal of social events [9]. The BIF is also linked with the Time Perspective theory [11] to figure out the concept of time. In fact, time is abstract concept in many literatures. We can get the abstract thinking level with the sum of the scores of the items. Table I shows the sample questions for measuring the abstract thinking value [7][8].

TABLE I. SAMPLE QUESTIONS FOR MEASURING THE BIF[7]

Questions	Alternative 1	Alternative 2
Making a list	a. Getting organized*	b. Writing things down
Reading	a. Following lines of print	b. Gaining knowledge*
Joining the Army	a. Helping the Nation's defense	b. Signing up
Washing clothes	a. Removing odors from clothes	b. Putting clothes into the machine
Picking an apple	a. Getting something to eat*	b. Pulling an apple off a branch
Chopping down a tree	a. Wielding an axe	b. Getting firewood*

*Higher level alternative. Total score is the sum of higher level alternative choices.

B. Software Metric

Software metric is an objective measurement of software complexity [12]. Software metric is necessary when software engineers establish their schedule and budget planning, cost estimation, and so on [13]. We can find a lot of software metric from the previous literature. In 2008, [14] compared the software metric tools including object-oriented programming. As new components appeared in new programming languages, software metric should be enhanced in order to measure the complexity of some software objectively.

Among the metrics, cyclomatic complexity has widely been used even though there was critique about the theory [12]. Let us get the cyclomatic numbers of the program P2 and the program P3 in Table II. The number for P2 is 3 and the number for P3 is 2. Thus, according to the rules for getting the cyclomatic number, the program P2 is more complex than the program P3. However, in this research, our students felt that P3 was much more difficult than P2. In Section IV, we present the reason for this phenomenon. In fact, there are various levels of programmers in the world. In the past, we did not expect that our kids have a change to learn computer programming at the school curriculum. So far, computer education has mainly focused on ICT literacy and cyber ethics. Thus, researchers such as software engineers have rarely paid their attention not to educate young kids but to develop software.

III. EXPERIMENTAL PROCESS AND TEST PROGRAMS

In this Section, we describe our experimental process and the test programs chosen by this paper. One of the authors of this paper works for J general high school, who majored in Computer Education. She taught C programming language at the high school. In the city where the high school is located, there are 17 general high schools. According to a report comparing the average test grade among the schools, the J high school was placed 9th in 2013 [15]. The author firstly taught 151 male students during 17 weeks of spring semester in 2014. And then, she taught 149 female students during 17 weeks of the following fall semester in 2014. Both of them were 10th grade students. She taught the concepts of variables and expressions, and then taught control structures such as

blocks, if-else statements, and do-while statements. She taught the same content to two different groups divided by gender with the same instructional method.

TABLE II. PROGRAM UNDERSTANDING PROBLEMS

Component	Questions
P1. Simple statements (2 points)	<pre>main() { int i, j=3; i = j+5; j = i*2; printf("i=%d, j=%d", i, j); }</pre>
	<pre>main() { int total; int apple=2, banana=3; total= apple * 2; total = total + (banana * 3); printf("total = %d", total); }</pre>
P2. Conditional statement (if-else) (2 points)	<pre>main() { int no, in=3; if (in + 2 > 5) no = in * 10; else if (in + 3 > 5) no = in * 20; else no = in * 30; printf("no=%d", no); }</pre>
P3. Iterative statement (while) (2 points)	<pre>main() { int x, y, z, noloop=1; x=1; y= 1; z= 0; while (noloop < 5) { z = z + x + y; x = y; y = z; noloop++; } printf("z=%d", z); }</pre>

We selected the same problems described in the research [10]. After 17-week learning was done, we asked the problems with the BIF questions and 4 mathematical problems such as the Perkins problem and the Krantz problem [16][17] for comparing the students in terms of gender and abstract thinking ability. We also asked if the students had any language experience before they learned C language in 2014.

The problems mentioned in Table II were not the final test but the survey questions for this research. Since this research is interested in the program understanding ability when they learn a programming language, we did not offer coding problems. In fact, there have been a lot of previous research about programming aptitude test and programming ability test [18][19]. However, the previous research mostly had the psychological perspective instead of the pedagogy of programming perspective [19][20]. This is a difference between this research and the previous ones.

IV. EXPERIMENTAL RESULTS

In this section, we firstly compare the characteristics of the students participated in our survey from the gender point of view. And then, we compare the program understanding ability from the abstract thinking point of view. Next, we examine the interaction effect among gender, abstract thinking, and language experience. Finally, we describe the difference in program complexity between software engineering field and computer education field. In fact, for the whole students, their program understanding scores were positively correlated with their mathematical problem solving scores ($r = 0.136$, $p = 0.019$).

A. Gender Difference

We examined the gender difference in the BIF, 3 types of program understanding problems, and the mathematical problem solving, and the language experience before the students entered the high school. Table III showed the mean differences between male (M) and female (F). The number of male students is 151 and the number of female students is 149.

TABLE III. GENDER DIFFERENCE

Factors	Gender	Mean	SD	<i>t</i>	<i>P</i>
The BIF	M	14.46	4.65	3.40	0.001
	F	12.68	4.42		
The program P1	M	1.25	0.84	-2.54	0.012
	F	1.47	0.69		
The program P2	M	0.95	0.50	-1.39	0.166
	F	1.11	0.50		
The program P3	M	0.17	0.28	-0.62	0.534
	F	0.21	0.31		
Mathematical problems	M	4.63	1.78	5.58	0.000
	F	3.50	1.72		
Language experience	M	1.19	0.48	2.84	0.005
	F	1.05	0.30		

As shown in Table III, the male students had a higher abstract thinking level than the female students ($t=3.40$, $p=0.001$). In addition, the male students had a higher mean of programming experience than the female students. For the language experience, we measured it as the number of programming languages the students knew. However, there was no significant differences in program understanding score except the problems that contained simple statements. In the simple statement programs, the female students had a higher score than the male students. The female students had lower levels of abstract thinking ability than the male students.

In summary, for gender, the female students solved the simple structured program better than the male students regardless of their language experience and the BIF. On the other hand, the male students did better in the mathematical problem solving. For the higher level language problem, there was no difference between two genders. In the following section, we divided the students into two groups with respect to the abstract thinking ability in order to examine if there is any difference in program understanding ability between a higher level in abstract thinking and a lower level in abstract thinking. In some cases, differences can be cancelled due to

considering the whole sample. If we divide the sample into a few groups with a meaningful measure, then we can get some meaningful results.

B. The Mean Differences between Two Abstract Thinking Levels

We firstly got the mean values of the abstract thinking for two genders. In fact, the abstract thinking ability is statistically different between two genders. Thus, when we divided into two groups for the abstract thinking, we use two different mean values of the abstract thinking. For the male students, the mean value was 14.46, whereas the mean value as 12.68 for the female students. Thus, for the female students, the scores between 1 and 12 were included into the lower level, where as the scores between 13 and 25 were included into the higher level. On the other hand, for the male students, the scores between 1 and 14 were included into the lower level, where as the scores between 15 and 25 were included into the higher level.

Table IV shows the differences in the 3 program types between the two abstract thinking levels. We divided the results into male (M) and female (F).

TABLE IV. DIFFERENCES IN PROGRAM UNDERSTANDING BETWEEN THE TWO ABSTRACT THINKING LEVELS

Program type	Gender	<i>t</i>	df	<i>P</i>	Mean Difference
The program P1	M	-0.56	149	0.58	-0.08
	F	-0.67	147	0.51	-0.08
	Total	-0.86	298	0.39	-0.08
The program P2	M	-0.57	149	0.57	-0.09
	F	1.10	147	0.27	0.18
	Total	0.35	298	0.72	0.04
The program P3	M	-2.64	105.44	0.01*	-0.24
	F	0.09	147	0.93	0.01
	Total	-1.69	281.4	0.09	-0.12

As shown in Table IV, there was no difference between two abstract thinking levels except the program P3 for the male students. In order to find out the reason, we analyzed the previous literature and found familiarity factor played an important role in computer program understanding [10]. Thus, we concluded that since the female students had lower abstract thinking levels than the male students and the female students also had lower language experience than the male students, there was no mean difference in understanding the P3 for the female students. In addition, when comparing the mean values of 3 types of programs, the understanding values of the P3 had the lowest score among the 3 programs. This result is consistent with the theory of Shneiderman et al. mentioned [1]. They proposed that programming novices focused more on specific code than the structure of a given program [1].

C. The Moderating Effect among Gender, Abstract Thinking, and Language Experience

We firstly examined if there was any moderating effect between abstract thinking ability and gender on program understanding in this subsection. And then, we also examined if there was any moderating effect between language

experience and abstract thinking ability on program understanding. A moderating effect means that it may reduce or enhance the direction of the relationship between an independent (predictor) variable and a dependent variable [21]. Or, when the relationship between the two variables changes the direction (positively or negatively), we can define there exists a moderating effect between them [21].

When we performed the analyses to see if there existed any moderating effects, we could not get the effects for the program P1 and P2. Only P3 had the moderating effect. Thus, we only present the program P3 (the iterative structure). Table V shows the result of the moderating effect. The number of the low abstract thinking level male was 75 and the number of the high level was 76, whereas the number of the low abstract thinking level female was 73 and the number of the high level was 76. For the male students, the mean gap between the two levels was significant. However, due to the female students, $F(1,296)$ value is 2.80 and $p=0.095$. There was no difference between the two genders ($F(1,296)=0.41$, $p=0.523$). Finally, the moderating effect between the abstract thinking level and gender was marginally significant ($F(1,296)=3.24$, $p=0.073$).

TABLE V. MODERATING EFFECT BETWEEN ABSTRACT THINKING LEVEL AND GENDER ON P3

Source	Sum of square	df	Mean square	<i>F</i>	<i>P</i>
Abstract thinking level (A)	0.24	1	0.24	2.80	0.095
Gender (B)	0.04	1	0.04	0.41	0.523
A * B	0.28	1	0.28	3.24	0.073
Error	25.64	296	0.09		
Total	29.00	300			

($R^2 = 0.011$, the dependent variable: P3)

Fig. 1 shows the graph that represented the meaning of the data in Table V. It represents that there is a difference in understanding P3 (a more complex program) between the two abstract thinking levels for the male students. Thus, the abstract thinking ability played a role in understanding more complex programs. However, we could not find any difference for the female students. We explained the result in the next subsection.

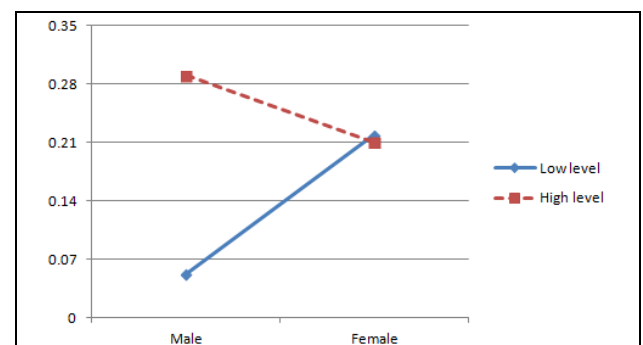


Fig. 1. The mean values of the point for P3 with two abstract thinking level and gender

Next, we examined if there was any moderating effect between abstract thinking ability and language experience on program understanding. For the abstract thinking level, the number of the high level students was 152 and the number of the low level students was 152. The number of the novice was 271 and the rest of them were experiencing another programming languages. Table VI shows the result of the moderating effect between the abstract thinking ability and language experience. Table VI showed that there existed a moderating effect between the abstract thinking and the language experience ($F(1,296)=20.55, p<0.001$). Also, for each factors, two groups were significantly different (A: $F(1,296)=22.61, p<0.001$, B: $F(1,296)=20.38, p<0.001$).

TABLE VI. MODERATING EFFECT BETWEEN ABSTRACT THINKING LEVEL AND LANGUAGE EXPERIENCE ON P3

Source	Sum of Squares	df	Mean Square	F	P
Abstract thinking level (A)	6.989	1	6.99	22.61	.000
Experienced (B)	6.301	1	6.30	20.38	.000
A*B	6.353	1	6.35	20.55	.000
Error	91.504	296	.31		
Total	116.000	300			

($R^2=0.118$, the dependent variable: P3)

Fig. 2 shows the graph that represented the meaning of the data in Table VI. As we expected, when the abstract thinking level became higher, the moderating effect occurred. In Fig. 2, the two lines were not parallel. It means that when the students' abstract thinking level was low, the difference gap between the novice and the experience students was not big. However, when the students' abstract thinking level was high, the difference gap between the novice and the experience students was very big. Thus, the abstract thinking ability enhanced the program understanding ability based on the language experience of the students. The result coincided with Kramer's work.

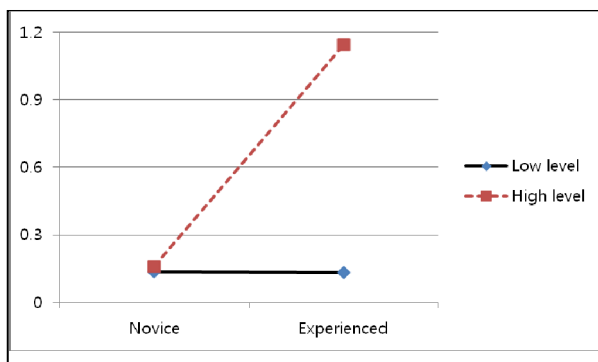


Fig. 2. The mean values of the point for P3 with two abstract thinking level and language experience

Finally, we examined if there was any moderating effect between gender and language experience on program understanding. Table VII shows the mean values for the 4 groups made with 2 genders and 2 language experience levels. In this case, the difference between the two genders was

significant ($F(1,296)=4.10, p=0.044$) and the difference between two levels of language experience was also significant ($F(1,296)=20.44, p<0.001$). However, there was no moderating effect between the two factors. The gap between the two language experience level for the female students was bigger than that for male students. Thus, we cannot expect a synergy between gender and language experience factors.

TABLE VII. MODERATING EFFECT BETWEEN GENDER AND LANGUAGE EXPERIENCE ON P3

Experienced	Gender	Mean	Std. Deviation	N
Novice	M	0.11	0.46	128
	F	0.18	0.58	143
	Total	0.15	0.52	271
Experienced	M	0.52	0.90	23
	F	1.00	1.10	6
	Total	0.62	0.94	29
Total	M	0.17	0.56	151
	F	0.21	0.62	149
	Total	0.19	0.59	300

D. Gender Problems and Difficulty Levels in Program Understanding

In this research, we authors wanted to examine if gender factor and abstract thinking factor influence program understanding for high school students, and then show how male high school students and female high school students are different. Also, we would like to show how language experience also affects the high school students' program learning. From the previous results of this research, the mean value of the female students' abstract thinking was lower than that of the male students. In Table III, the female students solved the program P1 better than the male students significantly. It is related to the fact that the female students think more concrete than the male students. In addition, Table V and Fig. 1 showed the difference in understanding P3 between two genders and two abstract thinking levels. Unlike the analysis with the whole sample, the male students at the high level in abstract thinking solved the complex program (P3) better than the female students at the high level in abstract thinking.

On the other hand, the mean values for P1, P2, and P3 are decreasing as shown in Table II. This means that our students felt different difficulties when they understood the 3 programs. According to the scores, we ranked the program P3 as the most complex program. In addition, the abstract thinking ability played an important role when the students understood more complex program. Thus, having a high level of abstract thinking is important while understanding programs.

Next, [22] described three types of software metrics such as McCabe, Halstead, and Program Knots [23]. And, [24] compared McCabe and Halstead for measuring psychological complexity. According to [24], software complexity metrics were related to the difficulty programmers experienced in understanding. However, from our experiment, we saw the difference between the existing software metric and the

difficulty level our students felt even though our programs were simple. For example, we calculated the cyclomatic number for P2 and P3 in Section 2. The number for P2 is 3 and the number for P3 is 2. Thus, according to the rule for the cyclomatic number, the program P2 is more complex than the program P3. However, in this research, our students felt that P3 was much more difficult than P2. This phenomenon tells us that for ordinary computer programmer and for the beginners who learn a computer programming language for the first time, different measurement will be needed. Also, educators should be more careful when they teach novice programmers because the difficulty levels are different with each other.

V. CONCLUSIONS

In this paper, we examined how gender and abstract thinking level affected program understanding ability when we gave a few programs having different complexities. In order to achieve the research goal, we proposed three different types of programs. By using these programs, how the students' abstract thinking ability affected the students' problem solving ability.

In summary, the male students were better in the abstract thinking, mathematical problem solving, and language experience than the female students. On the other hand, the female students did better in understanding the 3 programs in total than the male students. However, in the programs P2 and P3, there was no difference significantly. Only the program P1 (lower complex program) has the statistically significant difference. This phenomenon is related to the female students' lower abstract thinking level. Thus, they think more concretely than the male students do. It means that when the students solve less complex programs, concrete thinking is more important than the language experience and abstract thinking.

However, for the male students, the abstract thinking ability affected to solve the program P3 (containing while statement). When comparing the mean scores for understanding the 3 programs, we can find that the program P3 was the most difficult. Thus, if a student's abstract thinking level was higher, then the student could understand a difficult program better. It means that when an easy programming problem is given, the abstract thinking ability does not play an important role in the students' program understanding ability. However, when a difficult programming problem is given, the high level of abstract thinking ability plays an important role in understanding the problem.

Next, we found a common factor between the male students and the female students. It was the language experience before learning. Even though the number of students who had learned another language before they learned C in 2014 was too small, there existed statistical difference between the novices and the students who had language experience. In this case, the abstract thinking ability enhanced the students' program understanding ability. In other words, for the novices, the abstract thinking ability has no discrimination for measuring the students' program understanding ability. However, for the students who had language experience, the high level of abstract thinking ability plays an important role in understanding the problem.

Finally, from this research we found that the program experts' software complexity and the adolescents' software complexity were different. In other words, the same difficulty level programs for the professionals can be different for the adolescents. This is an important educational aspect when teachers teach programming languages to their students. Thus, more sophisticated measurement is needed in the near future.

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Stories of Black Women in Engineering Industry – Why they leave

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Abstract—The U.S. government has called for more STEM professionals in order to remain competitive as a nation. Increased participation of women and minorities in these fields will capture the rich diversity of their lived experiences and contributions. Many studies examine these issues for women or minorities, but less frequently consider the intersection of gender and race. There have been quantitative studies conducted in recent years that attempt to capture why women leave engineering. However, they lack the rich description at the intersection of race and gender necessary to understand the impetus to leave engineering industry.

Identity theory is the theoretical framework utilized for understanding how engineering industry culture fits with how these women see themselves and feel like they belong or do not belong in engineering. Identity theory can illustrate the meanings that Black women attribute to themselves as engineers and how they negotiate their perceived membership in engineering based on interpretations of status differences, legitimacy and stability of those status differences. This paper presents insight in to methods of data collection, analysis process, and preliminary research results.

Keywords—Black women, engineering industry, identity theory, intersectionality, phenomenology

I. INTRODUCTION

U.S. demographics are changing and currently women outpace men in engineering degree attainment in every ethnic category except white. For these reasons, there have been numerous studies and initiatives in place to broaden participation in engineering. Despite these interventions, more diverse populations are not being retained in engineering after earning a bachelor's degree [7]. These women do not just leave a sector of industry, but they leave engineering entirely [7]. Demographics on the progress of women and minorities in engineering, although staggering on their own, only convey a fraction of the narrative. Disaggregating the data down to the intersections, unveils even more disturbing information; Black women comprise 6.4% of the U.S. Population, 1.2% of the engineering undergraduate enrollment, 0.77% of the engineering graduates, and only 0.6% of the engineering industrial workforce [1,2,3]. In a report by Nelson and Brammer on African American or Black female engineering

faculty, they stated that, “[...] numbers this small would not survive the statistical treatment, which would be necessary if they were samples” [4]. An assertion, such as this one, pushes the experiences of Black women to the margins, and their stories are silenced. Nonetheless, their stories are important, as they contribute to a rich diversity of perspective and thoughts needed in engineering.

Consistently low diversity numbers have spawned \$700 million in U.S. government investment in STEM initiatives and roughly \$8 billion annually on diversity and inclusion strategies in the private sector [5,6]. Based on these numbers, the U.S. is invested in the broadening of participation in engineering. Despite this investment, women are leaving engineering at alarming rates. Fouad and Singh found that 9% of women never made it to industry after completing an undergraduate degree and 20% left industry after just 5 years of participating in the workplace [7]. Meanwhile, Lach reported on a survey taken by 1700 professional women of color that reported that nearly 73% of them intended to leave their company [8].

With the wealth of capital being invested in attracting and retaining women and people of color, why are numbers so low and in some cases declining in STEM fields? Why are they leaving? One plausible argument is that engineering, as a discipline, aims to solve a diversity problem in engineering without adequately understanding the true breadth, and depth of the problem. From prior literature, we are aware that there are factors that contribute to attrition (e.g. culture, environment, etc.) [7]; however, we have drawn these conclusions from a relatively broad categorization. Therefore, we miss the nuances associated with more fine scoped views. Historically, research has been shaped around gender-only (i.e. women in engineering) or race-only (i.e. minorities in engineering) lenses, leaving those that are situated at the intersection of race and gender without a presence in the current body of literature. In recent years, there has been some attempt at looking at the intersection of race and gender (i.e. women of color); however, this implies that all women of color experience bias in the same ways. Such assumptions leave the engineering community with misinformation and an incomplete description of the “diversity problem” in engineering. This work in progress study explores the

experiences of Black women in engineering industry in an attempt to shed light on the reasons for high attrition. This study would fill an evident void in literature on Black women in engineering industry.

II. THEORETICAL FRAMEWORK

The theoretical frameworks utilized while framing this study, in an attempt to shed light on the reasons for high attrition, are: social identity theory and intersectionality theory. Social identity theory provides insight into the identities of the women, the existence of competing identities, the effects of this competition on their engineering identities, and the effects of the interplay on their decision to stay or leave engineering. Intersectionality illuminates the experiences of a demographic at the juncture of race and gender.

A. Social Identity Theory

Social identity theory provides an established theoretical framework that has been utilized effectively in science education research [9]. Borrowing the effective operationalization of science identity for research in engineering could provide an easy transition from one discipline to another, while also contributing to the engineering education body of knowledge. Some science educators have measured identity in their participants through the ways in which they talked about science, how they acted/participated in class, how they described being in the science world (classroom) [10], how they described themselves [11], or how they related to others in the community [10]. They determined that new identities were developed when one began to take on new roles in the learning community, gained more knowledge, and had access to the discourse, tools, and more central aspects of participation in the science learning community [12]. These attributes were measured through the analysis of interviews with the participants, their parents and teachers, observations, and journals. They were able to identify the language used by the participants that reflected a low or high science identity salience. This same approach is used in this work when talking to Black women about their engineering identity. Interview questions were constructed to elicit participants' definition of an engineer and whether they consider their identity in congruence with their definition.

B. Intersectionality of Race and Gender

Intersectionality reminds us that oppression cannot be reduced to one fundamental type; in fact, multiple oppressions work together in producing heightened injustice [13]. Because the intersectional experience is greater than the sum of racism and sexism, analysis that does not take an intersectionality approach is deficient in addressing the particular manner in which Black women are subordinated [14].

Historically, some groups have been systematically underrepresented in research because they exist in small numbers. Under these circumstances, research has been conducted on (for example) minorities or women; this approach has rendered the women that are situated on the

intersection of these two groups (e.g., Black women or Native Women) invisible. Studies that focus on minorities are traditionally male-oriented, and the studies that focus on women are traditionally white-oriented. This results in subcategories (i.e., white women) that only partially represent a larger category (i.e., women); however, they have often been taken as representative of the whole category (e.g., white women, Black women, Hispanic women, Asian women, Native American women, etc.). Intersectionality was developed to describe an analytic approach that considers the meaning and consequences of multiple categories of identity [15]. An intersectional approach to understanding race/ethnicity and gender is one in which consideration is given to the unique positions that exist for people on the basis of the combination of their race/ethnicity and gender; it recognizes that gender and race/ethnicity can only be experienced simultaneously within an individual [16].

Giving attention to those that have traditionally been excluded obstructs the tendency to view a category in essentialist terms. An intersectional approach enables the diverse experiences contained within categories defined by multiple identities to be examined [15]. Failure to recognize that social categories depend on one another for meaning renders knowledge of any one category incomplete and biased [15]. Intersectionality makes it clear that gender, race, class, and sexuality simultaneously affect perceptions, experiences, and opportunities of individuals that live in a society stratified along these identities. Incorporation of previously ignored and/or excluded populations into knowledge construction in order to broaden our knowledge base could facilitate more adequate solutions to traditional questions posed by our discipline [17]. Intersectionality provides a means for answering contemporary questions that increasingly demonstrate the flaws of a race-only or gender-only approach [17].

III. METHODS

The research question for this study is: What effect does engineering industry culture have on engineering identity of Black women engineers? To examine this question, we are conducting an ongoing phenomenological study on the experiences of Black women across sectors of engineering industry. We are interested in stories of why some women stay in engineering while a large fraction leave. The methodology, sampling, research methods, preliminary analysis methods and preliminary results are described below.

A. Phenomenology

Phenomenological research describes the common meaning for several individuals of their lived experiences of a concept or a phenomenon [18]. We, as researchers, focused on describing what all participants have in common as they experience a phenomenon. Our intent is to reduce individual experiences with a phenomenon to a description of the universal essence [18]. The "essence" of a phenomenon from the perspectives of those who have experienced it, is the defining characteristic of phenomenological research [19]. Phenomenology involves the gathering of "deep" information

and perceptions through inductive, qualitative methods such as interviews, discussions and participant observations, and represents it from the perspective of the individual [20]. A phenomenological study attempts to understand an individual's perceptions, perspectives, and understandings of a particular phenomenon. Researchers conducting phenomenological research typically have had personal experience related to the phenomenon and seek a more in depth understanding of the experiences of others [21]. Examining multiple perspectives of the phenomenon, the researcher is better equipped to make generalizations of the experiences from an insider's perspective [22].

Interpretive phenomenology, also known as hermeneutics, was the approach selected for this study. Hermeneutics extends beyond mere description of core concepts and essences to look for meaning embedded in common life practices [23]. Hermeneutic inquiry is focused on what individuals experience rather than what they consciously know. Interpretive phenomenology embraces presuppositions or expert knowledge, on the part of the researcher, as a valuable guide to inquiry. The focus is on describing the meanings of the individuals' existence in the world and how these meanings influence choices. This involves analysis of the historical, social, and political forces that shape and organize experiences [23].

B. Sampling

Purposive sampling was the original method of sampling selected for the research study. Purposive sampling, as the name suggests, selects participants based on specific factors (e.g. race and gender as the topics of this work) [25]. At the Women of Color in STEM conference in October 2014 we gathered contact information for initial participants for the study; however, despite the women's eagerness to share their stories, when the conference concluded, the communication with most of these women ended as well. The few women that responded to requests to interviews were asked to identify other women to participate in this study in a snowball sampling method. This method is useful for sampling populations that are difficult to access, including minorities, marginalized or stigmatized groups [25]. These groups are often referred to as "hidden populations" [24]. Given Black women's small numbers in engineering industry, a snowball sampling was most appropriate to gather an appropriate number of participants

The snowball sampling for this study began with a close friend that, in turn, referred a friend that was unknown to the researchers. That woman in turn referred a friend. The study, to date, has conducted interviews with two women that are currently in engineering industry positions. Celia is a systems engineer with 14 years of experience, currently employed by a government contractor in Alabama, while Jessica is a manufacturing engineer with 9 years of experience with a government contractor in South Carolina. While this sampling, thus far, has been limited to government contractors in the southern United States, it is anticipated that through the use of organizations such as National Society of Black Engineers (NSBE), Society of Women Engineers (SWE), and use of the Women of Color in STEM conference again in 2015, that the

study will include more women from a variety of industry sectors and geographic locations for a target sample of 15-20 participants. We also hope that a snowball sampling approach will allow us to identify alternative cases of women that have chosen to leave engineering to compare their experiences and reasons for leaving with the experiences of women who are still working in engineering.

C. Data Collection and Analysis

Data collection has been achieved through a single, one hour in-depth interview that explored the areas of: background, work environment, identity in engineering, and social identities (e.g. race, class, gender, etc.). The interviews were conducted over the phone and were recorded and transcribed verbatim. The questions coded via a constant comparative method [26] to better understand each woman's journey into engineering industry, including their career selection process, educational background, career path to-date and future career. We also probed the nature of their work environment by asking questions about participants' perceptions of the culture/climate as well as work relationships (e.g. mentoring, social, and hierarchical). Use of the social identity theoretical framework prompted the inclusion of questions on defining an engineer, reflecting on personal engineering identity, as well as social identity (e.g. woman, Black, mother, etc.). These questions provide insight into these women's sense of belonging in the engineering workplace and how these women navigate their multiple identities in a white, masculine culture.

The interview protocol has undergone three iterations, thus far, ensuring ease of transition between categories, to add clarity to the questions, and to provide insight into the purpose of the study. The participants have been incredibly insightful, honest and gracious at the conclusion of the interview on the process of the interview and possible ways to improve the experience for future participants. Immediately, after each interview fieldnotes were drafted to capture a summary of the interview, immediate thoughts, notes about responses that elicited more questions, and potential follow-up questions. This immersion in the data, along with open and axial coding of the emerging themes highlighted by participants has allowed for valuable preliminary data on these two women's experiences. Follow-up interviews are planned, to expand upon topics that have emerged while reviewing the transcripts. To ensure respondent validation, the transcripts have been redacted, formatted, and sent to the participants for member checking. However, no final conclusions have been drawn and certainly, no overarching essence has been achieved.

IV. PRELIMINARY RESULTS

Results currently consist of a few emergent themes in the first two participants in this study. Although both women spoke of satisfaction with their jobs, they also spoke about power struggles at work, the perception of being treated differently due to gender, and the tendency of women to leave due to familial demands. Celia spoke about engineering identity as consisting of anti-social behaviors, power seeking, and territorial. She felt as if she fit right into these categorizations and therefore, has no concerns about belonging. She had taken on the cultural identities within engineering that

she identified in her interview, thus becoming a part of the engineering work culture in which she was immersed. Celia speculated that women left the engineering environment to be homemakers, which was not her desire or interest. She reflected on office pools at work when women went on maternity leave, betting against the woman's return.

[...] when someone goes on maternity leave we start taking bets, like are they coming back [...] we have one on maternity leave now [...] we get all these picture texts from her everyday with her baby [...] I'm like I might want to add a little bit more money to the "not coming back" fund. [...] the women that I've come encounter with, once they leave and have a baby they do not come back like, that's the only thing I've seen that is dwindling of women where I work.

Alternatively, Jessica spoke of not being respected in her role as a woman and mentioned that she was considering leaving work to stay at home with her children. She felt the opposite tensions that Celia described as a part of the inside crowd within engineering. As a woman and a mother, two salient identities, social and role, respectively, Jessica felt that she did not have the same insider status as others. When asked if she would consider leaving if she felt more satisfied in her career, she responded with a simple, "no." She expanded her answer by stating:

If I had more of a supportive leadership team. If I felt as if people were actually rooting for my success, then yes, I think I would feel more comfortable [staying in the workforce] and the pull [to leave work and be a stay-at-home-mom] would not be so strong.

During the one-hour interview she had divulged that she was in fact not satisfied with her career and this was a major contributor to her consideration to leave to be a homemaker.

These preliminary findings highlight interesting and different ends of power dynamics within engineering work culture. Both women in government sectors described environments where being a mother placed the burden of caretaker and worker on a woman's time and carried with it a stigma that inevitably a new mother would simply leave. The underlying assumptions of these cultures that began to emerge in data analysis emphasized a masculine norm consistent with prior literature that women who are mothers must perform both a role as a full-time engineer as well as a full-time parent – an assumption that was not described for men working in these engineering industry environments [27]. Even with two interviews at the beginning of this study, specific examples of microaggressions and structures within the workplace that disadvantage women emerged. By finding essential essences of how Black women's identities may be supported or eroded through practices in engineering culture, we can begin to highlight ways to improve engineering for these groups. These improvements may positively impact everyone. These changes may have the potential to begin to stem the tide of talented, Black women leaving engineering.

V. FUTURE WORK

The future consists of continued identification of potential participants, additional interviews, and conducting a thorough analysis of both individual interviews and the participants interviews collectively through a phenomenological lens and the theoretical frameworks of interest. The study is underway and has already provided some unique insight into Black women's experience in engineering industry; however, there is still much to learn. This study will expand the existing literature on women of color in science to engineering, providing more insight into solutions for solving the diversity problem in engineering.

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The Effect of Using Online Tutors on the Self-Efficacy of Learners

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Abstract— We conducted a study to evaluate the effect of using software tutors on the self-efficacy of students – in particular, whether the type of activity covered by the software tutor correlated with any improvement in self-efficacy after using the tutor along the levels of Bloom’s taxonomy; and whether any differential effects could be observed in the improvement of self-efficacy among the sexes and racial groups. The study was conducted over four semesters using two different software tutors. The collected data was analyzed using paired sample t-test and 2 X 2 ANOVA for three different sets of students – those who used the tutor, those who needed to use the tutor and those who learned one or more concepts by using the tutor. We found that if a significant difference was found among taxonomic levels of self-efficacy after using a software tutor, the improvement was statistically significantly greater on the taxonomic level directly relevant to the topic/activity of the tutor than any other level on Bloom’s taxonomy except comprehension. Such a difference was found at least among those who actually learned one or more concepts using the tutor, if not everyone who used the tutor. In most cases, the improvement in self-efficacy resulting from the use of the software tutor was indistinguishable across sexes and racial groups. (*Abstract*)

Keywords—Online tutors; self-efficacy; evaluation

I. INTRODUCTION

Self-efficacy is one’s belief in one’s abilities [1]. Abilities, in particular as related to computer programming, can be categorized according to the various levels of Bloom’s taxonomy [2], as follows:

- Comprehension – ability to identify and recall data types, data forms, control statements, etc.
- Application – ability to predict the behavior/output of a given program
- Analysis – ability to debug a given program
- Synthesis – ability to write a program for a given problem statement
- Evaluation – ability to critique, refactor and rewrite a given program to meet one or more objectives such as readability, efficiency, etc.

How does using software tutors on programming affect the self-efficacy of students along these taxonomic levels?

How does the activity covered by the software tutor correlate with their post-tutor assessment of self-efficacy along the levels of Bloom’s taxonomy? Is there any difference in post-tutor assessment of self-efficacy among demographic groups – sex (male versus female), or race (traditionally represented versus under-represented groups) [3]?

In order to answer these questions, we conducted a study over multiple semesters using problem-solving software tutors for computer programming, called problets (problets.org). After using each problet, students were asked to fill out a Likert-scale survey on self-efficacy. They were also asked to optionally fill out their demographic information.

The results of this study will be discussed in this paper. The results will be of interest to developers of software tutors as well as their users. Since self-efficacy affects retention in the major, the results will also inform the ongoing discussion on broadening participation in Computer Science.

II. PROTOCOL

Problets (problets.org) are problem-solving software tutors delivered over the web. Students typically use them after class as assignments. Problets cover all the topics typically covered in an introductory programming course, including expressions, selection, loops, functions, arrays and classes. They are available for C/C++, Java and C#, and have been continually used by third-party Computer Science educators since fall 2004.

When a student uses a problet on a given topic, the student is presented problems on specific concepts in the topic, the student is asked to solve the problem and submit an answer, and the tutor grades the student’s solution and provides feedback designed to help the student learn about the concept.

For this study, two problets/tutors were used, both dealing with the concept of functions:

- A tutor on **code tracing** – students were asked to identify the output of programs involving one or more functions. The tutor covered 10 concepts, including parameter passing, calling functions in expressions, multiple calls to a function, and variables with the same name in multiple functions (See Fig. 1).

- A tutor on **debugging** – students were asked to identify bugs in programs involving one or more functions. The tutor covered 8-9 concepts (depending on the language – C++/Java/C#), including mismatch in the number and type of actual and formal parameters, missing return statement in a function, incorrectly calling a function that returns void versus non-void, and re-declaring a formal parameter as a local variable in a function (See Fig. 2).

Both these tutors are on advanced concepts that students in introductory programming courses find to be difficult.

Each tutor was configured to administer the following protocol:

- **Pre-test** – During the pre-test, the tutor presented one problem per concept. If a student solved a problem correctly, the student was given credit for the corresponding concept. No feedback was provided to the student, and no more problems on the concept were presented to the student. On the other hand, if the student solved a problem incorrectly, feedback was presented to the student immediately after the student had submitted his/her solution to the problem. Additional problems were presented on the concept during the subsequent stages described below.
- **Adaptive practice** – During this stage, additional problems were presented to the student on only the concepts on which the student had made mistakes when solving problems during the pre-test. For each such concept, the student was presented multiple problems until the student mastered the concept, i.e., solved at least 60% of the problems correctly. On each problem, the student received feedback including step-by-step explanation of the correct answer, which has been shown to improve learning [4].
- **Post-test** - During this stage, the student was presented test problems on the concepts that the student had mastered during adaptive practice.
- **Self-Efficacy Survey** – Students were asked to respond on a 5-point Likert scale to eight statements related to their self-efficacy with the topic of the tutor.
- **Demographics** - Students were provided the option to identify their demographic information, including sex and race. Demographic information was solicited after the pre-test-practice-post-test protocol to avoid the effects of stereotype threat [5].

The entire protocol was administered online, back-to-back, with no break in between, all by the software tutor [6]. The pre-test-practice-post-test protocol was limited to 30 minutes.

During the self-efficacy survey, students were asked to respond to the following eight statements related to their self-efficacy with the topic of functions:

After using the tutor, I can do the following *better*:

1. Understand the grammar rules of defining and calling functions
2. Understand the meaning of function definitions and calls
3. Read function definitions and calls
4. Predict the output of programs with functions
5. Debug programs with functions
6. Write programs with functions
7. Design programs with functions
8. Critique programs with functions

The 5-point Likert scale used for the responses ranged from Strongly Agree (coded as 1) to Strongly Disagree (coded as 5).

Note that the eight statements on the survey correspond to levels of Bloom's taxonomy as follows:

- Statements 1-3: Comprehension, i.e., constructing meaning.
- Statement 4: Application, i.e., using learned material in new situations.
- Statement 5: Analysis, i.e., breaking down material into its components to diagnose it.
- Statements 6 and 7: Synthesis, i.e., putting parts together to form a new whole.
- Statement 8: Evaluation, i.e., critiquing the value of material for a given purpose.

The statement directly relevant to the topic of code-tracing tutor was statement 4 on application. Similarly, the statement directly relevant to the topic of debugging tutor was statement 5 on analysis. Both the tutors could also be argued to improve comprehension, as stated on statements 1-3. Neither tutor was designed or expected to affect synthesis, covered by statements 6 and 7.

If using the tutors affected the self-efficacy of students, we could expect to see the following behavior:

- Students would respond most positively on statement 4 after using code-tracing tutor, and on statement 5 after using debugging tutor;
- Statistically significant difference could be observed between the student responses to statements 4 and 5 after both tutors (code-tracing tutor did not cover debugging and vice versa).
- Statistically significant difference could be observed between the student responses to the directly relevant statement (4 for code-tracing, 5 for debugging) and statements 6-7, since neither tutor was designed to help students write functions.

III. DATA COLLECTION AND ANALYSIS

Data was collected over four semesters: fall 2012, spring 2013, fall 2013 and spring 2014. In each of these semesters,

students from multiple institutions used the tutors over the web.

The tutors had been used for a controlled study of the effect of using expressive writing on the test performance of students [7]. For the current study, the control and test groups of this prior study were analyzed separately.

The pre-test contained 10 problems in code-tracing tutor and 9 problems in debugging tutor. On each tutor, only those students who had solved at least 6 pre-test problems were considered for this study – this eliminated tentative and incomplete uses of the tutors from the study. Similarly, students who did not respond to the self-efficacy survey were also eliminated from the study.

After combining data from all four semesters, the numbers of students who participated in the study using the two tutors and under the two conditions were as provided in Table 1.

TABLE I. NUMBER OF STUDENTS IN THE STUDY

N	Control	Test
Code-Tracing	105	539
Debugging	348	119

For each of the four cases in Table 1, we considered three sets of students:

1. **Set A:** All those who had used the tutor – the numbers are as shown in Table 1;
2. **Subset N:** All those who *needed* to use the tutor – these were the students whose normalized pre-test score per problem was less than 1.0. In other words, these students solved at least one pre-test problem incorrectly, and could benefit from the subsequent adaptive practice session. These were a proper subset of all those who used the tutor (Set A) – this group excluded the students who solved all the pre-test problems correctly and never solved any practice problems.
3. **Subset L:** All those who *learned* one or more concepts by using the tutor – these were the students who solved pre-test, practice and post-test problems on at least one concept and demonstrated pre-post improvement in score on the concept [6]. These were a proper subset of the students who needed the tutor (Subset N) – this group excluded students who could not solve practice and/or post-test problems on any concept because they ran out of time, the tutoring session having been limited to 30 minutes.

For each of the above three subsets, in each of the four cases shown in Table 1, we conducted a five-way paired sample t-test of the responses on self-efficacy survey, with the pairings as shown in Table II.

TABLE II. PAIRED SAMPLE T-TEST VARIABLES

Variable 1	Variable 2
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	Variable 1	Variable 2
A	Comprehension (1-3)	Application (4)
B	Comprehension (1-3)	Analysis (5)
C	Application (4)	Analysis (5)
D	Application (4)	Synthesis (6-7)
E	Analysis (5)	Synthesis (6-7)

As mentioned earlier, we expected to observe significant differences in pairings C, D and E.

In addition, we conducted 2 X 2 ANOVA analysis, with sex and race as fixed factors, of the following three self-efficacy variables:

1. Average response on all 8 statements;
2. Response on statement 4 – the one most relevant to code-tracing tutor;
3. Response on statement 5 – the one most relevant to debugging tutor.

For this analysis, we considered two groups for race: traditionally represented, i.e., Caucasians and Asians [8], and the rest, i.e., Black/African American, Hispanic/Latino, Native American, Native Hawaiian/Pacific Islander and Other. In the study, we asked students to (optionally) identify their sex (biological notion of male/female) rather than their gender (social/cultural notion of man/woman) [9].

A. Code Tracing Tutor – Control Group

Table III lists the sample size N, mean and standard deviation of the responses to self-efficacy statements on comprehension, application, analysis and synthesis levels of Bloom's taxonomy. The data is for all those who had used the tutor (Set A). The score on comprehension is the average of the responses to the first 3 statements and the score on synthesis is the average response to statements 6 and 7.

TABLE III. CODE-TRACING TUTOR – CONTROL RESPONSES

Group	N	Mean	Std. Dev
Comprehension (1-3)	126	2.056	.906
Application (4)	126	1.94	.879
Analysis (5)	127	2.23	.986
Synthesis (6-7)	126	2.266	.997

Table IV lists the pairwise correlation (all correlations were significant at $p < 0.001$), the mean of the difference in pair-wise responses, the corresponding t-value and its 2-tailed significance for the 6 pair-wise comparisons.

TABLE IV. CODE-TRACING TUTOR – CONTROL RESPONSES

Pair	Corr.	Mean	t-value	Sig.
Compr. – Appln.	.911	.111	3.312	.001

Pair	Corr.	Mean	t-value	Sig.
Compr. - Analysis	.816	-.173	-3.371	.001
Appln. - Analysis	.705	-.286	-4.423	.000
Appln. - Synthesis	.724	-.321	-5.113	.000
Analysis - Synthesis	.842	-.035	-.717	.475
Comp. - Synthesis	.850	-.209	-4.457	.000

From Tables III and IV, it is clear that the student response was the most positive on statement 4 (application), which is the statement directly relevant to the topic of code-tracing tutor. Their response on this statement was statistically different from those on other levels of Bloom's taxonomy, e.g., significance of the pairwise comparison of Application (4) versus Analysis (5) is given by $t(125) = -4.423$, $p < 0.001$. In this instance, *the self-reported improvement in self-efficacy after using the software tutor was statistically significantly greater on the taxonomic level directly relevant to the topic of the tutor than any other level.*

The results of repeating the pair-wise analysis for the other subsets - those who needed the tutor (Subset N) and those who learned from the tutor (Subset L) – did not yield any different results.

The 2 X 2 ANOVA analysis of self-efficacy responses with sex and race as fixed factors did not yield any significant difference between the responses of the sexes or the racial groups, i.e., *improvement in self-efficacy resulting from the use of the software tutor was indistinguishable across sexes and racial groups.*

B. Code Tracing Tutor – Test Group

Table V lists the responses to self-efficacy statements for all those who had used the tutor (Set A) in the test group of code-tracing tutor.

TABLE V. CODE-TRACING TUTOR – TEST RESPONSES

Group	N	Mean	Std. Dev
Comprehension (1-3)	593	1.920	.943
Application (4)	593	1.87	.978
Analysis (5)	598	2.06	1.015
Synthesis (6-7)	593	2.127	1.028

Table VI lists the results of the 6 pair-wise comparisons of the responses to the self-efficacy statements along Bloom's taxonomic levels.

TABLE VI. CODE-TRACING TUTOR – TEST RESPONSES

Pair	Corr.	Mean	t-value	Sig.
Compr. – Appln.	.922	.051	3.300	.001
Compr. - Analysis	.875	-.143	-7.087	.000
Appln. - Analysis	.811	-.193	-7.645	.000
Appln. - Synthesis	.765	-.259	-9.149	.000

Pair	Corr.	Mean	t-value	Sig.
Analysis - Synthesis	.890	-.069	-3.485	.001
Comp. - Synthesis	.840	-.210	-9.098	.000

Tables V and VI confirm the results obtained earlier for the control group - student response was the most positive on statement 4 (application), the statement directly relevant to the topic of code-tracing tutor, and it was statistically different from those on other levels of Bloom's taxonomy. Again, *the self-reported improvement in self-efficacy after using the software tutor was statistically significantly greater on the taxonomic level directly relevant to the topic of the tutor than any other level.* The same results were also obtained for the students who needed the tutor (Subset N) and those who learned from using the tutor (Subset L).

Finally, the 2 X 2 ANOVA analysis of self-efficacy responses with sex and race as fixed factors did not yield any significant difference between the responses of the sexes or the racial groups.

C. Debugging Tutor – Control Group

Table VII lists the responses to self-efficacy statements for all those who had **learned** using the tutor (Subset L) in the control group of debugging tutor.

TABLE VII. DEBUGGING TUTOR – CONTROL RESPONSES

Group	N	Mean	Std. Dev
Comprehension (1-3)	285	2.172	1.025
Application (4)	285	2.22	1.071
Analysis (5)	288	2.17	1.049
Synthesis (6-7)	285	2.284	1.103

Table VIII lists results of the 6 pair-wise comparisons of the responses to the self-efficacy statements along Bloom's taxonomic levels for all those who had learned using the tutor (Subset L).

TABLE VIII. DEBUGGING TUTOR – CONTROL RESPONSES

Pair	Corr.	Mean	t-value	Sig.
Compr. – Appln.	.932	-.053	-2.289	.023
Compr. – Analysis	.920	.008	.329	.742
Appln. – Analysis	.901	.063	2.266	.024
Appln. – Synthesis	.902	-.06	-2.089	.038
Analysis – Synthesis	.856	-.109	-3.196	.002
Comp. – Synthesis	.877	-.101	-3.229	.001

From Tables VII and VIII, it is clear that the student response was the most positive on statement 5 (analysis) and statements 1-3 (comprehension). Statement 5 (analysis) is the statement directly relevant to the topic of debugging tutor. Their response on this statement was statistically different from those on all other levels of Bloom's taxonomy except

comprehension. So, *the self-reported improvement in self-efficacy after using the software tutor was statistically significantly greater on the taxonomic level directly relevant to the topic of the tutor than all other levels except comprehension.*

However, these results were obtained for students who learned from using the tutor (Subset L). Among all those who used the tutor (Set A) or those who needed to use the tutor (Subset N), no significant difference was observed between analysis (5) and application (4). So, we qualify the above results as *applying at least to those who actually learned using the tutor* (Subset L), which is a proper subset of those who used the tutor (Set A) and those who needed to use the tutor (Subset N).

The 2 X 2 ANOVA analysis of self-efficacy responses with sex and race as fixed factors did not yield any significant difference between the responses of the sexes or the racial groups for any of the sets (A, L or N).

D. Debugging Tutor – Test Group

Table IX lists the responses to self-efficacy statements for all those who had **learned** using the tutor (Subset L) in the test group of debugging tutor.

TABLE IX. DEBUGGING TUTOR – TEST RESPONSES

Group	N	Mean	Std. Dev
Comprehension (1-3)	97	2.179	.978
Application (4)	97	2.18	1.00
Analysis (5)	97	2.19	1.014
Synthesis (6-7)	97	2.273	1.00

Table X lists results of the 6 pair-wise comparisons of the responses to the self-efficacy statements along Bloom's taxonomic levels for all those who had learned using the tutor (Subset L).

TABLE X. DEBUGGING TUTOR – TEST RESPONSES

Pair	Corr.	Mean	t-value	Sig.
Compr. - Appln.	.948	.004	.107	.915
Compr. - Analysis	.898	-.007	-.148	.882
Appln. - Analysis	.892	-.01	-.217	.829
Appln. - Synthesis	.884	-.098	-2.00	.048
Analysis - Synthesis	.884	-.088	-1.782	.078
Comp. - Synthesis	.908	-.094	-2.195	.031

No significant difference was found among comprehension, application and analysis statements in Tables IX and X, although analysis (5) was the taxonomic level directly relevant to the topic of the tutor. Even the difference observed between synthesis and the other levels in Table X for those who learned using the tutor (Subset L) was not observed for those who used the tutor (Set A) or those who

needed to use the tutor (Subset N). In light of these results, we qualify the earlier results as *observable provided a significant difference is found among taxonomic levels of self-efficacy.*

On the 2 X 2 ANOVA analysis of the responses for statement 5 for the students who learned from using the tutor (Subset L), we found:

- Significant main effect for race [$F(1,81) = 4.931$, $p = .029$]: Caucasians and Asians agreed with the statement ($2.00 \pm .278$, $N=58$) more than students from underrepresented groups ($2.559 \pm .416$, $N=24$)
- Marginally significant main effect for sex [$F(1,81) = 3.073$, $p = .084$]: male students agreed with the statement ($2.059 \pm .266$, $N=60$) more than female students ($2.50 \pm .425$, $N=22$)
- Marginally significant interaction between sex and race [$F(1,81) = 3.073$, $p = .084$]: whereas Caucasians and Asians agreed with the statement the same whether male ($2.00 \pm .283$, $N=43$) or female ($2.00 \pm .479$, $N=15$), underrepresented male students agreed with it ($2.118 \pm .45$, $N=17$) more than underrepresented female students ($3.00 \pm .701$, $N=7$).

The above differences in self-efficacy were found even though no significant differences were found on:

- Prior preparation, i.e., average score per problem on the pre-test between the sexes [$F(1,82) = 1.22$, $p = .273$] or the racial groups [$F(1,82) = .188$, $p = .666$]
- Concepts learned, between the sexes [$F(1,82) = .012$, $p = .911$] or the racial groups [$F(1,82) = .00$, $p = .999$]

However, the differences between the sexes and racial groups on self-efficacy were not found for the other two sets – those who used the tutor (Set A) and those who needed the tutor (Subset N). They were not observed in any of the other conditions either: control group of debugging tutor, or control or test group of code-tracing tutor. So, *while there may be differences in the improvement of self-efficacy of sexes and racial groups resulting from the use of software tutors*, additional data collection and analysis is needed to confirm or refute it, and if confirmed, identify the conditions under which such differences manifest.

IV. DISCUSSION

We found that the improvement in self-efficacy after using the software tutor was statistically significantly greater on the taxonomic level directly relevant to the topic of the tutor than all other levels of Bloom's taxonomy except comprehension. That we found this result in three out of four cases adds credence to the result. However, we found that the correlation between the number of concepts learned and the response to the self-efficacy statement directly relevant to the taxonomic level of the software tutor was minimal in all four cases (e.g., .06). In other words, those who learned more concepts did not necessarily agree more with the statement about improved self-efficacy. This lack of correlation is to be expected, since, testimonials can mislead [10].

In three out of the four cases, the improvement in self-efficacy resulting from the use of the software tutor was indistinguishable across sexes and racial groups. Higher level of self-efficacy has been shown to result in higher performance accomplishments [11]. Given the significant underrepresentation of female and minority students in Computer Science, using software tutors to improve their self-efficacy has the potential to broaden their participation.

In the current study, students had to fill out the self-efficacy survey after having spent 30 minutes solving problems with the software tutor. Filling out the survey was optional, and contained eight statements. Cynicism would dictate that students would skip the self-efficacy survey altogether or fill it out perfunctorily, with the same score on all eight statements. The results of this study are all the more remarkable given these adverse conditions.

Whereas self-efficacy instruments have been created and validated on computing [12], programming [13], introductory courses [14], etc., the focus of this study was a small subset of programming, viz., functions. So, a self-efficacy survey was custom-created for the study, as recommended in literature [15]. Many of the principles for creation and administration of self-efficacy surveys listed in literature [15] were followed: survey items were phrased in terms of “can do” rather than “will do”; the survey was multi-faceted – the items were based on analysis of the programming domain along Blooms’ levels of taxonomy; students were instructed to judge their capabilities *after using the tutor*, and not their potential or future capabilities; and a nondescript title of “Feedback” was used for the survey rather than “Self-Efficacy”. However, the 5-point Likert scale used in this study is considered less sensitive and reliable – scales with 10 intervals or even 100 possible responses are recommended [16]. That statistically significant results were found even with the less sensitive 5-point scale makes the results all the more significant. However, the survey instrument has not been empirically validated, which is a confounding factor of this study.

We plan to repeat the study using data collected with some of the other tutors, including those on expression evaluation and advanced loop concepts, to see if we can replicate the results.

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Figure 1: Snapshot of Code Tracing Tutor in Java: Problem shown in the left panel, instructions for solving the problem shown in the top right panel and student's attempt is shown in the bottom right panel – correct steps are marked in green and incorrect steps are marked in red. Button to submit the answer is shown at the bottom right.

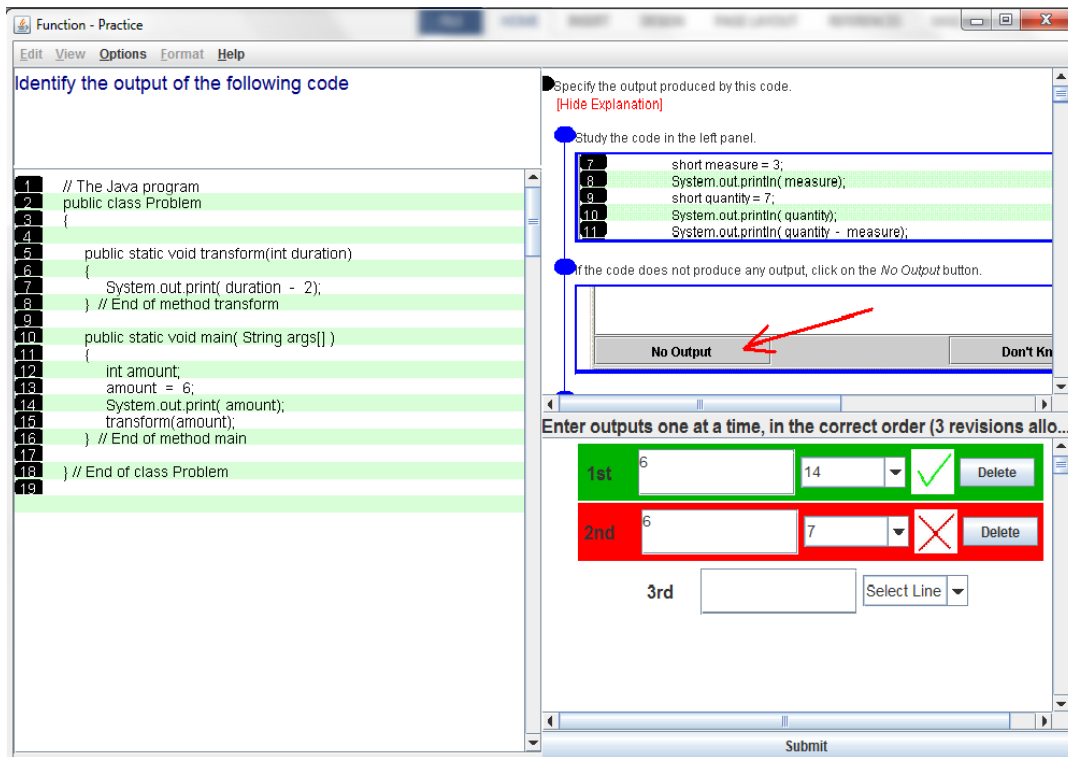
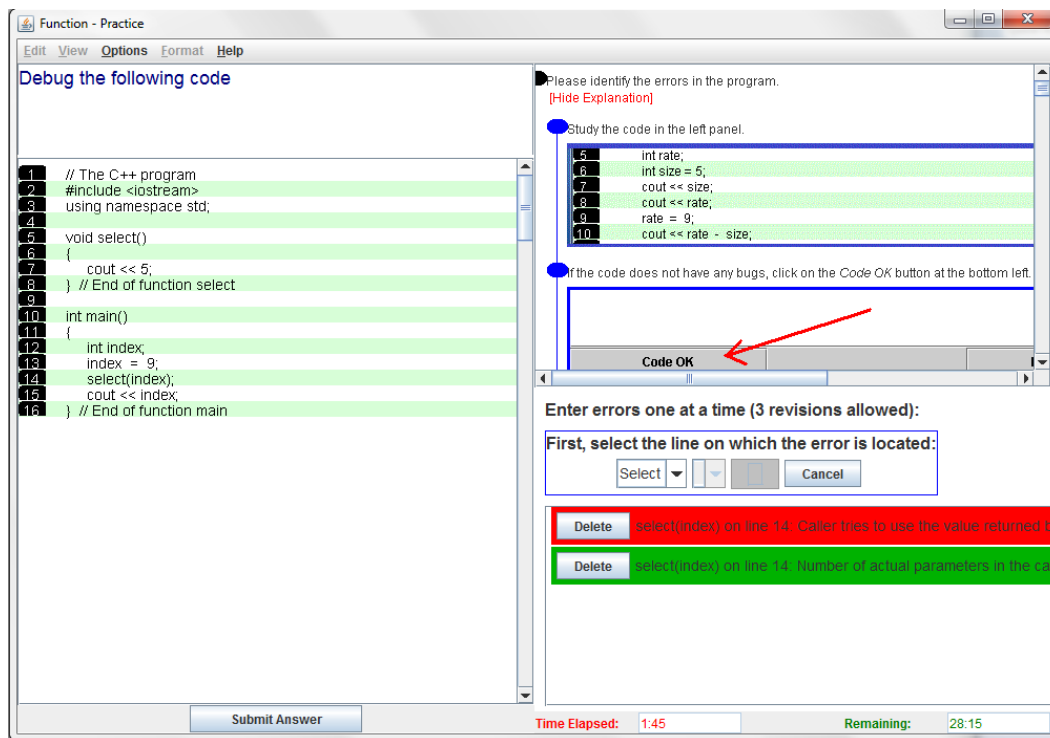


Figure 2: Snapshot of Debugging Tutor in C++: Problem shown in the left panel, instructions are shown in the top right panel and student's attempt is shown in the bottom right panel – correct steps are marked in green and incorrect steps are marked in red. Button to submit the answer is shown at the bottom right.



Teamwork Attitude, Interest, and Self-Efficacy: Their Implications for Teaching Teamwork Skills to Engineering Students

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Abstract—The complex and multidisciplinary nature of today's engineering problems demands that new graduates excel in not only technical knowledge but also teamwork skills. In fact, the lack of effective teamwork has been identified among the most important factors contributing to the high failure rate of complex engineering projects. In this paper, we focus on engineering students' attitudes toward teamwork, their self-efficacy and interest in teamwork knowledge, skills, and abilities. Self-efficacy in a domain is an important construct that can predict whether or not someone is willing to undertake a challenge in that domain. Research suggests that the sufficient level of self-efficacy can encourage personal growth and skill development. The relevant research also points out that interest is a construct that can predict students' professional development in a domain. For example, as someone becomes an expert in a domain, his/her interest in the domain becomes individual, which means there is a long-term personal connection resulting in further exploration of the domain. In this paper, we postulate that the development of students in teamwork knowledge, skills and abilities can be tracked by the progress in their teamwork interest. In addition, we argue that interest development should be measured as a part of the assessment efforts to evaluate the professional skills development of students. We have developed and validated an instrument to measure teamwork efficacy and interest. The instrument was used to collect data in a geographically distributed university. The collected data were analyzed to identify the factors affecting students' attitudes toward interest and self-efficacy in teamwork as well as their relationships. The preliminary results indicated that students had a high level of self-efficacy and a low level of interest, which makes it challenging to improve students' teamwork skills.

I. INTRODUCTION

Today's engineering challenges require a large variety of knowledge and skills from multiple disciplines, including non-engineering ones. Therefore, having effective teamwork skills in engineering contexts is important. Multi-disciplinary teams bring together a pool of talents, experiences, and knowledge base, which cannot be embodied in an individual. However, the multi-disciplinary nature of a team does not guarantee successful team performance. The research shows that the success of a team depends on how effectively team members are able to share information, assign tasks based on the strengths of team members, coordinate tasks, and provide feedback to one another [1]. It is essential that engineering graduates have teamwork Knowledge, Skills, and Abilities (KSA) to function effectively in teams. Engineering programs

have responded to this need by incorporating teamwork into all levels of academic curricula. However, the absence of robust assessment frameworks constrains the effectiveness of such efforts.

Previously, we have proposed an assessment framework based on the Model of Domain Learning (MDL) [2] for the assessment of professional skills [3], [4]. In this framework, student development is measured in three dimensions- knowledge, strategic processing, and interest. Within the MDL, three experience-based stages occur (i.e., acclimation, competency and proficiency), which are progressive and incremental. In this paper, our primary objective is to evaluate the feasibility and reliability of using interest as an additional construct to track student development in teamwork KSA. We introduce several questionnaire items to measure students' interest in teamwork. These questionnaire items can also be used in a broader instrument for assessing teamwork KSA.

The MDL considers two types of interest: individual and situational. Situational interest is the temporary interest that arises spontaneously due to external factors such as a new topic or an engaging text. On the other hand, individual interest is the long lasting interest that motivates students to gain deeper knowledge in a domain. Individual interest is an indicator of how much students are willing to immerse themselves into a domain. According to the MDL, an increased individual interest in a domain is a result of higher knowledge and strategic processing abilities in that domain. As one moves from the Acclimation to Proficiency stage in a domain, his/her interest changes as described in Table I. Individual interest is also a precursor for sustaining long-term learning [5]. Therefore, evaluating students' individual interest is especially critical for professional skills assessment, where sustainable, long-term learning is paramount.

II. AN EMPIRICAL STUDY

A. Data Collection Instrument

An online survey was designed to measure students' self-reported teamwork self-efficacy, attitudes, and interest. The survey was emailed to engineering students at a university with multiple campuses in the Northeast United States. It should be noted that the survey did not emphasize a specific engineering course or a class level, and it was available for any engineering student to take, regardless of their class standing

TABLE I. PROGRESS OF INTEREST FROM ACCLIMATION TO PROFECIENCY

Acclimation	Competency	Proficiency
Situational interest: Spontaneous, transitory, and environmentally activated interest	Increased individual interest due to increased engagement in a domain	Individual interest: long-term, deepening, personal connection to a domain, which in turn inspires further exploration of the domain

or the course content. Therefore, the survey measured only students' self-reported perceptions about their teamwork self-efficacy, attitudes, and interest.

To measure students' interest levels in developing their teamwork KSA, students were asked to rate their interest in performing several professional activities. After a preliminary analysis, the average rating of the following three questions (Cronbach's $\alpha = 0.738$) were used to measure interest:

- IQ1-Attending a free workshop on teamwork.
- IQ2-Reading literature about effective teamwork.
- IQ3-While you are browsing a news web site, you have spotted an article called "How to be Effective in Teamwork." Rate your likelihood of reading this article?

In addition, the following two questions were used to measure individual level interest since they demand more personal commitment than the previous questions.

- IQ4-Rate your level of willingness to take an elective course in order to improve your teamwork skills?
- IQ5-In your institution, a renowned teamwork guru will give a workshop on teamwork skills. If you have to pay \$10 for this workshop, rate your level of interest in attending this workshop.

The interest questions were operationalized using a four-point Likert scale ranging from (1)-Very Uninterested to (4)-Very Interested.

Twenty-five teamwork self-efficacy questions were developed based on the KSA areas described by Stevens and Campion [6]. The questions were grouped as follows (the number of questions in each KSA area is provided in parenthesis): Goal Setting (2), Performance Evaluation (3), Team Forming (5), Team Coordination (1), Communication (7), Conflict Resolution (4), and Problem Solving (3). These questions were operationalized with a four-point Likert scale, ranging from (1)-Very Unconfident to (4)-Very Confident. These questions are available upon request.

Attitudes toward teamwork can be defined as how agreeable a person is to work in any team [7]. To measure the overall attitude toward teamwork, the following four questions given in [8] were used (Cronbach's $\alpha = 0.73$):

- I usually have a negative experience with teamwork (reverse coded)
- I would rather work on team projects than on my own

- I like to participate in teamwork
- I am usually motivated to participate in teamwork

The attitude questions were also operationalized with a four-point Likert scale, ranging from (1)-Strongly Disagree to (4)-Strongly Agree.

B. Analysis of the Results

We coded student responses to the background questions into the binary independent variables as given in Table II to investigate the effect of student background and experiences on interest, self-efficacy, and attitude.

TABLE II. CODING OF STUDENT BACKGROUND AND EXPERIENCES INTO THE INDEPENDENT VARIABLES (NUMBER OF SAMPLES)

Independent Variable	Value	
	0	1
Class Standing	Year 1 and 2 (317)	Year 3 and 4 (242)
GPA	<3.5 (319)	\geq (236)
Teamwork Training or Course	None or single (416)	Two or more times (123)
Gender	Male (391)	Female (169)
Work Experience	No (127)	Yes (433)

We calculated Cohen's d values to measure the effect size of the independent variables on the dependent variables. In addition, we performed *t*-tests to evaluate whether the means of the dependent variables were different or not across the two levels of the independent variables. Table III presents the calculated effect sizes. In the table, statistically significant mean differences are indicated by * for *p*-value < 0.05 and ** for *p*-value < 0.01.

We did not observe any positive effect of class standing on the self-efficacy independent variables. Surprisingly, the first and second year students rated their self-efficacy as high as the third and fourth year students did. The negative effects of the GPA group on self-efficacy and teamwork attitude were unexpected. The GPA did not also have any positive effect on interest. The previous teamwork training had a small positive effect on self-efficacy and a small-to-medium positive effect on interest. In order words, students who have already gone through some types of teamwork training were more willing to invest further time and resources for advancing their teamwork KSA than the students who have not.

The dependent variables previous work experience, teamwork training, and class standing had a positive and statistically significant effect on the teamwork attitude dependent variable. In particular, the previous work experience variable had the highest effect size. This observation may imply when students are engaged in a large scope project, that draws skills and knowledge from multiple disciplines, they start appreciating the value of teamwork. At the university setting where the data were collected, the first year engineering curriculum features engineering design learning facilitated through a series of team-based projects supplemented by brief guidance on teamwork. However, these experiences do not represent the rigors of real-life engineering projects yet. Upon declaring the major at the end of the second year, as part of their studies in the third and fourth year of their curricula, students are frequently put in teamwork situations in an effort to prepare them for the actual work settings. Students are also expected

TABLE III. CALCULATED EFFECT SIZES

Dependent Variable	Effect Size (Cohen's d)				
	Class Standing	GPA	Training	Gender	Work Experience
Goal Setting	0.04	-0.06	0.23*	0.14	0.38**
Performance Evaluation	0.09	-0.04	0.17	0.05	0.26**
Team Forming	-0.07	-0.17*	0.13	0.24	0.26*
Team Coordination	-0.09	-0.03	0.07	0.15	0.32**
Communication	0.07	-0.30**	0.25*	0.06	0.32**
Conflict Resolution	-0.11	-0.22*	0.17	-0.08	0.29**
Problem Solving	-0.02	-0.13	0.19	-0.05	0.38**
Attitude	0.30**	-0.52**	0.23*	-0.12	0.37**
Interest (IQ1, IQ2, IQ3)	0.25**	0.10	0.43**	0.23	0.14
IQ4	0.02	-0.01	0.25*	0.16*	0.01
IQ5	0.04	-0.13	0.31**	0.25	0.07

to complete an internship where most of students are involved in teamwork in the context of real-life engineering projects for the first time. Specifically, capstone design experience in their last year is meant to simulate the complexity of the work setting in the rigor level of the project as well as the timeline and professionalism expected in terms of results and conduct. Frequently, students work towards a working prototype or research result sponsored by an industrial company and in doing so they hold regular meetings with company liaisons.

The most significant factor for the self-efficacy dependent variable was the previous work experience that involved teamwork. In summary, the relationships between the other independent variables and self-efficacy were not as anticipated. One of the reasons for this result is that students rated their self-efficacy very close to the level of very confident. Although the first and second year students rated their self-efficacy very high, they had relatively low teamwork attitude. This contradiction also casts a doubt on the validity of using self-reported efficacy as a construct to measure teamwork KSA. Therefore, we postulate that self-efficacy may not be a reliable construct to assess students' development in teamwork KSA based on the results observed in this research.

On the contrary, the relationships between the independent variables and the interest dependent variables conformed to the MDL. As per the MDL, an increased learning in a domain should lead to higher levels of interest in the domain. The class standing and teamwork training had a significant positive effect on interest. This result is particularly important for the feasibility of using the MDL as an assessment framework for professional skills because it shows that the changes in interest can be tracked during students' educational journey. In this paper, we did not observe a high level of individual interest development in the third and fourth year students. This observation is similar to our previous findings [4].

III. CONCLUSIONS

Teamwork self-efficacy was not found to be impacted by any of the academic background variables considered in this research. In terms of interest, we observed a growth from situational to individual interest throughout the engineering students' educational journey, which supported the MDL. In this research, interest was shown to have a stronger relationship with previous teamwork training and class standing than self-efficacy had with those variables. Therefore, we recommend interest as an additional construct to assess students' teamwork

KSA. In future work, we will survey the literature further about student reported self-efficacies and gauge other fields in the STEM disciplines, according to teamwork self-efficacy, interest, and attitudes. In addition, the collected data will be analyzed in multiple dimensions to verify the primary findings in this paper. To apply our findings from our team survey in engineering courses, professors could institute more relatable, intriguing group assignments and emphasize the importance of teamwork in the engineering discipline, so students will make an effort to be more interested and have a positive attitude toward teamwork.

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Engineering Self-Efficacy, Interactions with Faculty, and Other Forms of Capital for Underrepresented Engineering Students

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Abstract— To address the chronic issues of underrepresentation in engineering education, a small but growing body of research has examined social and cultural explanations for engineering persistence among women, racial/ethnic minorities, first-generation college students, and other underrepresented groups. In this exploratory study, we examine the extent to which relationships with engineering faculty and other forms of engineering-related capital (e.g., aspirational, navigational) are related to engineering self-efficacy among underrepresented engineering students. The findings of the study have implications for future research and practice to increase access to engineering education and persistence of underrepresented students in engineering.

Keywords—underrepresented students; student-faculty interaction; self-efficacy; engineering education

I. INTRODUCTION

The participation of women and underrepresented minorities in engineering has been “disturbingly slow” [1]. To address the chronic issues of underrepresentation in engineering education, a small but growing body of research has attempted to move away from a deficit perspective and has examined social and cultural explanations for engineering persistence among women, racial/ethnic minorities, first-generation college students, and other underrepresented groups. Frameworks emphasizing social and cultural capital; as well as the unique forms of capital possessed by students from marginalized groups (e.g., cultural wealth); offer alternate perspectives to focus on how underrepresented students navigate and persist in engineering.

As part of a federally funded project on the role of student-faculty interaction for the persistence of underrepresented racial/ethnic minority (URM) students in engineering, we have gathered qualitative and quantitative data from undergraduate engineering students. For the study reported herein, we focus specifically on an analysis of questionnaire data from junior and senior engineering students from underrepresented groups to understand how perceived relationships with faculty and other forms of capital are related to engineering self-efficacy.

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II. PARTICIPATION AND PERSISTENCE IN ENGINEERING FOR UNDERREPRESENTED STUDENTS

Differing participation and persistence in engineering has been investigated using theoretical frameworks from higher education [2,3], sociology [4,5,6], and psychology [7]. The importance of interactions, resources, and supports is prominent across these theories, as precursors to beliefs about one’s abilities and identity that support academic effort, performance, and career persistence. Research and theory on interactions with faculty, other sources of capital (i.e., cultural wealth), and self-efficacy, particularly for underrepresented students in engineering, frames this study.

A. Interactions with Faculty

Predominant frameworks of participation and persistence in higher education emphasize the role of student interaction with faculty [2,3]. Social capital frameworks offer another way to understand how and why interaction with faculty is important for persistence of students in STEM, through defining ties to institutional agents (faculty, staff, administrators) as links to important information needed to navigate and succeed in the college environment [8-12]. Student-faculty interactions (SFI) are vital to the success of all engineering students, but especially underrepresented racial/ethnic minority groups (URM). Research over the past 15 years has evidenced the relationship of SFI with academic performance, persistence, and academic and personal growth for URM students in STEM disciplines, including engineering.

1) *Academic performance*: Underrepresented students of color (i.e., Black, Latino, Native American) in STEM disciplines benefit greatly from faculty-student interactions. Frequent interactions with faculty and support from contact with faculty are linked with higher grades [13,14]. Additionally, faculty mentorship may lead to higher academic performance even if students had low testing performance prior to college [15]. The nature of interaction with faculty may also be important. While interactions related to course materials may not relate to higher GPA [14], conducting research with faculty members is associated with improvements in academic performance [16,17]. Faculty-student interactions are generally beneficial to URM students

especially when conducting research with faculty or receiving mentorship from faculty, however some literature suggests that receiving criticism from faculty or interacting with faculty to discuss course materials did not suggest that students would increase their GPAs.

2) *Persistence*: The academic persistence of engineering students is higher than students in other majors [18] yet research unfailingly reveals that Black and Latino engineering students are underrepresented and have lower persistence rates than their White peers. Additionally, the literature has found that Black and Latino students may resist initiating contact with predominantly White faculty out of fear of being stereotyped or negatively perceived by faculty and prefer same-race faculty mentors [19,20,21]. Conversely, one study found that interactions with faculty and peers outside of one's ethnicity were beneficial and increased underrepresented students' confidence [22]. Overall, engineering students' interactions with faculty are vital for retention and persistence [24,25,26] and are especially critical for Black and Latino students in ensuring their academic success [8,14,26,27].

3) *Intellectual & Personal Growth*: There are several benefits of faculty-student interactions for URM students in engineering including increased development in intellectual and personal growth while at higher education institutions. Students' interactions with faculty can provide high levels of satisfaction in intellectual ability, problem solving, career development, and scientific reasoning [28,29]. However, problem solving and intellectual growth are especially increased for students of color [28]. More frequent contact with faculty has also been linked to self-efficacy among engineering students [23,25].

URM engineering students' interactions with faculty members are important for developing intellectual thinking and growth because more exposure to knowledge and resources build students' abilities to perform tasks in and out of the classroom. Personal and intellectual growth for Black and Latino students in engineering increases when interacting with faculty because students are able to critically think when engaged with various research and engineering-related projects (as assigned by faculty) and gain more exposure and knowledge than they previously had. However, research shows that URM engineering and STEM students may have frequent interactions with faculty, but feel less satisfied with those interactions since they are less meaningful and are less likely to engage in undergraduate research with faculty members [21,26,30].

B. Cultural Wealth as Capital for Engineering

Traditional social and cultural capital theories [4,5] emphasize how the values and practices of dominant groups are rewarded in education. The notion of community cultural wealth (CCW) [31] was developed to show how communities of color and other non-dominant groups create wealth that is valuable for persisting in education. Six forms of CCW are proposed as part of this framework:

1) *Aspirational capital*: The ability to maintain hopes and dreams for the future, considering real and perceived barriers.

2) *Linguistic capital*: The ability to switch communication styles or languages based on environment (e.g., academic and nonacademic).

3) *Familial capital*: Knowledge gained from, and maintenance of a connection to the home community and culture.

4) *Social capital*: Networks of people and resources that provide instrumental and emotional support to navigate through institutions.

5) *Navigational capital*: Skills of navigating through social institutions that are designed for dominant social and cultural groups.

6) *Resistant capital*: Knowledge and skills developed through oppositional behavior that challenges inequality.

The notion of CCW as an alternative framework to understand the success of URM and other underrepresented groups (e.g., first-generation and students from low-income families) in engineering has yet to be explored in-depth. A recent dissertation study demonstrates this promise and reveals how Black and Latino engineering students are empowered by different forms of capital related to their background, culture, and experiences [32].

C. Engineering Self-Efficacy

Previous research on the role of self-efficacy beliefs in engineering support the notion that they are strong predictors of academic achievement and engineering interest [33,34]. Self-efficacy figures prominently in Social-Cognitive Career Theory (SCCT) [7] to explain achievement and career-related choices. The authors of the theory suggest that contextual factors are particularly influential for underrepresented groups, and have successfully employed the theory to understand engineering interest and goals [35,36,37], adjustment [38], satisfaction [39], and persistence [40] among college engineering students. Other researchers have employed the framework to understand persistence of ethnic minority women in engineering [41,42].

Marra and colleagues [43] developed the Longitudinal Assessment of Engineering Self-Efficacy (LAESE) to measure self-efficacy, feelings of inclusion, and outcome expectations of women studying engineering. This instrument was further revised by Concannon and Barrow [44] to include four subscales—engineering self-efficacy I and II (ESE I and II), coping self-efficacy (CSE), and engineering career outcome expectations (ECOE). In subsequent research, these authors found effects of gender for CSE (women lower than men) and ECOE (women higher than men) [45]. While researchers considered ethnicity and transfer status in this previous work, relationships with engineering faculty and other forms of capital that influence self-efficacy and outcome expectations were not explored.

III. METHODOLOGY

A. Design

This exploratory correlational study examines the relationship of interactions with faculty and other forms of capital with engineering self-efficacy among underrepresented engineering persisters (junior and senior class level) using data obtained from an online questionnaire administered at an urban research institution in the Southeastern United States. The study reported is part of a larger, mixed-methods project on the role of student-faculty interaction in the persistence of underrepresented students in engineering.

B. Instrumentation

The first 4 authors developed an online questionnaire as part of the larger project including support and interactions prior to enrolling in engineering (7 items), frequency of out-of-class interactions with faculty (4 items), assessment of quality of relationships with faculty, students, and staff (6 items), barriers experienced during studies (7 items), engineering self-efficacy (18 items), and cultural wealth (9 items). The focus in this study is on perceived quality of interactions with faculty, cultural wealth, and engineering self-efficacy.

1) *Perceived quality of interactions with faculty:* Students indicated extent of agreement with the statement “I have a positive and supportive relationship with College of Engineering faculty” on a 5-point scale from 1=strongly disagree to 5=strongly agree ($M=4.24$, $SD=0.82$).

2) *Cultural wealth:* While research to study the concept of cultural wealth has generally utilized qualitative methods, we developed nine items for our questionnaire to explore whether and how the different forms of capital could be assessed quantitatively. Social capital was divided into 4 items to assess different networks and resources (peers, faculty/staff, campus organizations, off-campus organizations). The wording of the statements was developed using the descriptions in reference [31], and students indicated a level of agreement with each statement from 1=strongly disagree to 5=strongly agree. The wording of each item, along with descriptive statistics, is shown in the findings in Table 2. Participants expressed high agreement with ability to maintain hopes and dreams for the future ($M=4.41$, $SD=0.73$) and having the ability to switch communication styles or language ($M=4.38$, $SD=0.83$), and least agreement with drawing on connections with off-campus community organizations to be successful ($M=3.37$, $SD=1.13$).

3) *Engineering self-efficacy:* Seventeen items related to engineering self-efficacy [44,45] were included on the questionnaire used for this study (see Table I). Items were rated on a 7-point scale from 1=strongly disagree to 7=strongly agree, as in the original instrument. Three items related to course taking were not included on our questionnaire because they do not apply to students in junior or senior year of studies. Exploratory factor analysis to identify factors among these 17 items supported a three-factor model – engineering self-efficacy (ESE, 5 items), engineering career outcome expectation (ECOE, 7 items), and coping self-efficacy (CSE, 5 items). While previous studies differentiated

between two engineering self-efficacy subscales (four subscales total), the factor analysis did not support separation of these items given the exclusion of the three coursetaking items. The internal consistency estimates are similar to those reported in previous studies, however CSE is lower.

C. Participants

“Underrepresented student” for this study was defined as a student who identified as a student of color (African American, Hispanic/Latino, Asian American) or a first-generation college student (neither parent completed a four-year degree). Of 90 total participants in the online questionnaire, 50 met this definition of underrepresented student. Nearly a third of the students in the underrepresented sample (30%) identified as both student of color and first-generation college student. Among the students of color (50%), the majority identified as Asian-American (30%), while African-American and Hispanic/Latino students each made up 10% of the sample. The majority of this sample (80%) indicated that neither parent had earned a four-year degree. The participants were roughly split between junior (46%) and senior (54%) class level, while the majority indicated they had transferred to the institution (62%). Women were highly overrepresented in this sample (34%) based on their proportion in the undergraduate engineering student population at the institution (9%).

TABLE I. ENGINEERING SELF-EFFICACY SUBSCALES

Scale	Item	Mean (SD)
ESE $\alpha=0.77$	I can succeed in an engineering curriculum.	6.26 (0.90)
	I can succeed in an engineering curriculum while not having to give up participation in outside interests.	4.90 (1.88)
	I can excel in an engineering major during the current academic year.	5.96 (1.32)
	I can complete any engineering degree at this institution.	5.54 (1.42)
	I can succeed (earn an A or B) in an advanced engineering course.	5.50 (1.49)
ECOE $\alpha=0.82$	Someone like me can succeed in an engineering career.	6.32 (0.94)
	A degree in engineering will allow me to obtain a well-paying job.	6.48 (0.68)
	I expect to be treated fairly on the job; that is, I expect to be given the same opportunities for pay raises and promotions as my fellow workers if I enter engineering.	6.40 (0.76)
	A degree in engineering will give me the kind of lifestyle I want.	6.24 (0.85)
	I expect to feel "part of the group" on my job if I enter engineering.	6.08 (1.12)
	A degree in engineering will allow me to obtain a job that I like.	6.27 (0.76)
	A degree in engineering will allow me to get a job where I can use my talents and creativity.	6.29 (0.74)
CSE $\alpha=0.55$	I can cope with not doing well on a test.	4.70 (1.85)
	I can make friends with people from different backgrounds and/or values.	6.46 (0.68)
	I can cope with friends' disapproval of chosen major.	6.16 (1.04)
	I can approach a faculty or staff member to get assistance.	5.88 (1.19)
	I can adjust to a new campus environment.	6.16 (0.91)

D. Analysis

Data collection is ongoing for the larger project at the time of submission, thus, we utilize bivariate correlation in the study reported here to investigate relationships between the variables of interest and prepare for further analysis once data collection is complete. We utilize only the data collected in Spring 2014, and will utilize the data collected in Spring 2015 (ongoing) for future analyses.

IV. FINDINGS

To examine the relationships between sources of capital for students (quality of interactions with faculty, cultural wealth) with engineering self-efficacy, we calculated bivariate correlations, which are reported in Table II. All of the sources of capital were positively related with engineering self-efficacy variables, and all but four correlations were statistically significant at the $\alpha=.05$ level.

A. Relationship of Capital to Engineering Self-Efficacy

Quality of interactions with faculty and most of the cultural wealth variables were significantly related to ESE. Only social capital associated with off-campus organizations and resistant capital did not reach statistical significance. Aspirational capital (maintaining hopes and dreams; $r=.563$), familial capital (maintaining connections to home culture, $r=.559$), social capital associated with faculty and staff ($r=.474$), and navigational capital ($r=.461$) showed the strongest associations with general engineering self-efficacy.

B. Relationship of Capital to Engineering Career Outcome Expectations

Quality of interactions with faculty and social capital associated with off-campus connections were not significantly related to ECOE. The strongest relationships were between ECOE and aspirational capital ($r=.631$), social capital associated with faculty/staff ($r=.529$), familial capital ($r=.522$), and social capital associated with peers ($r=.512$).

C. Relationship of Capital to Coping Self-Efficacy

All of the capital variables were significantly related to CSE. Social capital related to faculty/staff showed the strongest relationship ($r=.600$), followed by aspirational capital ($r=.462$), navigational capital ($r=.461$), social capital associated with peers ($r=.416$), and linguistic capital ($r=.415$).

V. DISCUSSION AND IMPLICATIONS

The descriptive results of this exploratory study suggest that beliefs about engineering ability and career outcome expectations are positively related to perceived sources of capital among underrepresented engineering students. Perceived positive and supportive relationships with faculty were positively related to engineering self-efficacy, but not as strongly as certain forms of cultural wealth.

TABLE II. CORRELATIONS OF FORMS OF CAPITAL WITH ENGINEERING SELF-EFFICACY

Forms of Capital	Mean (SD)	ESE	ECOE	CSE
Relationships with faculty: Positive and supportive relationship with College of Engineering faculty	4.24 (0.82)	.401**	.278	.371*
Aspirational capital: I can maintain my hopes and dreams for the future, even when confronted with barriers.	4.41 (0.73)	.563**	.631**	.462**
Linguistic capital: I have the ability to switch communication styles or languages based on environment (academic and non-academic).	4.38 (0.83)	.292*	.406**	.415**
Familial capital: I maintain a connection to my home community and culture.	4.06 (1.18)	.559**	.522**	.404**
Social capital – peers: I draw on connections with peers to be successful in college. (social-peers)	4.18 (1.02)	.399**	.512**	.416**
Social capital – faculty/staff: I draw on connections with individual faculty and staff members to be successful in college.	3.94 (1.10)	.474**	.529**	.600**
Social capital – on-campus: I draw on connections with campus organizations or offices to be successful in college.	3.64 (1.17)	.303*	.352*	.337*
Social capital – off-campus: I draw on connections with off-campus community organizations or agencies to be successful in college.	3.37 (1.13)	.223	.192	.352*
Navigational capital: I have developed strategies to navigate difficult people and situations at the university.	4.10 (0.86)	.461**	.333*	.461**
Resistant capital: I challenge university practices that seem inequitable.	3.66 (1.04)	.215	.343*	.318*

* $p<.05$, ** $p<.01$

Three forms of cultural wealth stand out in our analysis, and may be particularly important for students who are the first in their families to complete a college degree, or who come from marginalized communities of color. Students who maintain their hopes and dreams for the future despite real and perceived barriers (aspirational), remain connected to home culture and community (familial), and draw on connections with faculty and staff to succeed in college (social) enjoy more

positive beliefs about ability in engineering, expectations about career outcomes, and ability to cope in engineering studies. While previous research has considered first-generation college status as a negative factor for persistence in college [46], and has noted how URM students are less likely to persist in engineering [1], our findings in this study offer an alternative to a deficit perspective on underrepresented students. Further, these findings suggest that beliefs about engineering ability and future career success are linked to the use of connections with faculty and staff to succeed in engineering.

While the nature of the sample and design used in this study limit the generalizability of the findings, they suggest that our continued research should consider the role of cultural wealth in explaining engineering self-efficacy and persistence among underrepresented students.

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How the Application of Coping Strategies Can Empower Learning

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Abstract—In order to perform well, an engineer has not only to solve a task but also cope with the environment. This is very important in military operations, where underperforming might have fatal consequences. As a military academy, we have developed ten coping strategies that we use to increase students' ability to perform in military situations. These strategies have been introduced in the education, but not yet scientifically evaluated. This year, inspired by Peter Shull's FIE Workshop 2014 [1], we focused on the strategies also in engineering subjects. The usage of the strategies in different situations was evaluated by short questionnaires. The results show that all strategies are actively used in military context, and that they are also applicable in engineering subjects, having a positive effect on performance. However, the substance of the strategies in an academic perspective was not as clear as it was in military. In order to benefit from the strategies in engineering subjects the substance of the strategies needs to be discussed with the students. We also found that, the "ability to control", alone had high influence to performance through military and engineering events indicating that this strategy might be the dominant strategy to achieve good performance.

I. INTRODUCTION

In the FIE Workshop 2014 Peter Shull asked how a teacher can influence students self-determination. He identified significant correlation between performance and self-determination through the practice of implementing a victim/engineer awareness-decision model [1]. We saw this model as a light version of a series of coping strategies that we introduced into a two-week long military exercise at the Norwegian Defence Cyber Academy (NDCA); designed to support second year students' ability to perform. The ten coping strategies are introduced in Section III.

The NDCA offers a four-year cyber officer education where students gain both an engineering Bachelors' degree in Information and Communications Technology (ICT) and officer training. The core of the cyber officer study, as defined in the NDCA study handbook [2], is a combination of technical training, leadership development, military skills and physical training. Military exercises are an integrated part of the educational platform at the NDCA. The exercises are designed to develop all these skill sets and empower students' learning and self-determination through the use of coping strategies.

Inspired by Peter Shull's victim/engineer awareness - decision model [3], we introduced the military based coping strategies to our second year students four months earlier

than in previous years. In addition to the military context, we focussed on their usage also in engineering context, such as mathematics, electronics, and programming. The purpose of transferring coping strategies was to connect engineering subjects more closely to military subjects and vice versa. This gave us an opportunity to identify which of the ten coping strategies are actually applied in military contexts and which in pure engineering contexts, if any, and how the usage of coping strategies influences students' performance. We were also interested to know if students used any other strategies. The usage of the strategies was evaluated by short questionnaires where students evaluated their own performance in specific military and engineering situations and selected the strategies they had actively used.

In this paper, we summarise the background information used when the ten coping strategies of NDCA were developed, and link them to the learning process in Section II. After that the coping strategies of NDCA are introduced in Section III. Section IV explains the empirical experiment, and results and discussions are shown in Section V. The conclusion of the paper is given in Section VI. Section VII briefly explains the next steps for ongoing study of the coping strategies in engineering education.

II. STATE OF ART

Acknowledged stressors such as workload, task management, context switching, time pressure, heat, cold, noise and fatigue are all present to us in our modern world [4]. A student, an employee, a leader, an officer or a soldier all experience different levels of physical and mental stress related to their work environment. There are large bodies of literature focusing directly on each of these variables individually, and describing their effects on performance [4]. Lazarus [5] [6] argued that stress consists of three processes. Primary appraisal is the process of perceiving a threat to oneself, secondary appraisal is the process of bringing to mind a potential response to the threat, and coping is the process of executing that response.

Research has been conducted regarding the use of coping strategies in military operations as well as how we face difficulties in normal working life; for example [5] [6] [7] [8] [9] [10]. Sørensen [7] describes the word "coping" as referring to the tricks that we think work at the given moment to maintain balance. Coping strategies can be understood as skills and abilities used to handle physical and mental stress. They

are often referred to as different techniques like visualization, meditation, breathing, self-hypnosis etc. [11]. The more overall general idea of coping strategies is *to believe in yourself and your ability to perform*.

Coping strategies can be viewed as a form of active components used to face threats or demanding situations that may increase the likelihood of mastery. Eid and Johnsen [12] describe three main directions of coping strategies: task-oriented coping, emotional-oriented coping and avoidant coping. The task-oriented coping style is characterized as an individual trying to grasp the problem and then to solve it. The emotional-oriented style will emphasize discussion and analysis of own feelings, without necessarily grasping the problem. The avoidant coping style will attempt to withdraw and avoid dealing with the problem [12]. However, individuals with avoidant coping styles are more prone to both chronic [8] [9] and traumatic stress disorders [12]. On the other hand, individuals who have an active attitude towards coping are less burned-out than others [13].

Research has shown that preferable responses to stress can be learned [11], and that the capability of coping and performing under higher stress levels can be trained [12]. Awareness, reflection, emotions, self-regulating, and social support play an important part in learning to cope with stress [10] [11]. To learn from experience and develop preferable and conscious automaticity of coping strategies, the understanding of the connection between your emotions, actions and the perceived consequences are crucial to capture [14]. Systematic reflection is an important tool to gain this insight and understand these connections in order to develop individual higher order cognitive skills [15] [16]. In addition, the learning can be strengthened by repetitive positive feedback, which in turn can raise individual self-efficacy [11].

Both coping and not coping create emotions that influence self-perception [11]. Baumgardner and Crothers [17] say that: "Many of our feelings about the past are related to our success or lack of success in accomplishing personally important goals" [17]. Which, in turn, has an impact on future actions and performance. They further point toward strong correlation between self-perception and processing of information, regulation of emotion and motivation. In addition, achieving important personal goals is associated with increased self-esteem [17].

Looking at the educational research, we find that self-efficacy - *an individual's belief about his capabilities to complete a task with certain performance levels* - is the most central concept in contemporary psychology research [18]. According to Bandura [19] mastery experiences, vicarious experiences and social persuasion contribute to self-efficacy. Self-efficacy contributes to learning as a higher level of self-efficacy raises the probability of using and combining knowledge in new ways [19] [20]. However, as highlighted by Judge et. al [18] high self-efficacy does not equal high performance levels due to strong individual differences. Regardless, self-efficacy contributes to performance, and performance prediction based on self-efficacy is more accurate in task-related situations. Self-efficacy is an important part of learning, but one needs to be realistic about own capabilities and behavior in order to perform well and achieve good grades in an academic sense. Studies [3] [21] [22] have pointed out a need to make students understand

connections between their own expectations, capabilities and behavior regarding learning process and performance. As well as teaching students how to perform better through changing behavior and improving their own capabilities. As it can be seen, belief in ones capabilities is not only an important part of coping, but also in learning. Therefore, the task and solution-oriented coping strategies (introduced in Section III) can be considered to be usable in an academic learning process as well.

III. TEN COPING STRATEGIES OF NDCA

The ten coping strategies came to life in the late winter of 2011, and were the result of a comprehensive and experienced-based discussion and planning process. By reflecting on personal experiences from different military operative contexts, the research and education section of the academy were able to identify factors that were decisive in supporting mastering the mental and physical stress presented by the external environment. Intuitively three decisive strategies for coping were identified. It was agreed - despite different operative experiences - that *accepting the situation* is crucial to release a persons potential to perform. Let us say that there is a 50% attack probability during the next patrol. In order to move on and cope with this situation, a soldier needs to accept this fact. By accepting the attack probability, the focus can then be placed on *being proactive* and preparing and building confidence by applying the *skills and knowledge* acquired through training. These three steps of coping evolved further into the following ten coping strategies, which are explained within a context of a patrol operation.

Situational Understanding: With situational understanding we mean a person's *ability to observe* (to gain a comprehensive overview and to see current problems) and *ability to consider* (to understand the task and possible further problems that might occur). A person should actively strive to provide an overview of the situation, to begin a mental process of managing change: plan, prioritize resources, consider time and evaluate external and internal factors that can shape performance [23]. Contemporary military patrol operations incorporate a complex network of various types of human capabilities integrated with multiple levels of technical sensors, giving measurable details from the "current picture". However, these details are not the only factors that should contribute to decision making. Factors such as social, historical, cultural, legal and geo-political aspects are required to be included.

Accept the situation: By situation acceptance we mean a person's *ability to accept the facts* (the operational environment and the available resources) and then mentally prepare to work purposefully within these conditions to achieve a goal. Schunk [24] states that interpretation - based on historical and current facts - and self-regulation based on the ability to modify and transfer knowledge, makes individuals more likely to accept situations that include risk and uncertainty. As in the case of military patrol operations.

Use of knowledge and tools: This is the *ability to keep track of own and others' resources and make use of them*. To use logical common sense, to make it easy, to not over analyze tasks, to use experience and to apply theoretical and practical knowledge. At all levels of a patrol operation, the

individuals are using their cognitive capacities to support accurate decision-making. They are applying knowledge and skills gained in training and from experience, implementing knowledge acquired from understanding the situation, and learning to modify their skills to master the complex evolving operating environment.

Ability to be proactive: To be proactive means *to be forewarned and be prepared for changes in the situation*, to look forward and constantly revise, and to trust intuition. In a dynamic military operation, none of the participants can sit back and expect learning and knowledge to come to them. The urgency to maintain control of the situation demands every individual is proactive and seeking knowledge concerning the environment, the enemy, their own level of exposure and the risk.

Finding alternatives and solutions: By this we mean a persons ability *to be open to others' inputs, intuitive, creative thinking and logical thinking, and common sense*. In a military patrol operation it is important to find what assets can be used to perform best in a constantly evolving situation. Finding these assets requires rapid analysis, continuous awareness and the capacity to see alternative solutions.

Ability to prioritize: Prioritizing relates to *setting priorities among assignments, personnel, material and intellectual resources, and ability to make difficult decisions*. A team carrying out a patrol operation need to decide how to best use assets to capture relevant and important information, whilst at the same time minimising exposure. This prioritization must consider the type of mission and the level of risk that is acceptable to personell operating in enemy terrain. Prioritizing capabilities increases sustainability and enhances situational understanding that leads to better self-regulation and self-determination amongst all personnel involved. At all levels the interplay between human and technical resources contribute to performance abilities and getting the most out of the assets available.

Ability to control: Having the ability to gain control of a situation or a task means that a person has *a manageable level of oversight concerning available resources, areas of responsibility, risk, and own capacities and capabilities (emotional and practical) in the given context to effect change*. The ability to control also requires the person to be aware of the relative power and agency of those around them (both internal and external). Within a patrol context, controlling oneself and control of the overall situation demands a high level of interaction between human and technical resources as observations transfer from the physical domain, through the information domain and into the cognitive domain.

Ability to influence: By this we mean an individual's *ability to cut through complexity and tension to find suitable and effective means of affecting positive outcomes*. To be able to organize and motivate oneself and others in such a way that supports self-determination without losing sight of the purpose. To influence means the ability to implement and manage technical resources in such that their effects support operational outcomes; rather than adding to the complexity and clouding judgements. In a military context it is not only and always the designated leader who should have the means to influence the situation. The other members of the team

can also influence performance and outcomes through similar means. For example; by behaving correctly, keeping calm, keeping others calm, encouraging and motivating others and contributing with constructive ideas. It should be noted that, as a team leader, too much focus on control and influence or your own people could contribute to negative outcomes [25].

Self-confidence and belief in oneself: Self-confidence is *a feeling of trust in one's abilities, skills, knowledge, and judgement*. Self-confidence and trust amongst the team has an empowering effect. When all participants execute their tasks to the best of their ability, an acceptable level of performance is achieved [26]. The will to perform should be equal under all circumstances whether routine or critical.

Ability to handle uncertainty: This is the ability to *focus on ones own reactions and take steps to actively manage uncertainty*. The key element here is to experience what one can and what one cannot influence and then playing deliberately on the matters one can influence [27]. By using double loop learning [28] [29], the state of conscious action can be achieved. Double loop learning requires one to look back at the event or situation to see how one responded to uncertainty, complexity and risk, to study the outcomes and learn from them. Mosse [30] has a similar perceptive to handling uncertainty in development when he talks about opening the "implementation box". Instead of just boxing experiences, one should actively reflect on events and evaluate how behaviour, actions and decisions affected the outcome. A deeper understanding can then be gained by carrying out the same task again with all knowledge learned from the evaluation. This is a way to change one's behavior to handle uncertainty [30].

IV. EXPERIMENT SETUP AND METHOD

The ten coping strategies were presented to second year Bachelor engineering students in the beginning of January 2015. During the presentation each strategy was explored briefly, along with the intent of gaining individual experiences by using coping strategies and capturing learning through a process of reflection. The possible relationships between strategies were not discussed, the strategies were handled as equals. The idea behind presenting the strategies was to make the students more aware of how they think, how they react and how they mentally deal with stress in order to perform. We clearly stated for our students that the ten coping strategies were examples and not a definite recipe. They were encouraged to use other strategies that they felt appropriate. The coping strategies were also referred to when appropriate in military leadership courses during the spring semester of 2015. However, none of the specific situations where usage of coping strategies was evaluated were mentioned or discussed.

Students' continuous focus on coping strategies was gained by making students reflect over both military and engineering related situations. The students completed short questionnaires self-evaluating their own performance on a scale from 1 to 6 (6 being the best performance rate), selecting the strategies they had actively used in a situation, and informing if they used any other strategies. In addition, the questionnaire included an open question, where students could write their reflections over the situation and any specifics regarding the usage of the coping strategies.

The students self-evaluated 14 military and engineering events. The engineering situations contained four different electronic laboratory exercises (El 1, El 2, El 3, and El 4), four online status tests in a statistic and discrete mathematic course (Ma 1, Ma 2, Ma 3, and Ma 4), and three lectures: one in Computer Network Operations (CNO) and two in Python programming language (Py 1 and Py 2). The military situations were delivered through operational training scenarios: battle procedure phase (BP: battle preparation regarding all equipment and oneself), emergency shelter (ES: making a snow shelter and sleeping in it), and a night military patrol (NP). The military events took place during our winter exercise in February 2015 and the engineering events in February-April 2015.

V. RESULTS AND DISCUSSION

In total, we had 38 second year students. The total amount of participants answering questionnaires varied from 33 to 37 students depending on how many of them actually participated in a specific event. Not all students answered the questionnaire - even though they had taken part in the event - leading to the answering percent varying from 89% to 100%.

We computed the average self-evaluated performance level and the average usage percent for each coping strategy for each of the 14 events. In addition, the correlation between the average performance levels and the average usage percents in the cases of the military events, the electronic laboratories, the online mathematic test and the lectures was computed even though we intuitively suspect that there are dependencies between the strategies. We used Equation 1 to determine the correlation coefficients [31], where r is the correlation coefficient, x_i is the average usage percent of each strategy and y_i the average performance rate of the specific event.

$$r = \frac{\sum x_i y_i - (\sum x_i)(\sum y_i)/n}{\sqrt{[\sum x_i^2 - (\sum x_i)^2/n][\sum y_i^2 - (\sum y_i)^2/n]}} \quad (1)$$

Due to possible dependencies, the correlation coefficient might be slightly biased. However, in our opinion, strong positive correlation ($r > 0,7$) is a valuable indicator for a strategy having a positive influence on performance. The average performance rate, average usage percent of each strategy, and the correlation coefficient between the average performance rate and the average usage percent of a strategy for each 14 events are shown in Tables I, II, III, and IV.

TABLE I. AVERAGE PERFORMANCE RATE, AVERAGE USAGE PERCENT OF STRATEGIES, AND CORRELATION BETWEEN AVERAGE PERFORMANCE RATE AND AVERAGE USAGE PERCENT OF STRATEGIES IN BATTLE PREPARATIONS, NIGHT PATROL AND EMERGENCY SHELTER EVENTS.

	BP	NP	ES	corr.
Average of performance	4,79	4,09	5,09	
Situational understanding	100	91,7	94,4	0,52
Accept the situation	100	91,7	88,9	-0,02
Use of knowledge and tools	91,9	86,1	86,1	0,23
Ability to be proactive	83,8	69,4	75,0	0,58
Finding alternatives and solutions	91,9	61,1	80,6	0,79
Ability to prioritize	67,6	61,1	66,7	0,91
Ability to control	67,6	55,6	83,3	0,95
Ability to influence	70,3	63,9	63,9	0,22
Self-confidence, belief in oneself	83,8	75,0	66,7	-0,27
Ability to handle uncertainty	73,0	77,8	36,1	-0,80
Some other strategy	2,7	5,6	2,8	

TABLE II. AVERAGE PERFORMANCE RATE, AVERAGE USAGE PERCENT OF STRATEGIES, AND CORRELATION BETWEEN AVERAGE PERFORMANCE RATE AND AVERAGE USAGE PERCENT OF STRATEGIES IN ELECTRONIC LABS.

	El 1	El 2	El 3	El 4	Corr.
Average of performance	4,39	4,59	4,81	4,24	
Situational understanding	93,9	91,7	90,9	87,9	0,28
Accept the situation	87,9	86,1	90,9	90,9	-0,02
Use of knowledge and tools	93,9	100	100	90,9	0,93
Ability to be proactive	63,6	80,6	90,9	60,6	0,98
Finding alternatives and solutions	78,8	72,2	81,8	63,6	0,74
Ability to prioritize	60,6	61,1	57,6	48,5	0,55
Ability to control	66,7	69,4	78,8	66,7	0,91
Ability to influence	27,3	52,8	48,5	36,4	0,71
Self-confidence, belief in oneself	72,7	72,2	78,8	75,8	0,43
Ability to handle uncertainty	48,5	55,6	48,5	42,4	0,55
Some other strategy	3	0	0	0	

TABLE III. AVERAGE PERFORMANCE RATE, AVERAGE USAGE PERCENT OF STRATEGIES, AND CORRELATION BETWEEN AVERAGE PERFORMANCE RATE AND AVERAGE USAGE PERCENT OF STRATEGIES IN MATHEMATIC COURSE ONLINE STATUS TESTS.

	Ma 1	Ma 2	Ma 3	Ma 4	Corr.
Average of performance	4,36	4,38	4,33	3,74	
Situational understanding	85,7	73,3	87,9	81,8	-0,02
Accept the situation	85,7	83,3	81,8	87,9	-0,78
Use of knowledge and tools	94,3	86,7	90,9	81,8	0,80
Ability to be proactive	20,0	26,7	39,4	30,3	-0,15
Finding alternatives and solutions	68,6	56,7	72,7	54,5	0,60
Ability to prioritize	57,1	16,7	33,3	30,3	0,14
Ability to control	51,4	43,3	45,5	39,4	0,72
Ability to influence	11,4	13,3	24,2	24,2	-0,62
Self-confidence, belief in oneself	77,1	53,3	66,7	42,4	0,75
Ability to handle uncertainty	42,9	26,7	45,5	39,4	-0,12
Some other strategy	2,9	0	0	0	

TABLE IV. AVERAGE PERFORMANCE RATE, AVERAGE USAGE PERCENT OF STRATEGIES, AND CORRELATION BETWEEN AVERAGE PERFORMANCE RATE AND AVERAGE USAGE PERCENT OF STRATEGIES IN COMPUTER NETWORK OPERATION AND PYTHON LECTURES.

	CNO	Py 1	Py 2	Corr.
Average of performance	4,23	4,16	3,85	
Situational understanding	86,1	90,6	92,9	-0,86
Accept the situation	86,1	84,4	89,3	-0,87
Use of knowledge and tools	69,4	93,8	89,3	-0,50
Ability to be proactive	13,9	37,5	25,0	-0,14
Finding alternatives and solutions	16,7	78,1	71,4	-0,56
Ability to prioritize	36,1	53,1	46,4	-0,29
Ability to control	61,1	56,3	57,1	0,52
Ability to influence	27,8	31,3	35,7	-0,96
Self-confidence, belief in oneself	61,1	53,1	50	0,83
Ability to handle uncertainty	36,1	31,3	39,3	-0,69
Some other strategy	2,8	0	0	

As can be seen from Tables I, II, III, and IV the percentages of alternative strategies were very low. The alternative strategies mentioned by the students were "co-operation within a group" in the battle preparation phase (BP), "stop thinking" and "group support" in night patrol event (NP), "creativity" in the first electronic laboratory (EL I), "educated guessing" in the first mathematic test (MA I), and "wish to learn" in the CNO lecture. However, after a formative evaluation, we concluded that these additional strategies provided additional substance to the original strategies. "Group support, co-operation and creativity" are included in *finding alternatives and solutions* strategy. "Educated guessing" falls into *use of knowledge and tools* strategy. "Stop thinking" is a part of the *ability to handle uncertainty* strategy. "Wish to learn" is a motivation factor which includes the *ability to influence*

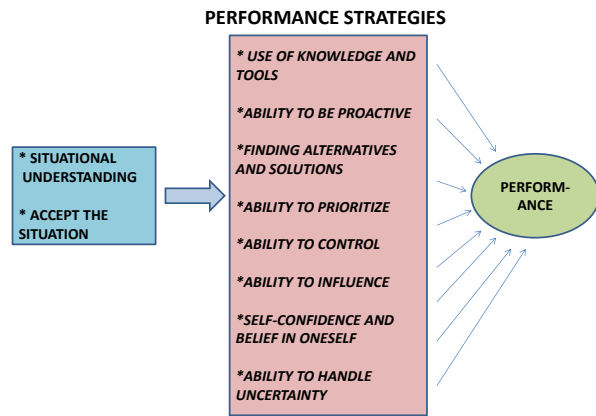


Fig. 1. Division to strategies into two sets of strategies.

strategy. The percentages of these have not been added to the original usage percentages of strategies, as the students had not fully understood the full substance of each strategy.

A. Situational understanding and accept the situation vs. the rest of the strategies

Tables I, II, III, and IV show that: *situational understanding* and *accept the situation* strategies, along with: *use of knowledge and tools* strategy, have the highest active usage percentages (more than 82% on average) among all strategies through the cases of military events, mathematic tests, electronic laboratories and lectures. However, neither *situational understanding* or *accept the situation* had strong positive correlation to performance. However, the rest of the strategies had stronger positive correlations to performance.

In our understanding, as mentioned in see Section III, one needs to understand and accept the situation before one can respond to a situation, a task or a difficulty. This suggests that the *situational understanding* and *accept the situation* strategies are applied when coping with an actual situation, and the remaining strategies are used to support better performance through empowered learning. In more complex situations and especially in dynamic situations, the relationship between the two first strategies and the remaining strategies are synergistic. However, in any context the first step is to understand and accept the situation, separating the rest of the strategies to "performance strategies" that actually have direct impact to performance. The relationship of the strategies in a simple case is shown in Figure 1.

Figure 2 then displays general usage of the performance strategies among military events, electronic laboratories, on-line mathematics test and lectures. Figure 2 also includes markings of correlations if the correlation coefficients between average usage of the strategy and performance is strong and positive (SPCP) or moderate and positive correlations (PCP), ($r > 0,5$). Neither weak or negative correlations are marked.

B. Performance strategies in extended military training

Table I shows gathered data in extended military training during the winter exercise in February 2015. As it can be

seen from Table I more than 50% of the students had actively used all strategies in the battle procedure phase (BP) and the night patrol (NP) phase. All strategies except *ability to handle uncertainty* were also used by more than 50% of the students in the emergency shelter activity (ES). Students commented that there was no need for *ability to handle uncertainty* strategy under the emergency shelter activity as the weather turned out to be a mild winter night. It was cosy to sleep under an open sky for a change instead in a tent. The fact was, there was nothing to be afraid of or concerned with, compared to the two other military activities.

Table I and Figure 2 show that in the military cases in general, the students performance was strongly and positively affected, ($r > 0,7$), by *finding alternatives and solutions*, *ability to prioritize*, and *ability to control* strategies. *Ability to be proactive* strategy also had positive effect, ($r > 0,5$).

C. Performance strategies in engineering subjects

In the spring semester of 2015, the students have studied and engaged in electronics, mathematics and military subjects. The mathematic course consists of both statistics and discrete mathematics. Both courses have had special events: laboratory days in electronics and online status tests in mathematics. In addition, they have been given a number of specific lectures focusing on specific needs concerning a two-week long military exercise in May. These engineering lectures included CNO (3 hrs) and two sessions of Python (total 8hrs).

The usage of the strategies in general was lesser in engineering subjects than in military subjects. The average usage of the strategies in four electronic laboratories was 72%. This was the closest to the average usage of the strategies in three military events (BP, NP, ES) that was 77%. The biggest differences were found among two strategies; less than 50% of the students used *ability to influence* and *ability to handle insecurity* in electronic laboratories (see Table II). Military events and electronic laboratories are both events where students have several things to do simultaneously and where good performance has a direct impact on their final grade. *Ability to handle uncertainty* strategy was understandably low in electronic laboratories due to the fact that the laboratory

	BP, NP, and ES	ELECTRO LABS	MATH TESTS	LECTURES
USE OF KNOWLEDGE AND TOOLS		SPCP	SPCP	
ABILITY TO BE PROACTIVE	PCP	SPCP		
FINDING ALTERNATIVES AND SOLUTIONS	SPCP	SPCP	PCP	
ABILITY TO PRIORITIZE	SPCP	PCP		
ABILITY TO CONTROL	SPCP	SPCP	SPCP	PCP
ABILITY TO INFLUENCE		SPCP		
SELF-CONFIDENCE AND BELIEF IN ONESELF			SPCP	SPCP
ABILITY TO HANDLE UNCERTAINTY		PCP		

Strategy used by more than 50 % and
 used by less than 50% students.

SPCP: strong positive correlation ($r > 0,7$) and PCP: positive correlation to performance ($r > 0,5$).

Fig. 2. The usage of strategies and their correlation to performance.

environment - the teacher and the procedures - were known to the students. In the laboratory, the students felt that they had limited influence on affecting the situation. However, they only considered the actual pre-determined tasks they had to carry out. They did not consider their surroundings or their own welfare. These have an impact on the execution of the actual tasks. Looking at the correlation coefficients (see Figure 2) most of the performance strategies had a strong positive effect to performance in the electronic laboratory ($r > 0,7$). *Ability to prioritize* and *ability to handle uncertainty* had positive effect ($r > 0,5$). *Self-confidence and belief in oneself* had weak positive effect ($r = 0,43$). The findings show that the use of military based performance strategies are transferable into electronic laboratory tasks.

The active use of the strategies was greatly reduced in the four mathematic status tests and in three lectures. They showed 54% and 57% respectively. Within these cases (see Table III and Table IV) less than 50% of the students had used *ability to be proactive*, *ability to prioritize*, *ability to influence* and *ability to handle uncertainty* strategies. Also, the correlation between all these four strategies and performance was either non-existent or negative (see Figure 2).

With *ability to handle uncertainty* and *ability to influence* strategies, the similar explanation as given in electronic laboratory tasks applies. The mathematic tests and lectures are both well-known situations. However, it is our understanding that the students have too narrow a perception of coping strategy substance. This limits their possibilities to identify and influence the factors that can have a positive effect on the situation and outcomes.

The usage of *ability to be proactive* strategy was low in the status tests and lectures. This came as no surprise. The status tests in mathematics were only check points confirming knowledge and skill level at that specific time. The results of the tests were not used when the final grade was given. This meant that the students did not study any more than normal for the tests, leading to low proactivity levels. In the lecture cases, the CNO lecture came as a surprise to the students. They were not able to be proactive in a formal, pre-studying sense. However, the programming lectures were known beforehand, but only a couple of students were motivated to study the programming language in advance of the lecture.

The students answered that there was little use for *ability to prioritize* strategy in the status test and the lectures. However, analysis of reflections in the questionnaire indicate that not all of students necessarily understood what the whole concept of *prioritizing* actually meant. When something is *prioritized up*, something else will automatically be *prioritized down*. In our cases, the students had higher prioritizing for the electronic laboratories than for the status tests and the normal lectures, as they do not have direct impact on final grades. Their answers were based on *what they prioritize* not *prioritizing in general*. We admit that in this case, answering the questionnaire was ambiguous, and the results might be slightly biased.

The strategies that had strong positive correlations to performance in the mathematic status test were *use of knowledge and tools*, *ability to control* and *self-confidence and belief in oneself* ($r > 0,7$). *Finding alternatives and solutions* had positive effect to performance ($r > 0,5$). In the case of the

normal lectures, *self-confidence and belief in oneself* had the strongest correlation to performance. Also *ability to control* strategy had a positive correlation ($r > 0,5$).

The results can be interpreted as follows: the more concrete the task is and the more impact it has to a final grade, the more actively the performance strategies are used in engineering tasks. In these cases, the effect of the strategies in performance is also high. The challenge for a student is to see the usage areas of the strategies in a task or a situation that generates low-motivation. In order to perform well when motivation is low, one needs to increase self-determination. In our study, the students who used *ability to influence* in electro laboratories or *ability to control* in mathematics performed well, even though these strategies were generally found to be non beneficial due to the situations generating low-motivation (see Figure 2).

In the end, Figure 2 reveals an interesting fact. Even though the strategies were originally presented to the students as equals, the results support the intuitive thinking that in reality there are dependencies between strategies. The results show that the *ability to control* strategy has strong or moderate positive correlation to performance throughout all the cases. A reason for this might be due to the dependencies between the strategies. Better control is achieved through the application of knowledge, being proactive, finding alternatives and solutions, being able to influence and steer positive outcomes. The control strategy gives meaning to the iterative nature of coping strategies. The product of better control supports increased situational awareness and improved acceptance of stressful or complex situations. Figure 3 shows a model of the possible relation between *ability to control* and the other performance strategies.

All in all, this indicates that the military performance strategies have a positive effect on performance in engineering subjects. However, the full substance of the strategies in an engineering context is not as easily understood as it is in a military context. The strategies, their substance and link to self-determination needs to be discussed with the students.

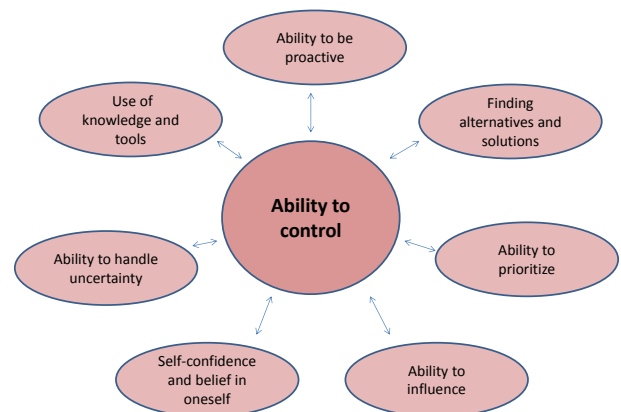


Fig. 3. Relationship between ability to control and other performance strategies.

D. Guidance of performance strategies in engineering subjects

As mentioned, the usage of coping strategies was not understood intuitively in a pure educational context. It is our understanding that this is based on two factors. The first being a mismatch with the phrase "coping strategies". We discovered that they should be called "performance strategies." The second reason was shown to be the narrower understanding of the strategies in an academic context compared to a military context. To address these factors going forward, we have decided to call the strategies "performance strategies", and introduce better guidance for using strategies within engineering subjects. An example is shown in the following paragraphs.

There are two main levels in *situational understanding* and *accept the situation* in engineering education. The first level is understand the bigger picture: what kind of education a student is entering, what does it take for a student to get through this education and what does a student gain by finishing this education. The second level is to understand and accept each smaller situation occurring during the education, e.g. lectures, individual studies, group works, home works, deliveries, laboratories, tests, and exams. In addition, other factors affecting education such as economical situation, family situation, and health situation should also be discussed. The educators can empower students earlier to understand their education in its wider context and help students to adopt a mind-set that the expectation on them at school is no less than that placed on a team of professionals engaged in a real time operation.

Use of knowledge and tools, finding alternatives and solutions, and the *ability to prioritize* are easily understood in an academic setting. However, it should be discussed that these are not introduced as methods to be used inside a classroom or a laboratory, when a specific engineering task is to be solved. Where Shull [3] encouraged reflection at the moment his students faced a problem, we encourage *reflection occurring in advance*. By supporting students to reflect early over situations, their own actions, behavior and performance, they might, for example, identify a potential problem in advance and avoid it. This we call a *proactive* response and it applies also to the *ability to handle uncertainty*. If a student is prepared to *reflect on uncertainty*, and see it as an opportunity and not a barrier to learning, then they might become more open to criticism and be more receptive to the idea of thinking differently. Encouragement can come from teachers, however it is best sourced from fellow students as this avoids any feeling of top-down pressure.

In our study, the students felt that there is no real need for the *ability to control* and the *ability to influence* in classroom teaching or in a test situation. One cannot control or influence the questions asked in the test, but one can control and influence environment. Things like alertness, nutrition and hydration level, and other personal physical needs can be controlled and influenced as well as the noise and light levels in the classroom. One also has control of the situation when the procedures in the test situation are known. For example, interactive discussion initiated by the students, can empower learning. It can be the case that there exists several students with the same problem but are too shy to say anything. This brings us to self-confidence. *Self-confidence and belief in oneself* increases by mastering the tasks. Therefore, it is important to start at a level that guarantees each individual the

feeling of mastery. Then increase the difficulty level of the task which simultaneously increases the students' self-confidence.

These "performance strategies" are not independent. They are integrated and fragmented, and complement each other. Their agility and transferability must be understood. To cope better is the sum of many parts. Applied in isolation, a coping strategy may support learning, however, it is unlikely to lead to deeper learning, change in behaviour and better outcomes. Learning to draw the best out of yourself, your team and the environment is a skill that requires capacity building in hard and soft skills.

VI. CONCLUSION

In this paper, we showed how the ten coping strategies of the Norwegian Defence Cyber Academy (NDCA) were developed. We showed how the strategies were originally used and how they are currently being used. The original use was limited to military contexts. However, inspired by Peter Shull's FIE Workshop 2014 [1], we have now introduced our coping strategies (*situational understanding, accept the situation, use of knowledge and tools, ability to be proactive, finding alternatives and solutions, ability to prioritize, ability to control, ability to influence, self-confidence and belief in oneself, and ability to handle uncertainty*) into engineering subjects.

In this paper we have identified which of these ten coping strategies were really applied in military contexts and which in pure engineering contexts. We have also studied if the usage of coping strategies influences the performance of the students. The usage of the strategies was evaluated by using short questionnaires. Students evaluated their own performance in specific military and engineering situations and ticked the strategies that they actively used.

We found that the strategies *situational understanding* and *accept the situation* are used first, before the other strategies can be applied. When a person has understood the situation and accepted it, he/she can start to act and by act we mean to perform. The rest of the strategies are then performing strategies, having positive correlations to performance. The *situational understanding* and *accept the situation* strategies are applied when coping with an actual situation, and the rest are used to support better performance through empowered learning. We also found that the *ability to control*, alone had high influence to performance through military and engineering events indicating that this strategy might be the dominant strategy to gain good performance. This experiment could not measure the role of the *ability to handle uncertainty* strategy due to the very secure events we used.

Furthermore, we found that the original name "coping strategies" should be changed to "performance strategies" as it would give more intuitive understanding of the usage areas of the strategies. The results showed that all strategies are applied in military context and that they are also applicable in engineering subjects, especially in electronic laboratories. They are also usable in other subjects. However, in order to get their full benefit, the strategies and their substance needs to be discussed with the students.

VII. FUTURE WORK

The research of performance strategies (earlier: coping strategies) continues to the end of the year 2015. We will be looking at relationships between performance strategies more deeply in cases where the level of complexity and uncertainty within every task is raised and the shifts in context are more rapid. This is achieved by simulating a high intensity operational environment where the applications of the educational skills are required to perform.

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Dynamic Assessment of Learners' Mental State for an Improved Learning Experience

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Abstract—It is very challenging to provide a learning experience which is meaningful, motivated and at the same time enjoyable in nature. This often affects the students who cannot learn or do not want to learn due to lack of engagement and guidance. The same scenario is also true for working professionals in industries. Cognitive flow, defined as the mental state in which a subject is fully concentrating with a feeling of full involvement and enjoyment, is reported to play a key role in this. There are different questionnaire based indirect methods for measuring ones' flow state. However, in our present work we attempt to measure the flow state more directly using Electroencephalogram and multi-modal physiological signals including heart rate variability and galvanic skin response. Twenty right-handed engineers from our research lab played a video game to induce conditions of boredom and flow. A modified colour based Tetris (similar to Stroop test) game is used for the said purpose. A comparative study is done between the offline questionnaire based and the physiological signal based flow measurements. From the results it is clear that flow/boredom state can be derived from brain signals, which is modeled using Markov chain, as well as from other physiological signals. Hence can be used as an important feedback in various applications for maintaining a steady flow state for a longer period. Finally, the flow-boredom model generated from brain signals has been used in Web Based Learning to automatically measure the learning experience.

Keywords—Flow state, Boredom, Anxiety, EEG, learning experience

I. INTRODUCTION

Teaching professionals have observed that children have limitless curiosity for knowledge before they enter school. Several years later those same children lack attention, motivation and suffer from boredom. Finally they disengage themselves from learning and have a negative feeling towards knowledge and learning. This is true for working professionals as well as they need to go through various training programs for new knowledge/skill development. The main purpose of the work is to provide a better learning experience by maintaining student's engagement as well as enjoyment with the help of positive psychology. In psychology, cognitive flow

[1] is defined as the mental state in which a person performing an activity is fully concentrating with a feeling of full involvement and enjoyment. A person's skill and the challenge of a task together result in different cognitive and emotional states. When skill is too low and the task too challenging, people become anxious. Alternatively, if the task is too easy and skill is comparatively higher, people become bored [2]. However, when skill and challenge are roughly proportional, people enter *Flow state* i.e. a state of focused concentration and enjoyment as shown in Fig. 1(a). Individual's performance measurement, emotional state assessment are some of the applications of flow while subjects perform different tasks. Application of flow in education will aid enormously in performance analysis, characterizing student's skill level against the given educational content, automatic adaptation/ suggestion of study materials etc. A modified Tetris game as shown in Fig. 1(b) is designed for the modeling and measurement of boredom and flow state of an individual. The details of the game is described later.

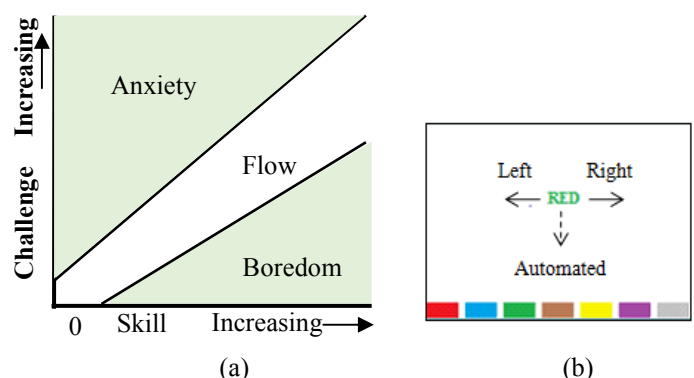


Fig. 1. (a) Flow state for skill and challenge, (b) Snapshot of the game

So far very few attempts for direct measurement of flow state have been seen. Most of current approaches use indirect methods for measuring flow [3], [4], [5]. In this paper we have used Electro-encephalogram (EEG) signals recorded by commercially available, low cost, single lead Neurosky¹ device. There are several approaches to study brain activations like functional Magnetic Resonance Imaging (fMRI) [6], functional Near Infra-Red (fNIR) [7] etc. We have used EEG as it is non-invasive, relatively low cost, and easy to use. Apart from the brain signals we have used two more

¹ <http://neurosky.com>

physiological sensing namely, heart rate variability (HRV) and Galvanic Skin Response (GSR) for measuring the level of stress for boredom and flow conditions.

In this paper, the approach involve two phases – (i) a game design for creation of a boredom-flow model, (ii) analysis of subjects' performance on a web based learning (WBL) material using the above model. The game design is motivated by the Tetris game [7] where the falling objects are replaced by Stroop color-texts and the bottom platform is replaced by seven color containers as shown in Fig. 1(b). The color of the texts are chosen to be different from the text itself. Subjects are asked to move the texts and place them in the container such that the color of the both matches. The speed of the falling texts is increased programmatically at certain intervals where a subject is expected to move from boredom state (at low speed) to flow state (at higher speed). This is validated through questionnaire based *Game Flow Inventory* (GFI) [8] [9]. A two state first order Markov chain is used for creation of the boredom-flow model. The states of the Markov chain are estimated as a Gaussian Mixture Model (GMM) using Maximum Likelihood Estimate (MLE). Finally, the model is used to estimate the performance of a subject against a given web based learning video material. The performance is derived with respect to the transitions between boredom, flow and vice-versa.

The paper is organized as follows. The Section I of the paper dealt with a brief introduction to the flow state of brain and its associated implications. Section II reviews the existing approaches to assess the flow state. The methodology used for the proposed implementation is discussed in Section III followed by the experimental setup in Section IV. Results and discussions of our findings are given in Section V. Finally the paper concludes in Section VI along with the future avenues of research.

II. RELATED WORK

As reported by Csikszentmihalyi [10] [11], flow state is experienced by workers who like their jobs, by teenagers who love studying, by drivers who enjoy driving [11]. Thus, “*flow*” can be attributed to the state of the brain in utmost involvement in a task of interest, thereby avoiding the distractions and other aspects not concerned with the task..

Flow has also been compared against the concept of ‘presence’. These two aspects share many things in common but at the same time, they are distinguishable from each other. Flow describes a state of immersion into a particular activity whilst ‘presence’ pertains to the immersion into a given environment (virtual in case of gaming). Fontane [12] described ‘presence’ state of consciousness to be most apt for performance in unfamiliar ecologies whereas the flow could be better attributed with familiar ones. Thus, ‘presence’ is relatively more focused on technological characteristics pertaining to a medium while flow stresses on task related characteristics [13].

It has been observed that at times, people spend most of their time in activities that do not lure them much. This could be attributed to the fact that every flow inducing activity expects a preliminary investment of attention. Very often, due to lack of discipline to overcome the hindrances, tiredness, anxiety or negligence; enables in avoiding a person to switch

to a flow inducing task. It then results into settling for any alternative, which seems more accessible, perhaps less enjoyable [10]. This factor is a serious issue that comes in the way of success of e-learning domains, thereby hindering their widespread usage. When it comes to games or social networking, the initial investment of attention is comparatively less challenging. Thus training programs must devise low initial attention demanding schemes in order to enjoy mass-acceptance.

There are different approaches for measuring flow state [3] [4] [5] namely, (i) semi-structured interviews – gives a qualitative measure, (ii) questionnaires – flow state questionnaires/scales used to describe user experience and performance, (iii) experience sampling method – objective is to measure flow and other states of consciousness occurring in activities encountered in everyday life. Jackson and Marsh had devised a feedback-questionnaire based method to evaluate flow, popularly known as the flow state-scale [14]. These feedback or indirect questionnaire based approaches seem to be feasible and less complex, but they are not reliable enough. Recent works show that brain signal analysis seems to be the most promising approach, due to its excellent data rendering, portability and cost effectiveness [15]. Based on the brain and physiological signals obtained, Maurizio Mauri et al, have found that *Facebook* usage induces a high positive valence and high arousal (Core Flow State) that can be attributed to its mass acceptance and increased usage [16].

In terms of educational perspective, flow state of mind is crucial for the involvement in the study process for the grasping of concepts. Flow measurement in case of piano playing [17], video-game playing [18, 19], online games [20], athletes subjects [21], using social networking sites [16] etc. have been extensively researched. Also, the advantages of flow are effectively used to foster e-commerce business [22]. Yoshida et al, have detected the increase in oxygenated Hemoglobin content in the right and the left Ventrolateral Prefrontal Cortex (VLPFC) during flow state using fNRI [7]. John Pearce, classified flow to be ‘task’ and ‘artefact’ oriented, for the students subjected to e-learning paradigm [23], wherein the multimedia aspects of e-learning sites culminated into the arousal of ‘artefact flow’ in the subjects. In case of collaborative learning in immersive virtual environments, flow was measured using Guo and Poole’s inventory model [24].

Recent attempts have been made to use low cost EEG devices for different applications like measuring cognitive load [25], user interface evaluation [26] etc. EEG is extensively being used in educational tasks through the advent of Brain Computer Interface (BCI) technology [27]. The analysis of cognitive load for different learning objectives is presented in [28] using low cost EEG device. In [18], greater left temporal alpha activity was noticed when compared to that of right temporal lobe affecting the performance associated with flow. In conjunction to this, the mid beta activity and theta activity also have an effect on performance whereas there was no significant results with respect to delta waveforms. In [16], higher alpha activity coupled with lower beta activity is found to be characterized for flow state.

Given the landscape of the work done on experiments with flow state for a given task, it can be seen that there have been

very less work done on web based learning materials. Moreover, there is no work that provides a formal way of measuring the performance of a subject in terms of boredom-flow models for web based learning.

III. METHODOLOGY

A. Game design

We have developed a game which is a modified version of the Stroop test and the standard Tetris game. The game is developed using Pygame. Here the names of the colours used in the Stroop test descend from the top of the screen. The falling words were pseudo randomized. The playing field is 24 cells high and 14 cells wide. The task is specially designed into 2 versions to induce flow and boredom conditions with variations in speed of the falling words. Seven different colored containers are placed at the bottom of the screen with a fixed distance between each of them. The screen shot of the game is shown in Fig. 1(b). The users are supposed to drop the falling texts into the appropriate containers so that the font color of the falling text matches with the color of the container. The subjects have the provisions to control only the left and the right movements of the falling texts and not the down movement. These movements are implemented using left and right arrow keys of the standard QWERTY keyboard. For boredom experience, the texts descend down at the rate of 1200 milliseconds per block. In case of flow state inducing condition, the texts initially descend at the rate of 1000 milliseconds per cell and then decreases by 200 milliseconds

at every 30 seconds per two cells. On each correct match, the score is incremented by one. Both the sessions have been designed to run for 2 minutes each. At the end of the game the final score is displayed on the screen.

B. Dimensions of flow experience

According to the flow theory, learning and practicing are essential to remain or re-experience the flow. Csikszentmihalyi [15] initially identified four flow components like control, attention, curiosity and intrinsic motivation. These are essential for experiencing the flow. Later Csikszentmihalyi modified these dimensions further and established that there are basically nine dimensions which are indicative of flow experience, namely, challenge vs. skill balance, concentration and focusing, direct and unambiguous feedback, loss of self-consciousness, clear goals, sense of control, time transformation, autotelic experience, and action-awareness merging. In this paper we have tried to measure flow based on these dimensions. For first three dimensions we have used direct measurement approach as shown in Fig. 2. We are using EEG signals for estimating skill-challenge balance and GSR signals for measuring concentration / focus during the task. Unambiguous feedback mainly can be of two types: internal feedback (like body movements, heart rate, etc) and external feedbacks (like performance score etc.). In this paper, we have used pulse rate as the internal feedback and the results of keystroke analysis as the external feedback. For remaining six dimensions, we have adopted a survey based approach.

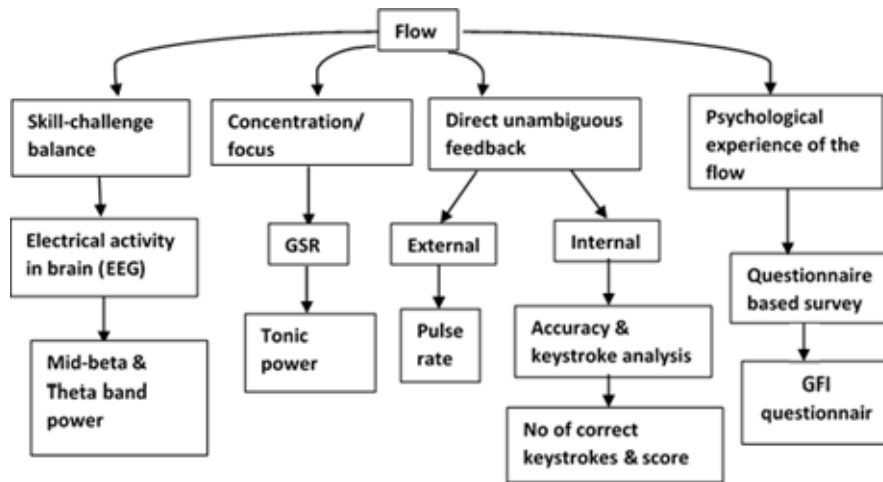


Fig. 2. Dimensions of flow experience and corresponding measurement approaches

1) EEG based skill-challenge analysis

For measuring the skill-challenge balance, we have measured direct electrical activities originated in brain. For this we have used a single lead EEG device from Neurosky. Participants are asked to play the modified Stroop game while wearing the device. The EEG signals along with certain metadata are recorded using an in-house Python based setup at a sampling rate of 512 Hz. The metadata includes the time stamps related to the presentation of various texts (Stroop color) on the screen along with the state of the game. The state

of the game is related to the speed in which the texts move and is detailed in the previous Section III.A.

In order to analyze the EEG signals, initially a window of length W is created with 50% overlap. Considering the short term stationarity, in our experiment, the window length is taken as 1 second. This also allows us to detect the windows containing eye blink and filter the same using algorithm proposed by Berka et. al. [29]. It is to be noted that, usually the duration of eye blink varies between 300 msec to 800 msec. In the present work, we have experimented with

frequency band energies [30], [31] and time domain Hjorth parameters [32], [33] as features as shown in (1).

$$F = \{E^\delta, E^\theta, E^\alpha, E^{l\beta}, E^{m\beta}, H^a, H^m, H^c\} \quad (1)$$

where the first five features are the energies in various frequency bands namely, delta (E^δ as 0.5 - 4 Hz), theta (E^θ as 4 - 7.5 Hz), alpha (E^α as 7.5 - 12.5 Hz), low-beta ($E^{l\beta}$ as 12.5 - 16 Hz) and mid-beta ($E^{m\beta}$ as 16 - 20 Hz) respectively. The energies in each band is extracted using Welch's power spectral density estimation [35]. The last three features in (1) are the Hjorth parameters namely Activity (H^a), Mobility (H^m) and Complexity (H^c) respectively as given by (2).

$$H^a = \text{var}(x(t)) \quad H^m = \sqrt{\frac{H^a \left(\frac{dx(t)}{dt} \right)}{H^a(x(t))}} \quad H^c = \frac{H^m \left(\frac{dx(t)}{dt} \right)}{H^m(x(t))} \quad (2)$$

where $x(t)$ indicates the time domain signal in a window and $\frac{d(x(t))}{dt}$ is the first order derivative of the signal.

The skill-challenge analysis is performed using a first order Markov chain where we have considered two states, $S = \{S_{bo}, S_{fl}\}$ corresponding to boredom (S_{bo}) and flow (S_{fl}) as shown in Fig. 3. The state transition probability p_{ij} is defined as the probability in which the chain moves from state S_i to state S_j , $i, j \in \{bo, fl\}$. In case of first order Markov chain, the transition probability depends only on the present state and is independent of any previous states. It is possible to use more number of states, including a neutral state, anxiety state etc. However, in order to understand the feasibility of the proposed approach, in this paper, we have intentionally used a simple model with minimum possible states.

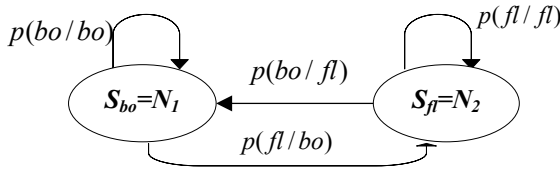


Fig. 3. Markov Chain with two states namely boredom and flow state along with the state transition probabilities

In the current work, the states (S) of the Markov chain are characterized by the Gaussian probability density functions (PDF). An unsupervised approach is used to generate a Gaussian Mixture Model (GMM) [35] of individual features (f) as given in (3). Maximum Likelihood Estimation (MLE) [36] is used to derive the Gaussian parameters ($N_j(\mu_j, \sigma_j)$, $j \in \{1, 2\}$) comprising of two mixtures. These two Gaussians correspond to the two states in Markov chain. Once the GMM is estimated, the probability of a feature belonging to a Gaussian is given by (4). Finally the detected state S^d for a given feature in a window of EEG signal is given by (5) and (6).

$$p(f) = \sum_{j=1}^2 P(j) p(f|j) = \sum_{j=1}^2 P(j) \frac{1}{\sqrt{2\pi\sigma_j^2}} \exp\left(-\frac{(f - \mu_j)^2}{2\sigma_j^2}\right) \quad (3)$$

$$P(j|f) = \frac{p(f|j)P(j)}{p(f)} \quad \forall j \in \{1, 2\} \quad (4)$$

$$S^d = S_b, \quad \text{if } P(1|f) > P(2|f) \quad (5)$$

$$S^d = S_f, \quad \text{if } P(2|f) \geq P(1|f) \quad (6)$$

The above model is generated using each features derived from the modified Tetris game. The intention behind performing the GMM on individual features is to find the most important feature which is able to generate a model that maximizes the state detection accuracy (A). The accuracy is derived by comparing the detected state S^d derived from the feature of each EEG window against the state $S^g = \{S_{bo}^g, S_{fl}^g\}$ of the game. The boredom and flow state of the game are denoted by S_{bo}^g and S_{fl}^g respectively. For a given feature, the accuracy for the boredom state (A_{bo}^f) and flow state (A_{fl}^f) are given by (7), where the function M is the number of EEG windows for which the detected state (S_{bo}^d, S_{fl}^d) and the game state (S_{bo}^g, S_{fl}^g) are same for a given feature $f \in F$. The total number of EEG windows for the boredom state and flow state for the game are W_{bo} and W_{fl} respectively.

$$A_{bo}^f = \frac{M(S_{bo}^d = S_{bo}^g | f)}{W_{bo}} \quad A_{fl}^f = \frac{M(S_{fl}^d = S_{fl}^g | f)}{W_{fl}} \quad (7)$$

The most important feature f_{imp} is derived as the feature that provides the maximum accuracy for both boredom and flow state as given in (8). The important feature thus derived is used for analyzing flow state of a subject for a given educational content as part of web based learning.

$$f_{imp} = \underset{f \in F}{\text{Arg max}} (A_{bo}^f + A_{fl}^f) \quad (8)$$

Finally, the parameters (λ) those are stored for the evaluation of the performance (in terms of boredom-flow) of a subject against a learning material are given in (9). This includes the two Gaussian distributions (N_1, N_2) and the state transition probabilities $p_{ij}^{g,bo}, p_{ij}^{g,fl}$ derived during the two types of games namely boredom and flow respectively. It is to be noted that the parameters can be stored for each subject for subject dependent analysis or can be derived as a global parameter while considering all the subjects. In this paper we have performed subject specific analysis.

$$\lambda = (N_1, N_2, p_{ij}^{g,bo}, p_{ij}^{g,fl}), i, j \in \{bo, fl\} \quad (9)$$

2) GSR based concentration measurement

The galvanic skin response (GSR) is an electro-dermal response where the skin conductance changes with the state of the sweat glands in presence of stressful, likeable events. Therefore GSR can be a good predictor of concentration, mental workload etc. in flow study. During flow experience, subjects should experience a higher concentration and complete focus on the task. Galvanic skin response can be successfully used to measure the level of concentration [37].

The GSR applies a constant voltage to the skin through two electrodes. The voltage is so small that it cannot be felt or perceived by the individual. However, the current that flows

through the skin, as the voltage is applied, can be detected. The GSR signal is characterized by two components: a fast component called ‘phasic’ and a slow component called ‘tonic’. Both tonic and phasic components contain information associated with specific physiological aspects of brain states. Here the tonic component is calculated only taking the inverse transform of first few Fourier coefficients as in (10), whereas the phasic component is calculated by inverting the higher coefficient of Fourier coefficients as given in (11).

$$\text{tonic component} = \text{IFFT}\left(\sum_{n=0}^{N-1} x(n) \cdot e^{-j\left(\frac{2\pi}{N}\right)nk}\right), k=0,1,2,3 \quad (10)$$

$$\text{phasic component} = \text{IFFT}\left(\sum_{n=0}^{N-1} x(n) \cdot e^{-j\left(\frac{2\pi}{N}\right)nk}\right), k=4,5,\dots,N-1 \quad (11)$$

3) Direct/unambiguous feedback

Individuals in flow state must receive direct unambiguous feedback on how well the task is being performed. There are two different ways of evaluating the subject performance: i) external feedback and ii) internal feedback [38]. Internal feedback refers to the feedback provided by bodily movements and external feedback is provided by the sources outside the body. In the present work, we have used heart rate as the internal feedback approach. We have also analyzed the keystrokes [39] as these gives the direct measure of the user performance.

a) Internal feedback - Heart rate analysis

Heart rate variability is an effective indicator of one’s present stress level [40]. Hence it can be used as a feedback for validating Csikszentmihalyi’s concept of moving from anxiety through Flow to boredom model. When the challenge of the undertaking task is low compared to the subject’s skill level, then the heart rate variability (HRV) is high compared to the flow state where the skill matches with the challenge level required. There are quite a few medically accepted HRV parameters. McDuff et al. [35] extracted the PPG from the face video, we have used the SPO2 device wearable on the index finger for sensing the Photoplethysmogram (PPG) signal. The HRV is computed in the similar manner as detailed in [35]. We have calculated three time domain HRV parameters namely 1) RMSSD (Root mean square of successive differences between adjacent NN intervals), 2) SDSD (Standard deviation of successive differences between adjacent NN intervals), 3) SDNN (Successive difference between NN Intervals).

b) External feedback - keystroke analysis

In this paper the external feedback is provided based on keystroke analysis and overall score of the game. The data capture tool was designed to log all the keystrokes (both left keystroke and right keystrokes) while playing the game (the task). The score was initially set to zero and was incremented by one, each time the user successfully placed the falling texts in the corresponding containers. At the end of the game timer (2 min), the total score is displayed on the screen.

For each falling text, total number of left keystrokes N_{KL} and total number of right keystrokes N_{KR} were extracted from the data file generated by the capture tool. For each text to be collected in the correct container, the user need to press either left key or the right key. Hence majority key-presses actually

represents the correct number of keystrokes for that particular object. If $N_{KL} \gg N_{KR}$ then number of correct keys N_{KC} is given by (12). Similarly if $N_{KL} \ll N_{KR}$ then the number of correct keys is given by (13). The total number of keystrokes for a particular falling text is given by (14).

$$N_{KC} = N_{KL} - N_{KR} \quad (12)$$

$$N_{KC} = N_{KR} - N_{KL} \quad (13)$$

$$N_K = N_{KL} + N_{KR} \quad (14)$$

Next a correctness measure was calculated by dividing the correct number of keystrokes by total keystrokes using (15).

$$C = \frac{N_{KC}}{N_K} \quad (15)$$

For boredom condition C is close to 1 as all the keystrokes are expected to be the correct ones. As the speed of the falling object increases, subjects tend to press some wrong keys and the value of correctness measure decreases. In the anxiety condition, the number of wrong keystroke is expected to be maximum and hence value of C is minimum.

4) Psychological experience of the flow

Apart from the first three dimensions of flow, remaining six dimensions are evaluated by a questionnaire based survey as they are mainly related to human perception. After finishing the game, the users are asked to fill up a questionnaire to obtain an indication of their perception during flow and boredom experience. For this purpose we used a 7 point rating scale called Game Flow Inventory (GFI). GFI has been derived from original 13 point flow rating scale and is specifically applicable for gaming environments [8] [9]. GFI measures level of engagement, enjoyment or happiness and intrinsic motivation.

C. Application of flow model in Web Based Learning (WBL)

The models created based on the EEG, GSR and physiological sensing is used for analyzing the behavior of a subject for an unknown educational content. In order to perform this experiment, subjects were shown two types of learning materials from web where one is in the interest area of the subject and other is in an unrelated area. The goal is to derive certain attributes for the subject for a given learning material. This is done using different types of sensing. Using the EEG analysis, the state transition probabilities (p_{ij}^t where $i, j \in \{bo, fl\}$) for the learning session are derived using a two state Markov chain whose states were earlier modeled with the help of the modified Tetris game. A distance metric D^k , $k \in \{bo, fl\}$ is computed to analyze the closeness of the Markov chain for the learning material with the previously generated boredom and flow Markov chains using the modified Tetris game. The distance metric D^k gives an estimate on the overall experience of the subject related boredom and flow.

$$D^{bo} = abs\left(\sum_{i \in \{bo, fl\}} \sum_{j \in \{bo, fl\}, j \neq i} (p_{ij}^{g,bo} - p_{ij}^t)\right) \quad (14)$$

$$D^{fl} = abs\left(\sum_{i \in \{bo, fl\}} \sum_{j \in \{bo, fl\}, j \neq i} (p_{ij}^{g,fl} - p_{ij}^t)\right) \quad (15)$$

The physiological signals are used to measure the heart rate variability (HRV) and then derive metrics on minimum, maximum and average HRV along with the duration of the same in percentage of the complete tutorial session. Longer duration in low HRV indicates that a subject is in flow state. This is derived from the HRV observation and the user study during the game analysis. The GSR analysis is also used to derive the maximum, minimum and average tonic feature along with the duration of the same in percentage for the given training material. Longer duration in high tonic feature indicates that the subject is in flow state.

IV. EXPERIMENTAL SETUP

A. Participants

We have selected a group of 20 subjects, 10 male and 10 female, from our research lab. They were all right handed engineers having normal or corrected to normal 6/6 vision with spectacles. The average age group of the subjects selected was 28-32 years. While selecting the subjects we also ensured that they are from similar cultural and educational background. These factors were taken into account to ensure minimum variance in brain lateralization across the participants.

B. Data collection setup

The physiological data collection has been accomplished using an in house python based data capture tool. The application enables us to show the stimulus in a standard computer screen and at the same time collect the EEG signals. Subjects are asked to play the game while wearing a single lead EEG device from Neurosky. It is a dry sensor with a lead placed in FP1 position and the grounding is done with reference to left earlobe. For recording the variance in skin conductance level, we use a GSR device from eSense. All our participants are right handed and hence we put the GSR sensors on the middle and ring fingers of the left hand. The right hand is kept completely free so that the user can play the game comfortably. The oxygen saturation level and the pulse rate are assessed by the pulse oximeter from Contec (CMS50DL1), through the left index finger. The devices used are shown in Fig. 4. During the gaming session, keystrokes (both left and right), game scores, GSR data, EEG data and SPO2 data were logged in for further analysis.

C. Experimental procedure

1) Creating the boredom-flow model

The experiment has been conducted in a block, in which the experimental task is performed four times: twice during boredom condition and twice under the flow condition. For half of the subjects the order of the conditions are boredom-flow-boredom-flow and for remaining participants the order is flow-boredom-flow-boredom. Each block lasted for 10 minutes and consisted of two tasks: 1) participants performed the experimental task for first 8 minutes (2 minutes for each conditions and 2 sessions per conditions) 2) next they completed the questionnaire based survey using GFI.

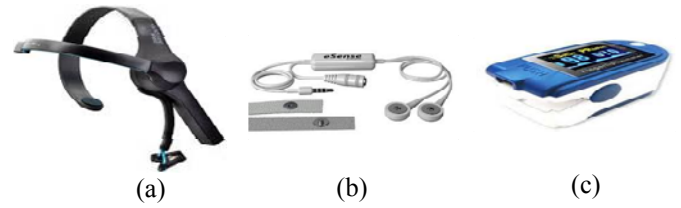


Fig. 4. Data collection devices: (a) Neurosky EEG device, (b) Galvanic skin response from eSense (www.mindfield.de/en/biofeedback/products/esense/esense-skin-response), (c) Pulse oximeter from Contec (http://www.contecmed.com/index.php?option=com_virtuemart&Itemid=592)

2) Application in Web-based learning

The experiment with web based learning is performed on a smaller subset of five subjects. These subjects are selected from the 20 subjects participated in the modified Tetris game. The selection criteria is based on the value of $(A_{bo}^{fimp} + A_{fl}^{fimp})$ derived from (7) and (8), where the top four subjects are chosen, whose detection accuracy of the boredom and flow state are maximum for the game task. These subjects were shown two types of videos namely one which is of their interest area and the other which is not. Each of these videos are of duration 5 minutes. The sequence of the two types of videos are distributed among four subjects in a balanced manner.

V. RESULTS AND DISCUSSIONS

This section provides the results for game based experiment and the web based learning. Initially, for the game, the following analysis are performed. Later the application of the boredom-flow model is demonstrated as part of the web based learning where the subjects flow state is measured.

A. Subject feedback as part of questionnaire

The subject feedback taken using GFI has been used to assess if a particular subject experienced boredom and flow experiences during the experiments. For doing this, the overall scores for both flow and boredom questionnaires are calculated assuming 1= strongly disagree, 2= disagree, 3 = undecided, 4 = agree and 5 = strongly agree. Next we performed t-test on the scores obtained to find out the differences between two conditions: flow and boredom. Next we observed the differences in mean and variance for both the conditions for each subject. Based on these differences, we finally concluded that 16 out of 20 subjects actually entered in flow state as there is a significance difference between the mean values. For remaining two subjects there are no differences between the mean values and hence are not expected to be in flow state.

B. Keystroke analysis

We analyzed all the left and right keystrokes logged by the capture tool. We calculated the correctness measure for both flow and boredom conditions using (15). Fig. 5 (a) and Fig. 5 (b) shows the correctness measure plots for both the conditions. As expected, for boredom condition most of values of C are close to 1 whereas for flow condition value of C decreases as the speed increases.

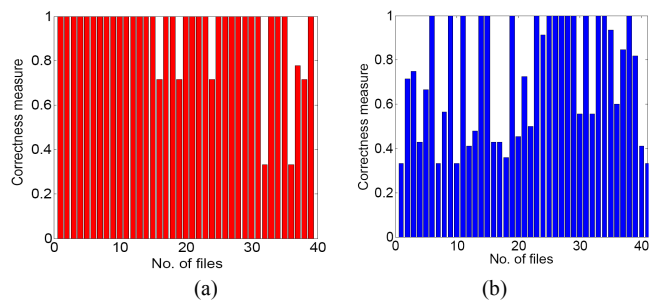


Fig. 5. Correctness measure for (a) boredom condition (b) flow condition

C. EEG analysis for boredom-flow model creation

The data analysis can be well understood with the aid of Fig. 6 which shows the 4 quadrants that partition the boredom and flow states against the 2 mixtures framed by GMM. The thick arrow represents the separation. Higher the value, higher is the capability of the HMM to distinguish the two cognitive states. Fig. 7 and Fig. 8 represents this separation achieved using 8 different features as given in (5), for 16 participants in total. It was found that the separation by each feature was not fixed for all subjects. However, it is evident from the graph that the difference value for the feature theta is greater than mid-beta for 12 subjects out of 16 subjects. When the four participants' feedback was assessed, it was found that they were not engrossed in the task, neither were they bored of the task. This state can be attributed to an intermediate state apart from the flow and boredom states.

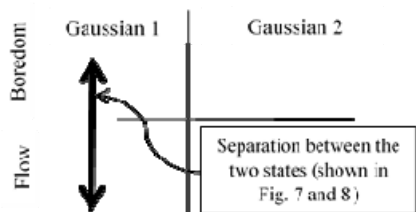


Fig. 6. Data analysis for based on the separation between Boredom and Flow

D. Results of GSR analysis:

The GSR data file is subdivided into a number of windows of duration 1sec. with 50% overlap between the windows. Next we calculated both tonic power and phasic power using (10) and (11). The phasic power does not show sufficient separation between flow and boredom condition whereas the tonic power gives good separation between those two conditions. Hence we used tonic power as the distinguishing feature for further analysis. Table I shows the maximum tonic power for all 20 subjects for both flow and boredom condition. From the table we see that for 16 subjects the tonic power is higher in flow state compared to that in boredom state. For four subjects reverse trend is observed (marked in red). For these four subjects the t-test results also confirmed that, there are no significant differences between boredom and flow state i.e. according to GSR results and the questionnaire based survey, they did not reach flow state. Fig. 9 (a) and Fig. 9 (b) show the tonic component of GSR for a particular subject during boredom-flow-boredom-flow and flow-boredom-flow-boredom conditions. Thus we see that, in flow state due to increased mental activity the sweat level is more which in turn changes the conductance, making the two tonic component of boredom and flow conditions far apart.

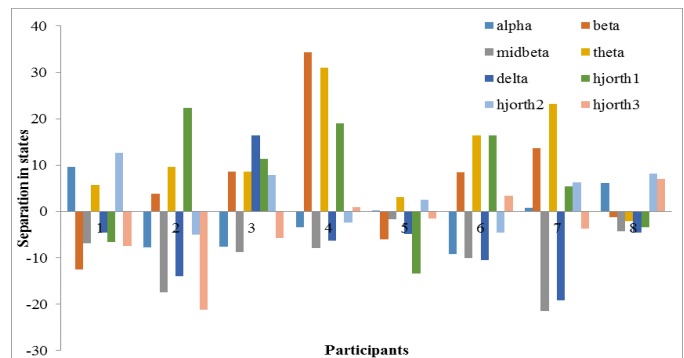


Fig. 7. Separation between boredom and flow state for all the features for boredom-flow-boredom-flow

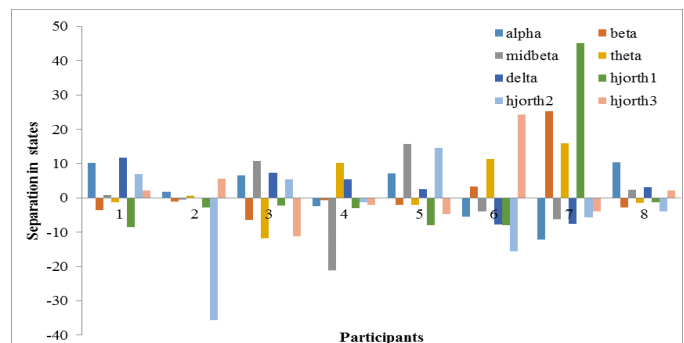


Fig. 8. Separation between boredom and flow state for all the features for flow-boredom-flow-boredom

TABLE I. MAXIMUM TONIC POWER FOR FLOW AND BOREDOM STATES

Subjects	Maximum Tonic in boredom state	Maximum Tonic in flow state
S1	0.89	0.96
S2	0.72	0.78
S3	0.65	0.58
S4	0.73	0.94
S5	0.28	0.31
S6	1.17	2.34
S7	0.49	0.52
S8	3.44	5.02
S9	0.23	0.27
S10	1.5	1.3
S11	12.9	14.7
S12	3.64	3.54
S13	0.26	0.32
S14	0.20	0.22
S15	4.99	6.77
S16	0.15	0.16
S17	1.43	2.02
S18	13.45	54.96
S19	0	0.184
S20	0.18	0.174

It is to be noted that, when subjects experience boredom condition first, and then move to flow state, there is a huge difference between the corresponding tonic components of the GSR data (Fig. 9).

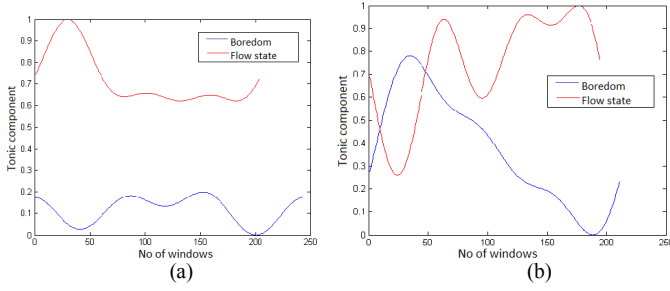


Fig. 9. Tonic component of GSR during (a) boredom-flow-boredom-flow condition and (b) flow-boredom-flow-boredom condition

On the other hand, if they first experience the flow state and then move to boredom state, then initially there is an overlap between the tonic components but finally there is a significant difference between the tonic components. This indicates that, it takes some time to get rid of the effects of the flow state. Similar trend is observed for all the subjects.

E. Results of heart rate variability analysis:

HRV values are calculated as given in [35]. Out of all three parameters, SDNN gives a distinguishable value for flow and boredom condition. SDNN for all the subjects for both the conditions are shown in Fig. 10. Here, it is visible that for 17 subjects, the HRV is more during boredom state and less in the flow state as the user have enjoyed the flow related experiment more and in the flow state they are expected to be in a calm, enjoyable state, leading to less variations in heart rate. For 3 subjects reverse trend is observed. The t-test results also show that for these 3 subjects the differences in mean values for two conditions are also very less.

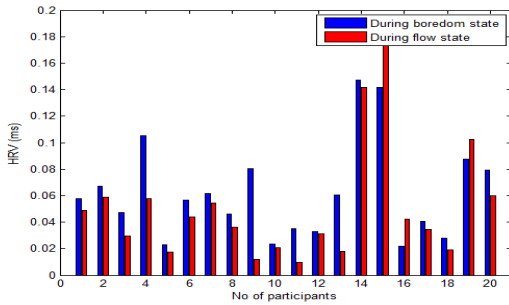


Fig. 10. HRV (SDNN) during flow and boredom conditions

F. Application of EEG based boredom-flow model in WBL

Two types of learning materials are used to experiment on 5 subjects chosen from the 20 subjects with the criteria as mentioned in section IV.C(2). These two types are one in the area of interest of the subject and the other not in the area of interest. The parameters λ given by (9) are used for each subjects to derive the state transition probabilities as given in Table II. These probabilities indicate how a subject shifts between boredom and flow state and how long the subject remains in the same state. Further the distance metric D^f, D^{bo} as given in (14) and (15) are given in Fig. 11 and Fig. 12. It can be seen from Fig. 11 that for the learning material not in the area of interest, for subjects 2, 3 and 5, the $D^{bo} < D^f$ indicating the Markov chains is closer to boredom Markov chain. From the feedback from the subjects 1 and 4 it is found that they came to know many new things from the learning

material which is not in their area of interest. From Fig. 12, it can be seen that in spite of having the learning material in the area of interest, the subjects 1, 2, and 5 didn't enter the flow state as $D^{bo} < D^f$ for them.

TABLE II. STATE TRANSITION PROBABILITIES FOR TWO TYPES OF LEARNING MATERIALS FOR 5 SUBJECTS (S) USING THETA FEATURE

S	Not in areas of interest				In areas of interest			
	$bo \rightarrow bo$	$fl \rightarrow fl$	$bo \rightarrow fl$	$fl \rightarrow bo$	$bo \rightarrow bo$	$fl \rightarrow fl$	$bo \rightarrow fl$	$fl \rightarrow bo$
1	0.005	0.98	0.007	0.007	0.39	0.25	0.17	0.17
2	0.045	0.93	0.01	0.01	0.005	0.97	0.01	0.01
3	0.115	0.63	0.12	0.12	0.04	0.81	0.07	0.07
4	0.105	0.58	0.16	0.16	0.164	0.49	0.18	0.17
5	0.046	0.81	0.07	0.07	0.42	0.26	0.13	0.13

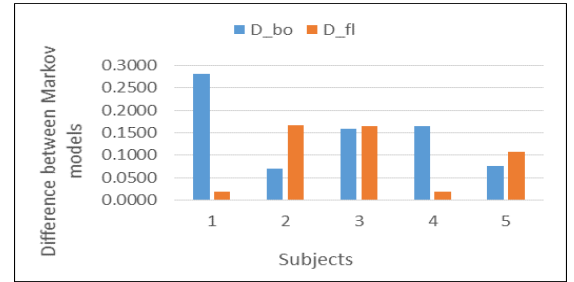


Fig. 11. Difference between Markov models for the learning material (not in the area of interest) and flow-boredom model derived from the game

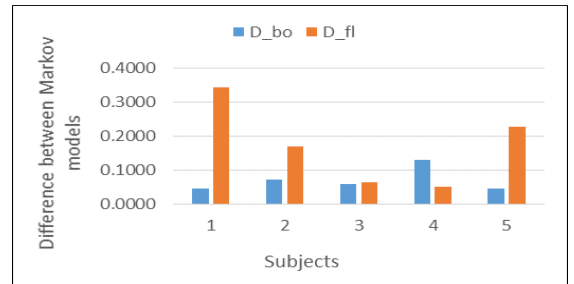


Fig. 12. Difference between Markov models for the learning material (in the area of interest) and flow-boredom model derived from the game

VI. CONCLUSION & FUTURE SCOPE

In this paper, we have tried to measure flow from brain signals and certain physiological signals like heart rate measurement, galvanic skin response. We have also tried to compare the results obtained from these direct approaches with the results obtained from questionnaire based survey and keystroke analysis. Results show that EEG signals can be successfully used to create a flow-boredom model based on first order Markov chain using a modified Tetris game. Results show that theta and mid-beta frequency band power are the most distinguishable features for flow and boredom experience. The Markov model is then used for deriving the flow-boredom state transitions for a given learning material and also getting insights on whether they enter flow state during the learning process. Future work involves fusion of brain and physiological signal and creation of a composite model with more number of states in Markov chain.

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A Summer Bridge to Calculus for Students with High School Calculus Experience

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Abstract—The University of Texas – Pan American (UTPA) is a minority serving institution in south Texas. The student population is predominantly made up of students from the local region, which includes two of the poorest counties in Texas. A significant number of high schools in the region offer some form of Calculus course, and in practice we find a number of incoming students with Calculus or Pre-Calculus on their high school transcript but who do not have college credit for these courses, and who are placing into College Algebra via the usual placement mechanisms. These placement mechanisms are largely test based.

The goal of this intervention is explore the possibility of improving these students preparation so that they will be successful in a Calculus 1 class in their first semester at UTPA. We have chosen an emporium model course design for the intervention in an effort to make use of student's previous experience as demonstrated by high school course work. In the first cohort we successfully transitioned 16 students to Calculus 1 for the Fall 2014 semester, and 10 of these were successful in that class. This is not a statistically significant better performance in Calculus 1 over the traditional pre-requisite pathway (College Algebra and Pre-Calculus), and in future cohorts we will continue to adjust the course content and support structure.

I. INTRODUCTION

The University of Texas – Pan American is a minority serving institution in Texas. The student population is predominantly made up of students from the local region, which includes two of the poorest counties in our state. The region has significantly lower levels of educational attainment and median incomes compared with the state as a whole. Most students are first generation college students. The student population is 90% Hispanic, and more than 80% of them are bilingual in Spanish and English. The College of Engineering and Computer Science at the university offers Bachelors degrees in Mechanical Engineering, Manufacturing Engineering, Electrical Engineering, Civil Engineering, Computer Engineering, and Computer Science.

Typically more than half of first-year Engineering and Computer Science students do not place into Calculus for their first semester. A fifth to a quarter of the students are placed into College Algebra. Given prerequisites for foundational courses in engineering such as Physics, this effectively delays the students' time-to-graduation by at least a year. Though they can attempt to catch up in the summer semesters, the abbreviated and intense nature of summer Calculus and Physics courses

can also inhibit the student's mastery of later coursework in their engineering program.

We also see a significant number of first-year students at the university with high school transcript Calculus courses, but without credit for those courses through the AP test or other mechanisms. Many are placing into College Algebra and not Pre-Calculus through the use of standardized placement tests or through not taking a placement test at all. Studies of students in College Algebra courses in Texas indicate that rates of test aversion and anxiety are high for students in these courses [1].

Engineering students who do not take Calculus 1 or 2 in the Fall of their first year are substantially behind the curve because Calculus is the primary gatekeeper to sequences of courses in each of the Engineering and Computer Science degree plans. We aim to improve the overall degree experience for Engineering and Computer Science students who demonstrate two key features: previous course experience in mathematics that is not reflected in their placement, and a level of engagement in their course of study. We have designed a summer bridge intervention that uses an emporium model course design and combines this with mentoring and engineering design challenges. The program targets students who have high school experience in Calculus or successful experience in Pre-Calculus, and who have achieved the Texas College Readiness Standard as defined by the Texas Success Initiative [2], yet whose other placement performance has been insufficient to place into Calculus or Pre-Calculus.

It is worth noting that an alternative approach would be that of the Wright State University model of engineering mathematics, which delays the formal instruction of Calculus until later in the student's academic career and instead focuses entering students on engineering applications of mathematics [3]. Our goal is to address students who have specifically demonstrated some prior work with concepts from Calculus in the relevantly recent past and to make use of that prior experience in our intervention. It would be interesting in the future to study whether allowing a delay in this effort would be as, or more effective, however such a redesign of the curriculum was beyond the scope of our project. We do make use of the engineering design challenges that are an important feature of the Wright State University model. We also note that one goal of our effort was to develop an intervention that if successful could be adapted as an institutional model for any student needing Calculus 1 in their degree plan.

The first cohort saw 17¹ of 22 participating students successfully transition to a Calculus 1 course who would otherwise have started their first semester in Pre-Calculus or College Algebra. This is a significantly higher success rate than has been found in other Pre-Calculus courses, including other courses with an emporium model design. Our hypothesis is that by asking participants to commit to a 6 week summer course before their first official semester at UTPA, we have successfully found a measure of student motivation and engagement in their degree plan. Sixteen of these students enrolled in Calculus 1, and ten of them successfully completed Calculus 1 with an A, B, or C. While this is an improvement in the passing rate over general Calculus 1 students, it is not statistically significant. We have included data on the continuing coursework of this first cohort in the Spring 2015 semester, particularly in the downstream courses of Calculus 2 and Engineering Physics 1. Future versions of the intervention will refine the focus on topics necessary for success in Calculus 1, and will also focus strongly on providing advice in life skills and education engagement for students. For the Summer 2015 cohort we utilized an advertising effort which targets students in the ROTC and Veterans programs at UTPA and our sister school the University of Texas at Brownsville.

Results for the Fall 2014 semester were previously reported in [4], this report contains further data on the performance of the students in subsequent courses in Spring 2015.

A. Alignment with Calculus 1 Courses

If successful in the intervention course, a student will be Calculus ready for the fall semester of their first-year. The intervention is producing students who have higher pass rates in Calculus 1, and higher GPA. However, for the first cohort we did not find that these increases were statistically significant. Still, by accelerating Calculus readiness and providing a learning environment that promotes general college readiness, we should have reduced time-to-graduation and hope to show improved knowledge mastery in later courses, especially those that are Calculus or Mathematics intensive.

Discussions with Calculus 1 instructors have identified two types of deficiencies in students: deficiencies in expected mathematical knowledge, and deficiencies in engagement in the Calculus 1 course. In the first cohort we focused heavily on aligning the topics in the course with the identified content knowledge and mathematical skills deficiencies. The engineering design effort focused some on the engagement aspect, trying to give students exposure to areas in Engineering where mathematical techniques they were studying would be used. Future cohorts will have activities focusing on working with students to develop work and persistency skills such as: time management, team work, stress management, and an overview of support services offered on campus. The course will develop a plan for success in Calculus 1 for participating students that will include using freely available online resources in addition to the class they register for. Combined with the emporium model used in the summer bridge, which emphasizes the importance of practice, participating students will have a significantly improved point of view on what is needed for successful completion of Calculus 1 and other courses.

¹Of these 16 took Calculus I in the fall and one was a concurrent enrollment high school student.

B. Emporium Model

The mathematics course is a specialized course combining material from the College Algebra, Trigonometry, and Pre-Calculus courses. Material is chosen based on feedback from Calculus instructors at the university on specific problems and techniques in which the student population in their courses is deficient. Subsequent interviews with Calculus 1 instructors indicate that student engagement is one of the most important identifying characteristics of successful students.

The course is structured as a partial emporium model class. The emporium model involves students using a computer program such as the Assessment and Learning in Knowledge Spaces (ALEKS) in a computer lab [5]; the students spend class time answering questions in the system and also use the system for their homework assignments. The instructor, along with student mentors, circulates through the lab providing one-on-one assistance for problems students struggle with. These in class helpers are also involved in the mentoring of students in their engineering degree plans and generally in their integration into the campus environment.

The software used is adaptive, and provides each student with an individualized version of the course. The first activity of the students is to take an initial assessment that attempts to identify what prior knowledge they have entered the course with. This is especially important for courses that are an initial step in a chain of mathematics courses, as with traditional mechanisms of placement students are entering the course with a wide variety of experiences. The software effectively rewards students for retaining prior knowledge, which is significantly different from a standard course design [5]–[7].

The emporium model is being used on many campuses for students who place into remedial mathematics courses (courses on content from below College Algebra). It is used at our university in remedial mathematics classes as well as sections of College Algebra and the Elementary Probability and Statistics courses. The emporium model works based on the hypothesis that students who have spent more time on task with the material from the class will have better mastery of the material, and will perform at a higher level in subsequent courses which depend on that material. Emporium model courses have shown large increases in the percentage of students completing their remedial mathematics courses at our university, and increases in students completing their college level mathematics courses. This course design incorporates many of the features of mastery-based courses. Students are not allowed to proceed until they have demonstrated mastery of earlier material. One further reason for the use of an emporium model for the course design is to attempt to address participating students' test aversion through the use of the extreme amount of practice emporium models put to students.

The use of software such as ALEKS in a summer intervention has proven successful as a method of improving student placement and preparation in the mathematics sequence at universities broadly and specifically in engineering programs. It has been shown to give a better predictor of student success than the typically used placement mechanisms of student test score [8], [9].

Our approach differs from other emporium models in that we are targeting the intervention specifically at Engineering

TABLE I. PRE-CALCULUS PASSING RATES

Grades	ABC	%	DFDrW	%	Total
Summer 2014 Traditional	34	29.8 %	80	70.2%	114
Summer Bridge	17	77.3%	5	22.7%	22
Fall 2014 Traditional	55	35.9%	128	64.1%	153
Fall 2014 Emporium	28	31.8%	60	68.2%	88
Fall 2014 Online	15	42.9%	20	57.1%	35

majors. We are including student mentors from their major as the in-class and out of class assistants. Finally the course includes design challenges through a partnership with the Railway Safety Center at our school; design projects were chosen which emphasize applications of algebra and trigonometry in railway engineering, and included a tour of the laboratory spaces used by the center. This aspect of the program will be expanded in future iterations to assist in focusing on improving the engagement of students in their university studies.

II. FIRST COHORT - SUMMER 2014

The first cohort entered the program in Summer 2014. We had 22 students, all had placement into our College Algebra or Pre-Calculus course (a difficulty was finding enough interested students from just the College Algebra placement). All had non-college credit for Pre-Calculus on their high school transcript, and ten had prior experience in a Calculus course from high school, however they had not received college credit for the course. The program was run through the university as a special section of the Pre-Calculus course, and we will compare the success rates with the other sections of Pre-Calculus. In the Fall semester three sections of Pre-Calculus were run as Emporium courses using the ALEKS software; these courses did not include the student mentors or an engineering design project, but otherwise used the same course materials as the summer program. There was also a section of Pre-Calculus run in the Fall semester that was fully online. All other sections of Pre-Calculus were traditional, largely lecture-based courses with students who either placed into the section or had completed College Algebra in a previous semester. Table III gives the results and grade distributions for the various flavors of Pre-Calculus offered in Summer 2014 and Fall 2014.

We observe that the success rate of students in the Summer bridge program differed significantly from that of the other Pre-Calculus sections. Most likely students who elected to participate in this summer bridge were self-selecting as mathematically ahead of their peers in general College Algebra and Pre-Calculus courses. They were declared as Engineering or Computer Science majors; they had some level of College Preparedness; and they elected to take a mathematics course prior to their first official semester as first-year students. Evidence that this population is special is that the effort needed to find 22 interested students for the first cohort was extreme. It is notable that attendance for the course was nearly perfect with no absences and only two tardies. Also note that no students dropped or withdrew from the course (their final grade would affect their GPA and potentially financial aid for AY2015-2016).

Of the 5 students who were not successful in the program, we found that 4 had significant work commitments outside of

TABLE II. PASSING RATES IN FALL 2014 CALCULUS 1

Grades	ABC	%	DFDrW	%	Total
Fall 2014 Calculus 1	205	27.4 %	211	50.7 %	416
Summer Bridge Students in Calculus 1	10	63%	6	37.5%	16

class. In the next iteration we will place a restriction on how much outside commitment students may have.

A. Success in Calculus 1

Of course the real measure of success for the program is how the students do in the subsequent mathematics (and mathematics intensive) courses. All but one of the passing students enrolled in a Calculus 1 course for the Fall 2014 semester. The one exception was a student who took the summer bridge as a concurrent enrollment student; due to him being a minor, and being in a unique situation we have not been able to secure permission to include his current activity in this report. Table II summarizes the grade distribution from the Fall 2014 sections of Calculus 1, and from the students who participated in the summer bridge program. Using a hypergeometric distribution we find that a random sample of 16 students from the Fall 2014 Calculus 1 classes would have a 20.5% chance of having 10 or more students successfully passing the course. So we cannot conclude that the success rate was statistically significant for this population. Likewise the Calculus 1 GPA of students who successfully completed the bridge program was 1.8 on a 4.0 scale, compared with a 1.55 from the general Calculus 1 classes. However the chance that a random sample of 16 students from Calculus 1 had a GPA of 1.8 or higher is 26%, so again we cannot conclude that this change was statistically significant.

In future iterations of the project we hope to show a significant improvement in performance in Calculus 1 over the traditional sequence of courses these students would have been asked to work through. The choice of an emporium model course design here was specifically made to make use of students' previous course work. It is not expected by the authors that this course design would be likely to have as strong an effect on students who lacked previous experience with Calculus 1 and its pre-requisite topics.

The emporium model course design asks students to work many examples. Figure 1 shows the grade in Calculus 1 in Fall 2014 for students who successfully completed the summer bridge program versus the number of topics marked as mastered by the software (obtained through repeated success in software assessments and by answering the question correctly three times without asking for help). It is important to note that throughout the emporium course it is possible for a student to have a topic marked as mastered removed because of a periodic assessment. Here we see a correlation, indicating that we almost certainly need to be including a minimum number of topics as a requirement for completing the program. This table and subjective questionnaires of the Calculus 1 instructors are going to be used to adjust the focus of the topics to better address Calculus readiness.

In table III we have included two more students from the

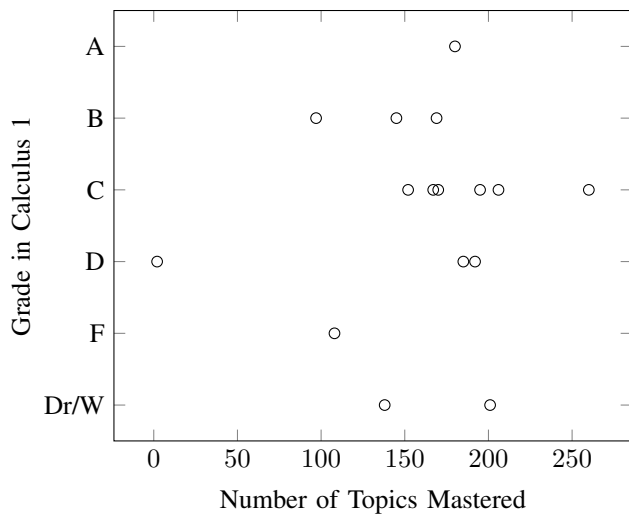


Fig. 1. This chart gives for those students who went on to Calculus 1 in Fall 2014, the grade they received versus the number of topics that they mastered in the summer bridge program.

TABLE III. COURSE PERFORMANCE BY SPRING 2015 FOR THE 2014 COHORT, ORIGINALLY 21 STUDENTS

Course	Number Completed
Calculus 1	12
Calculus 2	4
Physics for Engineering 1	7
Engineering Materials	2

16 who were successful and have subsequently passed their Calculus 1 course in the Spring semester. Of the five students who were not successful in the summer program: 4 have been unsuccessful in subsequent mathematics courses ranging from remedial to Pre-Calculus, and 1 has successfully completed College Algebra with a B.

B. Success in downstream courses

Currently the number of students in downstream courses is too small to draw broad conclusions. We have 12 students from the initial group of 21 who successfully completed Calculus 1 by the end of the Spring semester (ignoring the concurrent enrollment student).

One issue identified is students who are not registering for Calculus 2 the semester after completing Calculus 1, that is not all of the 10 who passed Calculus 1 in the Fall were enrolled in Calculus 2 in the spring; most likely this is related to the overall GPA of students completing Calculus 1 (5 of this cohort passed the course with a C).

We have discarded from the course topics some items which are included in the traditional Pre-Calculus syllabus because of their relevance in courses downstream from Calculus 1, and it is important that we understand whether the effect has been detrimental to students success.

Based on experience of the author in Calculus 2, students who have gone through the traditional sequence of pre-requisite courses do not typically demonstrate mastery of these topics in any case.

III. ADJUSTMENTS AND CONCLUSION

The program successfully transitioned 16 students to Calculus 1 for the Fall semester of their first-year; of these, 10 successfully completed this Calculus 1 course. A success rate that is comparable for that of students who place into Calculus 1 via other mechanisms. These 10 students took combinations of Calculus 2 and Calculus based Physics 1 in the Spring 2015 semester, overall the number of student persisting in the downstream courses is low, and the sample size is currently too small for broad conclusions. Regardless these students are one or two full semesters ahead of where they would be in their mathematics course sequence for the Engineering and Computer Science major if we had not conducted the intervention and they had registered for Pre-Calculus or College Algebra. One conclusion is that the UTPA may be able to successfully make use of students' high school transcripts for placement decisions and not rely solely on placement test scores.

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Computational Complexity of College Math Eigenvalue Problems

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Abstract—Providing students with suitably complex exercises is crucial to keeping them motivated and leading them to deeper understanding. Making such problems manually takes mathematics teachers' precious time which can otherwise be used to mentor students. Many software tools and services for automatic generation of math problems are found on the Web, but all of them provide only materials of high-school level or below. In addition, no standardized methods are provided to evaluate and control the computational complexity of generated problems. General concepts of complexity in various forms can be found in standard textbooks. The authors treat a different flavor of complexity, subjective complexity, where complexity is measured by the difficulty that learners feel. The authors proposed a new framework for evaluating computational complexity from learners' view, aiming to apply our framework to automatic generation of college math problems with controlled computational complexity. To prove the effectiveness of the new concept of complexity from learners' perspective, we developed some automatic generation tools based on our framework. In this paper, we will present one of the tools that supports automatic generation of eigenvalue problems. Controlling the complexity of eigenvalue problems involves restricting the number of calculation steps, the heights of the involved rationals, and the algebraic number fields appearing in the model solution of the problem. The small-scale experiments showed the relevance of our framework. Our system makes a path to strict quantitative control on various complexity from the learners' view. Future work includes the application of our methods to other areas such as differential equations, number theory and so on. We also should prove that this system has a positive effect on the engineering education at college level. Therefore, demonstration experiments in classroom will be scheduled in the next step of our research.

I. INTRODUCTION

We propose a framework for evaluating the computational complexity of college-level mathematics problems, with the aim of applying our framework to automatic generation of such problems controlled computational complexity.

Providing students with suitably complex practice problems is crucial for motivating them and facilitating deeper understanding. Manually constructing such problems consumes time, which mathematics teachers can otherwise use to mentor students.

Many software tools and services for automatic generation of mathematics problems are available on the web, but they provide only materials up to high-school level. In addition, no

***** Parameters *****

■ Dimension: 1 2 **3** 4 5

■ Multiplicity of Eigen Values: 1 == Slect from {1, 2, 3}

■ Field: ☒ 1 ☐ $\sqrt{2}$ ☐ $\sqrt{3}$

■ Hight of rationals: 100

■ How many: 1

***** Generated Problems *****

Start Generating

$$H = \begin{pmatrix} 4 & 0 & 0 \\ 0 & \frac{11}{2} & \frac{9}{2} \\ 0 & -\frac{9}{2} & \frac{11}{2} \end{pmatrix}$$

***** Model Answer *****

$$|H - \lambda E| = \begin{vmatrix} 4 - \lambda & 0 & 0 \\ 0 & \frac{11}{2} - \lambda & \frac{9}{2} \\ 0 & -\frac{9}{2} & \frac{11}{2} - \lambda \end{vmatrix}$$

$$= 40 - 54\lambda + 15\lambda^2 - \lambda^3$$

$$= -(-10 + \lambda)(-4 + \lambda)(-1 + \lambda) = 0$$

$$\therefore \lambda = \{1, 4, 10\}$$

($\lambda = 10$) ($\lambda = 4$) ($\lambda = 1$)
 $H - 10E$ $H - 4E$ $H - 1E$

$$= \begin{pmatrix} -6 & 0 & 0 \\ 0 & -\frac{9}{2} & \frac{9}{2} \\ 0 & -\frac{9}{2} & -\frac{9}{2} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & \frac{9}{2} & \frac{9}{2} \\ 0 & -\frac{9}{2} & \frac{9}{2} \end{pmatrix} = \begin{pmatrix} 3 & 0 & 0 \\ 0 & \frac{9}{2} & \frac{9}{2} \\ 0 & -\frac{9}{2} & \frac{9}{2} \end{pmatrix}$$

$$v_1 = \{0, 1, 1\} \quad v_2 = \{1, 0, 0\} \quad v_3 = \{0, -1, 1\}$$

$$H = UDU^t = \begin{pmatrix} 0 & 1 & 0 \\ -\frac{1}{\sqrt{2}} & 0 & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & 0 & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} 10 & 0 & 0 \\ 0 & 4 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & 0 & 0 \\ 0 & -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

Fig. 1. GUI for generating eigenvalue problems

standardized methods are provided to evaluate and control the computational complexity of the generated problems. Among the popular web sites and services, we list some examples. Wolfram Problem GeneratorTM [1] and Davitily Math Problem GeneratorTM [2] deal with mathematics problems for high-school students. SuperKids Math Worksheet CreatorTM [3] deals with arithmetic problems for children attending elementary schools. However, our framework is new as it deals with math at the college level and introduces suitable methods for evaluating computational complexity from the learners' perspective.

Eigenvalue problems are usually taught in linear algebra

courses at engineering departments. Since most textbooks do not provide sufficient practice problems, teachers must make additional problems to be used in classes, assignments, and exams. We took this topic as a case study to develop our framework.

Figure 1 shows a GUI for generating eigenvalue problems using MathematicaTM. Here, the user selects parameters such as the algebraic number field used in the calculation, the number of the calculation steps, and the matrix dimension, which determine the outline of the problems. The user then selects the problem category and provides the required parameters that control the computational complexity. To further reduce the burden for busy users, predefined sets of recommended parameters are also stored in the system, which eases the parameter selection process. Problems with the required complexity along with model answers are generated.

In this paper, we present an automatic generation of diagonalization problems for Hermitian matrices to illustrate the relevance of our proposed framework.

This paper is organized as follows. Section 2 describes the method of measuring complexity from learners' perspective. Section 3 and 4 demonstrate automatic generation under given conditions. Section 4 describes our experimental results and discussion. In the final section, we conclude this paper.

II. COMPLEXITY FROM LEARNERS' PERSPECTIVE

General concepts of complexity are available in various forms in standard textbooks such as [5]. We deal with a different variety of complexity, subjective complexity, where complexity is measured by the difficulty from learners' perspective.

Designing practice problems that are sufficiently but not excessively complex is crucial for keeping a learner motivated. We propose a new framework for estimating such computational complexity and demonstrate its relevance by developing a framework for automatic generation of complexity-controlled practice problems. Our framework enables us to

- 1) control the number of the calculation steps,
- 2) limit the height of rational numbers involved in a calculation, and
- 3) deal with algebraic numbers.

The computational complexity of generated problems is mainly determined by the sum of the heights of the rational numbers (the maximum ratio of the absolute values of the denominator and numerator) appearing in its model solution. In the hope of extending our work to other mathematics areas, we incorporated controls over algebraic number fields in our system. The user can select the calculation field from the rational number field and other algebraic fields extended by irrational numbers, especially, quadratic irrational numbers, and fourth-power irrational numbers.

A. Automatic Generation of Linear Equations

This subsection is a summary of our early work on the linear equation problems aiming to control the complexity from the learners' perspective. Solving linear equations is a part of eigenvalue problems. The system generates linear

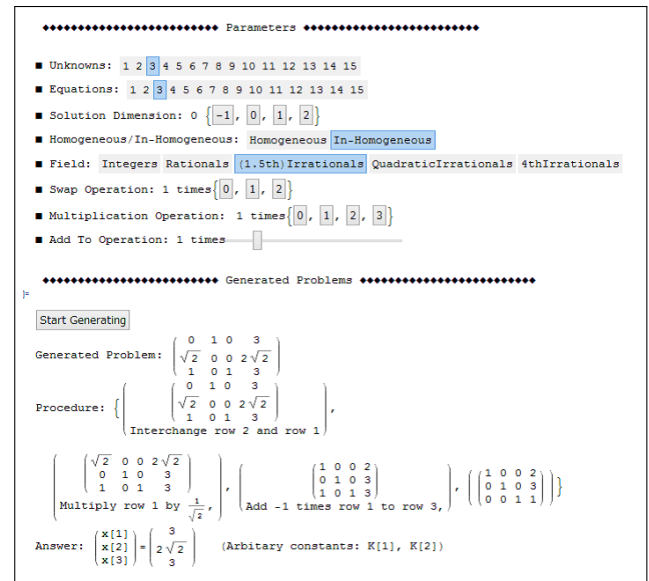


Fig. 2. GUI for generating row-operations problems

equations as the elementary row operations problems and model answers. The row operations are classified as follows.

- 1) Row switching (A row within the matrix can be switched with another row.)
- 2) Row multiplication (Each element in a row can be multiplied by a non-zero constant.)
- 3) Row addition (A row can be replaced by the sum of that row and a multiple of another row.)

It is commonly practiced that the matrix representation of the problem is reversely constructed from the solution space. Teachers do such reverse-row operations by their hands, controlling the level of difficulty at every step of the transformation by their naive concept of complexity. Our system does all these things automatically and controls perfectly the computational complexity as specified by the user. See Fig. 2.

The system controls the number of the calculation steps by limiting the number of the reverse-row operations steps, and limits the heights of rationals in the row multiplication and row addition.

In the following sections, we will show an application of our framework to eigenvalue problems and discuss the computational complexity from learners' perspective.

III. AUTOMATIC GENERATION OF EIGENVALUE PROBLEMS

Eigenvalue problems are usually taught in linear algebra courses at engineering departments. Eigenvalue problems appear in two forms: diagonalization of Hermitian forms and Jordan canonicalization of linear endomorphisms. In this paper, we deal with diagonalization of Hermitian matrices. The process of generating complexity-controlled eigenvalue problems includes

- 1) creating a pool of nice looking matrices,
- 2) generating eigenvalues with specified multiplicities,

- 3) generating a set of candidate Hermitian matrices, and
- 4) filtering out those matrices that are not suitable for exercises with some criteria.

We explain each step in detail. First, we generate nearly the entire set of tractable unitary matrices and classify them by algebraic number fields. We define an utility function that can extract all of the irrational numbers appearing in the entries of a tentatively generated matrix. For example, this function returns the list $[\sqrt{-1}, \sqrt{2}, \sqrt{3}, \sqrt{5}]$, where

$$\begin{pmatrix} \sqrt{-5} & \sqrt{2} \\ \frac{1}{\sqrt{3}} & 7 \end{pmatrix} \quad (1)$$

is entered as a primary material that is later subject to Gram-Schmidt orthonormalization. Diagonalizing a given Hermitian matrix requires

- 1) calculating eigenvalues,
- 2) selecting mutually orthogonal eigenspaces each of which corresponds to an eigenvalues, and
- 3) constructing a unitary matrix using these eigenvectors.

In the requirement 2, selecting an eigenspace is either giving an eigenvector or giving a set of eigenvectors. In the latter case, the eigenvalue has multiplicity greater than 1. Note that the choice of eigenvectors in degenerate cases does not affect the final result. Hence, the number of calculation steps does not vary once all the multiplicities are specified. General Hermitian matrices can be generated from a diagonal matrix D and a unitary matrix U as

$$H = UDU^\dagger \quad (2)$$

where U^\dagger is the conjugate transpose matrix of U . Equation (2) is rewritten as $D = U^\dagger H U$. The most difficult part is generating a unitary matrix with the specified properties. However, the number of matrices suitable for this purpose is relatively small because the entries of those matrices must be obtained from a given algebraic number field, and the heights of the involved rationals must be restricted, furthermore, all of the column vectors must form an orthonormal system. Therefore it is possible to predefine almost entire sets of unitary matrices that can be used to generate Hermitian matrices that can be diagonalized with specified complexity. This stage can be skipped once the pool is created. However, we may recreate another pool with slightly different parameters.

A. Generation of Unitary Matrices

This section describes the generation of 3×3 unitary matrices through examples. The procedure for generating a matrix comprises four major steps:

- 1) generating a unit column vector,
- 2) verifying that all the entries belong to the given number field,
- 3) constructing an orthonormal basis from two other linearly independent column vectors using the Gram-Schmidt procedure, and
- 4) verifying again that all of the entries of those basis vectors belong to the given number field.

```
u1 = Orthogonalize[{{1/10, 1/10, 7/(5*sqrt(2))}, {1, 0, 0}, {0, 1, 0}}]; u1 // MatrixForm
```

$$\begin{pmatrix} \frac{1}{10} & \frac{1}{10} & \frac{7}{5\sqrt{2}} \\ \frac{\sqrt{11}}{10} & -\frac{1}{10\sqrt{11}} & -\frac{7}{15\sqrt{22}} \\ 0 & \frac{7\sqrt{2}}{3} & -\frac{1}{3\sqrt{11}} \end{pmatrix}$$

```
FieldFilterFunction[u1]
{sqrt(2), sqrt(11), sqrt(22)}
```

```
u2 = Orthogonalize[{{1/10, 1/10, 7/(5*sqrt(2))}, {0, 0, 1}, {0, 1, 0}}]; u2 // MatrixForm
```

$$\begin{pmatrix} \frac{1}{10} & \frac{1}{10} & \frac{7}{5\sqrt{2}} \\ -\frac{7}{10} & -\frac{7}{10} & \frac{1}{5\sqrt{2}} \\ -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \end{pmatrix}$$

```
FieldFilterFunction[u2]
{sqrt(2)}
```

Fig. 3. Example of orthogonalization. The upper part shows failure in retaining the number field after orthogonalization in the case in which $(1, 0, 0)^t$ and $(0, 0, 1)^t$ are appended. The other shows success in retaining the field, when $(0, 0, 1)^t$ and $(0, 0, 1)^t$ are appended.

```
u3 = Orthogonalize[{{1/10, 1/10, 7/(5*sqrt(2))}, {0, 0, i}, {0, 1, 0}}]; u3 // MatrixForm
```

$$\begin{pmatrix} \frac{1}{10} & \frac{1}{10} & \frac{7}{5\sqrt{2}} \\ -\frac{7i}{10} & -\frac{7i}{10} & \frac{1}{5\sqrt{2}} \\ -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \end{pmatrix}$$

```
FieldFilterFunction[u3]
{1, sqrt(2)}
```

Fig. 4. Example of expansion of the orthogonalization to imaginary matrices.

In step 1, we generate various unit vectors that are the form in Equation (3).

$$e_1^t = (\pm \frac{i}{j\sqrt{k}}, \pm \frac{l}{m\sqrt{n}}, \pm \sqrt{1 - ((\frac{i}{j\sqrt{k}})^2 + (\frac{l}{m\sqrt{n}})^2)}), \quad (3)$$

where i, j, l , and m are rational integers, and k and n are 2, 3, 5, 7, or 1. In step 2, all of the irrational numbers such as $\sqrt{2}, \sqrt{3}$, and $\sqrt{-1}$ are extracted from the vector and matrix. We select the vectors whose entries belong to the specified number field. In step 3, e_1 and two other vectors are orthogonalized. Only an additional two vectors are required to form a linearly independent triple together with e_1 . Hence, for easy calculations, we can take them from sparse matrices, where only the positions of nonzero entries are important. Figure 3 indicates that the field may possibly be extended after orthogonalization.

We generated three patterns of unitary matrices by changing the position of the non-zero element of each vector. If the user wants a complex number field, then $\sqrt{-1}$ must be added in some entry of an initial vector (see Fig. 4). In step 4, the number field of the components is verified again. This step is necessary because Gram-Schmidt orthogonalization takes square roots which may cause further algebraic extension of fields. We select matrices all of whose entries have rationals of low heights in their subexpressions. These forms the basic

TABLE I. PREDEFINED ORTHOGONAL MATRICES

Field \ Dimension	2 × 2	3 × 3	4 × 4
Q	65	20	4245
$Q(\sqrt{2})$	27	33	2503
$Q(\sqrt{3})$	12	10	930
$Q(\sqrt{5})$	20	25	1714
$Q(\sqrt{7})$	12	3	927

TABLE II. PREDEFINED UNITARY MATRICES

Field \ Dimension	2 × 2	3 × 3	4 × 4
$Q(\sqrt{-1})$	129	20	25066
$Q(\sqrt{2}, \sqrt{-1})$	65	33	8488
$Q(\sqrt{3}, \sqrt{-1})$	30	11	2862
$Q(\sqrt{5}, \sqrt{-1})$	68	26	9068
$Q(\sqrt{7}, \sqrt{-1})$	24	5	2142

set of tractable unitary matrices. Of the 500,000 generated unitary matrices in a preliminary stage, the filter selects 681 matrices according to the criterion described in later sections. The number of predefined matrices are listed in Tables I and II. Though the basic set is relatively small (681), we can generate other tractable matrices by multiplying them among themselves and by taking direct sums as follows: given two matrices of the same dimension

$$U_1 \text{ and } U_2 \in U(n), \quad (4)$$

we obtain

$$U_1 U_2 \in U(n). \quad (5)$$

Given two matrices of possibly different dimensions

$$U_1 \in U(m) \text{ and } U_2 \in U(n), \quad (6)$$

we obtain

$$U_1 \oplus U_2 \in U(m+n). \quad (7)$$

Note that the number field involved is preserved under both multiplication and direct sum operations. For example,

$$\begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \text{ and } \begin{pmatrix} \sqrt{-1} & 0 \\ 0 & 1 \end{pmatrix}. \quad (8)$$

Using such methods, we can obtain sufficient unitary matrices, as presented in Tables I and II.

IV. DEMONSTRATION

We demonstrate the automatic generation of eigenvalue problems for Hermitian matrices and evaluate the complexity of the generated problems. Figure 5 presents the results of ten generated Hermitian matrices. The dimension of each matrix, multiplicity of eigenvalues, algebraic number field, height h of numerical calculation, and number n of problems is 3, 1, $\sqrt{-1}$, 100, and 10, respectively. The system generates n problems on demand. Each matrix

- 1) has a maximum absolute value of involved rationals less than h ,
- 2) has entries that belong to specified number field, and
- 3) differs from already generated matrices.

In this case, generating ten problems took 4.16 seconds. The time measurements for generating problems are listed in

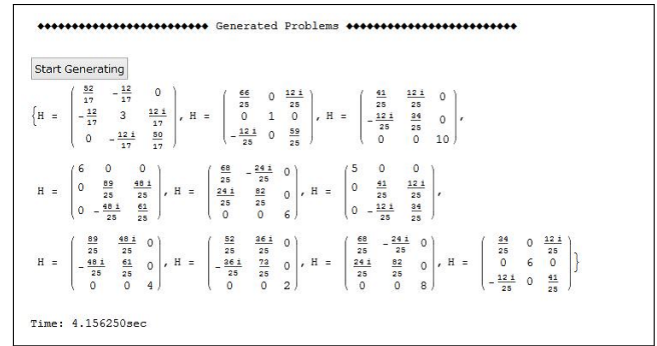


Fig. 5. Samples of generated Hermitian matrix

TABLE III. TIME (SEC) FOR GENERATING PROBLEM 1

	2 × 2	3 × 3	4 × 4
Q	5.33	17.14	1615.72
$Q(\sqrt{2})$	702.81	1185.03	768.2
$Q(\sqrt{3})$	702.00	1324.84	810.72
$Q(\sqrt{5})$	353.91	1677.19	484.39
$Q(\sqrt{7})$	320.05	3154.67	1684.18

Tables III and IV. The machine's specification is as follows. The adopted software is Wolfram Mathematica 9.0 (Windows 8.1, 64 bit, Intel(R) Core i5-4300U CPU 1.9 GHz. The main memory is 8.0 GB.)

Tests were conducted generating 1,000 problems for each number field. Generating one problem takes 1.18 seconds on average. As the tables indicate, generation consumes more time when the number field is complex because the system needs to decompose all of the matrix entries to check the maximum height of the rational numbers.

As a preliminary experiment, we asked 10 CS department students to solve two sets of problems: one set consists of the problems with controlled complexity, the other consists of uncontrolled ones. See Tables V and VI. On average, the former case, students required 2 min to calculate eigenvalues and 6 min to construct a unitary matrix, while for the latter case students required 6 min to calculate eigenvalues and 7 min to form a unitary matrix. In addition, 4 students could not reach the answers of the uncontrolled problems at first. These results demonstrate the validity of our proposed framework. Large-scale verification experiments will be conducted out with the cooperation of university teachers.

TABLE IV. TIME (SEC) FOR GENERATING PROBLEM 2

	2 × 2	3 × 3	4 × 4
$Q(\sqrt{-1})$	110.61	170.72	1712.11
$Q(\sqrt{2}, \sqrt{-1})$	655.34	2175.56	809.42
$Q(\sqrt{3}, \sqrt{-1})$	599.29	4585.61	924.39
$Q(\sqrt{5}, \sqrt{-1})$	691.75	3439.33	500.33
$Q(\sqrt{7}, \sqrt{-1})$	3543.17	22911.11	1821.26

TABLE V. THE NUMBER OF THE STUDENTS BELONG TO EACH TIME (MIN) FOR SOLVING THE GENERATED PROBLEMS.

	Eigenvalues		Eigenvectors
1s	1 student	4s	3 students
2s	5 students	5s	5 students
3s	4 students	6s	2 students

TABLE VI. THE NUMBER OF THE STUDENTS BELONG TO EACH TIME (MIN) FOR SOLVING THE NON-COMPLEXITY-CONTROLLED PROBLEMS.

	Eigenvalues		Eigenvectors
5s	1 student	6s	1 students
6s	3 students	7s	4 students
7s	6 students	8s	5 students

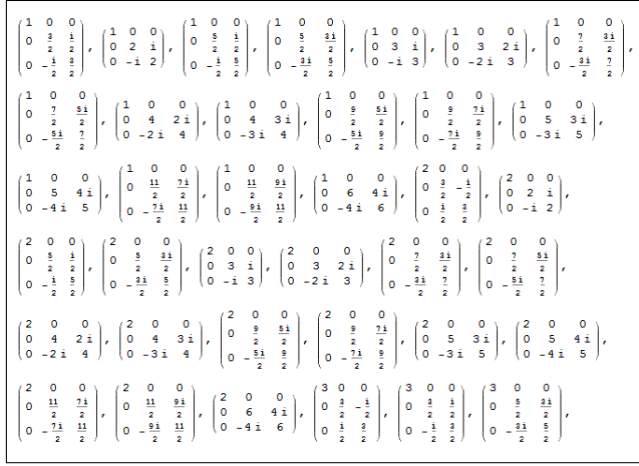


Fig. 6. Generation of Hermitian matrices from one unitary matrix by changing eigenvalues

A. Discussion

In our experiments, some learners felt excessive difficulty in calculating characteristic equations to get eigenvalues. The complexity of calculating eigenvalues can be reduced by restricting unitary matrices to more tractable ones. In other words, some of predefined unitary matrices are not tractable. We knew that the unitary matrices which generate good Hermitian matrices can be use to generate other good Hermitian matrices by rechoosing eigenvalues.

Some teachers criticized that irrational numbers such as $\sqrt{5}$ and $\sqrt{7}$ look ugly as exercise problems. Therefore we chose only matrices which include Q , $Q(\sqrt{2})$ and $Q(\sqrt{3})$. Finally, we got 174 tractable 3-dimensional unitary matrices after changing some parameters. These predefined unitary matrices include other variable number field such as $Q(\sqrt{10})$ and $Q(\sqrt{13})$ because these unitary matrices often generate nice looking unitary matrices regardless of including such irrational numbers.

The number of finally obtained matrices is 174. Although this number seems smaller than what we obtained in our previous work, we can still get virtually infinite Hermitian matrices because of virtually infinite assignments of eigenvalues to eigenspaces. See Fig. 6. These Hermitian matrices are generated by using one unitary matrix by changing a target diagonal matrix.

Learners also felt excessive difficulty because the number fields varied from ones that we specified. The number field varied because of procedure of orthogonalization. Learners should start orthogonalization of vectors in ascending order of the norms. When they refer the generated model answers, they may learn the importance of the procedure of orthogonalization.

TABLE VII. THE NUMBER OF THE STUDENTS BELONG TO EACH TIME (MIN) FOR SOLVING THE GENERATED PROBLEMS.

	Eigenvalues		Eigenvectors
1s	1 student	4s	4 students
2s	5 students	5s	4 students
3s	4 students	6s	2 students

Some parts of the automatic generation system of row-operations problems, our early work, can be reused in the generation of eigenvalue problems. Calculation of eigenvectors involve row-operations.

After this refinement, we conducted a second experiment in which we asked the same CS students to solve the generated problems again. See a Table VII. Students required 2 min to calculate eigenvalues and 5 min to construct a unitary matrix. And also, teachers satisfied the complexity-controlled problems.

V. CONCLUSION

In this paper, we presented a new framework for evaluating and controlling computational complexity from the learners' perspective. In addition, we developed an automatic generation system for eigenvalue problems based on our framework. The automatic generation of complexity-controlled eigenvalue problems is one of the sample implementations that validate our framework. Controlling the complexity of eigenvalue problems involves restricting the number of calculation steps, the heights of the involved rationals, and the algebraic number field appearing in a model solution. In small-scale preliminary experiments, we could decrease the computational complexity and answering time.

Constructing problems with sufficient computational complexity is essential for maintaining learners' motivation. The system can generate virtually infinite exercise problems. Our framework helps teachers prepare learning materials and thereby save time for mentoring students.

We expect our technique to be applicable to other subjects in linear algebra and analysis. Our system paves a path to strict quantitative control on various aspects of complexity from the learners' perspective. Future work include the application of the row-operations system to the evaluating the complexity of a constructing a unitary matrix. And also we will apply our methods to other areas such as differential equations, and number theory. We also would like to show that this system has a positive effect on college-level engineering education. Therefore, demonstration experiments in classroom will be the next step of our research.

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CalcTutor: Applying the Teachers Dilemma Methodology to Calculus Pedagogy

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Abstract—We have designed and built CalcTutor, an online educational tool for Calculus that employs the Teachers Dilemma methodology. This methodology is centered around a game framework where students take on, and are rewarded for playing well, both the role of learner and teacher. Students create machine-verifiable questions for each other and gain points based on not only correct answers but also asking good questions. This framework has been used and studied in a variety of projects, mostly in the K-12 arena. The CalcTutor tool expands this approach to college level classes, specifically introductory Calculus. In this paper, we are reporting on our experience with a pilot study of CalcTutor, as used in conjunction with a college Calculus class.

The system is designed to support learning in two ways, teachers can build quizzes for their students and the students can pair off and play games with each other. The students are given dynamic feedback about how appropriate their question is for their partner in the game as they develop each problem. During this pilot study, students asked and answered problems of two types: finding the derivative of a function and calculating the tangent line to a function at a point.

The system was simultaneously tested in five introductory Calculus sections which generated a sizeable body of system data as well as survey feedback. Unfortunately, like many new tools, some of the students found getting used to the interface hard and some of our theoretical concepts did not pan out. Nevertheless the technical parts of the system worked well; students and teachers were able to create and answer questions without any issues. Some of the untested ideas that we were trying out met with success. And many students enjoyed some features of the system, particularly the instantaneous feedback.

I. INTRODUCTION

One of the enticing promises of online education is the ability to scale up class size dramatically while maintaining, or at least not significantly lowering, the level of learning. The Teacher's Dilemma offers a way to realize this goal. By creating a framework within which peers are rewarded for being good teachers we can turn the usual limitation of having a large number of students into an asset. The hope is that this might be a viable way to improve larger classes and to improve open online learning.

The purpose of this pilot study was to take the Teacher's Dilemma one step closer to this goal. Previously the concept had only been applied to small isolated problems in the K-12 learning space. For example, figuring out how to make a specified cash amount out of quarters, dimes, nickels and

pennies. We wanted to pick a larger, more complete corpus in the higher education space. We decided that college level introductory calculus would be a sufficiently advanced, rich topic around which to build a system.

For the pilot study we wanted to demonstrate the viability of the system from a technical standpoint as well as make inroads into showing how some of the theoretical aspects might work. We built a new web based system on a foundation that will easily allow scaling up to a large number of users. The system has a custom differentiation engine and mathematical functional equivalence checker that allows question creation to be easy and answer checking to be automated. In particular, students can easily create questions because they don't need to know the correct answer to write the question. We also wanted to begin exploring some of the details that are needed for the theory to work. For example the basic version of the teacher's Dilemma requires a difficulty score for problems. This would ideally be generated by user data, but until that can be obtained we need to have a heuristic to bootstrap the process in a reasonable fashion. In this pilot study, we found that our initial heuristic for the student score correlates with difficulty as measured by number of student attempts to arrive at a correct answer.

II. RELATED WORK

Online support for learning, and more general computer support for learning, has been around almost as long as the internet, or indeed almost as long as computers have existed [1]. These educational efforts have taken a wide variety of forms and as such there are many efforts that are, at least tangentially, related to our work.

Perhaps the most traditional learning support comes in the form of sites which have example problems and solutions [2]. Other sites provide online tutoring from a live person [3]. Indeed, even many organizations that were initially brick and mortar tutoring and testing prep services now have online components [4]. Online learning spaces like Khan Academy [5], and Coursera [6] also routinely feature quizzes designed to target a specific skill. Like CalcTutor, all these systems have the ability to challenge the student with questions, but they either require the student to assess their own skill level and pick the appropriate challenge, or ask a human expert to

do the same. Also the systems that have automated questions have a fixed set of them and, unlike CalcTutor, adding more questions can be difficult and is often only possible by the creator of the system.

Online homework systems represent a sort of next step in customization and automation for these online resources. Systems like WebAssign [7] and WebWork [8] have large libraries of questions that can automatically determine if the student's answer is correct. Several papers have been published showing that these at least do not harm student learning [9] and in some cases can help [10]. These systems can also be effective pedagogical tools [11]. Generally speaking, studies find that students enjoy getting immediate feedback, that they often continue working until they get the right answer even if it takes many tries, and that they spend less time studying for the class for at least similar grades. Finally, the teachers find that it saves a great deal of grading time, which they can then use for other purposes such as office hours or research. The usual pedagogy for these systems is to have a teacher select the homework questions and the students simply do whatever work is assigned to them. It should be noted that, for example, WebWork does allow teachers to create problems but this is an advanced feature that requires coding knowledge. These systems are similar to CalcTutor in that they allow automated answering of questions but their selection is again done by experts and creating new questions is, at best, difficult.

Gamification is a general term used to describe systems that take advantage of the techniques games use to create motivation in non traditional game environments. There have been several strong arguments for using this strategy in education [12]. This motivation can come from competition or more esoteric means like storytelling. These gamified learning environments can take on a wide variety of formats, from adapting simple Board Games structure [13], to MMO based around science material [14]. Some have expressed worries that gamification or at least competitive games might have a negative emotional impact. But at least some cases studies have shown that competition has had little negative impact [15] or that it is possible to redesign games to reduce the negative effect [16]. While the CalcTutor is not heavily gamified we do hope students will become excited and learn better by having game style rewards (more points) for performing better. Additionally while the player interaction is largely framed as supportive we do provide leaderboards for students to check their standing compared to their peers.

Intelligent Tutoring Systems (ITS) are, in some ways, a strong parallel to the Teacher's Dilemma method. Both are centered around attempting to create a system that delivers the right level of content to a student. ITS systems do this by having a model of the student's capabilities and using that to determine what the student should be working on. For example, some do this by supplying the student with questions of the right difficulty to answer [17] [15]. ITS systems have been built for Calculus [18] and have, in some cases, been shown to be more effective than Online Homework Systems [19]. The key difference between our work and the

ITS domain is that we push the work of modeling the student and devising appropriate challenges onto their peer tutor and thus can avoid the difficulty inherent in the need to model the student properly.

Peer tutoring and online study group systems have been built for general education [20] as well as math learning [21]. These systems assist student learning in small group environments where a computer system provides structure, automation and support. They can generally be considered to fall under the Computer Supported Collaborative Learning umbrella (CSCL). There are a wide variety of such systems and the CalcTutor could also be considered a CSCL system. Where CalcTutor differentiates itself is by having an explicit reward system for a peer teacher. This allows us to provide immediate and definitive feedback that, in theory, helps peers become good instructors. For example, the Teacher's Dilemma method provides a student with a measure of the quality of each individual question they asked another student.

The work that the CalcTutor is most strongly related to is Dr. Ari Bader-Natal's 2008 PhD dissertation "The Teachers Dilemma: A game-based approach for motivating appropriate challenge among peers" [22]. We are directly continuing the Teacher's Dilemma concept and expanding it in the scope of domains to which it applies (i.e., Higher Learning, specifically Calculus) as well as expanding on the theory by attempting to keep track of a more advanced notion of "relative" question difficulty and a deeper insight into the error paths people take before getting the correct answer.

III. TEACHER'S DILEMMA

The goal of the Teacher's Dilemma is to have a framework that provides appropriate motivation for peers to become good teachers for each other. The end goal is to reduce or even eliminate what is normally a powerful limitation: a large number of students in a class. This would mean it would then be possible to efficiently scale up class sizes or greatly improve the effectiveness of MOOCs, which in turn could help equalize the education gap, or at least reduce the cost of bringing quality education to those who need it most. It could also be useful in the traditional higher education setting by promoting high quality study groups.

The core idea of the Teacher's Dilemma revolves around how to reward peer teachers. Bader-Natal's thesis covers this in detail but we will give a summary here. We consider the situation of two peers, one playing the role of teacher and the other student. If we simplify things and assume that a teacher's role is to ask questions of various difficulties (say ranging from 0, easiest, to 1, hardest), then the question becomes how hard a question should they ask to maximize learning? And, more to the point, how should we reward them given what question they asked and how well the student did answering it?

The response to this question is based loosely off the Prisoner's Dilemma notion from Game Theory (hence the name Teacher's Dilemma). We think of the universe as a payoff matrix. Did the teacher ask a hard question or an easy one and did the student answer the question correctly or not?

Again a full explanation of what assumptions are required to analyze this are covered in Bader-Natal's thesis but the condensed version is as follows. We reward the teacher a high number of points if they ask a hard question the student gets right or an easy question the student gets wrong. Intuitively the idea is that we want harder and harder questions that the student can figure out to push their limits. On the other hand, we also want to expose holes in the student's knowledge by asking them easy questions they get wrong.

More formally, if we call the question difficulty D , and C indicates if the student got the question correct we award the teacher points in the following manner:

if C is true the teacher receives D points if C is false the teacher receives $1-D$ points

This yields the desired result of rewarding hard questions that are answered correctly and easy question that are answered incorrectly.

One minor note of difference between our work and the original formulation of the Teacher's Dilemma is that we use a notion of relative difficulty when computing the teacher scores in games. What this means is that when we compute the teacher points for a game question we take the D in the teacher points formula to be the difficulty of the question divided by their partner's student points. Thus as their partner improves a user will need to keep asking more difficult questions to get the same number of teacher points. On the other hand, if they pair up with a less experienced partner they will need to adjust the difficulty of the questions they are asking or their partner won't get any correct.

IV. CALCTUTOR

The CalcTutor system is a semi-automated online learning system designed to teach students Calculus by asking them a variety of questions appropriate to their skill level. The system has instant answer checking so students get immediate feedback on whether they got a question right. It can be used by a teacher to easily construct a quiz that students can take or students can pair off and play games with each other. In this latter mode, students create questions for each other and are rewarded for answering questions correctly and asking good questions.

A. Organization

The CalcTutor system is currently designed with the classroom in mind (although it will be easy to adapt to a more open internet model later, and this is one of our goals). The system has a concept of Organizations that serve as umbrellas for Classes. Users can sign up for Classes, either as a teacher or a student. Teachers are allowed to create quizzes that are shared with everyone in the class. Quizzes are simply a list of questions that anyone in the class can attempt to answer. In general, users are allowed to attempt to answer a question as many times as they want. Every attempt is recorded and teachers can see all the attempts a student makes.

Other Player's History

When creating your questions it may help you to know what the other player has done recently. Below is a quick summary of the recent history of what questions they've answered correctly and incorrectly.

Correct

Here are the questions Tim-instructor-3 answered correctly recently:

1. derivative of: $-\sin(x)$
2. derivative of: $\frac{\tan(x)}{\cos(x)}$
3. derivative of: $\sin(x)$
4. derivative of: $5^{e^{3x}}$
5. derivative of: $\frac{\sin(x)}{\cos(e)}$
6. Tan line of: $\sin(x)$ @ 0

Incorrect

Here are the questions Tim-instructor-3 answered incorrectly recently:

1. derivative of: $\frac{\ln(x^2)}{\sin(2 \cdot x^2 - 1)}$
2. Tan line of: $\ln(3 \cdot x^2 - 2x) \left(2 \cdot e^{4 \cdot x^2} \right) - \frac{\ln(x+3)}{2x + e^2}$ @ 1

Fig. 1. Interface for students to see history of other students.

B. Games

Students can also initiate Games with other students in their class. To do this the student picks a partner (from a list of all the other students in the class) and the other student receives a request. The partner can see the request in a sidebar on most pages that indicates the current status of games. The students can also set up their preferences to receive emails notifying them about game updates. Each player then constructs a game quiz (a set of three questions) for the other player.

While the player is building a game quiz they have access to several important pieces of information. They can see a list of questions the other player got correct recently, as well as a list of their most recent incorrect questions (see Figure 1). As students are writing each question, they can see a difficulty rating for the question as well as how many points they will get if the other player gets the question correct or incorrect. (See Figure 2.)

C. Questions and Answers

Regardless of whether the question is being built for a quiz or a game the basic process is the same. The system allows users to create two different types of questions. Either: "what is the derivative of this function?", or "what is the tangent line to this function at this point?". Question creation is quick and easy. Users select the type of question they want to ask and then enter either a function (of x) to differentiate or a

Add a new Question

☒ Create a Derivative Question
 ☐ Create a Tangent Question

Enter a function (of x) to differentiate. When you are done hit "Save Question":

▲ $e^{\ln(x)}$

Save Question

Scoring Information

Skill Level	Difficulty	Correct	Incorrect
35.2	18	40%	59%

Fig. 2. Interface for students to create quiz questions

function and a value if they are asking a tangent line question. The functions (and values) are entered as text, "x^2 + 3" for example, in an html input box. As soon as anything can be parsed it is displayed to the right of the input in a nicer format. If the system can't understand the current input a red warning icon is displayed. Most operations and functions used in an introductory calculus class are understood, including +, -, *, /, exponents (which can be written as ^), log, exponential and trigonometric functions like sin, cos, tan, etc. are all valid. When the user is finished they click submit. Figure 2 shows the user interface where the user is about to close the parenthesis on $\sin(x)$. The system shows the nicely formatted part of the expression that it is able to parse and uses the red asterisk to indicate that the expression is not yet a valid formula.

It should be noted that the system is constantly checking what the user enters and it does not allow an invalid function to be submitted. Thus, whatever the user submits will be a valid function and (since we only allow differentiable functions) it will be differentiable. So anything that gets into the system will at least be a mathematically valid problem.

The system computes a difficulty level for a question when it is created, for use with the Teacher's Dilemma framework. We were unable to find a simple method for quickly ranking the difficulty of calculus questions numerically so we created a heuristic that we are using to bootstrap the system. The heuristic works by thinking about Questions in terms of constants, variables and functions. Functions include operations (like +, -, *, etc.) and differentiation rules (like product, quotient and chain rules) as well as functions like sin, cos, log, etc.. Each Question is broken down into a binary tree where terminal nodes are constants or variables and branches are functions. Each constant, variable or function adds a set number of difficulty points, determined beforehand by the authors, based on teaching experience. If one or more of a function's children are again functions the points are added recursively, along with points for applying the chain rule. Thus the difficulty of a Question is defined by starting at the root node, adding its value and then summing the values for all of the children below it, with additional points for embedded functions.

Answering Questions is done in a similar manner to their creation. The user gets an input box (or boxes) and types text versions of mathematical functions and/or numbers. Once the answer is submitted the system has a custom symbolic differentiation engine that allows us to differentiate the function for

Welcome to a question page for quiz: Pre-quiz

What is the Derivative of:

$$\frac{\ln(x^2)}{\sin(2 \cdot x^2 - 1)}$$

Type in your answer, and then hit the submit button

Submit

Back to Quiz

You answered this question 2 times

Answer	Result
$\frac{2 \sin(2 \cdot x^2 - 1) - \ln(x^2) (4 \cdot (x \cos(2 \cdot x^2 - 1)))}{(\sin(2 \cdot x^2 - 1))^2}$	incorrect
$\frac{2 \cdot \frac{\sin(2 \cdot x^2 - 1)}{x} - \ln(x^2) (4 \cdot (x \cos(2 \cdot x^2 - 1)))}{(\sin(2 \cdot x^2 - 1))^2}$	correct

Fig. 3. Question detail page showing all previously-entered answers

that question. The answer and the differentiated function are then compared on a large number of random points. If they ever disagree the answer is deemed incorrect and if they agree everywhere the answer is correct. For the purposes of the pilot study, students were allowed as many attempts as they wanted until they got the question correct.

It is possible, in certain cases, for the system to be unable to evaluate the function at a given point. This can lead to a case where the system simply cannot tell whether the two functions are equivalent. In this case the system sends that information back to the user and requests that they try again. In practice, because we restrict what functions a user can use and users are either teachers or introductory Calculus students, this eventuality has not occurred in any live tests.

D. User Information

The system has multiple ways it tracks and displays user progress. Users can review Quizzes and Games they've participated in and see both summaries and details.

For Quizzes, there is a Quiz summary page that shows the user which Questions they answered correctly. There is also a Question detail page which shows all of the answers they have ever entered for a specific Question. (See Figure 3.)

For Games, there are summary pages, one for the quiz the user took as a student and one for the quiz the user wrote as a teacher for their partner. In the former, the user can see which Questions they answered correctly and this page also lists their student score for this Game. The student score is simply the percentage of questions they answered correctly. (See Figure 4.) In the latter, the student can see which of their questions were answered correctly by their partner. They can also see their partner's skill level at the time of the Game; the difficulty level of each question they asked; the teacher score they earned for each of those questions; and their overall teacher score for that Game (which is the average of the three teacher scores for the three questions). (See Figure 5.)

We also keep track of an overall student score for each user, which the user can see in the upper right corner of every page. This score is currently set to be the average of the top five highest difficulty levels of questions they have answered correctly.

Student Game Score ?

You played a **game** with Player-63 on 4/1/2015 7:00:01 pm
Your results for each question:

question	correct
derivative of: $\ln(3 \cdot x^2 - 2x) \left(2 \cdot e^{4x^2} \right)$	correct
derivative of: $\frac{\ln(x+3)}{2x+e^x}$	correct
Tan line of: $\ln(3 \cdot x^2 - 2x) \left(2 \cdot e^{4x^2} \right) - \frac{\ln(x+3)}{2x+e^x} @ -1$	incorrect

Your score for this quiz: 67%

Fig. 4. Game summary for the quiz *taken* by the user (as a student)

Teacher Game Score ?

You played a **game** with Player-63 on 4/1/2015 7:00:01 pm
When you played the game Player-63 had a skill level of 41.6 ?

question ?	correct ?	difficulty ?	score ?
derivative of: $\frac{\tan(x)}{x^2+1}$	correct	19	37%
derivative of: $e^{(\sin(x))^2 + (\cos(x))^2}$	correct	59	100%
Tan line of: $x \ln(x) @ 1$	correct	18	35%

Your score for this quiz: 57%

Fig. 5. Game summary for the quiz *written* by the user (as a teacher)

Users can compare their standing to others via a Leader Board that shows the top players in terms of Highest Student Skill Level, Most Games Played, Most Unique People Played, Highest Total Student Score and Highest Total Teacher Score. (See Figure 6.)

E. Technical Details

The system was built in Scala using the Play Framework, a web development platform, it uses Postgres for storage and is designed to be deployed on Heroku. Play itself is a highly scalable platform that could support many users but pairing it with Heroku, a "Cloud Application Platform", means that we can dynamically request virtual hardware as usage demands and scale up dramatically if needed.

V. PILOT STUDY

We ran a pilot study of the CalcTutor tool in April 2015. Our goal was to obtain preliminary data and feedback to determine the effectiveness of the tool as it currently stands and to influence directions and priorities for future development.

The tool was used by students in the differential Calculus course (Math 10a) at Brandeis University. The students were asked to complete a "Pre-quiz", play at least three games with other students, complete a "Post-quiz" and then take a survey. This was assigned as a homework set, in which the students would receive 5 points for completing each of these obligations (regardless of performance). The questions on the post-quiz were essentially the same as the questions on the pre-quiz (with only minor changes, such as different numbers or swapping sine for cosine). The students had several days to complete the tasks.

Leader Board

Highest Student Skill Level

Rank	Player	Skill Level
1	Josh - Instructor-20	93.8
2	Player-49	72
3	Fresh2Death-24	67.8
4	Player-21	64
5	Becci - Instructor-2	62.4
6	Player-56	62.2
7	Player-79	61.8
8	Player-63	57
9	Calc2OP-17	56
10	Player-16	55.8

Most Games Played

Rank	Player	Games
1	Josh - Instructor-20	7
2	Player-32	6
3	Player-22	6
4	The b tiger-41	6

Fig. 6. Leader Board (partial view)

We had 117 students enrolled, split among 5 sections. Out of these 117 students, 96 participated in the study in some capacity. Of the 96 who participated, 94 tried the pre-quiz and 86 tried the post-quiz. We had 74 students who played at least 3 games, 10 students who played 2 games and 8 students who played only 1 game. We had 68 students who completed the survey.

This pilot study was performed after the students had learned the mechanics of taking derivatives and had been tested on their understanding in an exam. The pilot study was then viewed more as a review for the final exam rather than a formative assessment. Nevertheless we expected to see some learning, as not everyone in the class had fully mastered the process of applying all of the differentiation rules.

VI. RESULTS

The main goal of this pilot study was to gather initial data on the use of CalcTutor in all of the Calculus courses at a University. We were looking at several broad measures:

- Scalability. Does CalcTutor scale well to handle hundreds of simultaneous users?
- Learning Outcomes. Does CalcTutor have a positive effect on learning outcomes?
- Student Response. What do the students think about using CalcTutor?

We were also interested in a technical point that would help us fine tune the system for future experiments:

- Question Difficulty. Is there a positive correlation between the heuristic measure of problem difficulty and

an empirical measure - the percentage of students who answered it correctly, possibly weighted by the number of attempts required to find the solution?

A. Scalability

While users experienced some confusion about how to type in answers, there do not seem to have been any errors, delays, or sluggishness on the part of the system. All users were able to get into the system, create and answer questions. The symbolic differentiator and functional equivalence testing seem to have been up to the task of handling the quiz and game questions and answers. We did need to expand the Heroku platform beyond the free offering to the "2 dyno" level.

B. Learning Outcomes

There were 86 students who took both the pre-quiz and post-quiz in our experiment. Each quiz had 8 derivative problems and the questions for the post-quiz were created by making slight modifications of the pre-quiz questions (e.g. changing constants, replacing special functions by similar ones, e.g. sin by cos). We looked at three ways to measure learning outcomes.

- Correct on First Try. This corresponds to the traditional pencil and paper exam where students only get one attempt at answering the question.
- Correct Eventually. This corresponds to the exam where students get immediate feedback (as with CalcTutor) and are allowed to resubmit an unlimited number of times until they get the correct answer or give up.
- Average Number of Attempts per Question. This measures the average number of attempts a student makes on a problem that he or she eventually gets correct. Measuring the average number of attempts for incorrect problems would give a measure of persistence, but not necessarily of learning.

The data in Table I shows that students performed significantly better on the post-quiz than the pre-quiz when measured with "Correct on First Try" ($p = 0.016$) and when measured by the "Average Number of Attempts per Question" ($p < 0.001$), but there was no statistically significant difference when the "Correct Eventually" measure was used.

TABLE I
LEARNING OUTCOMES FOR PILOT STUDY

Test	Correct on First Try	Correct Eventually	Avg Attempts per Question
pre-test	52.75% (sd=26)	75.38% (sd=29.25)	1.52 (sd=0.85)
post-test	61.75% (sd=24)	74.63% (sd=24.00)	1.26 (sd=0.30)
diff	6.12% ($p=0.016$)	-0.75% ($p=0.40$)	-0.26 ($p<0.001$)

C. Student Response

We expected (from prior feedback on WeBWorK) that students would experience difficulty and frustration with entering mathematical functions on the computer. We did indeed see this feedback in our survey. The average response to our

survey question "How hard did you find it to input answers?" was 1.65 out of 5 (where 1 was "hard" and 5 was "easy"). Out of 68 survey respondents, 44 either mentioned (in open-response questions) that they did not like typing in math or suggested improving the input system and 23 of these students recommended having buttons for common mathematical functions and operations (like a calculator). We believe that some of this frustration around input of math would have been alleviated by having more time for students to acclimate to the tool and by having a schedule in which students were really using the tool to learn, rather than review (thereby increasing motivation). Several students recommended either showing answers or giving hints for students who had made multiple attempts without getting to the correct answer. A few students recommended showing which students are currently online in order to improve the experience of finding a partner for a game.

D. Question Difficulty

Ideally we would determine the difficulty of a question from data. But since we need to bootstrap the system we constructed the difficulty for Questions as described above. To verify that this heuristic is reasonable we looked at the results for our quiz questions for the Calculus students who used this system. Specifically we used linear regression to predict the number of students who got a question correct with the question ranking score heuristic as the only explanatory variable.

In terms of Derivative questions, there were a total of twenty two questions and a hundred and two students who were answering the questions. The result was that the ranking score is significant and accounted for a sizeable amount of the variance ($p = 7.88e-05$ with $r^2=0.5271$). So while it will take a great deal more experimentation to actually find a more conclusive difficulty metric, our approximation seems to be a solid starting point.

If we look only at the 16 derivative quiz questions used in the pre and post-quizzes, we can create a scatter plot of the empirical problem difficulty calculated as the percentage of students that answered it incorrectly, versus our heuristic. The scatter plot is shown in Figure 7. It clearly shows that the problems students have more difficulty with tend to also have higher difficulty heuristic values.

VII. PROBLEM SOLVING MARKOV MODELS

The CalcTutor system stores a time-stamped version of every attempt each student makes on every problem they attempt to solve. This allows us to conglomerate the data for all students' attempts on one problem into a Markov Model that represents a probabilistic model of the problem solving strategies of the class. We expected that these models would give us a deeper insight into the kinds of problems that students were encountering while trying to solve the quiz questions. We also suspected that comparing the Problem Solving Markov Models (PSMMs) for the corresponding pre and post-quiz problems would give us a deeper insight into

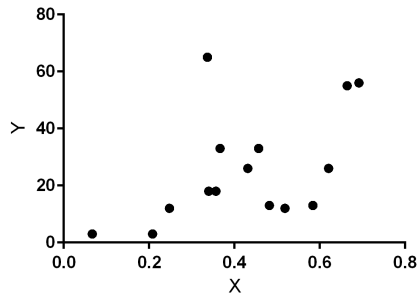


Fig. 7. X=percentage of students answered problem incorrectly, Y = difficulty heuristic value

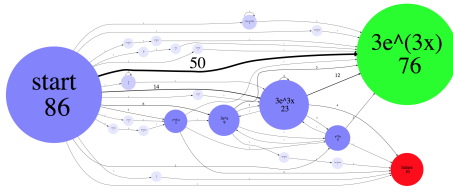


Fig. 8. Problem Solving Markov Model for pre-test question: $\frac{d}{dx} e^{3x}$

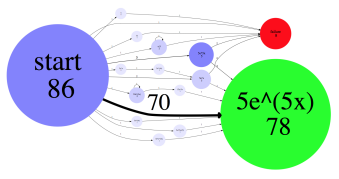


Fig. 9. Problem Solving Markov Model for post-test question: $\frac{d}{dx} e^{5x}$

the learning outcomes of our students' interaction with the CalcTutor tool.

Figure 8 shows the Problem Solving Markov Model (PSMM) for the problem of finding the derivative of e^{3x} in the pre-quiz. The nodes in this graph correspond to all of the answers that were submitted as possible solutions to the problem. The area of each node is proportional to the number of students that submitted that attempted solution. The edges between nodes are labeled with the number of students that went from one attempted solution to the next in one step. Thus we can see that 50 of the 86 students went from the start state to the solution $3e^{3x}$ in one step. Figure 9 shows the PSMM for the corresponding problem in the post-quiz – finding the derivative of e^{5x} . These two PSMMs provide a qualitative understanding of the effect of using CalcTutor on their pre and post-quiz performance. We can make the following observations:

- In the pre-quiz only 50/86 students went directly to the correct solution in one step. Another 10/86 students made one or more attempts before giving up, and 26 out of 86 students made one or more attempts before getting the correct solution.
- In the pre-quiz PSMM there are many more attempted solutions and several that are shared by multiple students.

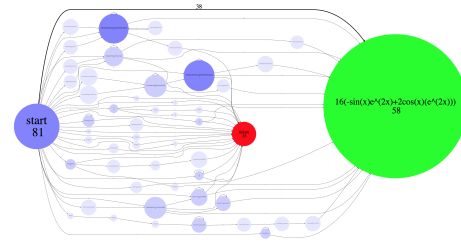


Fig. 10. Problem Solving Markov Model for pre-quiz question: $\frac{d}{dx} \cos(x)e^{2x}$

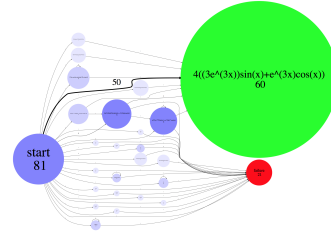


Fig. 11. Problem Solving Markov Model for post-quiz question: $\frac{d}{dx} \sin(x)e^{3x}$

The most common error is a syntax error where the correct answer " $3e^{(3x)}$ " is entered without the requisite parenthesis as " $3e^3x$ " which corresponds to $3e^3x$. The other most common errors are " $3e^x$ " and " $e^{(3x)}$ " which correspond to conceptual errors.

- In the post-quiz PSMM, the only common error is forgetting the parentheses in the correct solution: " $3e^{(3x)}$ " and it is made by many fewer students.

Figures 10 and 11 show a pair of more complex (but structurally similar) problems: to find the derivatives of $\cos(x)e^{2x}$ for the pre-quiz and $e^{3x}\sin(x)$ for the post-quiz, respectively. Again, visual analysis of these two graphs shows that the class problem solving behavior became more direct and effective between the pre and post-quizzes. Indeed, we observe

- In the pre-quiz, 38 students go directly to the correct solution, but the 20 other students that eventually get it correct take 15 different paths from the start state to the correct solution and some of these paths go through five or more attempted solutions.
- In the post-quiz, 50 students go directly to the correct solution, and the 10 remaining students that eventually get the correct solution take 7 different paths from start to the correct solution.
- The two common errors occurred less frequently in the post-quiz than the pre-quiz, and in general there were many fewer steps to get from the start state to the correct solution in the post-quiz.

VIII. CONCLUSIONS AND FUTURE WORK

In this pilot study we were able to show that the Teacher's Dilemma approach can be extended to more complex domains than had previously been tried. The heuristic metric for problem difficulty is well-correlated with the empirical

measure of difficulty and the system can automatically verify the correctness of any univariate function created by the user by combining constants, algebraic operations, and the standard trigonometric and exponential functions.

The study was not extensive enough to provide data on the pedagogical effectiveness of having students play the Teacher's Dilemma game, but it did demonstrate that after playing a few Teacher's Dilemma games students were able to improve their standard quiz scores and were able to get to a correct solution more quickly (i.e., in fewer attempts).

In the future, we plan a larger study where students use CalcTutor for several assignments. This will require us to greatly expand the range of questions that the students can create and which can be automatically graded. The current system only allows two types of questions:

- Find the derivative of the function
- Find the slope and intercept of the function at the point

In the coming months we plan to add many more question types that can be automatically verified by our system. For example, finding the maxima, minima, and inflection points of cubic polynomials, or determining the sign of the slope of a function at a particular point, or calculating simple antiderivatives. We will also need to create a difficulty heuristic for these new problems and to introduce student skill level and teacher skill level metrics that make sense over these larger domains.

We plan to make CalcTutor available to colleagues at colleges and high schools around the world and to more deeply explore the use of the Problem Solving Markov Models as a pedagogical tool for Calculus instructors.

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Taking Stock:

Using a Landscape Inventory to Drive Curriculum and Program Change

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Abstract— The Center for Engineering Pathways to Innovation (Epicenter)'s initiative for faculty development and institutional change – called Pathways to Innovation – is now working with more than 35 schools across the country to embed learning opportunities in innovation and entrepreneurship into the undergraduate engineering curriculum. At each institution, Pathways teams begin their work with a structured process of mapping the assets and identifying gaps at their school to create a "landscape analysis." This process can be useful as a starting point in any institutional change process, particularly when a broad set of stakeholders within engineering or across disciplines need to be considered and engaged. At this special session, participants will have the opportunity to explore the landscape tool using an authentic data set co-created by the group, and provide input into the next version(s) of the tool. Presenters will also provide case studies of how the tool has been used by schools of engineering to drive curricular and co/extra-curricular change at both small and large institutions.

Keywords—institutional change, curricular change, entrepreneurship, innovation, faculty development, evaluation

I. INTRODUCTION

The Pathways to Innovation program (Pathways) is a faculty development and institutional change initiative of the Engineering Pathways to Innovation (Epicenter) project, funded by the National Science Foundation and managed by Stanford University and VentureWell (formerly NCIIA). Epicenter's aim is to equip engineering students with the knowledge, attitudes and skills needed in a world marked by rapid technological transformation. Based on a preliminary literature review of effective strategies for faculty development and change in higher education [1], Pathways uses a team-based guided change process to help faculty and institutions introduce and embed innovation and entrepreneurship (I&E) into curricular and cocurricular educational experiences for undergraduate engineers.[2]

Schools participating in Pathways assemble a team of faculty and administrators (and students in some cases) to explore exemplary models for including I&E in engineering and then implement appropriate strategies on their own campuses. The two-year process is highly context-specific; the program provides teams with a range of possible opportunities and avenues and provides coaching as they select and combine

those most appropriate.

The remainder of this document summarizes the content that will be presented in the special session and describes the interactive components in which attendees will be invited to take part.

Note: a much fuller description of the tool, the basis of its development and use in the literature, and the results of its use, is being submitted in a separate full-length paper and will also be available to special session participants.

II. RATIONALE AND GOALS FOR THE TOOL

The literature review that informed the design of the Pathways program found limited evidence of research-informed transformation efforts in higher education (examples of change were plentiful in other fields, such as business). The literature did, however, identify key themes for staff to incorporate into the program, two of which became the goals for a tool to support teams in their work.

The first theme was the need for a mechanism to provide outcomes-based feedback to Pathways institutions themselves, Pathways program staff, and evaluators. The tool and accompanying process are intended to efficiently, systematically and (where possible) quantifiably document the state of the institution before and after the program intervention. By describing the status of the campus at a point in time, it can also serve as a mechanism to confirm campus awareness of said institutional changes. The tool also evaluates the degree to which Pathways provides effective tools and processes for effecting change on a campus.

The second theme identified emphases on context-specific changes, rather than "imposition" of a single approach. The landscape tool therefore fosters strategic change by providing teams with a clear assessment of their environment and the institutional strengths they might leverage in the service of a range of approaches.

III. TOOL DESCRIPTION

The original landscape tool (developed in 2013) was a spreadsheet comprised of six worksheets, each cataloging different parts of an institution's ecosystem that might foster I&E knowledge, skills, attitudes and experiences. In the "Courses," "Programs" and "co-curricular" sheets, teams document curricular offerings; in the "Spaces" sheet teams list

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physical spaces that foster I&E learning; in the “Leadership” worksheet, teams capture initiatives and strategies emerging from either central administration or engineering that could ultimately foster I&E education on campus (e.g., incentives for new course or program development, or faculty professional development); in the “Champions” worksheet, teams identify individuals that might have the enthusiasm, skills, knowledge and time to assist teams in their efforts. In keeping with the assessment goals of a traditional rubric, a “scorecard” column is included on each sheet, along with the number of students served by different programs where appropriate. Given the Pathways focus on the integration of I&E, various concepts deemed critical to this field of study are also incorporated.

In late 2014/early 2015, the tool was revised to address several shortcomings identified by evaluators and through user feedback:

The tool was converted from a standalone Excel document to a cloud-based spreadsheet using Google Sheets. All members of the Pathways team from a school are given access to the document and can work on it, synchronously if desired, from their own computers. This approach also facilitates the process of knowledge sharing[3] across the team. By ensuring the landscape tool can be completed by a broader group, teams are also better able to engage those beyond the core team, including faculty from other disciplines, students on campus and possibly even off-campus partners in this process. By engaging a broader group in the landscape completion process, the team members may develop a more expansive view of their campus ecosystem, an increased understanding of the opportunities available to students and the possibilities for cross-campus strategic collaboration.

A data visualization capability was added. This was deemed critical for two reasons: (1) given the complex nature of the tool, institutions, Pathways program staff and evaluators needed a way to be able to efficiently draw broad conclusions about the data, and (2) staff and evaluators needed a process for capturing and quantifying changes in the landscape over time. The resulting landscape data is now aggregated in a separate file and reviewed for accuracy before being stored in the cloud. Pre-defined queries on this data create data-driven websites with “snapshot” visualizations for each team that illustrate the status of their campus ecosystem on key dimensions using pie charts. The visualizations also compare their institution to the entire group of Pathways schools on these dimensions.

An update capability (and supporting data structure) was introduced. The landscape data is now stored together with the date of any changes made including modification to existing assets and new assets. This allows teams to make changes to their landscape, both in real time if they discover new information, but also at designated times for evaluative purposes. Those changes are presented in updated charts in the dashboard, and are also available to the teams and to program staff and evaluators to measure the impact of the program at individual institutions as well as in the larger cohort of participating schools.

I&E-specific modifications better aligned the tool with the project’s underlying theoretical base and with teams’

information needs. Some data points collected in the original sheets were deemed too granular and removed. Other elements were more fully incorporated into the tool because they were considered important to the work being undertaken. For example, teams now identify where each individual course lies on Duval-Couetil’s “innovation education continuum”[4] and the degree to which each course and program listed integrates active learning. To ensure teams consider change strategies that move beyond changes to curriculum and space, Graham’s[5] characteristics of a balanced and effective entrepreneurial university were incorporated with specific focus on student-driven change, collaboration with the off-campus ecosystem and campus policy and culture.

IV. EXPLORATION OF THE TOOL

The majority of the time allotted to the special session will allow participants to experience use of the tool in a abbreviated, but authentic participatory activity. This segment of the special session will include:

Introduction to the tool. The basic architecture of the tool will be described, with attention to how the categories of items collected are aligned with Graham’s taxonomy of successful university entrepreneurship ecosystems, given the specific context in which this version of the tool is used.

Co-creation of a data set. Participants will collaboratively assemble a set of assets for a fictional school, Midville State University, from what is offered at their own institutions (presenters will also have available a set of assets to supplement the group’s information as needed). Participants will use the tool to categorize the assets assembled in the session.

Data analysis. As is done by Pathways teams, participants in the special session will review the data visualizations of both Midville State’s information as well as the aggregated data. Participants will be invited to reflect on how (and why) Midville State’s profile might be similar or different from the aggregate.

Experiencing the value of the tool for curricular change. Participants will use the Midville State example to identify ways in which that institution could address a strategic objective through “linking and leveraging” one or more of the assets on their landscape.[6]

V. CASE STUDIES

The landscape tool helps teams identify many different kinds of opportunities for intervention on their campus, by:

- highlighting the lack of a particular kind of asset, such as a makerspace;
- revealing specific existing assets that could be targeted for improvement - *ie*, those rated by the team as “needs attention”;
- providing guidance on the degree to which courses were (and were not) being delivered using active learning strategies;
- identifying individuals and organizations (both on- and off-campus) that could be engaged to support the team’s efforts;

- showing areas in which the campus was significantly “out of step” with the larger Pathways community; and

- identifying a lack of strategies that fall outside of the more typical faculty driven intervention like curriculum and space (e.g. students driven efforts and off-campus collaborations).

In the special session, two case studies will be presented from among the 37 institutions now using the tool. The institutions will be chosen to provide contrasting perspectives on the ways in which data was collected and used over the course of the institutional change process. Team leaders or members from the case study institutions will be present to participate in the session.

Across the larger body of schools participating in Pathways, the program’s context-specific, asset-driven approach has resulted in the pursuit of a wide variety of initiatives. The case studies will elaborate on these various strategies, the ways in which the landscape tool led to the choice of these strategies, and the effectiveness of the strategies.

VI. POTENTIAL ENHANCEMENTS AND EXPANSIONS TO THE TOOL

Participants at the special session will be invited to identify ways in which it might be enhanced and/or expanded. The program staff have identified some preliminary options, but the session will provide an important source of “real-life” perspective on these ideas (as well as adding other possibilities for consideration):

Development and design of a data warehouse. The warehouse could incorporate the landscape data along with historical information about other activities the institutions have engaged in; IPEDS data could also be incorporated into the data warehouse. These kinds of technical modifications would enhance the end user experience by providing access to more extensive and customizable data sets. More sophisticated graphical outputs could also be incorporated to enhance the end user experience.

Use as an educational vehicle to campus constituents. To date the landscape tool has been conceived of as something that provides only Pathways teams, program staff and evaluators with information to better understand a campus ecosystem. However, the data collected could also be used to inform other campus constituents about I&E resources and spaces, for example through the design of self-service interactive campus maps that highlight I&E hotspots.

Marrying the tool with a project management interface. Designing a component that helps track and “grade” the outcomes of team’s campus-specific interventions may add additional value. The project’s external evaluators currently gather this data through surveys and interviews with team members, and manually map the teams’ efforts to the assets in their landscapes. Integrating this process into the landscape tool is under consideration.

VII. OPPORTUNITIES FOR RESEARCH

Finally, the special session participants will reflect on the research opportunities that might be available using the data

collected by the tool. Some of these opportunities may be specific to the domain of innovation and entrepreneurship, but others will be applicable across a range of domains. These opportunities may include projects such as the following;

Examination of the growth of campus entrepreneurial ecosystems over time. including the degree to which location, institution size, public or private status, Carnegie classification and an institution’s initial assets impact that trajectory and the kinds of strategies undertaken. As part of this examination, one could, for example, canvas a suite of institutions of a similar Carnegie classification and determine which offerings are most prevalent and use these findings as a springboard for rich qualitative investigations into how and why this might be the case. Such research might also inform best practices for modifying a campus ecosystem: for example, whether a school should undertake a more modest grassroots approach first, such as the launch of an extracurricular project, or a more ambitious project, like the launch of an entrepreneurship center.

Research into how the landscape is used. Some teams adopt a collaborative approach, while others treat it as a solitary task. One team used the tool as a foundation for creating a visual representations of their campus ecosystem. Another institution shared their landscape with high level administrators to realize a goal of strategically combining spaces and creating a new position. Additional research into these and other practices will increase the understanding of best practices for completing and sharing the landscapes.

Additional opportunities contingent on tool enhancements. If the more ambitious enhancements to the tool are undertaken, the research possibilities broaden. For example, through the inclusion of IPEDS data, one might research the extent to which I&E activity impacts retention and graduation rates.

VIII. CONCLUSION

The development and deployment of a landscape tool has proven to be a highly useful strategy in helping faculty teams plan and implement curricular changes in the domain of innovation and entrepreneurship education for engineering students. The data gathered through the tool provides ample opportunities for ongoing research, particularly as the tool is enhanced and expanded in future versions. While some of the data collected through the tool is specific to this domain, the underlying rationale for the tool - to collect a robust array of information that can inform decision-making while also developing the social capital and team behavior that will enable implementation of change - is broadly applicable to many of the challenges in engineering education. Participants in the special session will be able to experience first-hand some of the benefits of the use of such a tool, while also informing the development of its next generation.

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Helping Your Students Learn "Engineering-ese": Using the Results of Conceptual Change Research to Inform Your Instruction

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Abstract— The purpose of this proposed mini-workshop is to connect our research in conceptual change [Collaborative research: Getting Engineers to Talk Across Disciplines, EEC 1129447] to instructional practice. Our research suggests that one potential indicator of students' conceptual understanding across several engineering disciplines is their use (or misuse) of language. During this mini-workshop participants will be able to read excerpts from interviews we conducted, discuss how to draw inferences about student learning from these interviews, and then brainstorm how they can be more explicit about the use of language in their classrooms.

Keywords—conceptual change, misconceptions, research-to-practice

I. INTRODUCTION

Professors often think their students share their understanding of fundamental terms. But our research findings suggest that this might not be the case. A common theme in our findings across several engineering disciplines is that students misuse (and probably misunderstand) fundamental engineering terms [1, 2]. Students often confuse the specific engineering meaning of a term like "normal force" with the meaning of the term in common usage. We see this mini-workshop as an opportunity to have a discussion about how this tendency to misuse the language of engineering may play out in various disciplines and to brainstorm instructional strategies to mitigate this issue.

More specifically, the mini-workshop will be an opportunity to answer the questions: (1) So what? Why might this misuse of language matter? And (2) what can an instructor do to reverse these misunderstandings?

We will use a community of practice framework as a model for our session. We will form small ad hoc

communities [small groups] around specific domains [related engineering disciplines] and focus on practice [in this case, instructional practice]. Participants will share their pedagogical content knowledge to build a shared understanding of what parts of their field might contain problematic language (terms that are often misunderstood) and what strategies might be used to allow students to better understand these terms.

II. SESSION DESCRIPTION

A. *Intended Audience*

This workshop should have value for any engineering faculty member with instructional duties. Our examples will come from undergraduate engineering classrooms and so the information will be most easily transferred to undergraduate contexts.

B. *Goals*

The goal of this session is to use research on conceptual change to inform instructional practices.

C. *Expected Outcomes*

By the end of this session it is expected that:

1. Participants will be able to identify problematic language in their respective field of instruction.
2. Participants will be able to identify instructional strategies to mitigate the problematic language uncovered in learning objective 1.

III. SESSION AGENDA

Our session will be highly interactive and will allow participants to connect with the research as well as with colleagues in their discipline with whom they may form a

community of practice. The structure of the session is as follows:

- **Overview of the session and introduction of session presenters** (5 minutes)
- **Participants organize themselves into small groups of related disciplines and introduce themselves to each other** (5 minutes)
- **Distribute portions of anonymized transcripts taken from our research that highlight areas where problematic language is used.** These transcripts will contain sections that illustrate students' misunderstanding and misuse of fundamental terms. The examples will come from a variety of disciplines and will be matched as much as possible to the disciplines represented in the small groups. (5 minutes)
- **Small groups discuss the transcripts and predict instances of misuse/misunderstanding they see in their students' language.** (20 minutes) - Full group discussion. (15 minutes)
- **Presenters and participants discuss instructional strategies that may mitigate the issues raised in the previous discussion.** (25 minutes)

- **Individually, participants reflect on and document what they have learned in the session to (1) identify potentially problematic language in their courses and (2) identify instructional strategies to mitigate #1.** (10 minutes)
- **Participants complete session evaluation** (5 minutes)

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ShowNTell: An easy-to-use tool for answering students' questions with voice-over recording

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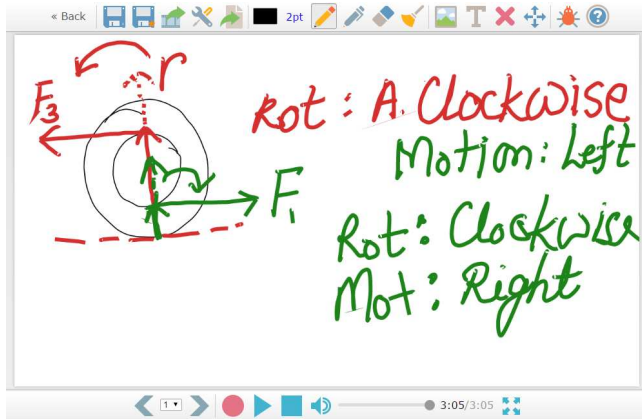


Fig. 1. ShowNTell Editor

Abstract—The use of recording applications for teaching is increasingly popular, with tools such as Ink2Go and ShowMe being available on many platforms and at reasonable cost. However, most recording applications available are typically native applications and do not work within the web browser. In this work, we study the feasibility of implementing a recording solution in the web browser environment.

I. INTRODUCTION & MOTIVATION

ShowNTell is an implementation of a screen recording application that runs within a web browser on a mobile device [1]. The application will provide an interface similar to a virtual whiteboard, and allows the recording and playback of drawings made on the whiteboard (see Figure 1). Audio recordings are supported to facilitate the creating of lessons and tutorials within the application for the purposes of eLearning.

We describe our motivations for this work in the following sections:

A. Web platforms

New browser technologies under the umbrella group of HTML5 technologies have provided new opportunities for new

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types of applications to run within the web browser, providing services normally done by native applications. For instance, the introduction of the 2D Canvas API allows images to be generated in real-time within the web browser, instead of being generated on the server [2]. This paves the way for applications such as interactive games and media that requires graphical content to be updated in response to user input.

Improvements in communication technologies such as access to higher and more stable bandwidth as well as faster transfer speeds can allow us to provide real-time services that may require continuous transfer of relatively sizeable amounts of data from the client device. This is crucial for ensuring responsiveness of the application which has data dependencies on content on the server.

As many mobile devices have access to the Internet, we would also perform user experience studies on the use of touch-based interfaces for the use of recording and drawing, which would be one of the primary input interfaces for ShowNTell. Many mobile browsers also support the new APIs that are available on desktop browsers, allowing our application to potentially work on those platforms without the user requiring installation of an application.

As a result of these emerging changes, it is now possible to implement a recording solution that runs on a web browser. Thus this acts as a primary motivation for pursuing this project. Our project would attempt to implement an application with native-like capabilities on the web platform by using APIs available on web browsers, as well as evaluate techniques that can potentially improve its usability or responsiveness in a web browser environment. Additionally, we would attempt to test our implementation on multiple platforms under different conditions, in particular the desktop and mobile browser environments.

B. eLearning

Recording applications are increasingly popular tools for the purposes of education and entertainment. For instance, the webcast system provided by the National University of Singapore (NUS) is able to generate automated recordings of a lecture in modules supporting that feature. Other modules have used other creative means aside from recordings such as gamification to improve the learning experience of the content in the module [3][4]. eLearning serves as an alternative or supplementary means for students to revise on topics that were

covered earlier through traditional mediums. For our project, our main focus would be towards approaches that involve recordings.

Recordings are also used as tools to illustrate ideas that are typically difficult to describe as text or images [5]. This is because with the inclusion of time-based events, animations such as circling or highlighting become more prominent. Additionally, annotation mechanisms such as free-style drawing are easier to use than other traditional inputs for displaying mathematical equations or simple diagrams. This coupled with audio capture can allow for easier conveying of ideas that might be difficult to convey with a static document.

In ShowNTell, we attempt to build a recording tool that works in a web browser, allowing the application to work on a wide variety of platforms without requiring the installation of additional software. Unlike recordings used for lectures, ShowNTell is designed for shorter recordings that typically last for a few minutes, typically sufficient for answering questions or explaining concepts. The tool would act as a complement to the existing eLearning tools available.

II. RELATED WORK

The idea of a whiteboard and video recording application is not a new concept, with many such applications available in the market. In this section we study several different types of applications that support screen recordings, enabling us to adopt similar techniques that allow us to manage data generated in recordings.

A. Desktop Implementations

There are many applications that support recording capabilities available on computers, such as CamStudio, Camtasia, and Open Broadcasting Software [6][7][8]. These applications are typically screen recorders which capture video input from the graphics hardware, usually through system APIs such as bitblt [9]. Screen recorders are applications that poll the screen and stores what is displayed into a file, thus capturing all visual details that are visible to the user. Screen capture applications may also capture audio from the audio input hardware. Other screen recording software may support annotation capabilities that allow adding details to the currently displayed screen, such as Ink2Go [10].

As recording generates cumulative data, different applications have different methods of handling the recording. Typically, a video recorder will continuously write frames to a file rather than retaining them in memory in order to keep memory footprint low. Ideal file formats for this include AVI files [11], as these files support the appending of video data into the file with minimal performance overhead. In other implementations such as Fraps [12], the recording may be distributed into multiple files, moving from one file to the next when a file size reaches a certain threshold. Distributing a recording into multiple files enables longer duration recordings on file systems that have an inherent file size limit, such as the 4GB limit in FAT32 systems [9].

In ShowNTell, we have adapted the file splitting approach which splits recording data into multiple fragments. This enables handling of certain data types such as audio much more easily, as well as allowing for responsive save times by allowing part of the document to be saved in the background while recording is ongoing. This approach is preferred over the single-file method because in a web browser environment, uploading of data to the server takes much more time compared to writing a file to the hard disk. Thus, we can reduce the perceived upload time by simply uploading parts of the earlier recording during the recording process.

B. Mobile Implementations

Mobile applications that support recording capabilities do not typically capture the screen, in contrast to desktop applications. Due to the sandboxed nature of mobile applications, capturing the screen is typically not allowed [13]. However, recording software with annotation capabilities and microphone support are widespread, such as ShowMe and ExplainEverything [14][15]. These fully utilize the touch-screen to provide an input suitable for free-style drawing.

Mobile applications face a larger resource constraint compared to desktop applications; in particular file-system access and computational resources are not a luxury. Thus recordings will typically record the input or the sequence of actions used to render the current scene, instead of recording the entire screen as a video. For example, when the user performs a free-style drawing, instead of capturing the image of the screen, it captures the coordinates needed to reproduce the same effect. This method of replaying events to simulate a recording will greatly reduce the storage, computational, and memory footprint of the recording, since only events will need to be stored instead of image frames. In the event a video output is desired, those events can be replayed to generate the video frames to produce the video.

In ShowNTell, we have attempted to emulate the same feature set provided by these applications, which include slide support, document import, and video export. Similar to ShowMe and ExplainEverything, ShowNTell will not actually record the screen contents, but instead the events to reproduce the visual state of the screen.

C. Web-based Implementations

Due to the resource requirements and limitations of existing browsers, there are not many recording applications available as a web application. There are some implementations such as BigBlueButton that provides recording and collaboration capabilities [16]. However, those implementations require the use of plugins such as Adobe Flash. Such plugins are typically not available on mobile devices due to either deprecation of the existing software packages or prevention of installation of the plugins by the operating system [17][18][19].

While there are web-based applications that provide drawing/annotation capabilities, or even provide the ability to collaborate with others over the internet, there are not many

TABLE I
API SUPPORT ON DIFFERENT BROWSERS.

Version	C 42	FF 37	IE 11	S 8	C(A) 42	FF(A) 37	S(iOS) 8.3
Canvas	Y	Y	Y	Y	Y	Y	Y
IndexedDB	Y	Y	Y	Y	Y	Y	Y
UserMedia	Y	Y	N	N	Y	Y	N
Audio	Y	Y	N	Y	Y	Y	Y
Worker	Y	Y	Y	Y	Y	Y	Y
Fullscreen	Y	Y	Y	Y	Y	Y	N
FileReader	Y	Y	Y	Y	Y	Y	Y
XHR2	Y	Y	Y	Y	Y	Y	Y
Blob	Y	Y	Y	Y	Y	Y	Y

C = Chrome, FF = Firefox, IE = Internet Explorer, S = Safari

C(A) = Chrome (Android), FF(A) = Firefox (Android), S(iOS) = Safari (iOS)

complete solutions that support the ability to record the annotations and drawings for later playback. However, with newly available HTML5 APIs, it is now possible to implement a drawing and annotation web-based application with recording support.

Because HTML5 is in the emerging state, most browser vendors have only implemented a subset of it [20]. Nonetheless, some browsers such as Google Chrome have implemented most of the required APIs on publicly available versions of the browser, providing feasibility to the implementation and deployment of our application.

III. SYSTEM DESIGN

As ShowNTell is a web-based application, we have chosen to use a client-server model for the application. The client will be designed to run within a web browser, and does not require the installation of additional software aside from the web browser. The server will use a normal LAMP stack to serve web pages and store data, as well as NodeJS for the video rendering and document import systems.

A. Feasibility Analysis

Prior to and during the implementation of the project, we have evaluated whether the project can be implemented using available APIs and tools. Preliminary analysis has given the conclusion that majority of the browsers on desktop environments have support for the features that we require for our application, particularly Canvas 2D and Media Capture APIs [2][21].

On the mobile platform, Google Chrome and Firefox on Android offer the features that we require. Browsers such as Safari on iOS and Internet Explorer on Windows RT do not support the Media Capture API, thus features requiring the use of the microphone would be disabled on these platforms. Nonetheless, because a sizeable fraction of the browser market supports the APIs that we require, we have decided to proceed with the implementation of the project. A comparison between the different browsers as well as their support for key HTML5 API features our application requires is summarized in Table I. We have attached the version number as the feature set

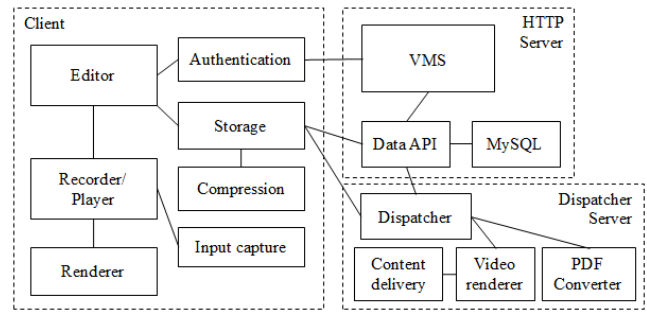


Fig. 2. Components in ShowNTell

available in a browser may change in later revisions of the browser.

B. Program Design

Our application uses a client-server model. Our client is designed to run within a web browser, and does not require the installation of any software aside from the browser itself, which is assumed to already be available on the user's device. The architecture used by ShowNTell is summarized in Figure 2.

The client is the front-end of our system, which is a website which the user can visit in order to use the services offered by our application. Using Canvas, we can implement whiteboard-like functions easily. We have also added other annotation tools such as highlighters and erasers which are tools available in similar software in other platforms. Browsers with Media Capture API support allow us to access the microphone on the user's device, allow us to capture audio for recording purposes. The Web Worker API which is commonly available on most modern browsers allows us to perform computationally expensive operations in the background, thus we usually perform data-related operation such as compression and conversion in workers.

The editor handles run-time drawing of visual data, as well as handles the state that will be displayed to the user. The editor includes the user interface such as the toolbar buttons, as well as the canvas drawing interface. The event recorder handles the capturing and replay of user input such as mouse coordinates. It also provides audio input capture if there is a microphone available. The storage component manages data belonging to the document and automated saving. The renderer renders the current document state to the user such as drawings, images, and textual objects.

On the server-side, we have two major servers, which are the HTTP and Dispatcher servers. The HTTP server hosts the web application for clients to access. The main scripting language used on this server is primarily PHP, which is a server-side language. The HTTP server also exposes external APIs for the uploading and retrieval of document data. The VMS (Video Management System) provides the front-end for users to manage their documents as well as share the documents with other users. Like typical HTTP servers, it uses

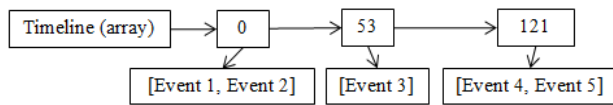


Fig. 3. Main timeline structure

normal LAMP stack which includes the Apache web server and MySQL database.

The dispatcher server is used to provide features that require long-running operations that should not be performed by the client due to its resource requirements. This server uses the JavaScript scripting language, and is run via NodeJS. The dispatcher server provides video rendering and PDF conversion capabilities.

IV. IMPLEMENTATION

A. Recording

During recording, audio from the microphone and user actions are captured simultaneously. In ShowNTell, user actions are referred to as events.

Events stored on the main timeline include slide change events and audio playback, which are typically global events that do not belong to any particular slides. Each document will only have one main timeline. During recording, events are added into the data structure representing the main timeline. Because recording involves time, time information has to be attached to each event. Playback requires an efficient means of traversing through events in the correct order.

Timeline data for the main timeline is represented in a 2-dimensional structure. The first dimension is the time, while the second is an ordered set of events occurring at that specific time. A visual representation of the timeline structure is shown in Figure 3.

During playback, we traverse across the time dimension, and process each event individually for each time slot. To reduce the amount of processing needed, each play-through will only go through the entire timeline once. Cumulative states are used to allow pause and resume without incurring significant costs. Fast forwarding of events is also efficiently supported.

B. Audio Recording

Audio capture is performed using the Media Capture API available in browsers such as Google Chrome and Mozilla Firefox. The API offers the ability to access raw audio PCM (Pulse-Code Modulation) data as it is generated [21].

In order to reduce the amount of time needed to save the document, we have chosen to upload audio as it is generated, rather than upload it at the end of the recording. Thus the audio is no longer a single contiguous file but instead distributed over multiple fragments. During recording, audio data is streamed to a buffer until a threshold is met. An interval of five seconds is chosen as the threshold as it offers a balance between the amount and size of fragments generated.

The number of fragments may increase complexity during playback and could also introduce additional overhead as each

fragment is treated as an individual unit. However the size of a fragment should not be too large as it can incur additional computational requirements in processing of each fragment. When the threshold is met the buffer is encoded as a WAV file and uploaded to the server, after which the buffer cleared.

Not all browsers support the Media Capture API, thus we have developed a fallback which will involve the use of the Adobe Flash plugin. However, this fallback may not work on platforms that do not support the plugin, particularly mobile-based platforms. In the event whereby the application is unable to gain access to the microphone due to the software or hardware environment, the audio recording feature in ShowNTell will be disabled.

C. Audio Playback

Because we are pushing data as soon as it is available during recording, the audio recordings are not available as a contiguous audio stream but instead as fragments. In order to play the audio as a contiguous track, we have to perform audio chaining. Audio chaining involves preparing each audio to be played at some point in the future. The process of audio chaining is summarized below

- 1) Obtain list of fragments belonging to an audio collection
- 2) Playback is paused to buffer audio fragments in the collection
- 3) Relevant audio fragments are downloaded
- 4) Once sufficient fragments are downloaded, the fragments are arranged to play at a specific time
 - a) Fragments whose end time precedes the current time marker are skipped.
 - b) Fragments whose start time precede the current time marker, but end time does not will be played partially. These fragments will have their playback time set to the appropriate location, and played immediately.
 - c) Fragments whose start time occurs after the time marker is to be played at a future time are queued at the appropriate time.
- 5) Once audio arrangement is done, playback is resumed

For smooth and seamless playback during audio chaining, each audio fragment should be encoded in a format that allows playback without any “gaps” or distortions. Formats such as MP3 and AAC may insert silence at the beginning of the audio file during the encoding process as compression artifacts [22]. Other formats such as Ogg and WebM do not have gaps as silence introduced as compression artifacts are already accounted for in the format. Lossless formats such as WAV will be gapless because there is no change in information in decoded audio data. We have used avconv which is part of libav [23] to perform audio compression on the server-side. The file sizes of the different formats are summarized in Figure 4.

The measured time (in milliseconds) to complete compression for a five second audio fragment is summarized in Figure 5. WAV is uncompressed data thus can be used as benchmark.

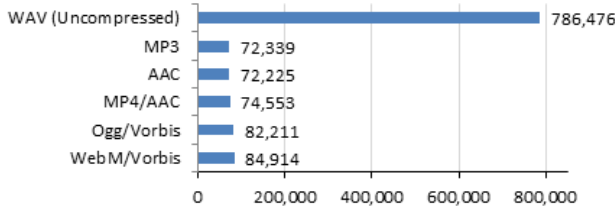


Fig. 4. Audio file sizes (in bytes)

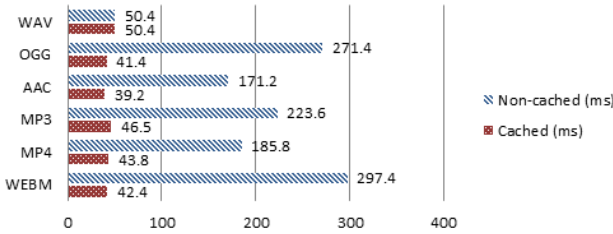


Fig. 5. Time taken (milliseconds) to compress and retrieve audio

Note that these timings do not include network transfer, thus while WAV takes the least processing time, the actual time taken to load a WAV file in the live environment could be slower than that of compressed files simply because compressed data is smaller in size. As compression of fragment can be done quickly, we can simply invoke the compression tool via PHP.

We have used caching to improve the server responsiveness during fetching of the compressed audio. Because audio data do not change, we can reuse data that was already compressed. Audio that have already been compressed are stored into the cache table in a similar manner as regular audio fragments, and retrieved when the relevant audio file is requested. Because the compressed audio fragments are small in size, storing them on the server will not require a large extra storage overhead.

D. Drawings

In order to generate drawings that appear smoother compared to the naive implementation (connecting points with straight lines), we have decided to employ a basic curve-fitting algorithm [24]. The following code snippet shows a portion of the curve drawing code that we have used when drawing a particular point:

```
if (thresholdmet) {
    var midX = (last.x + current.x) / 2;
    var midY = (last.y + current.y) / 2;
    context.quadraticCurveTo(last.x, last.y,
        midX, midY);
    last2.x = last.x; last2.y = last.y;
    last.x = current.x; last.y = current.y;
}
```

The above code generates a curve that passes near to the points, making it an approximation of a curve-fit. As we

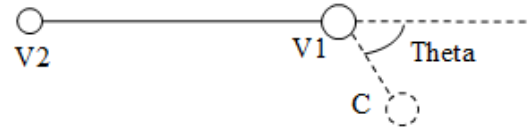


Fig. 6. Angle-based heuristic to account for changes in curve trajectory

are using Bezier curves[24], it will have the C-1 continuity property, giving a smooth appearance for the curve. Although the approximation introduces some small errors to the result, it still yields reasonable quality since the errors are usually small enough and not noticeable to the user. We are aware that there are algorithms that can produce curve-fits pass through all points however they will introduce greater complexity to the system [25]. Bezier curves require 3 control points. Hence, if there is only 2 points in the drawing we default to a straight line, and if there is only 1 point we simply render a dot.

Even with Bezier curves, the resulting curve still suffers from a “wavy” effect as a result of having points that deviate from the general path of the curve. These points are usually introduced due to vibrations during motion of the input device or by the user’s hand. We have applied a simple de-noising algorithm to produce even smoother curves by eliminating points that do not contribute to the overall shape of the curve, but are significant enough that they introduce artifacts in the curve.

We have used two factors to determine whether a point should be rejected, these are Euclidean distance and the angle. If a point is very close to the last accepted point, it should be rejected as it is likely to not contribute much to the shape of the curve. An exception would be the case of sudden changes in curve trajectory, whereby we will need to keep the points as they contribute to the shape of the curve even though they are close to each other. We define a sudden change in trajectory as a significant change in the relative angles of the points in the trajectory (see Figure 6).

The last (V_1) and second last (V_2) points are points that have already been accepted in the curve. The candidate point (C) is the one which will be added. We measure the angle θ between the two vectors which can be obtained via dot-product between $\vec{V_2V_1}$ and $\vec{V_1C}$ unit vectors. A larger angle implies significant deviation in trajectory. We still apply a distance condition to prevent points from clustering near each other. The conditions for accepting a point are summarized below:

- First point (0 points): Starting point is always accepted
- Euclidean distance (≥ 1 point): $|\vec{V_1C}| > 4$ pixels.
- Trajectory angle (≥ 2 points): $\cos^{-1} \frac{\vec{V_2V_1} \cdot \vec{V_1C}}{|\vec{V_2V_1}| |\vec{V_1C}|} > 1$ radians, and $|\vec{V_1C}| > 2$ pixels.

Figure 7 illustrates the difference between the scenario where no de-noising is applied, and when de-noising is applied. The overall shape of the curve should be the same, although in the de-noised version there are less “wavy” patterns, particularly at gentler curves. The algorithm used

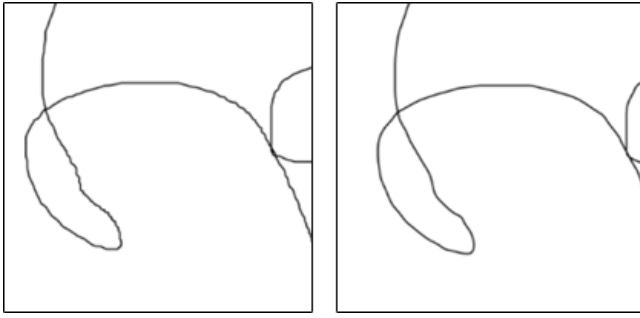


Fig. 7. Comparison between non-denoised (left) and noise reduction (right)

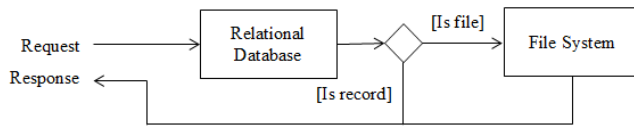


Fig. 8. Storage mechanism in ShowNTell

gave reasonably good quality drawings, and does not require expensive computation, allowing it to be deployed for the web browser.

E. Storage

Like most typical client-server and web-based solutions, data is stored on the server as the persistency of data on the client is not guaranteed. There are two common mechanisms for storing data for a client-server application, one of which is storing as records in a relational database such as MySQL, and the other is storing as regular files in the file system. As data is associated with a document, we represent this property as a relationship, thus the relational database was initially chosen as the storage mechanism. However, in practice we find that we can yield greater performance by storing larger records in the file system [26], thus we have adopted a hybrid storage mechanism which is shown in Figure 8.

Because we need to preserve relational information of all records in order for other components to perform lookups of document data, all units of data would have an entry in the database, including those that are stored on the file system instead of as a record on the database. If a unit of data exceeds a certain size threshold, it would be stored on the file system, thus we set a flag in the record to determine if the data returned would be from the database value or from the file system.

There will be some overhead when storing data corresponding to a record into a file, since the file must be created or overwritten on top of setting a flag in the database record. We observed that for file sizes less than 100KB, the difference in timings between the file system and database are minor and comparable to each other. The variance in timings is observed to be due to io-bound operations and network latency which affects both mechanisms. Beyond 100KB, we find that the database method will require significantly more time to

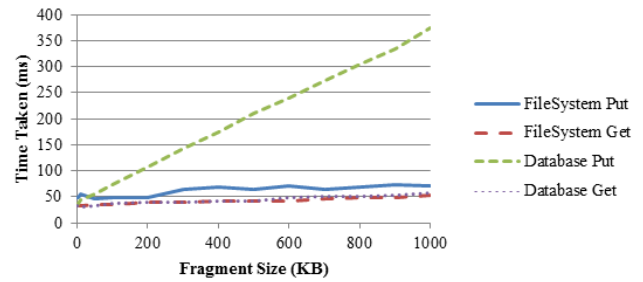


Fig. 9. Comparison between file and database storage

perform the put operation, and at sufficiently large sizes, the put operation would fail. We also observed that the get operations for both systems are comparable. The following experimental results were captured from our experiments. In the experiment we simulate a client-server interaction and measure the time taken (in milliseconds) to upload or retrieve fragments of different sizes (in kilobytes) from the browser to the server using both methods. The results are summarized in Figure 9.

For our system, we have set 128KB as a threshold for determining which storage system to use. Small records such as metadata are stored in the database. Records larger than 128KB, which are typically audio fragments, images, and timeline data, are stored into the file system.

F. Other services

There are some services that do not run within the web browser, but instead performed on the server as it requires significant computational resources. These are usually handled by the dispatcher server, which provides video rendering services. Our video renderer is written using JavaScript and runs as a NodeJS application. When a user requests for a document to be rendered, the document ID is passed to the dispatcher service, which spawns the video rendering process. The video rendering process performs the following actions:

- 1) Download the document chunks.
- 2) Render the timeline data into a video frame-by-frame, using avconv (from libav) "pipe2image" feature. Each frame is rendered as a JPEG using node-canvas. The intermediate video (without audio) generated uses the MKV format.
- 3) Combine the audio chunks into a contiguous audio file. We are using SoX to perform the splicing of audio. The intermediate audio file generated uses the WAV format. The audio file may be re-encoded to 44100 sample rate to ensure that all fragments have the same sample rate.
- 4) Combine the generated video and audio into a single video file. The resultant file uses the MP4 (H.264) format. We are using avconv to combine the files.
- 5) Upload the final video file to the CDN (Content Delivery Network).
- 6) Send an email to the owner of the document informing them that the video has been rendered completely.

When rendering the frame, we have chosen JPEG as it provides a smaller sized image while retaining image quality, reducing the amount of time needed to transfer the image from our renderer to avconv. We have used WAV as the audio input since WAV files are generated by our client application. The intermediate video format is MKV as we find that the generated video track is of good quality, and does not suffer from significant compression artifacts when re-encoded to MP4 in the final stage. The resultant video format is MP4 with H.264/AAC encoding as it is supported by most of the modern CDNs and our CDN of school's Integrated Virtual Learning (IVLE) platform [27].

In addition the the video renderer, ShowNTell supports PDF documents which can be imported as slides used by ShowNTell. Document conversion uses the imagemagick tool which has support for PDF to image conversion [28]. The output image chosen is PNG as it offers good image quality.

V. EVALUATION

In this section, we highlight the usability, performance and scalability of ShowNTell system. The evaluations include analysis of user feedback on our system, as well as other evaluations we have drawn from our testing of the system.

A. User Study

We conducted field tests on our application with users. Most of these users came from the Faculty of Computing, although there were others from the Faculty of Science of our University. In this initial study, students and instructors from the following modules tried the system: PC1431 (Physics IE), CG3204L (Computer Networks) and CS3247 (Game Development). Our user study primarily focuses on participants from the CS3247 module.

During the March of 2015, we allowed students from the class of CS3247 to complete their assignments using our implementation of ShowNTell, thus allowing us to gather some information on user behavior, preferences, as well as the readiness of our system in terms of scalability. Altogether there were over 40 participants. The experiment was conducted over a period of one week, thus the load on the system could be confined and evaluated during this period. Prior to the student study, we had also opened up the system to other educators who were interested in our implementation so as to make any adjustments to the system if needed.

During this experiment, participants were to complete a recording to answer two technical questions of the module assignment using ShowNTell tool. The use of slides was required for the assignment, and was limited to 10 slides, thus it was expected that most students would attempt to use the PDF import feature. As the presentation was to be delivered orally, the students must also use the audio recording feature. There was an original requirement to use the video export, but that was lifted due to technical issues experienced towards the end of the experiment. The expected recording duration was at most five minutes. Upon completion of the experiment, the students were asked to fill in a feedback form.

TABLE II
USER STUDY DEMOGRAPHICS

Participants	45 (30 respondents)
Participant type	Students (97%) Academic Staff (3%)
Browser used	Google Chrome (80%) Mozilla Firefox (17%) Safari (7%)
Recording duration	<3 minutes (7%) 3 to 5 minutes (49%) 5 to 10 minutes (42%) >10 minutes (2%)
Input used	Mouse (93%) Touch (40%) Stylus (50%)

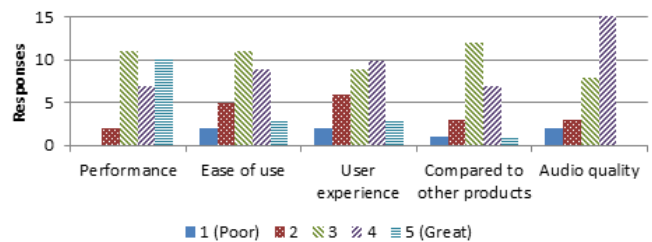


Fig. 10. User responses to various aspects

B. Evaluation Results

The survey primarily covered on user demographics as well as their preferred methods of using the system. Other feedback questions were also designed so as to inspire future iterations of our project. The survey results are summarized in table II. Majority of the users used ShowNTell on Google Chrome for Windows. Most of the participants were familiar with other video recording solutions, in particular Camtasia, Camstudio and OBS. The most common recording duration created by users was approximately five minutes long. The most commonly used input device was the mouse, as many students were using ShowNTell on a computer instead of a mobile device.

In general, most participants (76%) find our implementation easy to use and adequate (see Figure 10). The participants have indicated that ShowNTell provided sufficient capabilities to complete the requested assignment, although most have indicated the system could be improved further. Participants have indicated that ShowNTell is usable with the mouse and stylus, although participants who have used touch-based inputs mentioned them to be less comfortable. We hypothesize that touch-based input is harder to draw objects accurately for extended periods of time compared to a stylus or mouse.

Most participants (93%) have indicated that the performance of ShowNTell is adequate. Playback, recording, and saving of documents were perceived to be completed within reasonable time, fulfilling the main objective of our project which is to implement a responsive and usable recording solution in a web browser. Most actions on a recording can be completed within seconds, without the user needing to wait too long before

getting a response.

In terms of features, many participants (43%) find the PDF import function to be the most useful feature. It is observed that most participants (97%) have used the feature to import their slides, allowing them to quickly create the materials for a recording. Users have also found the sharing functions useful and easy-to-use.

It is observed that a number of documents (32%) have no additional drawings/image annotations. As the use of slides coupled with audio overlay is sufficient to complete the assignment, we suppose that these users do not use the annotation functions simply because it is not needed to complete the task.

Among those who have tried adding annotations, there were some who have found it frustrating to use the feature, particularly those using only a mouse-based input, thus only use the annotations in a limited way. For users who have tried a stylus or touch-based input, their rating is split between easy-to-use and challenging-to-use. We find that most users who have prior experience with recording solutions that do not have annotation capabilities (such as Camstudio) are more likely to indicate a negative experience with annotations.

Many users have suggested non-linear editing of the recordings. While we have evaluated the idea of introducing non-linear editing to ShowNTell, we find that it might be too technical challenging to implement it in the remaining time frame, thus we would leave this challenge as a form of future work that others could take up.

C. Evaluation Conclusions

We find that ShowNTell is a reasonably good implementation of a browser-based recording solution. However, we find that most users prefer to use it as a simple recording tool that overlays audio on top of slides. Nonetheless, we find that ShowNTell offers sufficient capabilities to act as an eLearning tool, and thus is capable of satisfying the tasks outlined in the experiment. There are many possible improvements that could be done to improve the usefulness of ShowNTell, such as support for rewriting past recordings.

Most users indicated that ShowNTell is responsive, implying that our performance optimization techniques and management of data is adequate for our solution to deliver a responsive experience within a web browser. Users were able to create recordings up to 10 minutes or longer, showing that ShowNTell is capable of supporting recordings of sizeable duration.

An Individual educator's evaluation statement: "The application is very good for the modules such as physics and mathematics which have lots of equations and drawings. I have used the import pic, free hand drawing and writing using stylus, highlighting, voice over recording and video rendering to answer students query. All these features makes the explanations very clear, with minimum text usage, saves time to input equations and symbols and brings it to a level which is comparable to face to face consultations with the students".

VI. LIMITATION

As some browsers have not implemented the APIs used by ShowNTell, the application is not expected to work on all browsers available in the market. However, as the application uses standards compliant APIs that are in the W3C draft specifications, the application will eventually be supported by browsers in the future that eventually implement those specifications.

At present, ShowNTell works well on Google Chrome and Mozilla Firefox. For browsers that only support a subset of the APIs required by ShowNTell, we may opt to use a fallback mechanism or simply disable the feature that uses the API. Due to performance limitations particularly in the mobile environment, certain techniques such as client-side compression might not be feasible in practice thus we use alternative approaches like server-side compression to obtain a similar result. However, this limitation is expected to ease with better hardware in the future.

ShowNTell is currently supported on most browsers for desktop and notebooks, which includes Internet Explorer, Google Chrome, Mozilla Firefox, and Safari. For Internet Explorer and Safari, we have taken steps to address the lack of support for certain APIs by providing a fallback, such as in the case of audio playback and recording.

On Android, ShowNTell is supported by Google Chrome and Mozilla Firefox. Among these browsers, we find Google Chrome to be more stable in performance compared to Firefox. Other browsers on Android such as the stock browser is not capable of supporting ShowNTell as it lacks many of the required APIs needed by many basic functions in ShowNTell.

On iOS, ShowNTell is partially supported by Safari and Chrome. As there are no browser-based APIs for microphone access in these browsers on iOS, ShowNTell will not be able to record any audio on those platforms. Nonetheless, other features in ShowNTell are still supported, thus users can still watch documents on these devices.

VII. CONCLUSION

We have found that it is feasible to implement a recording solution for the web platform that is supported on most web browsers. We have also presented solutions that can enable a fairly responsive application even when manipulating sizeable amounts of data. User studies have indicated that ShowNTell is comparable to other similar tools in the industry.

Overall ShowNTell works well in providing the features of a standard whiteboard recording system over the browser, and provides sufficient features to accomplish the basic requirements for its purposes in E-Learning. As ShowNTell is supported across multiple platforms and does not require installation of any software, it poses a low barrier to entry for students and instructors to use it, making e-learning more effective. ShowNTell is continuously evolving. Future releases will include complete video editing and real-time collaborative content editing modules to further enrich the learning experience.

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Innovative Mobile Tool for Engineering Embedded Design and Security Educations

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Abstract — In the current electronic industry, embedded systems have become essential components in most electronic devices. The fast growth mobile devices have been used in every sector and brought wide applications in many aspects of our society. These devices involve in internet connections, wireless communications and even cloud computing, which increases the necessity of both hardware and software securities. Therefore there is an urgent need of efficient education in EE, CE and CS in embedded systems, especially in hardware and software co-design with the concepts of modern security methods. In this paper, we present a work-in-progress development of an effective learning tool which benefits from active learning concepts and modern mobile technologies. The contributions of this tool on promoting engineering students' learning of embedded system designs and security are also investigated.

Index Terms – Mobile embedded labware, low-cost and portable, modular design, authentic and creative learning.

I. MOTIVATION

In the modern engineering industry, embedded system (a.k.a. microcontroller unit (MCU)) has become an indispensable component with profound influence in many different applications, such as consumer electronics, robot controls, industrial automations, military services, aviation systems, modern architecture, and telecommunications [1]. Combined with embedded technologies, wireless monitoring and remote sensing have shown significant potential to promote better services in healthcare, environmental protection, and national security [2]. These advances fuel the growing requirement of wireless embedded system especially the hardware and software co-design education due to its importance at the nexus of future global competition and strong workforce demands. Much progress has been made to promote and implement underlying courses in various engineering fields of education, such as electrical, mechanical, mechatronics and computer engineering. However, the quality and quantity of the trained engineers with both hardware and software skills still lag behind the demand from all aspects of industry. This challenge would be mainly subject to less students' engagement in computational programming skills, shortage

of practice in real-world relevant questions, and unsustainable learning and training strategy.

Empowered by different types of personalized functions on ubiquitous pattern of people-people communication, the mobile technology has profound changed the mechanism of the information processing, influenced people's life styles, thinking, working and even the strategies to acquiring new knowledge and developing new skills. Mobile learning (m-learning) has become an emerging topic and various researches have been launched to show values of implementing mobile technologies in teaching and learning. In an early pioneer work in m-learning, Madeira et al. reported the development of a mobile learning course for a classic analog electronics [3]. The course was structured in several interactive modules to teach students analog circuit designs and all underlying theories. Sukittanon demonstrated using a quiz-style application (app) to test different electrical engineering subjects including digital logic analysis, discrete signal convolution, and digital filter design [4]. Vate-U-Lan et al. studied the topic of how mobile learning would be suitable to whole university students in different disciplines. Their study revealed that mobile learning could be more extensively used on different subject learning, especially in STEM educations [5].

In regard to the value of m-learning, Batagan et al. reported their analyses of the m-learning impact on the educational process. They concluded the flexibility, collaboration, motivation, accessibility and portability are all main reasons invoked in supporting of m-learning [6]. Bruns et al. in their review of m-learning further addressed that "...mobile technologies are able to support learners' engagement in creative, collaborative, critical, and communicative learning activities." which emphasized the students' engagements in leaning with mobile technologies [7]. The authentic learning, which involves real-world relevant problems or projects solving, was also studied with m-learning. Traxler reported a case study of authentic learning and multiple benefits from m-learning. In his analysis, m-learning enables students engaged in exploration and inquiry around authentic tasks, allows learning tasks on data capture, location awareness and collaborative works from physically remote students [8]. All these studies demonstrated that learning with mobile technologies is motivating for both students and instructors. It also represents an effective pedagogical method as compared to

any other conventional education models. However, employing the same idea using mobile technology to improve students' learning of the modern embedded system design is still dearth. This encourages PIs to develop an innovative learning method combining with the mobile learning technology in this project.

II. METHOD

To overcome the abovementioned difficulties in cultivating professional embedded system engineers and broaden students' technical skills in emerging topics such as embedded security, we present herein a new learning tool to promote the effectiveness of learning mobile embedded system design and significantly enhance students' active and authentic learning. The tool is designed as a labware to engage students' active and hands-on learning in topics of embedded system designs and embedded security. We adopted the method of using smart phone app technology to integrate all lab activities in the tool and cloud computing technology to allow the tool to be used anywhere and anytime. The app was named "embedded systems" which corresponds to the course to be implemented. The app consisted of several function pages, and each page showed clear images and instructions to provide a convenient user experience (Figure 1).

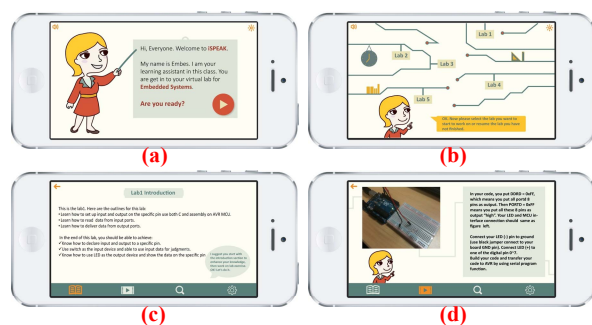


Figure 1. Schematic illustration of the contents of the learning app. (a) the main entry page; (b) the lab selection page; (c) the introduction page of a Lab. (e) a page shown in the "lab exercises" section.

We employed a module lab style in the app for different lab activities. This design creates an easy-to-adopt benefit for tool disseminations and keeps the flexibility to add or remove the contents in a specific curriculum based on the duration of the course, instructor knowledge, difficulty of materials, and budget of lab activities. Each module (lab) focuses on a group of topics or concepts in embedded systems designs, and is constructed as a self-contained lab package with all learning materials associated with the topic. The difficulty level in each lab is mutually the same so students will not be frustrated if they miss or forget the concept in previous topic. In addition, since each module is independent, students can gain self-efficacy by finishing each lab and accumulate their confidence through the whole course.

As shown in figure 1(a), we designed an animated characteristic to lead whole activities in the app. The design has two fold. First, we want to create a relaxing environment to let students work on their lab without any stress and pressure. It is believed that students with good emotional state may easily gain self-efficacy and vice versa [9]. In addition, a growing number of studies have demonstrated teens in this generation prefer informal type of communications through online communities such as google+, Facebook, twitter or YouTube [10-12] to learn information and share information [13-15]. We want to use this design to further promote the *participatory cultures* [16] to students' learning and eliminate their fears in the difficult topics in this engineering discipline. From students' point of view, learning from an animated character is similar to learning from their peers, and therefore, is more attractive and confidence inspiring than a professor-lead lab section. Secondly, this female avatar reinforces efforts to reduce disparity in engineering education. As the matter of fact, enrollment and graduation rate of women is low in most of the engineering fields. The number of female professors or instructors is even scarce. We want to put the effort on advancing women in engineering by using the animation female model to lead the technical teaching in the learning tool. Based on the social cognitive theory, observers can easily engage with vision recognition of a model in behavior they learned. We believe by dissemination of the project, the animation female character will be the role model to inspire more female students' interest in engineering subjects and further encourage them to pursue engineering degree or career.

The app consists of 5 labs which are essential to embedded systems designs (2 labs), wireless communications (1 lab) and embedded security (2 labs). Each lab consists with "concept introduction", "lab exercises", "real-world problem" and "report and discussion", where the "lab exercises" and "real-world problem" are designed to enhance students' hands-on experiences. The students can work on these sessions in sequence or randomly. The "concept introduction" provides a material review on the specific lecture covered techniques to be used in the lab. The "lab exercises" section provides step-by-step video demonstrations on hardware interfacing and software coding techniques with several examples on pre-defined questions (Fig 1d). Students learn these techniques through completion of all exercises. The user can stop, accelerate and replay the video anytime in the process. By completing all exercises and repeatedly reviewing these videos, students are able to gain solid fundamental skills with their mastery experiences and further inspire themselves to continue work on other topics. The real-world relevant problem features a special situation or a problem. The problem is real-world relevant to allows students to work on a question by using their creativity as well as integrating technologies they learned with their working knowledge in different aspects. This problem is designed without a predetermined solution, so students need to

evaluate their knowledge and ability with their creativities to accomplish the task. It will lead to diverse answers based on culture, finance and life experience. Thus, students are able to explore different thinking and problem solving from others, broadening their experiences and knowledge base. In “report and discussion”, students take a video of their working processes and their result demonstration and then post it on social media (i.e. YouTube) and join discussions with others.

We designed a hardware kit accompanying with the learning tool for students’ hands-on experience. The components of the kit include a low-end smart phone, an embedded IC, Bluetooth module and off-the-shelf peripheral devices. We have controlled the budget of the kit to \$100 and the kit is re-useable for students in different terms of the same course. All necessary electronic components are packed in individual bags. Students use the tool kit on all their lab exercises to learn hardware techniques. This portable kit allows students to work on hands-on exercises actively. They can also practice all exercises by constructing components repeatedly and gain experience as well as learn from their failures iteratively until they are proficient in the skills. Scheduling a lab time or not remembering all techniques learned are no longer concerns. Students work individually and are not affected by the deficiency of their prerequisite knowledge to slow down the progress of the group working in a team. The tool also provides a choice to encourage students to try different hardware constructions by themselves after they finish all required exercises. This extra task builds not only on their knowledge in the topic but also on their confidence and self-efficacy gained from all previous tasks. Figure 2 shows some components of the tool kit to employ in preliminary evaluation.

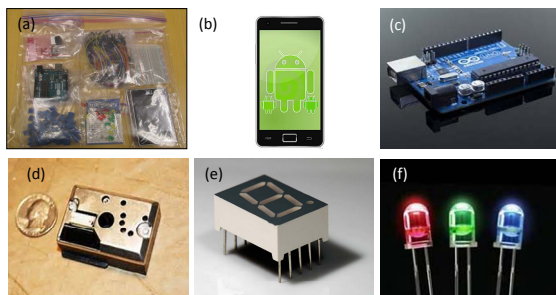


Figure. 2. The tool kit used for students’ hands-on activities. (a) All components used for all lab activities in a big Ziploc bag. (b) Low end android smart phone. (c) Microcontroller unit. (d) ~ (f) Peripheral electronics.

III. PRELIMINARY EVALUATION

The tool has been tested on volunteer students for the preliminary evaluation. All students in the evaluation have working knowledge in C/C++ programming learned from pre-requisite courses. None of them has experience on

embedded designs but all of them are highly interested to learn the skills. For the time being, students only worked on 2 modules (labs) related to embedded systems I/O programming and device communications. Emphasizing the enhancement of the self-efficacy by using the tool, we conducted an entry/exit survey on student participants. The questions are:

- Do you think embedded systems design is a difficult subject?
- Do you worry your software programming skill is not enough to handle all labs in this course?
- Do you prefer to work individually or in groups?
- Do you want to demonstrate your learning outcomes in public? For example, show your ideas and results in a video clip and upload it to YouTube?
- Do you believe you can work on a real-world relevant project on your own?



Figure 3. A screenshot of a YouTube video shows that a student demonstrated his idea and design results after learning embedded design with the tool.

Most feedback from our preliminary evaluation was positive and encouraging. After using the tool in a short period of time (4 weeks), students were confident to show their knowledge in hardware and software embedded co-design and understood the basic MCU communication issues. In addition, they were eager to learn more topics in the embedded systems and techniques to enhance mobile device securities. Students would like to apply the knowledge and skills they learned to other aspects such as their senior design projects. Figure 3 shows a screenshot of a YouTube clip of student demonstrating his idea and the results of his senior design project.

IV. PROJECT IMPLEMENTATION

We will redesign our embedded system curriculum following the model curriculum of 2004 IEEE/ACM [17] to implement the developed tool into the related courses. At this time, the tool can be applied on courses in electrical engineering, computer engineering, and software engineering and we would like to continue our efforts to

make the tool usable for more engineering courses and benefit all underrepresented students in engineering education.

In the redesigned curriculum, the related concepts and skills among the impacted courses will be emphasized by utilizing previous designs as components in subsequent courses. This vertical integration of concepts and skills of mobile embedded system among courses is expected to significantly increase students' proficiency in mobile embedded system design.

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CommEasy: An Innovative Interactive Communication System for Promoting Communication and Participation

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Abstract— The advancements made in handheld devices and the widespread use of these devices among users all over the world has opened up new avenues for the use of these devices in education. Many applications have been developed to work on these devices to support the teaching and learning process in all its dimensions. CommEasy is an innovative, interactive communication system for smart handheld devices based on Internet and WiFi technology. This system has been developed mainly to enhance communication and participation in distance-learning classrooms that use video-conferencing technology. It allows students to pose questions for the instructors using their own Apple smart handheld devices, guarantees them complete anonymity and allows the instructors to respond to their students. It also enables instructors to evaluate the learning of their students by posing questions with multiple answers to which students can respond through their devices. This paper concentrates on the role of CommEasy in enhancing teacher-student communication and interaction. The hypothesis to be tested is that CommEasy will increase the level of student participation in the distance-learning classroom. According to the results of the experiment conducted in King Saud University, the null hypothesis is rejected, and the experimental hypothesis mentioned above is accepted.

Keywords—*PRS; communication; participations; distance learning; smart handheld devices.*

I. INTRODUCTION

The nature of the "information age" and communication is changing quickly. Many technologies that previously were considered advanced are becoming commonplace and new ones are being developed. This trend affects many aspects in our lives and changes the way we live. Distance-learning is one of field that has been affected by this revolution. The rapid advancement in computers, mobile technologies and telecommunications capabilities has made a paradigm shift in distance-learning, in all its dimensions. Many institutions worldwide take advantage of these new technologies and offer advanced distance-learning courses as an alternative to traditional education, in order to respond to students' demands to learn.

Distance-learning have been defined as "planned learning that normally occurs in a different place from teaching and as a result requires special techniques of course design, special instructional techniques, special methods of communication by electronic and other technology, as well as special organizational and administrative arrangements" (p.2) [19]. Schlosser and Simonson [25] have defined distance-learning as "institution-based, formal education where the learning group is separated, and where interactive telecommunications systems are used to connect learners, resources, and instructors" (p.1) [25]. Most definitions of distance-learning have emphasised the role of technology in the successful building of distance-learning. These technologies allow learning to be delivered to students and bridge the instructional gap between them and their instructors. Many technologies have been used, ranging from video tapes, printed material and instructional television to the advanced two-way audio and video conferencing technologies used today.

Video conferencing is an advanced technology that allow to deliver real-time, bi-directional interactive communication through using telephones or internet technologies to allow instructors and students in different locations to communicate interactively. Numerous advantages has been reported for using video conferencing technology in distance learning such as encourage collaborative in the classroom, encourage interaction in the classroom, allow immediate feedback to be delivered to students and allow to transfer non-verbal communication such as body gestures and facial expressions that considered an essential part of successful and effective communication [17,23]. In King Saud University (KSU), video conferencing technology has used to allow male instructors to teach female students in distance-learning classrooms. In such communication, female students can hear, watch, ask and answer questions from their male instructors while males instructors can hear females and create discussions without seeing them (Fig. 1).

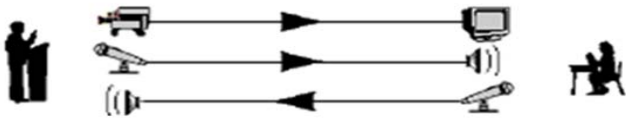


Fig. 1: One-way Video Conferences in Saudi Arabia

It has been argued that the effectiveness of distance-learning is dependent upon how interactive the process is and how the barriers that are faced by students in this regard are overcome. Lack of motivation, resistance to change and anxiety, lack of technical support and equipment failure, lack of student-teacher interaction, lack of student preparation and training are all examples of the barriers that students faced in distance-learning [7,12]. Among these barriers, this paper will consider overcoming the communication and participation barriers faced by students in distance-learning classrooms and how to encourage students to participate and interact.

Effective ways of communication and interaction in the classroom are the cornerstones of learning and have a basic role in the transfer of knowledge from the instructor to the students [12]. Any barriers that might hinder the communication and interaction process between instructors and their students should be considered and solved [7]. It has been reported that there are many reasons that can prevent students from interacting and participating, including psychological, social and cultural reasons [5,13]. Hesitating and shyness to interact and ask questions, overcrowded classrooms, lack of lecture time, fear of being labelled as incapable by their instructor, are all examples of reasons that might affect interaction in the classroom and prevent students from participating with their instructors [4]. Such problems can be minimised by adopting new methods of teaching as well as adopting new technologies. Adopting different teaching methods that encourage interaction and discussion in the classroom are known to benefit learning. However, some factors, such as the large size of the classroom, make the teaching methods alone insufficient to encourage students to participate and, therefore, some advanced technologies should be used to help instructors in this regard.

II. THEORETICAL FRAMEWORK

The significance of student participation and interaction in the learning process has been confirmed by many educators and researchers worldwide and is supported by strong evidence [20,31]. Cohen stated that participation is a way to bring “students actively into the educational process” and to help in “enhancing our teaching and bringing life to the classroom” (p.699) [6]. Numerous benefits of participation have been reported, including increased attention, improved learning ability, increased motivation to learn, higher grades, ‘higher levels’ of thinking and improved problem-solving, decision-making and communication skills [10,16,18,31]. Enhancing participation and interaction in distance-learning settings is no

less important than in traditional settings and has received much attention recently.

Despite the importance of communication and participation, and although educators encourage questions during lectures, many students still do not participate. Many reasons for this have been reported in the literature, including shyness, overcrowded classrooms and short lecture times [5,13,4]. Such barriers are faced by students and educators in Saudi Arabia and worldwide.

Researchers and educators are making considerable efforts to overcome these barriers and encourage students to participate in the classroom. One solution is to incorporate new technologies into the classroom and use them to encourage students to participate. Mobile-based educational systems have become popular and are used for many educational purposes, including enhancing interaction and participation in classrooms. The spread of these applications has been supported by strong pedagogies as well as the increasing number of higher education students who own and use mobile devices. It has been reported that using mobile technologies in the classroom can enrich students’ learning experiences, improve their level of participation and interaction and overcoming many of the challenges they face [12]. CommEasy, a personal response system that can be used in both traditional and distance-learning classrooms, is one example of an innovative interactive communication system that can be used to enhance communication and participation for distance learning students as will be discussed in this paper.

III. TECHNOLOGIES TO SUPPORT COMMUNICATION AND INTERACTION

Communication and interaction in the classrooms has been affected by the continuous growth of technologies and the tools that are used to support the teaching-learning process in all its dimensions. Many technologies and tools have been developed, mainly to increase interactivity and to support the communication between students and their instructors. These technologies support many platforms, ranging from old desktop computers to laptops, to the latest generation of handheld devices with touch screen capabilities. The huge advancements made in the development of these devices and their widespread use among students all over the world has pushed educators and researchers to use these devices in education to bridge gap between the way students live and the way they learn and to support the teaching-learning process, as well as to solve the problems faced by students. Numerous applications have been developed to work on these devices during the past few years. Interesting results have been reported about the positive impact of these applications in supporting communication and interaction in the classroom, as well as minimising and reducing barriers faced by students [14, 15].

This paper has taken into consideration the advantages of this widespread use of smart handheld devices among higher education students in Saudi Arabia and the positive impact of mobile applications in enhancing communication and participation. It has implemented, from scratch, an innovative interactive communication system that runs on smart handheld devices, CommEasy. CommEasy is a type of Personal Response System (PRS) that allows students to pose questions for the instructors using their own smart phones (iPhone and iPads) and allows the instructors to respond and send answers to their students. It also enables instructors to pose questions for their students in the form of voting and presents the result for instructors in an appropriate format. This system has been used to enhance interaction and participation in the distance-learning classroom that uses video conferencing technology in KSU.

IV. PRS TO SUPPORT COMMUNICATION AND INTERACTION

As stated previously, communication and interaction in the classroom has been affected by the continuous growth of the tools and technologies that have developed to support the teaching-learning process in all its dimensions. Many technologies have been developed during recent years mainly to support and increase interactivity and participation in the classroom and to tackle the communication and participation barriers faced by students. One popular technology that has gained recognition during the past few years is the PRS.

PRS is a technology consisting of a combination of hardware and software that enables students to communicate with the instructors and answer the questions, without the need to speak to the instructors or raise their hands. PRS has been defined as a communications system that allows instructors to collect and analyse large amounts of data about students' learning and consequently investigate whether learning has taken place [22].

PRS consists of a sender device (clickers), which is a small handheld device given to each student to allow them to respond to the instructors' questions; receiver devices, which are usually connected to the instructors' computers and allows instructors to receive a signal sent by students' devices and present the results for the instructors; software is used to allow instructors to create questions and process the information sent by students' devices, as well as to tabulate and display student responses, e.g. in the form of bar charts [1].

In older generations of the PRS, Radio Frequency (RF) technology and Infrared (IR) technology was used to establish communication between clickers and the instructor's computer. In the latest generation of PRS, many personal handheld devices such as PDAs, smartphones, etc. can be used as input devices instead of older clickers and WiFi technology can be used to establish communication between these devices and instructors' computers. This shift in using PRS has enabled the development of numerous applications that work on personal

handheld devices and can be used in both a traditional setting, as well as a distance-learning setting, as it is based on internet and WiFi technology. These applications were used for many purposes, one of which was to increase interaction and participation in the classroom.

Numerous advantages have been recorded for the role of the PRS in supporting the teaching-learning process, such as increasing interaction and participation in the classroom [30], supporting collaborative learning [24], monitoring students' performance [3], encouraging proactivity by shy and deprived students [28], improving student performance in exams and assignments [21] and making the classroom a happier and livelier environment [9]. However, students' anxiety, instructor resistance to change and technical issues are some concerns related to using PRS in the classroom.

This paper has concentrated on the role of PRS in enhancing teacher-student communication and interaction and increasing the level of students' participation in the distance-learning classrooms that use video conferencing technology. Many studies have revealed that the use of PRS in the classroom can support teacher-student interaction and lead to increased student participation in the classrooms [8]. Students are more likely to participate and tend to stay focused on task in the classrooms using PRS, compared with the typical classroom that does not use PRS [27]. Quieter students or students who are shy or easily embarrassed found PRS to be a comfortable and easy way for them to participate with instructors [28,24]. Hall et al. [11] have confirmed that PRS has been used for many years and helps to increase the level of student engagement and participation in the classroom.

The advancements made in the PRS that are based on the latest wireless technologies and handheld mobile devices have allowed it to be applied in the distance-learning setting. The PRS has proved its positive impact in enhancing communication and interaction in distance-learning classrooms [26].

V. COMMEASY, A SYSTEM TO SUPPORT COMMUNICATION AND INTERACTION IN DISTANCE-LEARNING CLASSROOMS

CommEasy is an innovative type of PRS that is based on personal handheld devices (iPhone and iPad) and *WiFi* technology. It has been used to support communication and participation in the distance-learning classrooms that use video conferencing technology in KSU in Saudi Arabia.

The main advantages of the CommEasy system are that: it allows instructors and students to interact instantaneously during lectures; it allows students to pose text-based questions to their instructors, as well as receive answers for their questions once they have been answered by instructors; it enables instructors to evaluate the learning of their students by posing them questions with multiple answers in the form of

voting to which students can respond through their devices, the instructors can browse the results of voting in an appropriate format; it enables instructors to post announcements to their students and the students can browse these announcements. Both the instructor and students are able to use Apple's devices that they already own, so this saves the cost of using other response devices, such as clickers. Finally, CommEasy can be applied to enhance participation in traditional learning, as well as in distance-learning classrooms.

To fulfil all these requirements, CommEasy has been developed to include two applications: the student application and the instructor application. Both applications will run on the individual iPhone / iPad devices of the instructors and students and allows them to communicate interactively with each other. The applications supports iOS version 5.0.1 to iOS 7.0.4.

Both applications allow the instructor and students to create an account using their chosen email address and passwords (Fig. 2).

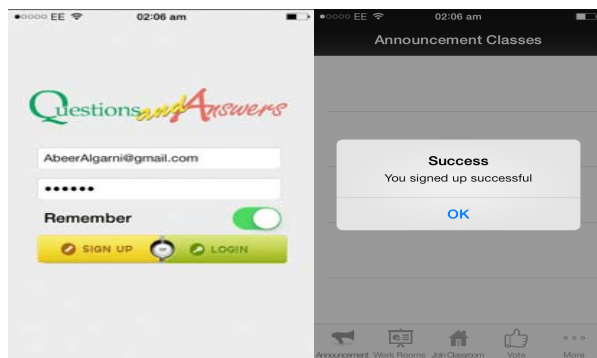


Fig. 2: Main Screen of the Application

The instructor application allows instructors to create a new virtual classroom with venue, date and time. The instructor is provided with a unique access key for each classroom created, to be given to students to allow them to join this classroom and interact with instructors (Fig. 3). The instructor can add a list of topics for each classroom and such topics will be used by students when they want to pose questions to their instructors (Fig. 4).

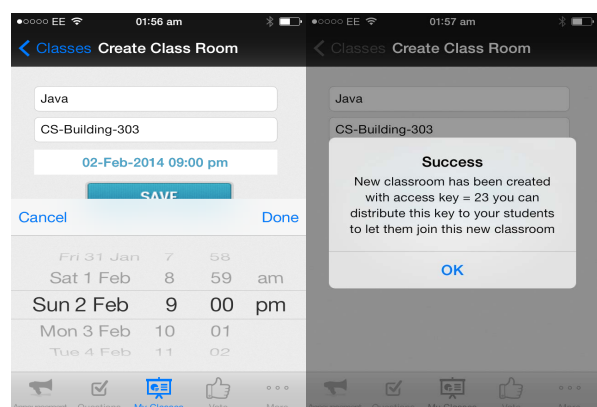


Fig. 3: Create New Classroom

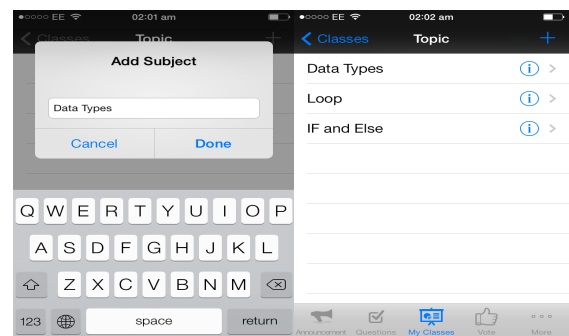


Fig. 4: Add Topics to the Classroom

The student can register to the classroom with the key given to them by their instructors (Fig. 5) and will be able to pose questions for their instructors, as well as chose topics (subjects) for their questions (Fig. 6).

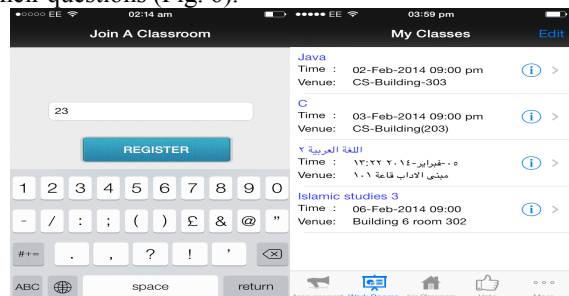


Fig. 5: Registering to the Classroom

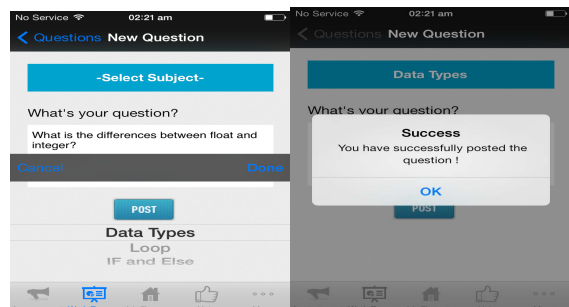


Fig. 6: Pose a Questions for Instructors

The questions will appear on the instructor's application instantaneously and the instructor can post an answer back to the student (Fig. 7). The answers will appear on the student's application once it has been posted by the instructor (Fig. 8). Instructors can also create voting questions with multiple answers (Fig. 9), and students can respond to these questions (Fig. 10). The instructors can browse the results on their own application (Fig. 11).

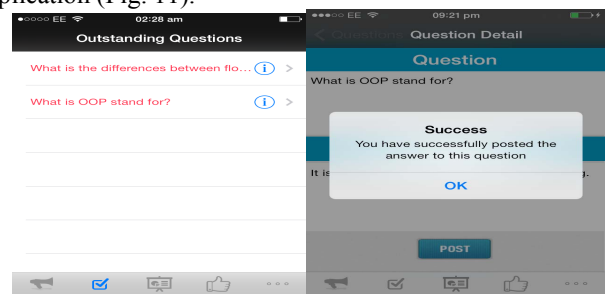


Fig. 7: Sending Answers to the Students

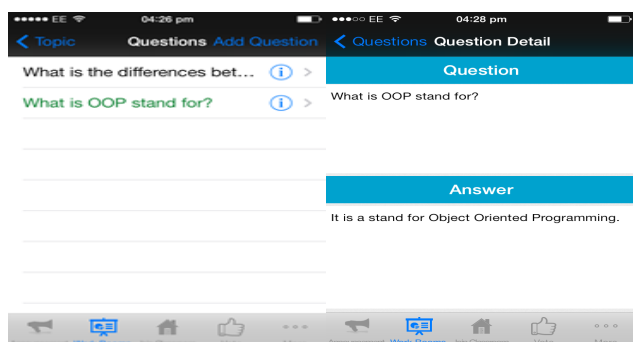


Fig 8: Browsing Answers in Students' Application

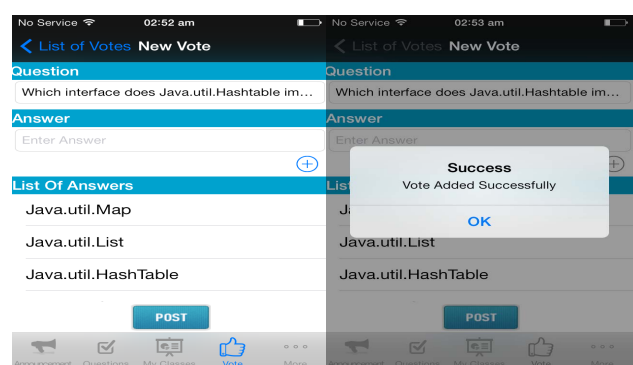


Fig. 9: Create the Question for Vote (Instructor Application)

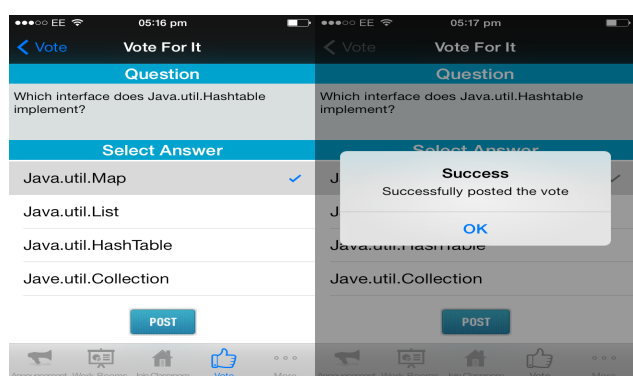


Fig. 10: Answer the Voting (Student Application)

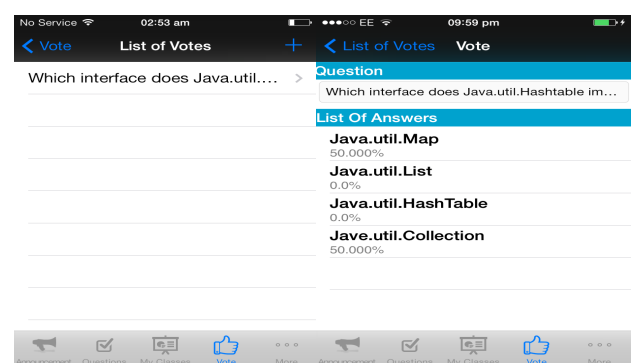


Fig. 11: Browsing the Voting Results

The instructors can also post announcements to their students (Fig. 12) and students can browse these announcements in their application.

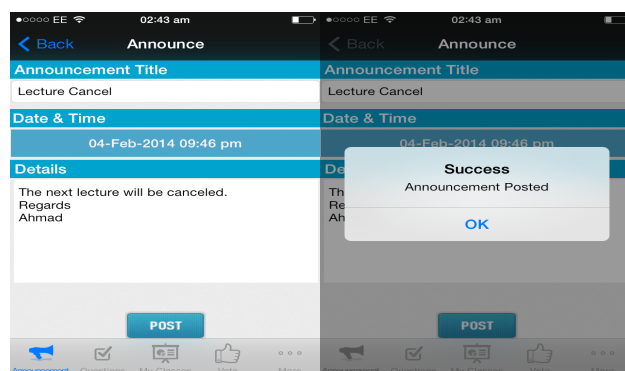


Fig. 12: Create Announcement (Instructor Application)

Both applications also have all the basic functionalities that allow students and instructors to signup, login, remember password, reset password and logout and include all the required help and contact us information.

VI. EVALUATION

A one-month-long quasi-experiment was conducted to evaluate CommEasy. The experiment was carried out in the KSU and involved 30 female students who were enrolled with a male instructor in a distance-learning classroom through video conferencing technology. Before the experiment began the system was introduced to the students, a link to download the system was sent to the participants' devices and a manual of six pages was given to the students. The utility of the system was evaluated using comparative analysis: measuring the students' participation in the classroom with and without use of the system and then conducting a comparative analysis between the two outcomes. Four lectures were observed over a four-week period. In the first two weeks students participated with the instructors traditionally, by leaving their seats and walking to the microphones that were spread along the walls of the classroom where they push a button and speak to the instructor. In the next two weeks the students were allowed to use the CommEasy application downloaded on their own devices and were able to send their questions to the instructors, as well as receive answers on their handheld devices (iPhone and iPad). The number of participations of each student in each lecture was observed and recorded to be used in the analysis. In order to control other variables, as far as possible, between the two conditions (with CommEasy and without), the experiment was conducted in the same classroom, the same module (Islamic Studies), the level of lectures were similar as they were chosen according to advice of the instructor and the lectures were held at the same time every week. Once the participations were recorded for the month, a data analysis was undertaken to evaluate the role of the system in increasing students' participation and to accept or refuse the hypothesis.

Figure 13 gives an overview of students' participation by week by displaying mean and median. It shows the average number of times students participated in class. As shown in the figure, student participation was positively affected when using CommEasy. As the intervention began in week three,

the data shows an expected trend with a steep increase in participations between weeks two and three.

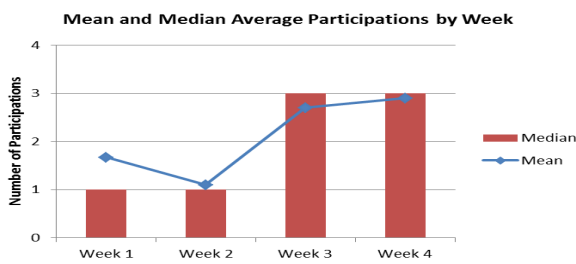


Fig. 13: Mean and Median Average Participations by Week

It can be concluded from this chart that student participation in weeks 1 and 2 differed from that in weeks 3 and 4. However, to formally test the hypothesis, a Paired t-test was carried out. This test looked at the changes in levels of a measurement that occurs at two points in time for the same group. In this case, it looked at how students' participation differed in weeks 1 and 2 in comparison to weeks 3 and 4.

To use the paired t-test, each pair of weeks is combined to create single measurements for 'before' and 'after'. The number of participations of each student were added in weeks 1 and 2 (before) and compared with the number of participations they had in weeks 3 and 4 'after'. Table 1 shows the mean and median values for the combined pairs of weeks, as well as the difference between the weeks. The difference is calculated by subtracting the number of participations in the 'before' weeks from the number of participations in the 'after' weeks. This difference variable will be used in the t-test

Time	n	Mean	Standard Deviation	Median
Before (Weeks 1&2)	30	2.77	2.67	2
After (Weeks 3&4)	30	5.60	3.32	5
Difference (After-Before)	30	2.83	2.41	3

There is an assumption of normality in parametric testing procedures, so it is important that the difference variable is normally distributed. To test this, a normality tests, Shapiro Wilks and Kolmogorov-Smirnov, were used (Table 2). As both tests have a p value >0.05 , the Differences variable follows normal distribution. Therefore, it is safe to use the paired t-test.

Test	Test Statistic	Probability (p)
Shapiro Wilks (W)	0.94	0.1058
Kolmogorov-Smirnov (D)	0.12	0.1500

The result of the paired t-test indicates a very significant difference between Weeks 1-2 (Before) and Weeks 3-4 (After)

($p < .0001$). Therefore, it can be concluded that there was a very significant increase in participation in Weeks 3-4 compared to Weeks 1-2. According to these results, the null hypothesis was rejected and the experimental hypothesis, which states that female students' participation with male instructors in distance-learning classrooms will increase using the CommEasy system, compared with not using CommEasy, is accepted. These results confirmed the ability of CommEasy to enhance communication and interaction between students and their instructors. The system encouraged students to be more active in the classroom and to participate and interact with their instructor, as observed in the classroom. This was also confirmed by the instructor. Students showed great enthusiasm for using the system in the classroom and expressed appreciation for the system's features. Most of the students commented that the anonymity of CommEasy made them feel safer and many female students found it very convenient and easy to use. They also enjoyed the fact that CommEasy provides all students with a chance to participate and interact with the instructor. Furthermore, they appreciated the fact that they could participate without leaving their seats; in the past, they had to walk to a microphone to speak, which was stressful, especially for students who were shy or embarrassed. However, as stated previously, the experiment only lasted one month due to time and administrative restrictions. It is recommended that further experiments be conducted over longer periods of time, as this may lead to more interesting results.

VII. CONCLUSION

The CommEasy system for enhancing communication and participation in the classroom has been presented in this paper. The system allows students to pose questions for the instructors using their own smart handheld devices and allows the instructors to respond and send answers to their students. It also allows instructors to pose questions for their students in the form of voting and obtain the results. The intended goals have been met, according to the results of the experiment, which proved that the CommEasy system increased the level of students' participation in the distance-learning classrooms that use video conferencing technology. This study contributed to previous literature by confirming the positive impact of CommEasy, a mobile-based educational system, on communication and participation in the classroom. It encouraged students to ask questions and overcame all the barriers to participation that students had faced previously, such as shyness, crowded classrooms and lack of lecture time. These problems are faced not only in Saudi Arabia but also worldwide, so this system could help students all over the world. Additionally, the system should be transferable to any traditional or distance-learning educational setting. In the near future, CommEasy will be supported by additional platforms, such as Android, making it accessible to even more students. Further longitudinal experiments are recommended to obtain more interesting results.

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Perceptions of Students and Instructors toward the Role of CommEasy in tackling Communication and Interaction Barriers in Distance-Learning Classrooms

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Abstract— The educational field has been greatly affected by the current revolution in ICT, especially the advancements made in the use of handheld devices such as smartphones with touch screen capabilities, which have become extremely popular among university students worldwide. Universities and educators have realised that using such devices in education can help to bridge the gap between the way students live and the way they learn as well as enrich the learning experience and tackle the problems students face. This trend has led to developing numerous educational mobile systems to support the teaching-learning process and to tackle the problems that students and instructors face. Hesitation, shyness and crowded classrooms are barriers that can discourage students from participating. This paper presents the perceptions of instructors and students of the interactive communication system CommEasy. This system was developed mainly to tackle a number of communication barriers that female students face in distance-learning classrooms and provide them with a convenient way to pose questions to instructors using their own handheld devices. Results of the evaluation show that students and instructors have a very positive attitude toward the role of CommEasy in supporting communication and participation and removing the barriers they face.

Keywords—Participation; Communication; Handheld devices.

I. INTRODUCTION

There is a considerable part of the literature that emphasizes the importance of interaction and participation in creating an effective learning environment and in enriching the learning experience of students. Effective communication methods through discussion, asking questions, debating, etc., has proved to support active learning, encourage comprehension, encourage collaboration, improve teacher-student relationships and a better atmosphere will be created for both the instructors and students [2]. Such communications methods have influenced how students feel about learning as well as their level of participations and their achievement in the classroom [7].

In distance-learning, effective communication and interaction methods have also been regarded as a pivotal element for

creating a successful distance-learning environment [6,12,13]. These interactions influence many other factors, such as student satisfaction and achievement and the quality and quantity of learning [4,10]. This interaction takes place with the help of technology, including asynchronous and synchronous communication technologies. However, some barriers might hinder the interaction process between students and their instructors in a distance-learning, and such barriers should be considered and solved. Crowded classrooms, lack of time, and shyness and embarrassment when asking questions are examples of communication barriers that discourage students from participating in distance-learning classrooms.

In Saudi Arabia, most universities use video conferencing technology to allow male instructors to teach female students in distance-learning classrooms, as this is the only authorised way for males to teach female students. In such communication, female students can see and hear the male instructor, and can interact in the classroom by asking questions, responding to instructor's questions, etc., while the male instructors can interact with female students without seeing them (Fig. 1).

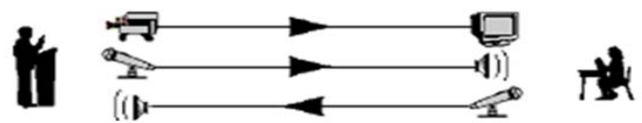


Fig. 1: Video Conferencing Technology in Saudi Arabia

Female students who enrol in such distance-learning classrooms in King Saud University (KSU) have reported many barriers that hinder their communication and interaction with their male instructors. The most common barriers reported by students include [1]:

- Hesitation and embarrassment in terms of speaking to the male instructor and in asking questions.
- A shortage in the number of microphones available in the classroom, there are only four microphones in a

classroom that accommodates up to 100 students and these microphones mounted on walls on both side of the classroom.

- A crowded classroom makes it difficult for students to move around the classroom and reach the microphones, preventing them from participating. Crowded classrooms also reduce opportunities for student participation and interaction.

The CommEasy system has been designed to tackle all of these barriers and pressures. The CommEasy system has been developed to provide female students with a convenient way to pose questions to their instructors using their own handheld devices (iPhone/iPad), and allows instructors to respond and send answers to their students on their own devices. The system also allows instructors to send questions to their students in the form of quiz and get feedback from their students.

II. PEDAGOGICAL CONSIDERATIONS

The recent revolution in handheld devices such as smartphones, and the falling prices of these devices have driven an increase in the number of students all over the world who use and own such devices. Such a trend has led to the development of many educational mobile systems and applications that are used to support the teaching-learning process in all its dimensions. One of the main purposes that such applications are used for is to facilitate interactivity in the classroom and to encourage students to participate and interact in the classroom. There is evidence that the use of mobile technologies in the classroom can enrich the learning experience of the students, as well as to encourage participation and interaction in the classroom [5,8].

Encouraging students to participate and ask questions in the classroom is a major concern of educators worldwide. Asking questioning during lectures are critical to learning, because it create an active engagement in the learning process. Whilst most instructors welcome questions during class, students mostly hesitate and are embarrassed to ask questions [9]. Educators have reported numerous reasons that can prevent students from asking questions and participating, including psychological, social and cultural factors [3]. Such reasons have been mentioned by female students in KSU, as stated previously. Other reasons can include lack of lecture time, the fear of being labelled as incapable by their instructor, the prospect of embarrassing oneself in front of fellow students, a large number of students in the classroom, etc.

This paper takes into considerations the spread of smart handheld devices among students in higher education in Saudi Arabia and the positive impact of using such devices in supporting and increasing participation and interaction in the classroom. The paper presents the CommEasy system that runs on the individual handheld devices (iPhone and iPad) of students and instructors, and provides them with an easy and

convenient way to communicate and interact. This system has been used to increase communication and participation in the distance-learning classrooms and to tackle the problems reported by students in this regard.

This system provides students who are shy to ask questions, are embarrassed to talk to male instructors, or cannot participate due to overcrowded classrooms or a shortage of microphones in the classroom with an easy, convenient way to pose questions to their instructors and receive answers using their own smartphones. This system also allows instructors to ask questions and receive responses from their students in a form of quiz. This system provides many features: It guarantees students complete anonymity, allows instructors to deliver immediate feedback to students, and enables instructors to evaluate students' learning through posing questions with multiple answers. It can be used in both classroom-based and distance-learning settings as it based on WiFi technology.

III. COMMEASY, SYSTEM DESCRIPTION

CommEasy consists of two applications - the students' application and the instructor application. Both applications work on the personal devices of the students and the instructor (iPhone and iPad) and allows them to interact instantaneously during the lecture. Both applications allow the instructor and the student to create an account with their chosen email and password (Fig. 2).

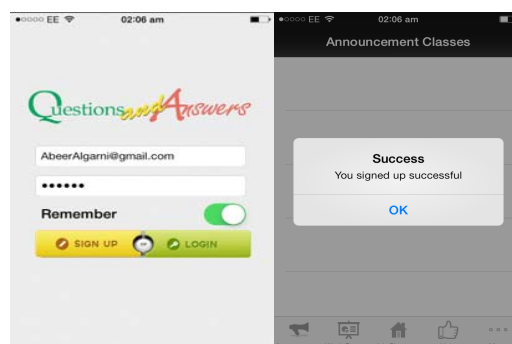


Fig. 2: Main Screen of the Application

The instructor application provides the following features:

- It allows the instructor to create a new virtual classroom with its own details (title of the class, venue, date and time) and the system will provide the instructor with a unique access key (Fig. 3). This access key will be given later to the student to allow students to join the class.
- It allows the instructor to add a list of topics that will be discussed in the classroom. This helps to categorise the questions posed by students under these categories.
- It allows the instructor to answer any questions posed by students and to send an answer to the students;
- It allows the instructor to pose questions to their students in a form of quiz (questions with multiple

answer) and allows the instructor to browse the results of such voting (Fig. 4 and Fig. 5).

- It allows the instructor to post announcements related to the class with the following details (title of announcement, date and time, and details of the announcement).
- The instructor application will also provide the instructor with many basic functionalities such as login, logout, remember my password, change password as well as allowing them to browse the Help, FAQ and Contact Us for technical assistance.

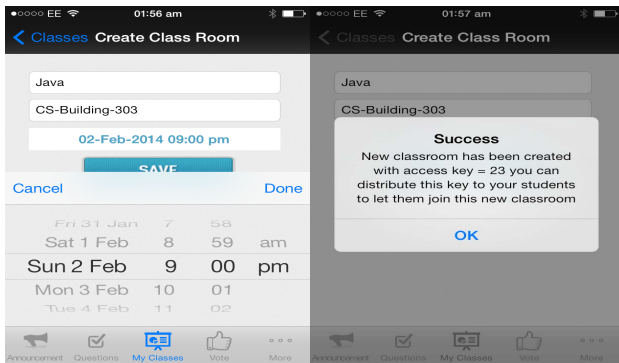


Fig. 3: Create New Classroom (Instructor Application)

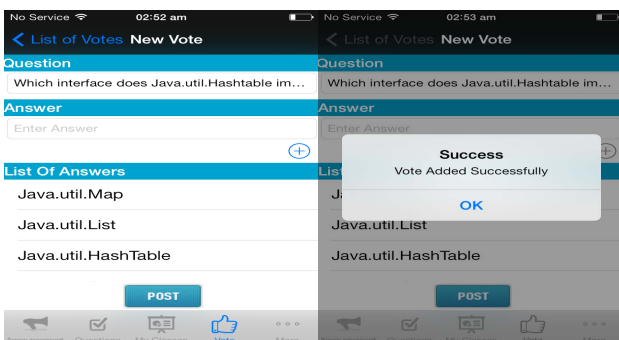


Fig. 4: Create the Question for Voting (Instructor Application).

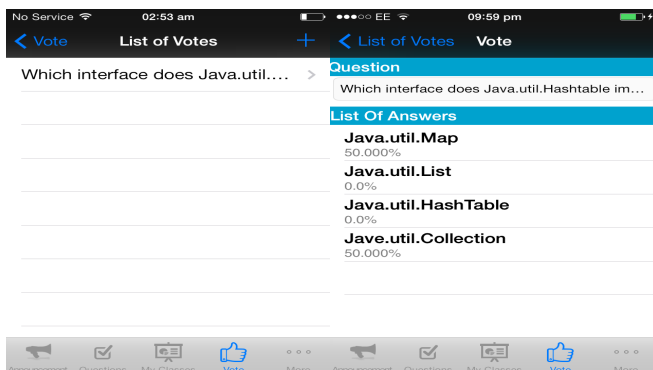


Fig. 5: Browsing the Voting Result

The student application provides the following features:

- It allow students to join the class using the access key given by their instructor (Fig. 6);

- It allow students to pose text-based questions to their instructors as well as to browse the answer sent by the instructor (Fig. 7 and Fig. 8);
- It allows students to browse the questions sent by their peers, along with the answers provided by the instructors to these questions;
- It allows students to answer the questions sent by their instructor and to post the answers to their instructor (Fig. 9);
- It allows students to browse announcements sent by their instructor (Fig. 10).
- The student application also provides students with many basic functionalities such as login, logout, remember my password, change password as well as allowing them to browse the Help, FAQ and Contact Us for technical assistance.

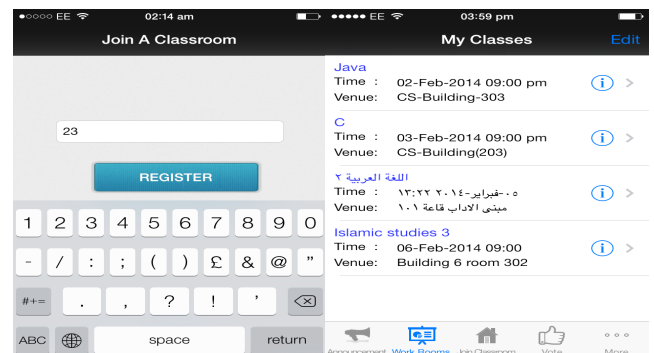


Fig. 6: Registering to the Class

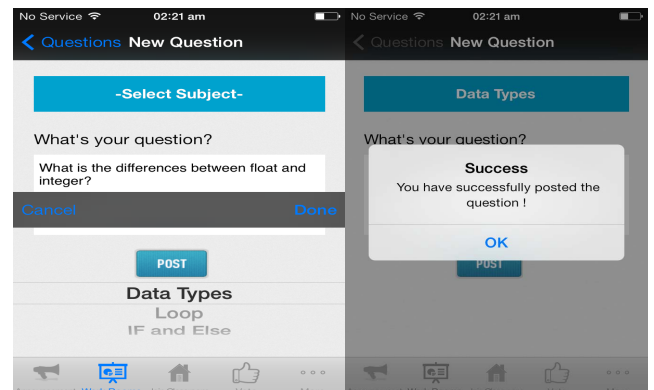


Fig. 7: Posing a Questions for Instructors

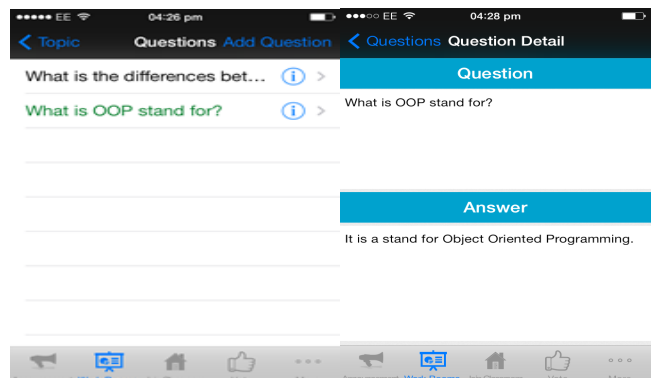


Fig. 8: Browsing Answers in Students' Application

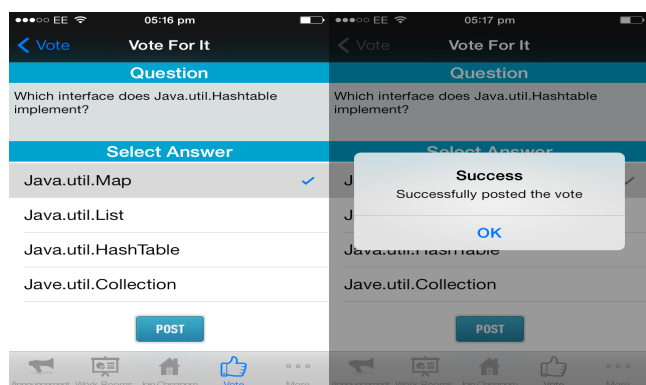


Fig. 9: Answering the Voting (Student Application).

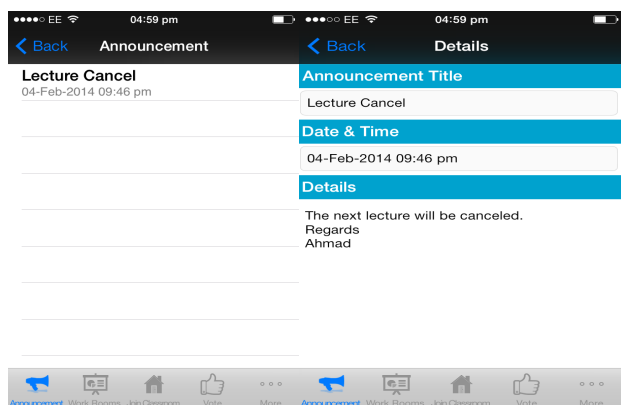


Fig. 10: Browsing the Announcement (Instructor Application).

IV. METHODOLOGY

One of the most useful approaches to obtaining information regarding people's characteristics, opinions, attitudes, perceptions, etc., is by using a survey approach [11]. In the survey approach, many different data collection instruments can be used, including questionnaires, interviews, etc. Participants' perceptions and attitudes can be effectively measured using a questionnaire that asks participants to express their level of agreement with the questionnaire items using a five-point Likert scale [14].

In this paper, it has been decided to design two questionnaires - one for measuring students' perceptions with regard to the student application, and the other for measuring instructors' perceptions with regard to the instructor application. Both questionnaires were evaluated with the assistance of a group of five experts who were majoring in Computer Sciences, Software Engineering and Technology Enhanced Learning. The participants included 30 female students from KSU who were chosen randomly from 63 students and were enrolled with a male instructor in a 'Islamic Studies' subject in a distance learning classroom through the use of video conferencing technology. Data collection was carried out in March-April 2014. Both students and their instructor were allowed to use the system for one month. During the first two weeks, students and instructor communicated without the using of CommEasy. In the following two weeks they were able to communicate with

each other with the use of the CommEasy system. At the end of the month, online questionnaire were emailed to both students and instructor in order to identify their attitude towards the system.

The aim of the student questionnaire was to identify the perceptions of the students with regard to the role of the CommEasy system in terms of enhancing communication and participation in the classroom, and in solving the problems students face in this regard. It is also aimed to evaluate the application by using some metrics such as ease of download, ease of use, ease of run, etc. The survey also aimed to identify the advantages/disadvantages of the application from the students' point of view, as well as gathering students' comments and suggestions.

The student questionnaire included two parts: the first part concentrated on evaluating the role of the system in solving the problems that students faced in terms of participation and communication with the male instructor. In this part, students were provided with a list of items and, for each item, they were asked to express their level of agreement using a five-part Likert scale (Strongly Agree, Agree, Neutral, Disagree and Strongly Disagree). The second part of the questionnaire was used to assess the application based on some metrics such as ease of download, ease of run, ease of use, etc. Similarly, students were asked to express their level of the agreement using a five-part Likert scale (Strongly Agree, Agree, Neutral, Disagree and Strongly Disagree). The questionnaire also included an open question to allow students to express their own opinions regarding the advantages and disadvantages of the application, and to offer any comments they might have (See Appendix A).

For the questionnaire aimed at the instructor, it had similar objectives to the student questionnaire. The aim was to explore how instructors perceive the system in terms of facilitating and supporting communication with their students. The instructor questionnaire included similar parts as the one directed towards the students (See Appendix A).

V. RESULTS

Descriptive statistics have been used to analyse the results of the questionnaires. In general, the results of the questionnaires showed that both students and instructor exhibit a very positive attitude towards the role of the system in enhancing communication and participation in the classroom, and solving the problems students were facing in this regard.

The results of the student questionnaire showed that the majority of female students (70% or more) agreed that the system provided them with a convenient way to communicate with the male instructor, to pose question to him and to answer question that he posed (Table1; Table2; Table3).

Table1: Evaluation of CommEasy from students' perspective (1)

Question	The system provides a convenient way to communicate with male instructors in the distance-learning classroom.				
Response	SD	D	N	A	SA
Frequency	2	6	1	11	10
Percentage	7%	20%	3%	37%	33%

Table2: Evaluation of CommEasy from students' perspective (2).

Question	The system provides a convenient way to pose questions for instructors during the lecture.				
Response	SD	D	N	A	SA
Frequency	1	3	0	15	11
Percentage	3%	10%	0%	50%	37%

Table3: Evaluation of CommEasy from students' perspective (3).

Question	The system provides a convenient way to answer the instructor's questions during the lecture.				
Response	SD	D	N	A	SA
Frequency	3	2	2	18	5
Percentage	10%	6%	7%	60%	16%

In terms of the role of the system in solving the barriers that students were faced in communication and participation in the classroom, 67% of the students confirmed that they no longer felt embarrassed with regard to communicating with the male instructor when using the CommEasy system, 73% confirmed that they were able to participate easily even if they were seated far from the microphones, and 87% confirmed that they could participate easily in the crowded classroom using the CommEasy system. However, 53% mentioned that they felt more engaged and interested in the learning environment as a result of using CommEasy, compared with 20% who were neutral and 27% who disagreed with this.

In terms of the impact of the system in terms of increasing and enhancing students' participation in the classroom, 83% confirmed that they participated more when using the CommEasy system in the classroom.

With regard to evaluating the system according to the given metrics, the results show that more than 75% confirmed that the system was easy to download, easy to run, easy to use, the GUI was user-friendly, and the Help feature of the system was informative.

In terms of the aspects that students like/dislike regarding the system, the anonymity provided by the system in posing questions to the instructor and in answering the instructor's questions was the aspects most commonly mentioned by the students. Aspects of the system such as it being reliable, easy to download quickly, and easy to use, were also liked by students. Students did not report any aspect that they disliked with regard to the system.

In terms of further comments provided by the students, they mentioned that they would prefer to improve the system in order to support additional mobile platforms such as Android.

In terms of the instructor questionnaire, the instructor agreed that the system provided him with a convenient way to communicate with female students, to receive questions from students, to answer the students' questions, to evaluate students' learning, and that the system helped to promote students' participation in the classroom.

The instructor also agreed that the system was easy to download, easy to run, easy to use, that the GUI is user-friendly, and that the help feature of the system was informative.

The instructor commented that he found the system to be an excellent endeavour to promote communication and interaction in the distance-learning classroom and appreciated the value of the system in terms of increasing the level of female student participation compared with traditional lectures where the system was not used. He also strongly welcomed using mobile applications in higher education as the majority of university students in Saudi Arabia owned such devices and they had become a part of their everyday lives. However, he mentioned that it would be better if the application could be improved to support additional platforms such as Android.

VI. DISUSSION

From the results presented above, one can conclude that both the female students and their male instructor had a very positive attitude toward the role of the CommEasy system in enhancing communication and participation in the distance-learning classroom. The system encouraged students to be more active in the classroom and to participate and interact with their instructor, as observed in the classroom and as they reported. All students who used CommEasy were enthusiastic about continuing to use the system and reported that it is the best way to participate in the distance-learning classroom as it is very convenient and easy to use. The majority of students (70% or more), as presented in the results, confirmed that CommEasy provide them with a convenient way to communicate with their male instructor and ask questions as well as receive answers. The male instructor also confirmed the importance of the system in supporting interaction in the classroom. He reported that the level of student participation increased when CommEasy was added to the classroom and that the female students became better engaged in the learning environment. Furthermore, the system allowed him to evaluate students' learning through post them quizzes. Therefore, CommEasy proved its value in enhancing students' participation in the classroom, which, as stated previously, is a very importance part of the learning process and has numerous advantages, including leading to better learning and better marks and enhancing students' motivation to learn.

However, as presented in the results (Table 1), a minority of students (27%) did not perceive CommEasy as a convenient way to communicate with male instructors in the classroom. The comments those students provided suggest that this could be due to some psychological reasons. In Saudi Arabia, female students are not used to engaging with male instructors, having spent more than 18 years studying in completely segregated learning environments. Thus, those students mentioned that they preferred not to participate with male instructors, with or without CommEasy. They expressed that they preferred face-to-face classrooms with female instructors instead.

The students and their instructor also demonstrated a very positive attitude toward the role of CommEasy in overcoming the barriers they were facing in distance-learning classrooms. Female students appreciated the value of CommEasy in reducing and removing the barriers they faced in these classrooms. The system allowed female students to participate and interact easily with their instructors without a need to leave their seats, use the microphones or speak to the instructors. As previously mentioned, such elements were pressures or barriers for female students in Saudi Arabia, and CommEasy has effectively solved all these problems. Hesitation to speak to the instructor, hesitation to ask questions and crowding in the classroom are major concerns for educators not only in Saudi Arabia but also worldwide. CommEasy has proven to offer a valuable solution that can help to abolish such barriers and provide students worldwide with a convenient and easy way to pose questions to their instructors, as well as to respond to instructors' questions.

CommEasy includes many features that make it an excellent endeavour that can be used to enhance communication and participation in both traditional settings as well as distance-learning settings. The system guarantees students complete anonymity. This is considered by many educators to be a major feature that encourages students to participate and interact in the classroom. The system allows both students and instructors to use their own smart handheld devices, and this reduces costs compared with other technologies such as clickers. The system proves that is easy to download, run, use, with an effective graphical user interface and effective help and support as reported by the students and instructor considered in this paper.

Therefore, CommEasy supports the current trend and pedagogies that assert that using mobile applications in education can promote student communication and participation in the classroom.

VII. CONCLUSION

This paper presented the perceptions of instructors and students with regard to the role of the CommEasy system in enhancing communication and participation in the classroom and in removing the barriers that students face in this regard. The perceptions of instructors and students have been

identified through the use of two questionnaires: each included a list of items, and the participants were asked to express their level of agreement using a five-point scale (Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree). According to the results of the questionnaires, both students and instructors show a very positive attitude towards the role of the CommEasy system in support of communication and interaction, and in solving the barriers that student faced in this regard. However, support for additional platforms such as Android will be provided in following versions of the system.

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APPENDIX A

The perceptions of female students towards the CommEasy system

With regards to the CommEasy system that you have used in the participations with the male instructor during the last two weeks, please respond to ALL of the following items by choosing the response that best matches your opinion (Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree).

- The system provides a convenient way to communicate with male instructors in the distance-learning classroom.
- The system provides a convenient way to pose questions for instructors during the lecture.
- The system provides a convenient way to answer the instructor's questions during the lecture.
- I no longer feel embarrassed to communicate with the male instructor with the CommEasy system.
- I feel more engaged and interested in the learning environment with using CommEasy.
- I participate more with using the CommEasy.
- CommEasy makes communication with male instructors after lecture easy.
- I can participate easily in the crowded classroom using CommEasy system.
- I can participate easily even if I sit far from microphones.
- The system is easy to download (application loads quickly and does not crash).
- The system is easy to run (account can be created easily and quickly).
- The system is easy to use (you can launch and navigate within the app easily).

- The GUI is user-friendly (allowing you to interact with the application in a natural and intuitive way).
- The Help of the system is informative (the system's help page provides useful information).
- What aspect(s) of the CommEasy system did you like/dislike?
- Do you have any suggestions or comments to improve the system?

The perceptions of the male instructors towards the CommEasy system

- The system provides a convenient way to communicate with female students.
- The system provides a convenient way to receive questions from students.
- The system provides a convenient way to answer the students' questions.
- The system helps instructors to evaluate students' learning.
- The system promotes students participation in the classroom.
- The system is easy to download (application loads quickly and does not crash).
- The system is easy to run (account can be created easily and quickly).
- The system is easy to use (you can launch and navigate within the app easily).
- The system is user friendly (the GUI is functional and visually stimulating).
- The Help of the system is informative (the system's help page provides useful information).
- What particular aspect(s) of the CommEasy system did you like/dislike?
- Do you have any suggestions or comments to improve the system?

Online Game-based Programming Learning for High School Students – a Case Study

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Abstract—[Context] The inclusion of programming concepts in high school education has been emerging, since applying computing in high school education is a way to motivate and prepare students into the field of technology. [Objective] This work evaluates the teaching programming games for high school students based on different forms of distance education (online video lessons, broadcasted live or recorded, and tutorials in PDF). [Method] A case study was performed in the second half of 2014 with 30 high school students enrolled in an online game programming challenge. The students had access to the different formats of online lessons and they were monitored by tutors in a online learning environment. [Results] Over 75% of the students performed and sent all the activities requested in the study, suggesting that all investigated online formats are effective. However, 85% of students indicated their preference to use recorded video classes to learn programming. Finally, 100% of the students said that they would participate again in such challenge, showing the attractiveness of the game development. [Conclusions] We considered that online formats (specially recorded video) can be used to promote the development of games to introduce programming knowledge in high school education. However, the lessons learned (difficults found and improvement suggestions) should be taken in consideration to implement online solutions in large scale.

Keywords—Game; Programming; Learning.

I. INTRODUCTION

The advance of the information technology industry is demanding more computer professionals than they are provided by the graduation courses. In fact, the search for undergraduate courses related to computing is decreasing, as well as the proportion of students who graduate in these courses [1].

To attract more students to the computing area, a lot of initiatives are teaching programming concepts to students still in K-12 education. Some of these initiatives use games to make the process more playful. Despite the easiness offered by these learning platforms, its uses often require minimal knowledge of programming by the high school teachers, making the scalability of these proposals more difficult. The use of online teaching-learning solutions, on the other hand, might not be so efficient for students who are too young.

In this context, this paper evaluates the online teaching programming, based on video lessons (broadcasted live or recorded) and tutorials (PDF text), that teach high school students how to program games. The videos and additional didactic materials utilized were created in a way that allowed the student himself to perform the proposed activities in their schools or even at home. Each lesson focuses on the development of a game, starting with the game design and going through to its implementation, organized in a sequence of steps followed by students.

Thus, to evaluate this online learning proposal, a case study was performed in the second half of 2014 with 30 students enrolled in high school education. This study aimed to evaluate the implementation of tutorials and video lessons, in order to characterize the effects of this approach on these students, regarding the teaching of introductory programming concepts – variables, data types, selection/decision structures, etc. – using the context of games. Another purpose was to capture useful information to allow the creation of new methods of online teaching-learning programming.

Promising results indicate the viability of online learning of game programming in high school education, their effectiveness and ability to scale, satisfying a considerable number of students (75% of study participants) at reduced costs. In this perspective, we hope that this paper inspires new initiatives in the online programming education, especially based on video lessons. The rest of this article is organized into six more sections. Section II presents a background of related studies. Section III describes the execution of the study. After that, in Section IV, the methodology used; In Section V, the overall results; a discussion in Section VI, and finally, in Section VII, the conclusions and perspective of future work.

II. BACKGROUND

A. Teaching programming in high school

Although computing is present in all sectors of society, there is a lack of knowledge and interest of the population in this area. One of the reasons is the lack of teaching programming in high school.

Studies involving teaching programming with K-12 students, both in distance education and on-site presence, with the gaming theme, have been reported by other researchers [1][2][18][19]. In addition to contributing to the development of problem-solving skills and logical thinking of students, these works eventually disclose the computing area as a possible professional career. The introduction of programming concepts, as a science, in the high school, is of fundamental importance and relevance [3], both to spread this concept in schools, and to possibly attract new talent to the area.

In this context, there are many factors that point to the importance of the insertion of programming education in schools. In [4], two factors are highlighted. The first is that the programming education enables the development of capabilities that contribute to improve the logical thinking of students, and the second is that such proximity can help setting the vision and attitudes of students regarding the use of technologies that they usually handle. On the second factor, Resnick (creator of Scratch software [5]), presents his point of view about the term "Digital Natives" [17]. For him, there is a mistaken view about the ability of digital natives regarding the use of technology. According to Resnick, young people spend most of the time consuming technology, but that does not make them fluent in it. In his perception, they end up developing the ability to be good consumers of information, but they are not able to realize the potential of producing technology.

In this perspective, some countries have implemented a programming curriculum in their schools [3]. Estonia has implemented a program for teaching programming to students from seven years and up [6], Israel has also implemented a coherent computing curriculum for their schools [7] [8]. The United States have been keen to build those skills early on, from the very first levels of education. According to [9], this is because the governments of these countries understand that this will generate impacts on their economies and on the ability that their citizens will have to adapt to changes. Other countries have also placing these concepts in their curricula, such as UK [20] and New Zealand [21].

However, in most countries the learning of programming concepts in general is still reserved for those who choose graduation courses in the area or related courses. In general, the main goal of this study is to investigate the introduction of programming concepts to students in high school through game programming, since these are part of the reality of many students, motivating and working on them the vocational awakening and development of computational thinking.

B. Online learning

New innovative practices in education include the use of video classes. The goal of using video classes is to enrich the process of teaching and learning.

Video lectures for content related to programming learning are easily found. Many teachers have created materials to support student learning and posted on the

Internet, for example, through YouTube or Khan Academy¹. Studies have also highlighted the efficiency of video lectures in the programming learning process [14] [15]. The main differences of video lectures with other teaching methods are the following [16]: (i) Instructive, encourage students to think independently; (ii) Practical emphasis, emphasizing the application capacity; (iii); (iv) Teachers guide students to participate, in the importance of communication; (v) Emphasis on teamwork, developing the collaboration sense of students.

Being an audio/visual feature, a video lecture plays a didactic function, where the transmitted information can be heard and viewed, facilitating the understanding of them, thus contributing to spread the use of video lectures as a way to insert the programming concepts in high school .

III. STUDY CONTEXT

This study was conducted in the context of an online training challenge and competition of gaming programming. This initiative aimed to: (i) encourage creativity and skills related to the design and development of digital games; (ii) encourage the programming in high school ; (iii) work the vocational awakening and attract new talent to the computing area; (iv) train and develop students' skills in the development of digital games through the use of game tools (engines) such as Construct2; (v) promote an online learning environment in order to enable students into the development of digital games in the academic area; and (vi) engage students and teachers in activities that stimulate knowledge about computational thinking and use of digital games in high school .

This challenge was built and made available as an online learning environment (Moodle) with recorded classes, live online classes and tutorials that taught the programming of digital games through the Construct2², a visual programming environment for creating games, that is, no coding is required to create games. The students create games in Construct2 by manipulating graphical elements according to the programming logic to be used (events, conditions, actions, etc.).

Despite being an open challenge to any Brazilian student, its disclosure was more restricted to the state of Rio Grande do Norte. In this challenge, three online Moodle tutors were made available during the morning, afternoon and evening, while the initiative was running. The tutors were scholarship students of a research lab in games and educational platforms. They were students from computing undergraduate courses with knowledge in game development with Construct2.

Although we provided tutors for students, the interaction between them in the carrying out of activities by the students was in the form of "learning by developing," that is, there was no prior training of the students and it was not

¹ <https://www.khanacademy.org/computing/computer-programming>

² <https://www.scirra.com/construct2>

determined prior requirements for the participation of students, for example, having initial knowledge of programming logic or algorithms.

The challenge was divided into three steps: Dissemination, Training and Competition. The disclosure was carried out through social media (Facebook, Twitter and Google+) and visits to some schools in the city of Natal, Brazil.

The training step aimed to enable students into the game development with the Construct2 tool. At this stage, classes were recorded and online classes and tutorials were transmitted. The classes took place between the period from September 1st to 16th, 2014, every Monday, Wednesday and Friday. These classes were available on Moodle, where students could access the lessons and question the tutors. In each class, it was provided a different game that worked various concepts, such as variables, conditional structures and the introduction of the tool's features.

The competition step aimed to evaluate, select and award the best participants of this initiative. At this stage, the participants met in teams of two to five members and submitted one game for competition. Each team had to have a teacher as advisor, and all games developed in this step had to be educational games. At the end of the challenge, the best games were awarded.

IV. CASE STUDY PLANNING

This study aims to evaluate different forms of online teaching in game programming for students of high school, in particular, the recorded video lessons. For the case study design and report, we followed the guidelines proposed in [10] [11].

A. Research Questions

The Research Questions (RQ) addressed by this study are the following:

- **RQ1:** Is the way of teaching used in the study efficient?
- **RQ2:** What is the impact of the lessons transmitted online, recorded and tutorials on the students' views?
- **RQ3:** Is this kind of study attractive?
- **RQ4:** What is the scalability of the study?
- **RQ5:** What difficulties were shown by the students by participating in the study?
- **RQ6:** What difficulties were shown by the tutors for the conduction of the study?

B. Participants

The participants are students who participated in the game programming challenge. Although the challenge was open to students of any educational level, only the results of students enrolled in high school education were considered to answer the research questions of this study.

The challenge had more than a hundred of participants, but only 49 were from middle and high school (target audience of the study). From these 49 students, only 30 of them answered our online questionnaires (22 men and 8 women). The oldest student was 19 years old and the youngest was 14. The average age was 17 years old. Table 1 shows the number of participants by level of education. See that nine students were from technical high school.

TABLE I. AMOUNT OF STUDENTS PER EDUCATIONAL LEVEL.

Level of Education	Quantity
High School	21
Technical high school	9
Total	30

C. Study Object

The objects investigated in this case study were the classes used in the challenge. There were 17 classes in total, with 12 recorded video classes, 3 tutorials described in text and 2 live classes transmitted online. The high number of recorded video classes is due to restrictions by the rules of the challenge, which prioritized the use of recorded video classes. Each lesson was about a different game, displaying the game at first and then, the walkthrough for the implementation of it with Construct2. At the end, students should create extended versions of the game and submit them in the Moodle platform.

The games utilized in each class had approximately the same development complexity. They all exercised the basics of programming (variables, loops, conditional structures, etc.). To respect the rules of the challenge, the 12 recorded video classes were utilized first, 3 per week, on Mondays, Wednesdays and Fridays for 4 weeks. After that, the students had access to other 4 classes, 2 per week, a written tutorial on Wednesdays and a lecture broadcasted live on Saturdays. The choice of transmitting on a Saturday was made so a greater number of students could participate.

D. Analysis Unit

The analysis unit in this study was each student, of high school, that participated in the challenge. In each class, it was monitored if the student had accessed the lessons and sent their task, if he had performed interactions with tutors and participants, etc. They also had their opinions collected through web forms, applied by the end of the challenge.

E. Data Collection

In this case study, the following data were collected from participants: The executable file of the games; Dialogues of students enrolled in discussion groups and chat rooms; Answers to questionnaires applied to students and tutors; Notes on the behavior, questions and difficulties of students in carrying out activities.

The data were collected through forms available in Moodle, where students answered voluntarily.

V. RESULTS

In this section, it will be presented the study results according to the answers to the research questions.

A. [RQ1] - Is the way of teaching used in the study efficient?

One way to encourage students to improve their knowledge in a particular area is the development and engagement in knowledge competitions in specific areas, in our case, the teaching of programming. When entering the study, the participating students were engaged in the mission to prove their knowledge by carrying out the activities, in other words, the proposed challenges (development of games).

The way of teaching in the initiative was inserted to provide the student with a situation that arouse curiosity and love of learning and investigate; ability to solve problems, predict outcomes and choose solving strategies of a particular problem, and with that, we could note that the motivated students tend to be more persistent and show higher levels of performance.

To participate in the study, students had to carry out activities like, watch video classes and tutorials, and at the end of these activities, submit a game with a requested improvement. The whole process was accompanied by tutors. Therefore, in this study, 17 activities were made available, being 12 recorded video classes, 3 written tutorials and 2 lessons transmitted online.

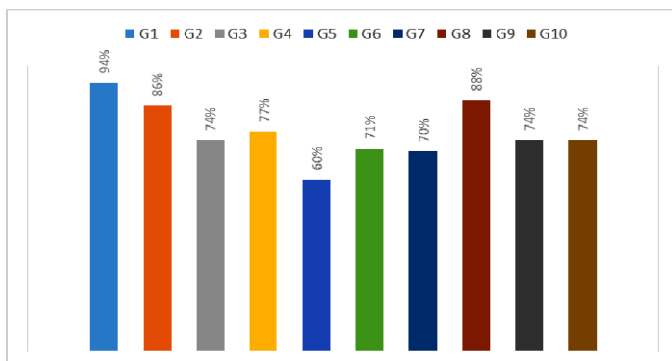


Fig. 1: Percentage of submission of activities by the groups.

To answer the research question 1, we randomly divided the students into 10 groups of 3 students each, to analyze the rate of submission of activities. Figure 1 summarizes these results.

As can be seen in Figure 1, for the 17 activities, most groups have managed to send over 75% of the activities. Analyzing the data individually, 20 of the 30 participants were able to send all activities.

It became clear, then, that studies like this, in which the activities are carried out in a playful way, with the teaching programming linked to game development, may enhance the development of initial concepts of programming. Also, it brings this knowledge to the daily lives of students by showing them how to apply it to solve real problems and that

involving playful activities, using games, is a healthy way to insert teaching programming in schools.

Therefore, by looking at the results obtained, we believe that this teaching method is effective for teaching programming to students who are enrolled in basic level of education, finding that over 75% of the students performed and sent all the activities requested in the study.

B. [RQ2] - What is the impact of the lessons transmitted online, recorded and tutorials on the students' views?

To answer this question, an online form was made available to students with seven questions; six subjectives and one objective. In these questions, students presented the advantages and disadvantages of the three formats used in this case study and by the end, chose the most appropriate way for them. To administer the questionnaires, we adopted Google products, because they are stable tools and known to most students.

Regarding the recorded video classes, a particular student described the following advantage: *"The main advantage of the recorded lesson is to be able to pause and/or return to the video and follow the explanation at your pace, and that in the video we can see the teacher actually making the game work"*; another student added: *"to be able to watch at any time, if you cannot attend the scheduled time because of some unforeseen event"*. As a downside, a particular student presented *"the lack of interaction with the teacher"*.

However, regarding the video classes transmitted online, another student pointed the following advantage: *"watching a live class can be more of a privilege to some people, like you were actually in a classroom with the teacher"*. Another recurring point was the interaction between student and teacher. A downside of online classes was highlighted by a student: *"the impossibility of returning the classes immediately"*. Another point mentioned was that, since the classes had a specific schedule, there was the possibility that some students were not available at a given time.

Ultimately, another available method was the use of tutorials with a walkthrough of the developed games. This aspect was highlighted as essential by the students, because it presented written instructions of steps for the development of games. This method was highlighted as relevant by students in the programming learning process. One student highlighted the following benefit of this method: *"the tutorial format may be the easiest form of access to all and also a format that allows the student to do the proposed activities and to monitor the lessons at his own pace"*. As a downside: *"The reading of the tutorial makes this format a little more tiring and we lose a little more interaction with tutors"*.

The results of our case study showed a higher preference for the use of recorded video classes, 85% of students indicated that they prefer to use this method to learn programming. However, 10% prefer online classes and 5% prefer tutorials.

In this context, we believe that the study had a considerable impact on the participants about teaching and

learning of programming with the use of games. However, we did not have, in practice, the knowledge of what would these impacts be and how they would contribute to the learning of the students. After the study, the following results were observed:

- The students learned the initial concepts of game programming in a short period of time: programming is usually taught as a basic subject in the beginning of a college course. Thus, inserting this concept in high school , we are encouraging new talent to the computing area and working the vocational awakening of these students;
- The challenge was organized based on a constructivist approach to learning [12], in which each student learns at their own pace and steadily builds their own knowledge through the development of games. We believe, as many researchers [1] [13], that this kind of approach can attract new students to computing and also spread this knowledge in the basic level of education, by inserting this subject as a way of solving problems through programming.

C. [RQ3] – Is this kind of study attractive?

We observed in the study that 100% of the students who participated in this first study said that they would participate again in a second version. This analysis was performed using a questionnaire during the execution of the study. For these students, this way of teaching is attractive because it presents the programming concepts through an instrument that is of use and knowledge of them, the games. The volume of applications was large, 300 students signed up, but only 30 answered the questionnaire.

By applying the practices presented in this study, we could see a good feedback from the participants, and this was reflected in the results of the questionnaire that was used during the study, which its results are presented below.

Considering a general assessment of the quality of the study, 84% said it was excellent, while 16% of people thought that was good. It was also questioned, how often students would like to have programming classes of digital games in schools. This response is illustrated in the graph of Figure 2.

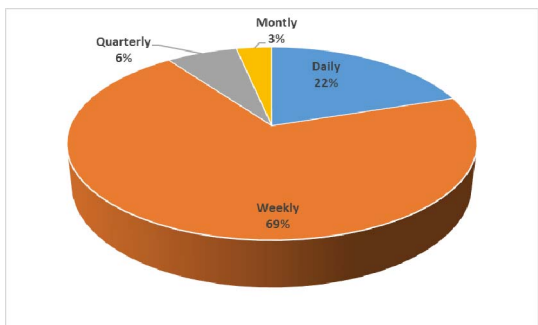


Fig. 2: Frequency of digital game programming classes in schools.

As seen in Figure 2, students of this level of education have interest in learning programming in the schools they attend weekly. This factor shows the need for more research that insert this content for students. These data justify the need for this study, to work computational thinking in schools and attract new talent to the computing area.

We believe that the teaching of algorithms related to the activities seen in class motivates students to learn, both the content of the discipline and programming, because they are working concepts involving school subjects content with the programming elements.

In another point, students were asked to evaluate the statements presented in Table 2, and answer between Strongly Agree (SA), Partly Agree (PA), Neutral (N), Partly Disagree (PD) and Strongly Disagree (SD).

TABLE II. EVALUATION OF AFFIRMATIVES.

Affirmatives	SA	PA	N	PD	SD
AF1: The study is meeting my expectations	27	3	0	0	0
AF2: The time of video classes are suitable	12	16	0	2	0
AF3: I managed to perform all activities.	20	10	0	0	0

Regarding affirmative AF1, the 3 students who agreed partially wanted the video classes to present more advanced features of the tool, and to provide more advanced content of programming. But the goal of the challenge was to insert basic programming concepts and that goal was achieved. In future studies, classes will be offered with more advanced content.

Regarding AF2, 2 students said that the duration of the video classes was not appropriate. The video classes had an average of 30 to 45 minutes and for some students this time was excessive. At this point, a questionnaire was given to students with the following question: How long do you think video classes should be? By seeing the answers, we realized that there is no homogeneity of the students regarding appropriate video classes duration. At this point, 8 students thought the ideal duration is 30 minutes, 6 considered that the adequate duration is 40 minutes and 5 reported that the duration should be 35 minutes. To another 5 students, the duration should be 45 minutes, but to other 3, 60 minutes is enough. Finally, 3 students thought 25 minutes is the ideal duration. In the future, we will elaborate classes of up to 15 minutes and resources for specific functions, for example, a lesson to resolve collisions problems, at most 4 minutes.

Regarding AF3, we found that most students were able to send, totally or partly, the activities. In this statement, we could identify two problems in which students were unable to send the activities in its entirety. The first is that the activities had a deadline to send and some participants waited to do the activities near the end of it and, consequently, there was no time. The second point was regarding the activities of the schools, which were on exam period, and some students could not do these activities on time. In such cases, it was given a second chance to students to send the activities.

At the end of the initiative, it was noted that the students had acquired knowledge regarding the common concepts present in most algorithms, such as variables, loops and

control, and that may help them learn a programming language. In this perspective, the intention is that the next edition we will include other technologies, such as HTML5.

These results demonstrate that this study is attractive to students of high school, and that could be analyzed through the performance of the activities, the interaction of students with tutors, either through chats, like the forums, and especially, by the fact that 100% of the students said they would participate in future studies involving programming and games.

D. [QP4] – What is the scalability of the study?

To answer this research question, we used the questions reported in the forums and chats exchanged between students themselves, and between students and tutors. The scalability question is related to how many students we were able to meet in different locations and affordably, and this is related to the volume of generated questions.

The scalability of the proposal was considered high after analyzing the total number of access to forums and chats through logs in Moodle, and also the fact that we should be able to meet students located in different physical locations. The number of students involved is considered great, since these students participated voluntarily and had no initial incentive to participate in the study, like for example, saying that the students who participated in the study would gain a higher score in a given discipline.

To increase the scalability of the proposal, it was decided to perform synchronous and asynchronous activities. We defined that the activities should take place three times a week, regardless of the time that each student was willing to use them, and we considered this part as an asynchronous activity. But to avoid the difference in the learning pace and so we could track the progress of students in the study, we set a deadline for the delivery of activities and online service hours (performed by tutors), and this step was defined as a synchronous activity.

With the results of the study, we considered that the proposal is scalable and can be implemented for teaching programming in primary schools without having to significantly increase the number of tutors, as many of the questions were common and answered in the forums, including by the participants themselves in some cases.

E. [QP5] – What difficulties were shown by the students by participating in the study?

To answer this research question, we used feedback from students in the questionnaire that was applied after the case study. We will deal with the difficulties of students considering their own opinions. We also presented suggestions for improvement, according to reports of the students.

Difficulties related to classes and functions of construct2

The difficulties reported by students were regarding the amount of lessons per week. Since the study was performed within one month, it was made available 3 per week, and

some students thought that was too much because they also had other activities related to schools in which they studied.

Another difficulty was noted regarding the use of specific events in Construct2. As can be observed, the following two questions were in a discussion between a student and a tutor:

Student A: *I can only make the first enemy shoot and the enemy's frame does not change.*

Tutor A: *if the frame does not change in the event 'Every 2 seconds', add an action to the enemy and then 'Stop', he'll stop in the first one you choose.*

Student B: *when an object collides with another, how do I get a different reaction if they collide again? Example: the ball object collides with a block, adding 1 point to the score, but when it collides again, it adds another point to the score. What can I do to make sure that the score does not change at every collision with the same object or anything that's in the collision event?*

Tutor B: *Create a variable, assign 0 to it and make the score, if the variable has value 0. If the ball hits the object, increase the score and the variable changes its value, so it no longer counts the point if the ball hits again.*

As seen in the examples, whenever the students had a doubt about the functionality of the tool or difficulties in the development of the game, tutors answered these questions with possible implementable solutions. It was not given a direct solution, the tutor always helped the student to think by himself to find a solution to the problem, working only as a facilitator in this process.

Suggestions for improvement

The students reported the following suggestions for improvement: Extend the time for delivering the activities; Provide one class per week; Fictitious awards to encourage students, for example, using gaming resources.

F. [QP6] – What difficulties were shown by the tutors for the conduction of the study?

To answer this research question, we used the results from the questionnaire answered by the tutors, which was applied after the case study. The three tutors who participated in the study completed the questionnaire.

In this study, tutors had the responsibility to encourage and answer questions from students when they were in doubt and guide them in solutions of the games, since the course was not compulsory and students participated voluntarily.

Therefore, we presented the answers obtained in this questionnaire in a summary form and arranged in the form of threads, as shown below.

Observed difficulties in students

According to the tutors, the main difficulties encountered were:

- **Contact by chat:** at the beginning of the activities, students did not have the initiative of questioning tutors when in doubt. Because of that, tutors

initiated the interactions encouraging students to question;

- **Time to carry out the activities:** students also questioned about the time given for submission of activities. Since there were 3 lessons per week, they found that it were too many classes in a short period of time.

Suitability of the material provided to students

The tutors consider that the material provided to the students is suited. The suggestion for improvement is to have specific classes for certain functions in Construct2, for example, how to use the behavior platforms, using the Physics behavior, and so forth. This brings benefits, because the student learns more about the tool and the classes would have a shorter duration. These specific classes would help students to solve certain problems during development. For example, if a student is in doubt about how to make a particular character jump, he will attend the particular lesson on this functionality. These specific classes are now being developed for the next editions of the studies.

Encountered difficulties by tutors in conducting the study

When starting the activities, tutors felt difficulty in engaging students in discussion forums and chats about the activities that would have to be sent, as well as guide them to think about the development of activities applied for each class. To keep students active, tutors used the following strategies: Keep students motivated to develop their own solutions to the requested activities; Monitor the activities of the students; Avoid piling up questions.

Suggestions for improvement

Tutors pointed as suggestions for improvement to reduce the number of lessons per week and develop lessons for specific functions of the game.

VI. DISCUSSIONS

Given the difficulties of the study, we sought to establish a close relationship between tutors and students. In the challenge, all the tutors were responsible for all students. Each tutor had three fixed online schedules every week to serve the students and it was the students' responsibility to choose the most appropriate time to get in touch with the tutor. A disadvantage of this point is the lack of proximity between tutor and student, but the upside is in the aspect of scalability because it was possible to help a higher number of students with the amount of available tutors and also in the flexibility of the study for students, for there were always tutors available at the specified times to clarify any doubts.

In addition to using the specified schedules of tutorials, students also used the forums for discussions about usual questions. In the analysis of the forums, a question was answered by an average of 30 minutes. An important point in this regard was the fact that the students themselves were helping solve the problems, maintaining a cooperative learning environment.

Regarding the programming classes (video lectures both recorded and online, and tutorials) it became clear in the evaluation of students that these features facilitate the construction of programming learning. The study identified that the integrated use of video resources, with the use of games in the learning process of basic concepts of programming, attracts attention and the interest of students for this discipline, even if they do not have an initial knowledge of programming, and they also have their participation stimulated in the process, providing an interactive and dynamic programming learning environment.

It should be noted that the objective of the study is not to make the students experts in programming, but to present this science so it can be used cooperatively in the learning process and in solving school activities.

A. Validity Assessment

For the conducted case study, it were evaluated threats to three types of validity: external, internal and construction.

- **External validity:** The results of the study refer to the creation of mini-games (within 2 hours/work) and the use of the Construct2 tool. To evaluate other scenarios, further research is required;
- **Internal validity:** The questionnaires revealed that 30% of students had some previous experience with initial programming concepts. In addition, activities were carried out at distance, without the supervision of the staff. Despite these facts may have influenced the outcome of the study, we did not detect any sign of such influence;
- **Construction validity:** capturing the data of the implementation of this case study was carried out through the application of impersonal questionnaires (without identification of the students). The interpretation of data was conducted by a researcher who avoided errors and tendentious interpretations in the study.

VII. CONCLUDING REMARKS

This case study described the results of the insertion of programming concepts in elementary school with the use of games. The students were very receptive to the proposed activities, comprehending the concept of programming, realizing its application in solving problems and contextualizing them in their daily activities.

These results provide new ways of looking at contents that are able to involve students more efficiently, so the application of these new techniques, such as, the programming education through games, is providing a new way to enrich the teaching-learning process and thus should contribute, in a playful and accessible education form. On the issue of applicability of the study, we can highlight two characteristics: feasibility and benefits for students.

The feasibility is related to how easy working with Construct2 is, which is focused on the development of games. To use this tool the student does not need to have

programming knowledge for the development of games. The feasibility characteristic is also related to the aspects involving the development of the game, like images and scenarios to be used in the game.

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Regarding the benefits for students, we can highlight: vocation awakening; attract students to the field of computing; work cognitive and social skills that can be explored through games. For example, in the cognitive ability, we can highlight the ability to solve problems, plan, make decisions and think creatively. In social skills, they learn how to work in teams and deal with rules.

With this initial study, it became clear that we still have much to do to innovate teaching and learning of students who are attending the basic level of education, about programming. The implementation of studies that can encourage them to participate more effectively, in studies involving the teaching of programming to students who are not in colleges or universities in the area, may contribute to the formation of new professionals in this area.

Therefore, we conclude that this study, that works with programming concepts, which is housed in what theorists call the computational thinking, in high school, means fostering interest in the computer science area, showing its versatility and relevance in solving problems and demystify common knowledge that computing is a difficult and complicated area. Of course, not all students who participate in studies like this and who are enrolled in high school will graduate in the computing area, but this educational strategy can create and intensify relations with other areas.

In this case, considering the initial results already achieved, and thinking of perpetuate and improve them, there is a proposal to develop a methodology in which students participating in this study, will perpetuate this knowledge in schools.

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Reinforcing Student Understanding of Linked List Operations in a Game

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Abstract— Linked lists play an important role in learning basic Computer Science (CS) concepts among a number of different data structures. They are the basis for more complex data structures such as tree data structures. Recursion, stacks and queues can be effectively implemented using linked lists. We observe over the years that our students struggle with linked lists more than some other data structures. While students understand the concepts of stack and queue data structures faster, they need more time to understand and visualize the linked list and its operation algorithms. This paper presents a game-like instructional module called *Space Traveler* that aims to assist students to better understand and master the concepts of linked lists. Four CS undergraduate students developed it using GameMaker Studio in three months. The *Space Traveler* game looks like a classic snake game. The game supports practicing the linked list operations such as insertion, search and deletion. This paper presents the game design and implementation in detail and shares our experiences using this module in the CSC2331 Data Structure class at Winston-Salem State University (WSSU) in 2014. This module has been refined based on the feedback from students and instructors. The refined version will be used again in the upcoming semesters. A pretest, a posttest and a survey were developed and used in the evaluation process. In addition, a lab assignment was designed to accompany the game module. Initial assessment outcomes showed very promising student improvements as a result of the use of this game module in the classroom. The module has been made available online to benefit students at other institutions.

Keywords—Computer Programming; Linked List; Game-Based Learning; Data Structures; Motivation

I. INTRODUCTION

A linked list is a non-contiguous data structure composed of nodes. Each node contains a data compartment and one or more link compartments. Links are references to the successor nodes and optionally to predecessor nodes as needed. The linked list nodes are not stored in contiguous memory locations as opposed to array-based structures. Linked list is a dynamic data structure, which expands and shrinks at runtime during every insert and delete operations. Thus, linked list has the capability to utilize the entire fragmented memory unlike array-based structures.

In static array-based structures, insertions and removals may require moving and relocating the following array elements to keep the array organized. On the other hand, insertions and deletions can be made without moving any elements in the linked lists. Only a few corresponding links are altered in case of insertions and deletions.

Linked lists play an important role in learning basic CS concepts among a number of different data structures. They are the basis for more complex data structures such as tree data structures. Recursion, stacks and queues can be effectively implemented using linked lists. We observe over the years that students struggle with linked lists more than some other data structures. While students understand the concepts of stack and queue data structures faster, they need more time to understand and visualize the linked list and its operation algorithms.

Linked list data structure incorporates new concepts and challenges for students such as pointer manipulations or reference operations and list traversals besides other concepts of linked lists. The linked list operation algorithms should satisfy several conditions in order to be correct. We can list the followings among those conditions:

- The head pointer or reference which points at the beginning of the list should not be lost or should always be kept pointing at the first node in the list.
- No node in the list should be made unreachable
- Lists should be free of cycles unless it is a circular list
- The list should be kept in linear structure; it should not be broken or split.

Several researchers in Computer Science Education have addressed the challenges with learning the linked lists concepts for CS students. Fossati et al. proposed an intelligent tutoring system, which is called iList, to assist students with understanding and visualizing the concepts of linked lists [1]. Bloch identified recursion and linked list among difficult data structures concepts for students and proposed a teaching approach without using conditionals and null [2]. Goldwasser proposed a software to assist students in visualizing the linked list and understanding its memory model [3].

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Research studies show that learning difficult programming concepts in the gaming context will create high levels of enthusiasm and excitement about programming which will ultimately help students improve their performance [4]. A model of instructional games and learning that highlights the process of engagement was presented in [5]. Many educational games have been successfully used in helping students learn difficult programming concepts [6-11]. Most of our students who major in CS are minority students. Some of these students are underprepared and it usually presents a challenge for the instructor to engage these students in understanding and using data structure concepts. Many years of our own teaching experiences show that linked list operation is one of those topics that our students struggle with most. The authors have successfully developed and used several game modules in teaching [12-15].

To help our students master the concept of Linked List in the Data Structures' course, we developed the *Space Traveler* game. This game module aims to provide the students with a fun environment to visualize and master the important Linked List operations. The module supports practicing inserting a node at the front of the linked list, inserting a node at a specific location in the linked list and deleting a node from an arbitrary location in the linked list.

To evaluate the potential impact of this game module on student learning, a pretest and a posttest were developed and used in the evaluation process. A lab assignment was designed to use with the module. To collect feedback from students, a survey was conducted after the gaming session. Initial assessment outcomes show promising results and the feedback from students is very positive according to the survey. The module has been made available on the project website to benefit students at other institutions. We believe that this game module will help instructors to engage students in understanding and learning the concept of Linked List presented in class by making the learning process a fun activity.

The rest of this paper is organized as follows: Section II describes the design and implementation of the game module in detail. Section III reports our experiences using the game module in the classroom and presents the assessment results. Section IV presents our conclusions and future work.

II. GAME MODULE DESIGN AND IMPLEMENTATION

A. Game Overview

The *Space Traveler* game was developed in GameMaker Studio, a game development environment that allows developers to create games faster through drag-and-drop features and GML scripting language. Four undergraduate students (three programmers and one artist) developed the game from scratch in about three months. The gameplay time is about fifteen to twenty minutes and it does not require any prior experience in gaming. The tutorial part of the game provides step-by-step guidance.

The *Space Traveler* game looks like a classic snake game, which was used to come with some cell phones. The objective of the game is to keep a space ship alive in the space against its enemies. The space ship grows in length when it collects orbs. The ship is damaged when it is hit by enemies. The player can protect the space ship by purchasing some weapons such as a cannon or booster and adding the weapon after or before specific orbs of the space ship in a docking station. Similarly, the player needs to remove the damaged orbs of the space ship in the docking station to keep it alive longer.

The orbs of the space ship represent the nodes in a linked list. The game supports practicing the following linked list operation algorithms:

- Inserting a node at the front of the linked list
- Inserting a node at a specific location in the linked list
- Deleting a node from an arbitrary location in the linked list



Fig 1. Screenshot of the Space Traveler Game

B. Educational Component

The *Space Traveler* game not only assists students with understanding and visualizing the hard-to-understand concepts of linked lists, but also better motivates them to learn this difficult data structure concept and master its operation algorithms such as insertions or removals of nodes.

The game provides four levels of tutorials as shown in Fig. 2 to train students about the basic game controls, insertion at the front, insertion at a specific location, and deletion. Tutorials cannot be skipped. Upon finishing the tutorials, students are expected to play the game and perform at least three insertions at the front, three insertions at a specific location and three deletions, to be able to successfully complete the linked list lab session with game module. Students are allowed to access the tutorials during the actual game if they need further help. The missing parts of the code come with drop down menus, which list a couple of options including the correct expression to assist students in completing the code.

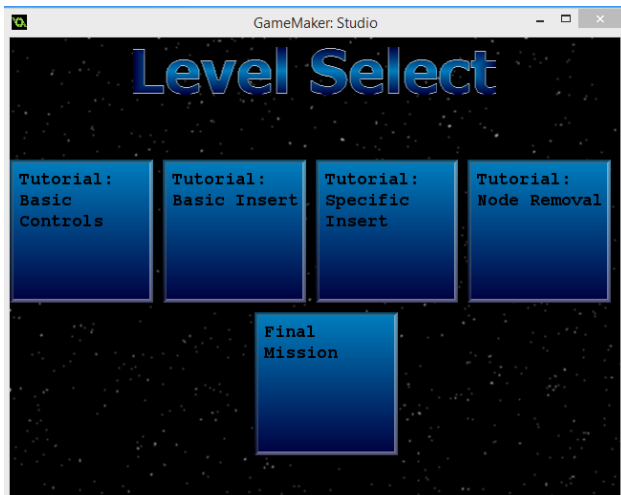


Fig 2. Game Level Select

The pseudo code segments in the game are primarily intended for the students who learn data structures in Java. Therefore, we assume using references rather than pointers. However, the game may still help understanding and visualizing the linked lists for those who learn data structures in a pointer-based language such as C++ even though the pointer operations are not elaborated in the game.

- Inserting a Node at the Front



Fig 3. Screenshot of the Docking Station When Inserting a Node at the Front

A player can add a weapon anywhere in the space ship such as at the front or after a specific orb somewhere in the middle. To be able to attach a weapon successfully at the front of the space ship, the player is expected to complete the missing parts of a pseudo code for inserting a node at the front of a linked list. The missing parts of the code come with drop down menus so students will select one from the menu to complete the statement instead of writing the statements. The player is required to perform this operation three times during

the final mission. The screenshot of the game in Fig. 3 illustrates an insertion at the front. The execution of the following statements by clicking the Run button will insert the Shield node at the front of the list.

```
Node s= new Shield();
s.next = head.next;
head.next = s;
```

- Inserting a Node at a Specific Location

The player is expected to complete the missing parts of a pseudo code for inserting a node at a specific location in the linked list to be able to attach a weapon successfully somewhere in the middle of the space ship. The player needs to perform this operation three times during the final mission. The weapon will be inserted at the specific location once the missing parts are completed and Run button is clicked. The statements are checked line by line. The player can edit the next statement only if the current statement is right. An immediate feedback will be given to explain the errors if there are any. The screenshot of the docking station in Fig. 4 illustrates an insertion at a specific location.

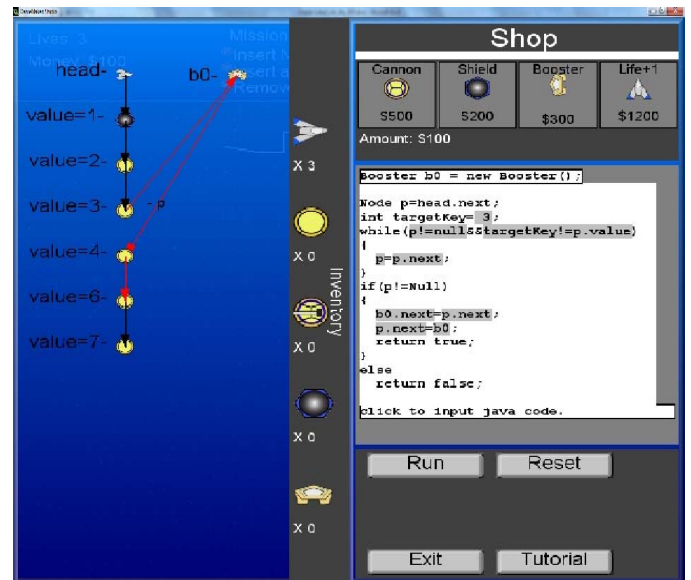


Fig. 4. Screenshot of the Docking Station When Inserting a Node at a Specific Location

- Deleting a Node

The player can remove any damaged orb of the space ship to keep it alive longer. While insertions only need one auxiliary reference/pointer variable, deletions require two auxiliary references/pointer variables, which traverse the list side by side. To be able to remove a damaged orb successfully from the space ship, the player is expected to complete the missing parts of a pseudo code for deleting a node from a linked list. The screenshot of the docking station in Fig. 5 illustrates a delete operation. Final mission requires the player to perform this operation three times as well.



Fig. 3. Screenshot of the Docking Station when Deleting a Node

III. RESULTS AND DISCUSSION

The *Space Traveler* game has been used in the CSC2331 Data Structures class at WSSU in 2014. In order to evaluate the impact of this game module on student learning, we have developed a pretest, a posttest and a lab assignment to use with this module. The module was built into a required lab assignment. Students took a pretest before they played the game during the lab session and took a posttest a few days after playing the game. A survey was conducted as well. The feedback was very positive and the assessment outcomes show promising results.

A. Pretest vs. Posttest

A pretest and posttest were created and used in the evaluation process. The pretest and posttest are very similar as shown in the following table. The pretest is shown in Table I. Each question is worth 10 points and the total possible points are 30 points.

TABLE I. PRETEST QUESTIONS

Questions	
#1	<p>The below code inserts a new node (a new Shield node) at the front of singly linked list. Fill in the missing parts.</p> <pre>Node s= new Shield(); _____ = head.next; head.next = _____</pre>
#2	<p>The below code inserts a new node (a new Shield node) in a singly linked list after the node #3. Fill in the missing parts.</p> <pre>Node s= new Shield(); Node p=head.next; int targetKey=3;</pre>

```
while (p!=null && tagetKey!=p.value){
    p=p.next;
}
if (p!=null){
    _____ = p.next;
    p.next = _____
    return true;
}
else
    return false;
```

The below code deletes the node #4 from a singly linked list. Fill in the missing parts.

```
Node q=head;
Node p=head.next;
int targetKey=4;
while (p!=null&&tagetKey!=p.value){
    q=q.next;
    p=_____;
```

#3

```

}
if (p!=null){
    q.next = _____
    return true;
}
else
    return false;
```

B. Lab

A lab assignment has been designed to use with the game module as shown in Table II. It requires students to play the game, perform the list operations in the lab sheet and answer the lab questions. Thus, students will play the game with a specific goal in mind and the game module will train them to understand the missing code needed to complete their lab assignment. In addition, students are asked to record the game score to ensure that they find the answers by playing the game.

TABLE II. SAMPLE LAB ASSIGNMENT

Task #1: Insert a Shield Node at the Front

```
Node s0= new Shield();
s0.next = _____;
head.next = _____;
```

Task #2: Insert a Shield Node at a Specific Location (e.g., after node #3)

```
Node s1= new Shield();
Node p=head.next;
int targetKey=3;
while (p!=null && tagetKey!=p.value){
    p=p.next;
}
if (p!=null){
    s1.next=_____;
```

```

    }
    else
        return false;
}

```

Task #3: Delete a Node (e.g., delete node #4)

```

Node q=head;
Node p=head.next;
int targetKey=4;
while (p!=null && targetKey!=p.value) {
    q=_____ ;
    p=p.next;
}
if (p!=null){
    q.next=_____ ;
    return true;
}
else
    return false;
}

```

Task #4: Game Score: _____

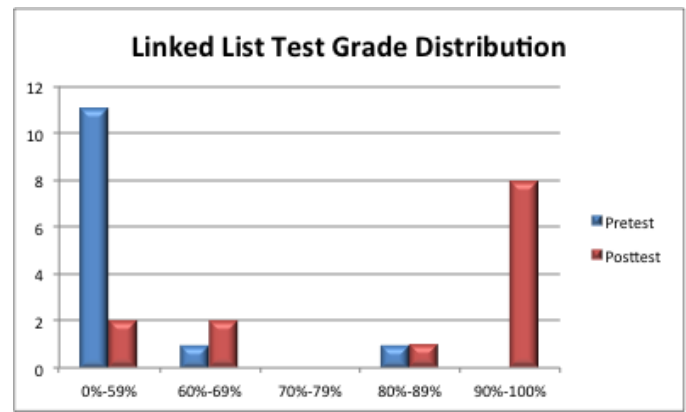


Fig. 6. CSC2331 Linked List Grade Distribution Pretest vs. Posttest

While Fig. 6 shows the grades distribution for this class, the comparison between the pretest and posttest for this class is given in Table III. These statistics show a very promising student improvement as a result of the usage of the linked list game module in the classroom.

TABLE III. STATISTICS OF PRETEST VS. POSTTEST

	Points Possible	Average	Median	Std. Dev.	Variance
Pretest	30	8.85	5.00	7.12	50.64
Posttest	30	24.62	30.00	8.28	68.59

C. Assessments

The *Space Traveler* game module has been used in CSC 2331 Data Structures course at WSSU in 2014. Understanding the concept of linked lists is among the objectives of this class. Students had the lectures on the linked list before this experiment. The test group was fairly small at thirteen but the results were very positive. Students took the pretest, played the game in one lab session and took the posttest a few days later. The pretest and posttest were very similar and the results of the pretest were not disclosed prior to the posttest. The class consisted of six male students and seven female students. Twelve of the students were African-American.

The results for the pretest were fairly dismal, only two students managed to achieve passing grades (60% or above). The passing rate for the pretest was 15.3%. Eight out of thirteen students were actually either unable to answer any of the questions correctly or only answer one correctly. The class average on the pretest was 8.85 points out of 30 points.

Student scores were improved significantly in the posttest. The passing rate for the posttest was 76.9%. The class average was 24.62 points out of 30 points on the posttest. The class average was improved by 178% from the pretest to the posttest. Eight out of thirteen students managed to get a perfect score on the posttest. While the percentage of A students in the pretest was 0%, it raised to 61.5% in the posttest.

D. Student Feedback

Overall student feedback was very positive. Fourteen students completed the survey online. The survey consisted of nine questions regarding their experiences with the game. The likert scale used on the questionnaire was Strongly Agree, Agree, Neutral, Disagree and Strongly Disagree. Table IV. shows the percentages of students who marked Strongly Agree/Agree for each question. Fig. 7 shows the response distribution for each question on the survey. We are glad to report that 93% of the students thought that they had a better understanding of linked list operations after playing the game. Some students made additional comments on the survey such as:

- “This game is awesome!”
- “Great Game!”
- “This game was fun...”
- “Very helpful to understand link list concept”
- “Great fun working with linked lists!”

TABLE IV. STUDENT FEEDBACK AND PERCENTAGE AGREE

Survey Questions	Percentage Agree
The game is enjoyable to play.	79%
I had a better understanding of how to insert a new node at the beginning of the list after playing the game.	86%
I had a better understanding of how to insert a node at a given position in a linked list after playing the game.	93%
I had a better understanding of how to search a node in a linked list after playing the game.	93%
I had a better understanding of how to remove a node from a linked list after playing the game.	93%
Visualizing the code execution in the game helped me understand the concepts.	79%
The game provided relevant feedback when a mistake was made.	79%
I would like to see more concepts covered by game modules such as this.	93%
This game module improved my motivation to learn programming.	79%

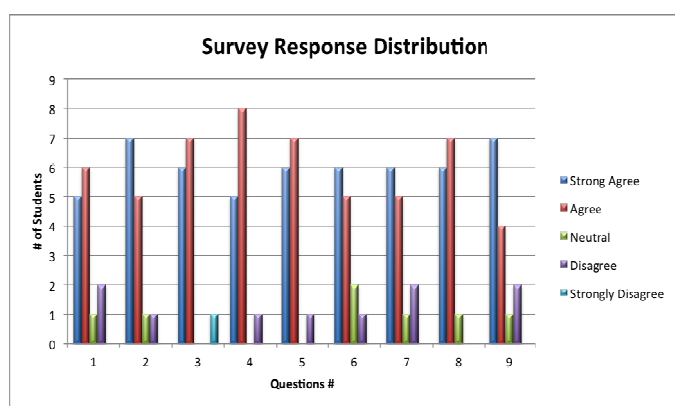


Fig. 7. Survey Response Distribution

IV. CONCLUSION AND FUTURE WORK

The *Space Traveler* game module was designed to help students understand the Linked List operations. A lab assignment was designed and used with the game module. Students have to play the game in order to complete the lab assignment. The module has been used once in Data Structures class. Assessment results based on the pretest and posttest comparison show that the module has a positive impact on student learning. The feedback from students also indicated that they better understood the linked list operations after playing the game. The module has been refined based on the feedback from the students and the advisory board. The refined version will be used in the upcoming semesters. The module has been made available for students at other institutions at <http://compsci.wssu.edu/tip>.

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Syntax Circuitry: A Mobile Game for Practicing Programming Language Syntax

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Abstract— According to the U.S. Bureau of Labor Statistics [1], computer science professions are among the fastest growing occupations in the U.S., and computer science occupations will add more than half a million new jobs in the next ten years. Simultaneously, universities in the U.S. and worldwide are seeing poor retention rates in computer science, with a major reason being that students often view the early courses in the subject as uninteresting and dull [2]. We have developed a mobile game that provides an engaging way for students to practice the basic syntax of C, C++ and Java. Learning programming language syntax is a tedious process. Practicing by actually programming is, of course, ideal, but we believe that a game which is fun for students to play in their spare time will help them get used to distinguishing correct syntactical constructs quickly. The initial version of the game was evaluated by a small population of first-year computer science students at Norfolk State University. The results showed that students enjoyed the game, and that a modest improvement in the students' abilities to identify correct and incorrect syntax was achieved.

Keywords—computer science education; mobile computing

I. INTRODUCTION

According to the U.S. Bureau of Labor Statistics [1], computer science professions are among the fastest growing occupations in the U.S., and computer science occupations will add well over a half a million new jobs in the next ten years. Simultaneously, universities in the U.S. and worldwide are seeing poor retention rates in computer science, a major reason being that students often view the early courses in the subject as uninteresting and dull [2].

We have developed a mobile game that provides an engaging way for students to practice (not learn) the basic syntax of C, C++ and Java (since these languages share the same syntax for basic constructs like declarations, selection and iteration). The game gives the player a means to hone her ability to quickly distinguish between correct and incorrect syntax for C, C++ and Java (simply because these languages share the same basic syntactical structures for declarations, iteration and selection). Learning programming language syntax is a tedious process. Practicing by programming is, of course, ideal, but we believe that a game which is fun for students to play in their spare time will help them get used to distinguishing correct syntactical constructs quickly. The intended audience for the game is students taking their first

programming course, either in high school or college. The game should be introduced to students directly after they have covered the appropriate material in class; it is not meant to be a learning tool, but rather a practice tool.

II. BACKGROUND

The importance of computer science as a 21st century skill is becoming accepted by governments and academia, and computer science is being added to the core requirements for high school and university curricula around the world. However, there remains a problem attracting and keeping students interested in the subject. Although there is much more to computer science than just programming, eventually computer science students must study programming.

Some environments have been created to allow students to learn programming concepts without having to be concerned with complex programming language syntax, and they achieve this by generally preventing students from making syntax errors. Examples of these environments include MIT's Scratch [3, 4] and App Inventor [5, 6] and Microsoft's Kodu [7, 8]. In other environments, such as Alice [9, 10] and Greenfoot [11, 12], students do engage with a specific programming language's syntax (Java), but in a controlled and limited manner. These environments all allow students to build games (and many other interesting applications), and have had significant success in helping attract and retain computer science students of all ages. There are also games that attempt to teach programming concepts. In order to progress in the game, the player must program solutions to challenges. Such games include LightBot [13], Robocode [14], a new Doctor Who game [15], and numerous others. As with the programming environments mentioned earlier, some of these games expose the player to the issues of programming language syntax and others do not.

All these environments and games form an effective bridge for students who will eventually learn to program in a language such as C, C++, C# or Java. In our own work, we made significant improvements to the retention of computer science students by using Scratch in an introductory programming course [16]. However, our students still faced the inevitable frustration of learning a programming language's syntax when they reached a later course.

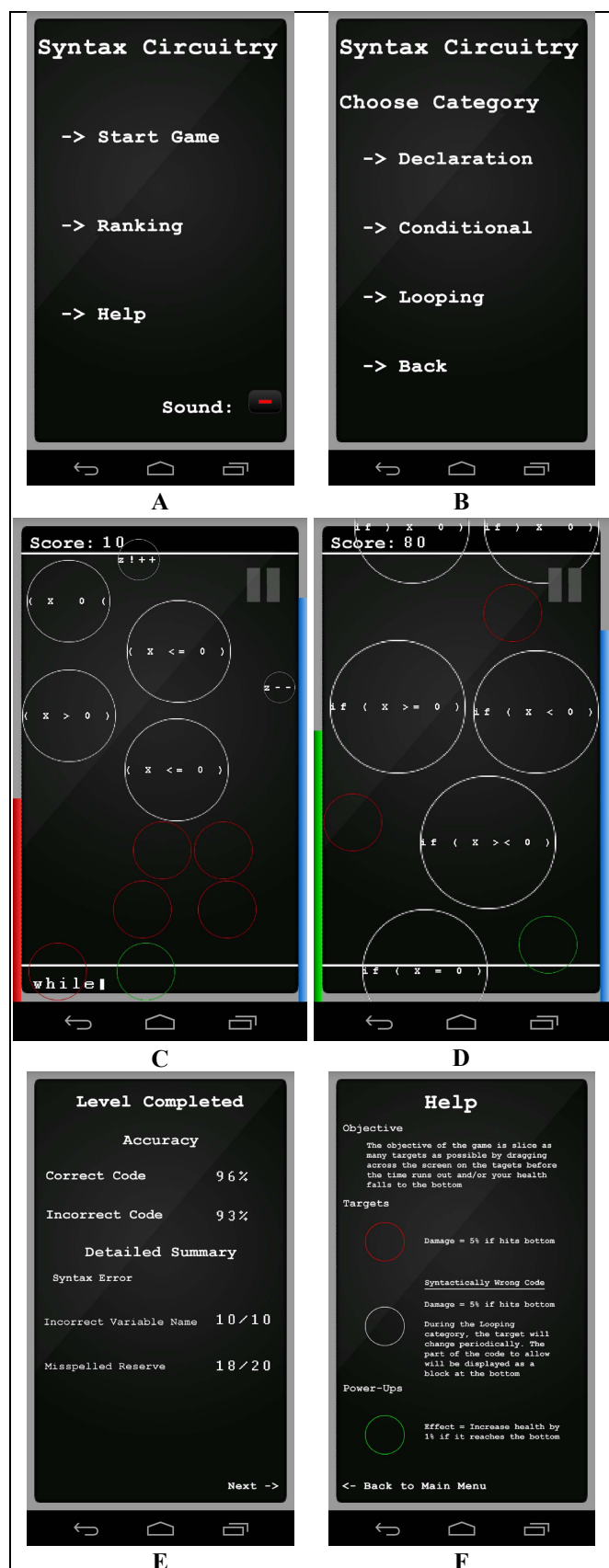


Fig. 1. Some of the game screens

Although modern IDEs do an excellent job of identifying and automatically correcting syntax errors, the necessity for the student to master the language's syntax still remains. Similarly, the autocorrect facility in word processing software does not teach people how to spell, nor does it make it unnecessary for people to learn spelling. Our game is in the same category as other games that aid in memorization, such as those for spelling and basic arithmetic rules. Its role is a practice tool for syntax rules, and it attempts to make the ability to distinguish between correct and incorrect syntax second nature to the player.

III. METHODOLOGY

The game, Syntax Circuitry, has been developed for the Android platform, and is targeted to mobile phones. Android was selected over iOS because of its free and more open development environment.

A. Game Design

The game is designed to look like an old-school arcade game, with highly pixelated fonts and very simple graphics. It has a complementary low-fidelity soundtrack. The color scheme is primarily white on black. The screenshots in Figure 1 show the game's main screens (A and B), some examples of the game play (C and D), and the results and help screens (E and F). The results screen (Figure 1-E) lets the player know how many and what types of errors were made. The game also includes a rankings screen for each category of play.

At the beginning of the game, the player must enter her name; this name is used to identify game results that are stored on a server. Currently, the server database is being used to retain detailed accuracy statistics for each player for the purpose of evaluating the game. The length of time played and statistics including those shown in Figure 1-E are recorded. The scores are also used to create high score rankings.

B. Game Play

The game-play is as follows: bubbles containing small snippets of code float down the screen. Those which contain incorrect syntax must be popped with a slicing motion, similar to that used in the well-known *Fruit Ninja* game, while bubbles with correct syntax must be allowed to reach the bottom of the screen intact. There are also plain red and green bubbles that add more challenge and interest to the game. The red bubbles (injury bubbles) subtract from the score if they make it to the bottom without being sliced, and the green bubbles (health bubbles) add to the score if they make it to the bottom of the screen unharmed.

The game has three categories of syntax (declaration, selection, and iteration), as shown in Figure 1-B. Selecting a category takes the player to a screen to choose a difficulty level, from 1 (easiest) to 3 (most difficult). Code and injury bubbles are created more frequently at the higher levels. The progressively faster play at each level requires that distinguishing correct from incorrect syntax becomes second nature to the student.

In the declaration category, various different errors that might be made in variable declarations are shown, for example: misspelled keywords, illegal variable names, and missing commas. The types of errors in the selection category are misplaced parentheses and incorrect relational operators. For iteration syntax, the context of the problem is shown at the bottom of the screen. The possibilities are the comparison clause of the “while” statement or the initialization, comparison, and increment sections of the “for” statement. Syntax errors in this category include misspelled and incorrect reserved words, incorrect operators, and misplaced parentheses or other symbols.

The game randomly creates correct and incorrect syntax bubbles with equal likelihood. It creates the code using preset examples of correct and misspelled reserved words. It combines these with templates for both syntactically correct statements and commonly made errors to form the numerous variants.

IV. EVALUATION

A. Experiment Design

The evaluation methodology used consisted of pre- and post-tests, the collection of usage and play data from within the game, and surveys about the usability and enjoyment factors of the game. Initially, the study participants were given a unique identifier, and they completed a simple self-assessment (beginner, intermediate, expert) about their familiarity with the three categories of syntax rules.

When the participants signed into the app, and selected a category to play in, they were prompted to take a pre-test on the category syntax. The game app provided the option to open the pre-test form on the server. After playing a certain amount of time in a category, the participants were prompted to take the appropriate post-test. The pre- and post-tests measured the students’ familiarity with the various syntactical constructs and rules that are presented in the game (see Table I). Finally, to measure retention of the information practiced, some of the study participants took a combined post-test again one week after playing the game.

TABLE I. SAMPLE PRE- AND POST-TEST QUESTIONS

Declaration	
Select the syntactically correct declarations:	
a.	int l;
b.	int h_k, title;
c.	char \$a;
d.	float your_name;
Selection	
Correct or Incorrect Syntax?	
	if (x != 0)
Iteration	
Correct or Incorrect Syntax?	
	for (i = 0, i < 10, i++)

At the end of the experiment, participants were given a survey about the game’s usefulness and usability. The participants were given five questions with a 5 point Likert

scale, one question with a numeric answer, and two open-ended questions.

TABLE II. SURVEY QUESTIONS

Q1	How user friendly is the game’s interface?
Q2	How successful is the game with helping you learn syntax rules?
Q3	How useful are the reference documents for the game?
Q4	How useful would this game be to you?
Q5	How likely are you to recommend the game to others?
Q6	How many times did the game freeze or crash?
Q7	What changes would most improve this game?
Q8	What was most difficult about this game?

B. Results

Thirteen people participated in the preliminary study, but not every participant completed the entire experiment. Nine participants were students in the first programming course (CS1) at Norfolk State University. Three participants were students in CS2, and one participant was not taking a programming course and had no programming experience.

The sample was too small to draw significant conclusions from the pre- and post-test data. Most students (those from CS1) participated in the study after having learned declaration and selection syntax, but before having studied loops. In the declaration and selection categories, there was a slight average increase in score (10% and 8%, respectively) from pre- to post-test. However, in the iteration category, there was an average decrease in score (11%) between the pre- and post-tests. Only four participants took the later composite post-test, and the results were inconclusive. Similarly, no correlation could be found between the game statistics (how long and how accurately the game was played) and the pre- and post-test results.

It was the survey that produced the most useful results. Twelve of the study participants took the survey. The results of the Likert-style questions are shown in Figure 2 below, where the question numbers map to the questions shown in Table II. Response 5 corresponds to the most positive response and 1 to the most negative. It is apparent that the general user response to the game was quite positive, and the players felt it was beneficial.

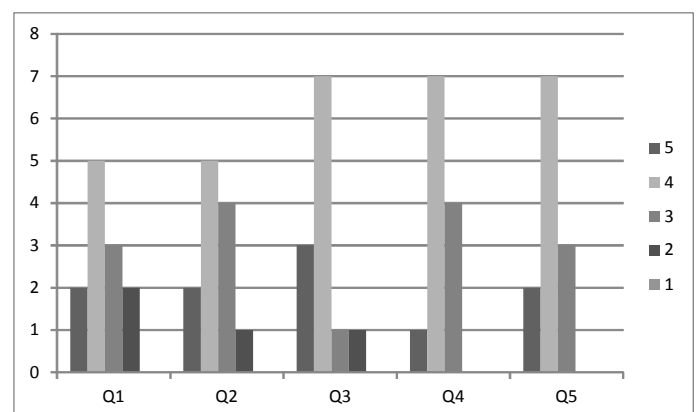


Fig. 2. Survey results

In response to the open-ended questions, the most common response had to do with the graphics. The game's GUI designer, a graduate student, deliberately chose the 80's old-school look-and-feel, and other members of our team (old enough to remember playing 80's games) also liked the retro theme. However, four of the survey respondents mentioned the graphics negatively, one asking explicitly for a "more modern user interface", and another wishing the graphics were more "aesthetically pleasing". Three students also specifically mentioned the difficulty of reading the code on a phone screen, and the screenshots bear out that complaint.

However, the fact that the participants rated the game positively in general, and that all survey respondents answered the first open-ended question with specific constructive criticism and suggestions, showed that they saw promise in the game and really liked the idea of it. Three participants asked for more: one, for more levels, and the other two, for new types of code structures.

V. CONCLUSION

We have developed a game to help students memorize the syntax rules for programming languages such as C and Java. The game is targeted at students in introductory programming courses who are beginning with or transitioning to a programming language such as Java. This is a time when many computer science students become frustrated or overwhelmed and some decide to leave the major. Unlike many games designed to help students learn programming concepts, the game is intended to be simply an engaging practice tool.

Our preliminary evaluation showed that students enjoyed the game and found it valuable; however, many students did not like its *retro* style user interface, and found that the font size and color made it difficult to read some of the code. The students achieved modest improvements in recalling syntax rules that they had already studied in their programming classes. However, the sample size was small, and, at the time of the evaluation, many students had not been introduced to one of the categories (iteration) that the game features.

Since the preliminary evaluation shows the idea has merit, we plan to update the game's user interface to a more modern, colorful look, make sure that the fonts are readable, and create a tablet version. For the next evaluation, we plan to use a

larger sample size and introduce a control group. We will also evaluate the game's effectiveness at the appropriate points in the course as the students learn the different categories of syntax.

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Teaching Programming Concepts to Elementary Students

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Abstract—Educators and parents alike are seeking innovative ways to introduce young students to computer programming. The hope is to capture children’s attention and foster learning at the same time. The goal of this work was to not only introduce elementary students to the fundamentals of computer programming, but also help them explore more complex concepts in an engaging way. Studies have shown that factors that inspire children’s continued interest can sometimes vary by gender at this age; this work specifically addresses how to incorporate elements that will appeal to these potential differences in motivation. This study describes the design and implementation of a computer microworld game designed to introduce the core constructs and techniques of computer programming. By instructing a virtual robot to complete obstacle courses, students become familiar with core programming concepts such as: algorithms, repetition, conditional logic, debugging, functions, and optimization.

We conducted several interactive sessions with a group of elementary school students in order to evaluate the effectiveness of the game. Our results showed the game effectively familiarized students with both computer language constructs and the essentials of algorithmic thinking. Students were quickly able to learn core-programming concepts and apply these concepts to free form solutions.

Index Terms—Elementary education, Educational software, Computer programming

I. INTRODUCTION

Introducing technology to young students has become a critical objective of STEM education programs in today’s world. Although more students are introduced to computers at a young age, many do not receive the opportunity and encouragement necessary to pursue computer programming as they get older. This challenge in particular requires innovative approaches in order to capture children’s attention while encouraging learning at the same time. The goal of this work was not only to introduce elementary students to the fundamentals of computer programming, but also to help them explore more complex concepts in an engaging way. Studies have shown incorporating elements that appeal to different motivations can be necessary to capture children’s continued interest at this age.

To address these challenges, this work builds upon prior efforts to teach basic algorithmic skills and then aims to leverage students’ creativity and encourage exploration of more advanced concepts. This study describes the design and implementation of a computer game to meet these goals and introduce young students to the core constructs and techniques of computer programming. By instructing a virtual robot to

complete obstacle courses, students become familiar with core programming concepts such as: algorithms, automation, repetition, conditional logic, debugging, functions, and optimization. We conducted several interactive sessions with a group of elementary school students to gauge the effectiveness of the game at teaching these core concepts. In addition to surveying participants to understand their knowledge and motivations before and after playing the game, the team also collected analytical data during game play.

Our results showed the game effectively familiarized elementary students with both computer language constructs and the essentials of algorithmic thinking. Students were quickly able to learn the core programming concepts introduced by the game and apply these concepts to free form solutions. The results demonstrated both males and females enjoyed the game and developed an enthusiastic interest in further learning about computer programming.

II. PROJECT GOALS

The goal of this project was to develop an application that both introduced students to programming, and built upon the latest findings for ways to appeal to eight to ten year old students. A focus of this study was to incorporate ideas that have been shown to engage both boys and girls with potentially different interests and motivations, while also creating an effective learning environment. The objective was for the students to learn core-programming concepts such as automation, parameterization, loops, conditions, functions, and debugging through self-regulated learning while still having fun. We hoped to show that by appealing to different sources of motivation, such as story based advancement, problem solving, and score, we could encourage an understanding of these programming concepts that could be applied to more free form applications. A sub-goal of this study was for the children to understand that in programming there are sometimes multiple ways to approach a problem. We believe such a grasp reflects a deeper understanding of the underlying concepts.

To accomplish these goals, this study describes the design of a robot microworld game, Robot Training, to teach these concepts through structured problem solving. The game focuses on introducing children to the basic concepts needed to write a computer program while trying to help a robot, Robo, collect the parts he needs to get home. The game uses story-based challenges and visual context to motivate

students to understand the mechanics of programs in solving programming challenges and achieving the story goal. The game also provides support for children through the availability of debugging and persona based help functionality.

Based on the success of other research in elementary computer education, our belief was that a game format that incorporated multiple forms of incentives could help guide students in developing a deep understanding of the purpose of programming constructs. The hope was that once introduced to these concepts in this way, the children would be able to demonstrate that they could apply the concepts to more complex problems with less guidance as well as extend their understanding of the concepts outside of the game environment. Although this project specifically targeted younger audiences, this application could likely serve as an introductory lesson on programming to a wider range of students by adjusting the graphics to the target age group.

III. OVERVIEW

The basis of our approach of directed student self-relegated learning is driven by studies showing that children naturally learn through interacting on their own in challenges through creating and extending their thinking to their environment[1]. For example, with Legos, children are often not told the purpose of a specific section of a sequence of picture-based instructions when building. However, throughout the building process, children learn design and construction techniques, reinforced by their own intuition and creativity. Work by Resnick suggests that environments that encourage self-regulated learning can lead children to develop, test, and experiment with their ideas and ultimately help them refine their abilities[2]. As Papert noted, programming can be a very empowering and creative experience for children, which can help motivate engagement[3]. We believe this technique should also work well for children learning computer programming.

In exploring this type of application of learning programming concepts as applied to our target age group, we build upon the ideas of Michalakakis. Specifically, rather than describing a programming concept to children and then asking them to apply it, Michalakakis presented them with the structure and their exploration intrinsically built their understanding[4]. Michalakakis described a unique approach to teaching programming concepts to young children of five to seven years of age. Rather than attempting to describe the abstract inner workings of a computer system, Michalakakis placed the children directly in the role of a programmer. The children and their parents worked together to solve an obstacle course, often in a school gym or other locale. The parents took the role of “robots,” and the children worked to develop instructions for their parents to solve the obstacle course. Michalakakis started the children with a simple “programming language” which consisted of instructions such as “move right foot forward” or “pick up ball.” The child had to develop a set of instructions with which his or her “robot” can navigate the obstacle course, retrieve a ball, and return it to the child. After solving the initial puzzle, the children were encouraged to use their creativity to come

up with new instructions or categorize multiple instructions into higher-level concepts. For example, children might have grouped the “move right foot forward” and “move left foot forward” into a single instruction “take step.” Michalakakis also described how some children quickly discovered the concept of parametrized operations, such as “take 10 steps,” rather than repeating the same primitive instructions many times. Young students quickly displayed an understanding of the core concepts of computer programming through problem solving.

For our Robot Training game, we base the general flow of the game on this same idea. Rather than telling the students specifically what to do, the game sets the context: the child’s role is to help the robot, Robo, recover his lost parts so he can get home. Within this context, the student proceeds through solving puzzles in the form of obstacle courses to get the robot closer to getting home. In the early stages, students are incrementally given new tools necessary to solve the course. Concepts such as combining instructions, constructs such as repetition, and approaches to help them such as debugging are presented for them to learn the benefits of each as they advance through the game. When additional capabilities are added to their environment a brief description of what it is used for is given to the students, but they must then figure out how that tool can help them solve the next puzzle.

For each of the initial obstacle courses, there are constraints that require the students to incorporate the new concept to solve the problem without explicitly telling the child that it is needed. In this way, the levels require the child to think about what the concept adds beyond what they already have in their repertoire. As a result, not only does the student learn how to use the concept, the student also develops an understanding of the new concept’s benefit as compared the other concepts already learned.

IV. LEARNING ENVIRONMENT DESIGN

In structuring the game-based self-regulated learning framework, we looked to Rieber’s findings of the most effective ways to blend learning and play[5]. He suggested the most effective practice was combining elements of Piagetian learning theory with elements of Flow Theory[6], [7]. Specifically, what he termed “microworlds” provide an environment where learners explore increasingly more sophisticated and complex ideas that require little or no training. They provide an environment that is intrinsically rewarding; learners are able to evaluate and monitor their own learning; and individuals can select the environment that best suits their learning style. To realize these traits, we incorporated findings in a couple of key areas. In order to provide an environment that is intrinsically rewarding, we combine different elements of appeal, including gameplay and character-based story involvement. In addition, the latest findings in programming environment development, discussed below, that require little or no training are incorporated to better suit a self-regulated learning style. In addition to these concepts, elements are added to address multiple learning styles and ways for students to self-evaluate their learning without impeding their advancement through the game.

A. Game-based learning

Over the past several decades, research has shown a game-based approach to learning can be engaging as well as effective. Work by Malone and Lepper proposed that by making learning fun, the motivation could lead to effective intrinsic learning[8], [9]. Engaging students' learning through gaming does not only motivate them, but has also been shown to make them more focused and willing to persist over time[10], [11]. More recently, work by Shaffer has shown that computer gaming environments can be both an effective way to engage children, while helping them to learn in the process[12]

While many applications have been developed to address introducing programming concepts to school-age children of various levels through gaming, we believe there remained opportunities to improve the framework for self-regulated learning through better use of a broader range of factors motivating the eight to ten year old age group. Specifically many efforts have been made regarding quick introductions such as those commonly used in The Hour of Code and other programming environments that are aimed at an initial programming exposure. However, the majority of these applications do not incorporate findings of related work in this area that have been shown to help appeal to wider range of interests and motivations.

B. Story and character-based influences

In creating the Robot Training game, a central goal of the application is to design it so that it appeals to all children, but a specific focus was to incorporate elements that interest both girls and boys. Kelleher and Pausch discovered that sociological barriers were more challenging than the technical details of languages and tools[13]. They found that motivation and support for programming was critical for learning, and suggested that motivational stories and students working together in groups helped to provide the necessary context. Furthermore, motivational stories need to be broadly appealing to encourage entire audiences to have interest in programming. For example, battles are not necessarily appealing to all girls, artistic, or musical students. Other work inspiring the inclusion of a character-based storyline, found that students using a story-based environment spent 42% more time engaged in programming than those with a non-storytelling version[14].

To achieve these benefits, a storyline was added as a central element to improve wider student interest and engagement related to student motivation to help the robot get home. Based on this, the motivation to advance through the game is built around helping Robo find the spaceship parts he needs to get home. Students are told that the object of the game is to help teach Robo how to find his spaceship parts by training him with the programs the students create. The story takes the player through a number of different virtual environments ranging from space to the Wild West. A character named Eddy the Alien advances the storyline and acts as a guide, introducing each level. The character explains new concepts, such as repetition, that will be needed to solve the level.



Fig. 1. Eddy at level completion

Within this storyline students are encouraged to figure out what each programming concept means on their own. A further benefit of storytelling in games is it can further motivate children to read what is presented as they complete different levels in a game[13], [14], [15]. To take advantage of this, upon completion of each level, Eddy congratulates the player while articulating the benefits of what the student just discovered on his or her own to help reinforce the reason for that tool and the specific concept (Figure 1). In addition, while these aspects did not affect the student's advancement through the story or gameplay, Eddy provides feedback on the strengths of their accomplishment such as completing the level with the fewest instructions possible. The feedback is designed to allow students to self-assess their learning and encourage them to think about what they are learning in different ways.

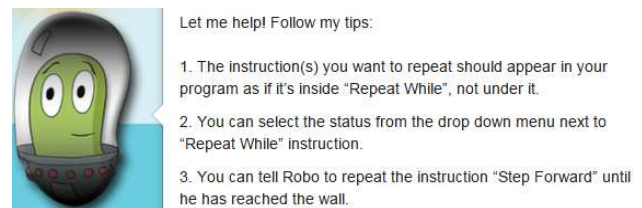


Fig. 2. Eddy when asked for help

Additional components are also incorporated to engage a wider variety of learning styles. In Kahn's study of fourth grade students using the programming simulation game ToonTalk, he found that while some children enjoy struggling through a problem for the satisfaction of finding the solution, others were more motivated and less discouraged when they were assisted by a character named Marty who acted as a coach[10]. To help address this potential factor in Robot Training, if a student ever becomes frustrated with a particular puzzle, they can ask Eddy for help in solving the problem and Eddy will provide tips on how to reach a solution (Figure 2).

C. Programming environment

A key goal for Robot Training was to make it easier to focus on the concepts by making the underlying programming environment easily understandable and not distracting from comprehension of the concept. In a study by Kim et al., they found by removing the focus from programming language syntax, middle school students were better able to focus on algorithmic correctness and other learning goals[16]. They

concluded, given the problem context, that students used computers as a tool for problem-solving rather than focusing on specific implementation details. Kelleher and Pausch found teaching children programming could be made easier by simplifying mechanics and syntax and providing support documentation and tools[15]. Thus, helping students focus on learning the programming concepts rather than being bogged down in syntax or intricacies was a key goal. To address this in the Robot Training game, a simplified drag and drop programming language based on block constructs was created. Thus, each robot instruction, such as “Step Forward,” is represented visually rather than typed. The goal was to leverage the findings related to the Scratch programming environment, which suggest such a language allows students to focus on the algorithm correctness rather than syntax or compilation errors[17], [18]. While the Scratch environment has far more capabilities than the language developed for Robot Training, our goal is to provide a more simplified problem-solving environment for an initial introduction to the same concepts.

A somewhat related goal we wish to address in Robot Training is to provide an environment that encourages understanding of why a particular solution works, and to provide easily understandable tools to help when a solution does not work. In Lin et al.’s study of teaching eight to twelve-year-olds programming using Stargate Creator, HANDS and Visual Basic, they found a significant challenge was explaining the reasons for program errors and the result being students resorting to trial and error rather than understanding why a particular instruction did not work[19]. They also observed that in the rush to write code, students frequently included extraneous code without trying to make sense of whether the statement was needed. These findings were a critical factor in developing the game and assisting students to understand the need for certain statements and concepts. In particular, the game provides a strategically limited amount of each instruction type available to guide students’ learning through requiring students to critically evaluate whether a specific instruction is necessary. Furthermore, this was a key factor to provide a visually understandable debugging experience that allows students to investigate their program errors without the complexity of a debugger such as the one found in Visual Basic.

The debugger in Robot Training allows children to run their program step-by-step and observe how the robot executes each instruction just as a typical debugger would. The aspect of it that sets it apart from other work in this area is the “Robot Status” window which lists the current state of the program in a way that is both helpful for finding problems as well as discovering other information that may provide ideas on other types of concepts that may be incorporated into the program. For example, as Figure 3 shows, in addition to the direction of the robot, information is also provided about what conditions are true and false, whether they are being used in the program or not. In this way, the information can help students that are already making use of conditionals as well as present children that are not using conditionals with information about the

environment that can be incorporated in conditionals if they choose to use them.

V. INSTRUCTIONAL DESIGN

The game is structured into two parts: introductory levels and free form challenges. First, introductory levels expose students to different programming concepts and tools in a structured way through the story. Then more free form challenges require the students to apply what they learn to new contexts requiring them to incorporate multiple elements without directly telling them what is needed. This encourages them to explore and find multiple different ways of approaching the problems, thereby learning different concepts in the process of finding the solution.

The game begins with eleven levels, each of which introduce different programming concepts. Challenge levels are then presented, where the children’s task is finding the solution to complete the course using knowledge they acquire from earlier levels. The game interface is composed of three primary components. First, the student is given a “Toolbox” of computer instructions, which they can use to develop a program for Robo. The student drags and drops the toolbox instructions into a window called “Your Program,” which contains the instructions Robo executes. Finally, the main area of the screen features the obstacle course, the goal, and the Robo character. Students can execute their program in the obstacle course by choosing the “Run” option in their program window.

A. Level Design

The first eleven levels each focus on teaching an essential concept of computer programming as follows:

Levels 1 and 2: Computer automation *Once a program starts running, it cannot be altered. It runs in an automated fashion.* In the first two levels, the students build basic multi-step programs. When each level is completed, users are able to see how a program is executed visually. This also emphasizes the importance of having all instructions correct before starting the program.

Level 3: Debugger functionality *A debugger can be used to step through a program, providing developers with additional information that may help in solving problems with a program.* For this level, students again solve the same course as level 2, but this time they must execute the program through the debugger. In doing so, they will see that they can execute their program in a step-by-step fashion seeing where their robot is in relation to which instruction of their program is currently being executed. Having them step through a program they already know introduces them to the additional information that is available regarding the robot’s status at each step of execution. For example, it provides program status such as if Robo detects there is a wall or a part nearby, thus, showing information that may be helpful to a student to begin thinking in terms of conditional statements.

Level 4: Algorithmic thinking *Programming requires you to think about the different ways you can build a program.* The level design is such that there are multiple routes to the finish,

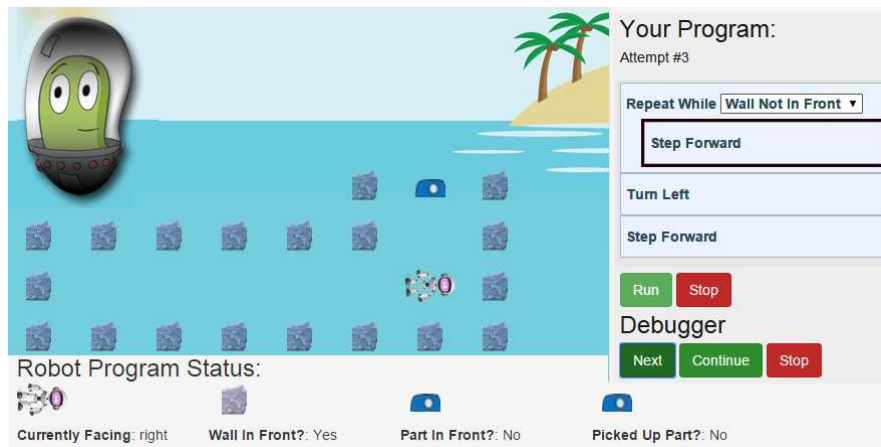


Fig. 3. Step through debugger, visual status and conditions available

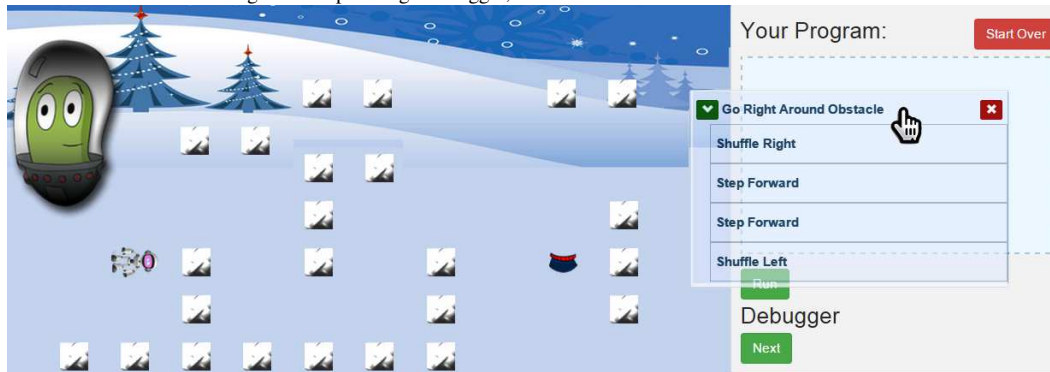


Fig. 4. Incorporating functions

but due to a limit on the number of each instruction, only some approaches actually allow the target to be reached. The goal is for students to realize there may be multiple ways to achieve the same result, but determining which best suits their needs requires them to think through how the program will execute.

Levels 5 and 6: Repetition with parametrization *Loops can simplify a program when a set of instructions should be repeated a number of times.* Level 5 introduces repetition and requires the user to construct a program using a loop to repeat an instruction a specified number of times. This is then followed by a course that requires the students to figure out how to incorporate multiple instructions in a loop.

Levels 7 and 8: Conditional repetition *A condition can also be used to specify how many times a loop should be repeated.* These two levels present problems that once again require the user to incorporate repetition in solving the puzzles, with the second level requiring the user to use two different conditions.

Level 9: Optimization *Simplify your programs.* Level 9 encourages students to look for the simplest way to solve a problem in the fewest number of steps. This level is also intended as a setup for the subsequent levels about functions to demonstrate how functions can reduce the number of steps in a program.

Levels 10 and 11: Functions *Functions can be used to group a logical set of steps.* In Level 10, a course is presented such

that there are two places in the course where the same logical steps need to occur. Specifically, Robo needs to go to the right around an obstacle. A function to perform this action showing the associated steps, is added to their toolbox, and the students must figure out how using this function can help them solve the level. Level 11 builds upon what they learned in the previous level by having the students create their own function to solve the new course in a similar way. Specifically, the intent is for students to see the similarity between the current task and the function they used in the previous problem so that they realize on their own that they can create their own function in order to perform a mirror of that functionality.

Levels 12 through 28: Challenge levels While in the initial levels students are challenged to solve a problem by discovering how to apply a concept on their own, they were guided that to solve the problem they must incorporate a specific concept. After level 11, the goal is for students to determine which concepts they previously covered can be used to solve the challenge. While the obstacle course structure is more open to encourage students to think about multiple ways to reach the goal, constraints are placed on number of times each instruction can be used. The result is that while there are multiple ways to reach the goal, only some of the options are possible due to the limits on instruction use. By doing this, not only does it require students to consider the different ways programs can be written to achieve the same goal, but it also

pushes them to think about how the different concepts they have learned can be applied in multiple ways.

B. Scoring feedback

One of the factors Rieber identified as contributing to effective self-regulated learning, was for the subjects to be able to self-evaluate their progress so that they might look for ways to explore improvement[5]. To provide this feedback we incorporate an idea of bonuses for fewer attempts, simpler programs, and students thinking through the problem on their own. For example, if a student is able to complete a challenge with their first execution they receive more points than if they take three times to reach the solution. In addition, while there is specific help available to students in the form of level specific tips provided by Eddy, to encourage students to try solving the problems on their own first, a student receives a higher score if they solve a level without requesting help.

VI. METHODS

A. Assessment inputs

In order to assess the effectiveness of the game at achieving the goals of this study, the team used a variety of evaluation methods. First, an anonymous online survey collected basic demographic information, prior computing experience, and preliminary opinions at the beginning of the study, and follow up questions were asked at the end of the study to evaluate changes in opinion. The second evaluation technique involved direct observation of participants during the game via anonymous analytics recording of game play. The team recorded a variety of statistics including length of time spent on each level, both successful and unsuccessful level solutions, when the debugger was used, and detailed information about the program elements used to solve each level. Finally, observations and comments made by the students were also used as a third input in evaluation.

B. Procedure

Two after school sessions were designed for the participants.

1) *Session one:* After introducing participants to the research team, the children would be directed to complete an anonymous online pre-survey. Once complete, the project team would ask the students to form groups of three to four. Each student would work on his or her own lab computer, but the students would be encouraged to talk with the members of their team. The team approach was chosen due to studies indicating it is easier to learn programming in groups and gain the benefit of discoveries made by peer teammates[20], [15]. The decision to have each participant work on their own individual lab computer was driven by the hope that this model would encourage the students to try out concepts on their own as well. The children would be given about one and a half hours to play from level one to level thirteen on the first day. These specific levels introduce all of the functionality, controls, and each of the basic programming concepts the game presents. At the end of the first session, students would be encouraged to think about something that they do before

the next session and how they might program a robot to do that activity. This would then be discussed in the next session.

2) *Session two:* In the second session, children would begin playing the challenge levels from level 14 to level 28. For these levels, rather than introducing new concepts, they focus on making students think of different ways they can apply the concepts they have learned. These levels require more in-depth thinking and creative use of the computer instructions available to them. During this session, students would also be asked to write down their program for the activity they were told to think about at the end of session one. After students had played the game for an hour, for a total of two and a half hours over both sessions, they would be directed to complete another anonymous online survey to assess the impact of the game experience.

C. Participants

The experiment took place in November of 2014 in West District Elementary School in Connecticut's Farmington Public Schools district. The research team conducted two sessions of two hours and fifteen minutes each, after school in the school's computer lab. The participants consisted of seven boys and four girls in that school's fourth grade between the ages of eight and ten years old.

VII. RESULTS

A. Pre-survey

The pre-session survey revealed all of the participants used computers frequently for both games and in a learning context (see Table I). In addition to having used computers for homework, all of the students had also used Chromebooks in their classrooms. Furthermore, all students emphatically agreed that they liked using computers. Of the students, 21% indicated they had programmed before, 36% recorded they had not, and the remaining 43% were unsure.

B. Gameplay

Within the first session, each of the first three levels focus on introducing the basics of the environment, building a simple program, and use of the debugger as described above. All students seemed to easily grasp how to play the game. This could be seen in them taking on average only a minute and 13 seconds to complete the level and just over 3 attempts on average for each of the first two levels. In addition, while the introduction to the debugger was brief, we believe usage statistics indicate students learned the benefits of the debugger on their own. Based on the average in-game analytics, for the 14 levels that required 3 or more attempts per completion, the debugger was used an average of 71% of the time. Whereas, on the three levels that averaged fewer than 3 attempts per completions, the debugger was only used 33% of the time, which demonstrates an understanding of the benefit a debugger can provide in solving a more challenging problem.

Level 4 introduces students to one of the central mechanisms used throughout the Robot Trainer application, limits being placed on the number of each type of instruction. This

mechanism is used as a means to introduce epistemic conflict of what the student has discovered to that point, by deliberately requiring them assess and understand the limits of these concepts. This self-reflection and understanding is the requirement for the desired self-regulated learning necessary for students to arrive at how to incorporate the new programming concept[5]. In this level, for the first time, the participants has to solve a challenge where while there appears to be multiple ways to solve the obstacle course, students need to think through the different algorithm possibilities to find a solution that would work given the constraints. This additional complexity resulted in a jump of over two additional attempts per completion and the resulting increase in average completion time by nearly three minutes.

This was then followed in levels 5 and 6 by an introduction to repetition. For example, students had to learn rather than placing three series of “step forward, turn right, step forward, turn left” instructions in their program, they needed to instruct Robo to repeat the group of instructions three times. Based on the amount of time to complete these levels (4.5 minutes) and just over 5 attempts per completion, it appears that it was initially challenging grasping how a multi-step program would repeat a fixed number of times. However, when levels 8 and 9 introduced conditional repetition, students easily applied their gained understanding requiring just 2.5 attempts per completion. We believe this result in part demonstrates how the instruction limiting method of stimulating self-regulated learning allowed students to develop an understanding that they could easily translate into different contexts.

In level 10, the concept of using a function is introduced. Based on the attempts per completion (5.3) and just over 5 minutes average completion time, using a given function appears to have been more challenging to understand compared to the initial exposure to loops. However, when many students solved challenge levels later in the two sessions they chose to use given functions rather than specifying the steps themselves indicating they developed an understanding of their purpose.

One observed weakness in either the approach used in Robot Training, or the way it was presented was observed related to student’s defining custom functions. Level 11 first introduces students to the concept after they have demonstrated how to incorporate predefined functions to solve Level 10. Within this level, while the attempts per completion remained nearly the same as the predefined function level, the average completion time jumped by 60% to nearly 9 minutes. While this by itself does not necessarily indicate a difficulty in understanding, upon examining the student programs in later levels it was clear not all students clearly grasped the concept. While some students demonstrated understanding succinctly encapsulating logic and even using their functions multiple times within a level, other student programs consisted of a single instruction or the entire program solution as a function. This likely indicates understanding the purpose of creating functions was a more difficult concept to grasp without either further repetition or additional ways within the design to encourage a deeper understanding.

In the final “challenge levels,” rather than the application using instruction limits to require the incorporation of a new concept, they are used to require students to figure out which of the multiple concepts they have learned are necessary for a particular solution. The purpose in this change to more free form thinking in problem solving is to require students to understand how the different concepts they have been exposed to fit together. From Level 14 on these challenges became increasingly harder. At first, there was a sharp increase in attempts per completion reaching over 9 for levels 15 and 16, but once students became more familiar with this type of problem solving, the attempts per completion dropped once again to around 4.5 attempts per completion.

We observed that while students were aware no other student saw their scores, the scoring idea still motivated them to continue to try to solve the problem on their own even though they knew help was readily available if they needed it. An example of this was when two students were overheard talking to one another regarding solving a level they were having difficulty with. One student suggested the two of them use the persona for help, but their teammate’s response was that if they did, they would not get as high of a score so they should instead figure the solution out on their own together. In addition, while the debugger was used on 64.8% of levels, help was only used on 12.2%.

C. Learning outcomes

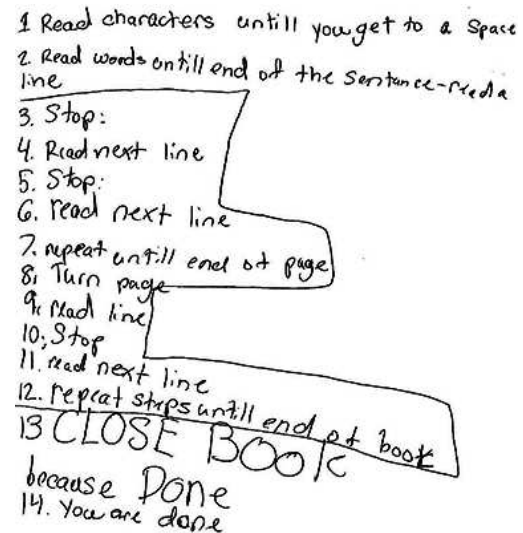


Fig. 5. Student made algorithm

Recall, as described in the procedure, at the end of the first session, students were encouraged to think about something that they do and how they might program a robot to do that activity at the next session. Following gameplay, as a means of assessing how well students could extend the concepts they learned to algorithmic thinking outside of the game environment students were asked about what activity they picked and told to discuss with their group how they would tell a robot to do that activity.

Question	Definitely Agree	Agree	Not sure	Disagree	Definitely Disagree
Pre-session survey results					
I use computers a lot	45.45%	54.55%	0%	0%	0%
I like using computers	100%	0%	0%	0%	0%
I play games on computers	54.55%	45.45%	0%	0%	0%
I use computers for homework	45.45%	54.55%	0%	0%	0%
<i>I know a lot about computers</i>	9.09%	45.45%	45.45%	0%	0%
<i>I think programming computers is fun</i>	54.55%	45.45%	0%	0%	0%
<i>I want to learn more about programming computers</i>	81.82%	18.18%	0%	0%	0%
<i>I want computer programming to be taught more in my school</i>	63.64%	27.27%	9.09%	0%	0%
Post-session survey results					
<i>I know a lot about computers</i>	40%	50%	10%	0%	0%
<i>I think programming computers is fun</i>	80%	10%	10%	0%	0%
<i>I want to learn more about programming computers</i>	50%	40%	10%	0%	0%
<i>I want computer programming to be taught more in school</i>	80%	0%	10%	10%	0%
The game helped me to understand how computers work	60%	30%	10%	0%	0%
I would like to play the game again	50%	40%	10%	0%	0%
I would recommend this game to my friends	70%	30%	0%	0%	0%

TABLE I
PRE AND POST-SESSION SURVEY RESULTS

The programs the students came up with surprised us with how clearly they demonstrated the students' understanding of the core concepts of algorithmic thinking, repetition, and conditional logic. An example of one program two students came up with for telling a robot to read a book can be seen in Figure 5. In all of the student programs, a clear multi-step execution was described that included conditional logic and most also included some form of conditional repetition, such as "brush your teeth side-to-side and repeat for 30 seconds, then move to the other side and repeat."

D. Post-survey

Question (5 = Definitely Agree)	Pre	Post	p-value
I know a lot about computers	3.64	4.30	0.0005
I think programming computers is fun	4.55	4.70	0.02
I want to learn more about programming computers	4.82	4.40	0.01

TABLE II
IMPACT OF SESSION

The lower part of Table I displays students Likert feedback from the post-session survey on the benefit and enjoyment of game. To evaluate the impact of the session there were a number of questions we asked both pre- and post-session (italics). To evaluate the significance of any changes we used a five point Likert scale with "definitely agree" being a five and "definitely disagree" being a one. The p-value was then calculated to determine statistical significance[21]. There were three statistically significant changes. First, there was a huge increase in students' confidence in their knowledge of computers. In addition, there was a increase from an already high opinion that programming computers is fun.

Finally, one result we did not anticipate given the increase in students thinking programming computers is fun, was a decrease in student's agreement that "I want to learn more about programming computers." While the change in the overall average of opinion related to "I want computer programming to be taught more in school" was not significant, the change in distribution of the responses that can be seen in Table I may provide some insight into the previous question.

Specifically, while the overall average remained fairly constant the students that previously were in "Agreement" shifted either positively or negatively. While it is encouraging to see the positive shift and that those in "Definite Agreement" remained there, the negative shift obviously indicates the method of learning introduced in this application was not for everyone unfortunately. It is worth noting however that while it was a small sample size, the four girls shifted from three out of four "Definitely Agree," to all four "Definite Agree" after the gameplay. In addition, all four indicated "Definitely Agree" for the statement "I want to learn more about programming computers" both before and after the game. Thus, while the overall shift was not significant, there is some indication that the game was very successful in encouraging or maintaining high interest in programming for girls.

VIII. CONCLUSIONS

As the results demonstrate, the Robot Training game was successful in teaching many fundamental computer-programming concepts that students were then able demonstrate their understanding in applying the concepts outside of the game environment. Pre- and post-survey results proved that the game sessions had a positive impact on the students' confidence in their knowledge of computers, as well as, their thinking of programming as a fun experience. In addition, the instructional design used in this work of using limited instruction availability as a mechanism to focus concept grasp shows promise for avoiding some of the challenges other studies have observed related to this.

During the sessions, students enjoyed working in teams, discussing different solutions to solve the obstacle course, suggesting improvements on each other's work such as the shortest path to the goal, and enjoyed helping each other debugging their programs. We also observed while they really enjoyed this team aspect, the vast majority still wanted to create their own programs on their machine indicating their desire for personal engagement as well. Finally, all students expressed being very proud of themselves when they successfully completed each level.

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Playing and learning with gamification: an in-class concurrent and distributed programming activity

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Abstract— It seems that education is working fine, especially in several good and traditional Universities around the world. Nokia was also doing very well in a business world until clients' needs change. Are we academics really offering what the students and the labor market need and demand? We have offered the same product for decades, but we haven't realize that the client is different and is demanding another product. Sometimes, we may have the feeling that our students are beyond this world when they are connected in the internet. Some say that the new generation is not using technology in a properly way to study; however are academics using it better? We are not using the new generation's language to communicate with students and to transfer knowledge. Games and competitions is the "language of the new generation" and it may promote a desired long-term learning experience we academics always wished. This paper describes the use of gamification as a tool to support the lectures of concurrent and distributed subjects, for undergraduate students of computer science course. In the game students should create and optimize the production line of a specific product. In the programming class, students should create and balance the same production line to beat competitors. Students have to use concepts of distributed programming and concurrency, and create strategies to organize the threads (production line) in order to be more efficient than the other competitors. The best production lines sell more and get more benefits. This paper discusses the preliminary results obtained from a survey of learning inhibits, which were applied before and after doing the course activity. The study compares the results obtained in both surveys and indicate that with the use of gamification to support class activities the learning inhibits tend to reduce at same time that transversal competences are stimulate on students. The discussion conducted after each round of the game indicated the interest and motivation of the students with this type of class.

Keywords— *gamification, concurrent programming, learning inhibits, programming game*

I. INTRODUCTION

This paper discusses about a business game adapted to teaching concurrency and distributed programming concepts. By using games in class, we expected to make the educational task more realistic, stimulate and motivate students to get involved on their own learning process. McEwen [1] discussed that the introduction of realistic elements into teaching improve motivation and boosts learning effectiveness.

Students' environment is different from decades ago and we need a different method to optimize their performance. Games are part of student's life nowadays and we can take advantage of that making interesting, fun and motivating classes, fostering student's involvement with their own learning process. Maybe we are just not using the potential aspects of all these technologies in class.

Gioia and Brass [2], in the article "Teaching the TV Generation", emphasize that teaching and learning are enhanced when teaching style are commensurate with learning style. At that moment, in 1986, the authors suggested that students who had been raised in an environment dominated by visual images - the TV Generation- should no longer be taught only by verbal stimulus. Proserpio and Gioia [3], on the paper "Teaching the Virtual Generation", say that "we no longer teach a verbal, nor even just visual generation, now it is virtual". They reinforce the idea that optimal teaching and learning occur when teaching styles align with learning styles.

Using game mechanics to non-game environments has been called gamification [14]. This study focus on the use of gamification in class to support theory and practice. Games are part of youth life nowadays and even older people are getting involved on this penchant. The initiative to use a business game to teach concurrent programming could also be defined as serious game according to [15]. The use of the term gamification in this work is appropriate because the business game used to do this proposal was designed to be a board game with the design, elements and characteristics of a game in non-game context.

For Brown and Vaughan [4] say that play is apparently purposelessness, do not seem to have any practical value, but it has inherent attraction, it is fun, it makes you feel good and provides psychological arousal. Although play involves anticipation, expectation, wondering, curiosity, anxiety and uncertainty, the play leads one to surprise, unexpected situations, discovery, new sensations and shifts perspectives, producing pleasure and good feeling [4]. Play gives freedom to improvising, provides a freedom from time when you are fully engaged, makes you stop worrying about many things, makes you even assume a different self [4].

Kapp [5] says that people like playing games because they are fun, engaging and they have the power to inform and educate. When the play is structured by rules, goal oriented,

challenge and promote interaction of the participants it is often defined as "game". A narrow way of understanding what is gamification, according to [5], is visualizing activities where you get points, rewards and badges for doing daily stuff, at work or home, could even be "getting rewards for brushing your teeth". However, [5] says that the real power of the game-based thinking is on the engagement, the storytelling, the visualization of characters, and the problem solving.

Kapp [5] does not try to mislead, he says that gamified learning is difficult, challenging, and stressful, but if well-designed games can help learners acquire in a safe environment skills, knowledge, and abilities in concentrated periods of time with high retention rates, and effective recall. In addition, gamification accelerates the experience curve of the learning, allows reaching complex subjects and provides a systemic view of the whole process [5].

Several studies demonstrate that there is no longer a game player stereotype. Anyone could be game player for several purposes, with several ages, not only kids or teenagers [6] and [7].

Wright, Bitner and Zeithaml [8] said that business schools begun to be criticized, already in the 1990's, for been failing to prepare students for the complex, fast-paced, and global work environments they would face as employees. In [8] it is suggested that students should be taught both new content and new skills in order to meet the changing business needs in U.S. Other studies demonstrate that students involved in experiential learning and subsequently stimulated for reflection on that experience tend to reach effective learning [9] and [10]. Camarero, Rodríguez and San José [11], say that students can approach a task by active experimentation (doing) or by reflective observation (watching). For Hawtrey [12], the experimental learning occurs whenever the student shifts from the role of passive listener to that of active respondent.

II. THE FACTORY GAME AS A PROGRAMMING EXERCISE

On this study it is analyzed the possibility of increasing students' performance by using games to help teaching concepts and stimulate competences. Regarding the knowledge aspect, we focus on the students' understanding, absorption and retention of knowledge. Regarding the students competences, we focus on stimulating skills by games and competitions, instead of classical programming exercises in laboratory.

The "factory game", that was originally used to simulate business and production problems, have been modified to teach computing concepts. The original game has a production line of dices composed by several types of machines, each one for a specific task and different characteristics. Each machine represents a task that students should do. To produce dices on a computational environment, each machine was programmed as a thread. Each thread represent a different machine and each machine has specific characteristics. The threads have inputs that depend on the finalization of the previous thread, which may cause production delays. Different types of products demand different threads on the production line. The market and suppliers send and receive data from the production line through messages in the local network.

A. The Factory Game

At the beginning of the game students are informed about the rules of the production and about the expected market demand.

On the factory game, from time to time (each season - one round), the game stops and the groups have to pay salaries according to the number of employees they have on the team (usually it is charged G\$ 5 (five gramilus) per employee per season). In the programming exercise, one employee controls one machine (one thread). The group directly relates the salary to the number of threads instantiated in each season.

The goal of the game is to maximize the benefit. It is emphasized that this goal cannot overcome ethical and legal principles, like using unauthorized raw material and tool, appropriating things from other competitors, cause damage in the network or other software components of the game, etc. One of the rules previously stated is that the state (professor) decision cannot be questioned.

For the programming exercise purposes, before the game begins, student must write their threads, one for each kind of machine, according to previous programming requirements. Such requirements includes the sequence of machines in order to create the proper production line, the interface between machines to exchange data (interfaces between threads), the data representation of all elements of the game, and the structure of all messages that could be exchanged between each factory and the market.

Suppliers of raw material deliver requirements to the market. Such companies run on a server and are available in the laboratory environment. Students may develop the communication mechanisms between companies as threads that follow the data communication requirements.

It is previously informed that when the game begins the demand per period can oscillate from zero up to 1000 dices per order. The demand must be supplied on time (in each period), placed on client's location (table of the instructor - on the OM game), with a note containing the name or a logotype of the supplier and the bid on it. The Factory programming developed must inform at the end of the order production all data related with the production such as the type and quantity of dice produced, the elapsed time, the number of threads running.

For each order the students may change the strategy plan, i.e., the company is able to buy more or less raw materials (three types of board) and to program machines (template, painting (gluing dots), cutting, folding threads) to begin its production. This means that students may choose to have more threads to increase production, since each kind of dice demands some time to be processed in each machine. In order to study several concepts of concurrency programming such as race condition, critical section and mutual exclusion (mutex), each kind of dice demands different resources about raw material and production time.

The products demanded can be separated in five different market segments or categories, according to the Bowman's Strategy Clock [13] (no frills, low price, hybrid, differentiation, and focused differentiation). It is informed that the:

- "No frills" dice have approximately 30% of the market segment. This category is composed by small dices as dimension criteria (it is provided a number of dice templates that can be done in one board), nor type of raw material or painting color. The price the client is willing to pay for each unit of this product is G\$ 10. The decision criteria of the client when demanding this type of dice is the price.
- "Low price" paper dice have approximately 40% of the market segment. The only criteria this dice have to follow is the minimum size of the dice (again, the number of dice templates in one board), the rest is optional. This dice need to be sufficiently cheap to compete on the market. The maximum price the client is willing to pay for each unit of this product is G\$ 25. The decision criteria of the client when demanding this type of dice is the price.
- "Hybrid" paper dice have approximately 20% of the market segment. The minimum criteria for this dice are: the big size of the dice, the demanded color of the dot painted, and the raw material is optional (it can use the cheap one). This dice need to have a good relation of quality and price to compete on the market. The maximum price the client is willing to pay for each unit of this product is G\$ 50. The decision criteria of the client when demanding this type of dice is the quality/price relation.
- "Differentiation" dice have approximately 8% of the market segment. This high quality dice must have the big size, the good raw material (special paper) and the demanded color of the dot painted. This dice must have good quality to compete on the market. The maximum price the client is willing to pay for each unit of this product is G\$ 100. The decision criteria of the client when demanding this type of dice is the quality.
- "Focus differentiation" dice have approximately 2% of the market segment. This high quality dice must have the big size, the good raw material (special paper) and the dot painted is specific (forcing the company to postpone the painting). This dice must have good quality and attend to the customized dot criteria to compete on the market. The maximum price the client is willing to pay for each unit of this product is G\$ 250. The decision criteria of the client when demanding this type of dice is the customized quality.

In the programming class, each kind of dice represents the type of material that the factory must take from raw material supplier, a production time for each machine (thread) and the cost of each machine to produce the order. In the general situation, the time to produce a "no frills" dice in each machine is lower than to produce a "low price" dice, and so on until the "focus differentiation" dice. Any machine can produce all kind of dices, since it is programmed to do so. For that, the thread must be programmed with all production times related with each kind of dice.

B. Programming Strategies Examples

During the game, the demand changes each round. At each round, all factories receive an order and cannot offer anymore the previous request. The student has up to 10 minutes to organize how many threads they will launch to attend the order as best they can according to price and quality criteria of the product demanded. The consumer must buy an amount of dices in each round or can buy all produced dices off all factories in a certain elapsed time.

Any order is presented to students as depicted in figure 1 and 2. For each one of the order students may organize their production line launching any quantity of each kind of machine to best fit the order. Figure 3 presents one possible strategy to fit the first demand (figure 1) in which it was launched four threads, one of each machine and one thread to buy raw material. Figure 4 presents another strategy in which students launches more threads to slower processes and creates intermediate stocks. Each one of the strategies present concerns about concurrency concepts.

<div> <div>1</div> <div> Consumer criteria: All dices produced to any factory in the next 5 minutes Hybrid consumer price 50 G\$ (big size – cheap raw material – black dot color) </div> </div>				
Type of strategy	Dice template marking	Painting or gluing dots	Cutting	Folding
Focused Differentiation	t=1s per dice 5 dices/board	t=1s per dice	t=1s per dice	t=1s per dice
Differentiation	t=1s per dice 5 dices/board	t=0,5s per dice	t=1s per dice	t=0,2s per dice
Hybrid	t=0,5s per dice 10 dices/board	t=0,3s per dice	t=1s per dice	t=0,2s per dice
Low price	t=0,2s per dice 20 dices/board	t=0,2s per dice	t=1s per dice	t=0,2s per dice
No frills	t=0,1s per dice 40 dices/board	t=0,1s per dice	t=0,5s per dice	t=0,2s per dice

Fig. 1. Order example – time criteria

<div> <div>2</div> <div> Consumer criteria: Market will buy the first 500 dices and will pay the consumer price Low Price consumer price 20 G\$ (big size – cheap raw material – black dot color) </div> </div>				
Type of strategy	Dice template marking	Painting or gluing dots	Cutting	Folding
Focused Differentiation	t=1s per dice 5 dices/board	t=1s per dice	t=1s per dice	t=1s per dice
Differentiation	t=1s per dice 5 dices/board	t=0,5s per dice	t=1s per dice	t=0,2s per dice
Hybrid	t=0,5s per dice 10 dices/board	t=0,3s per dice	t=1s per dice	t=0,2s per dice
Low price	t=0,2s per dice 20 dices/board	t=0,2s per dice	t=1s per dice	t=0,2s per dice
No frills	t=0,1s per dice 40 dices/board	t=0,1s per dice	t=0,5s per dice	t=0,2s per dice

Fig. 2. Order demand example – quantity criteria

After stimulating a healthy competition, compliance with the deadlines during the game and finding the best possible performance from each team and before saying what was the winning team, stands out the most important activity is the learning and carry it. Teams are requested to comment on their strategies, successes, mistakes, and think what would change if

done similar to this activity. The amount of money each company got (selling dices) at the end is dividing by the number of threads of the company (number of employees). The winner is the company that -at the end- gets more money by thread used on production.

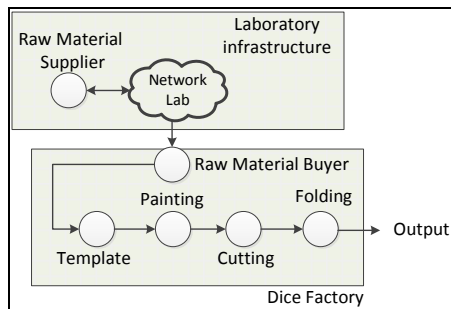


Fig. 3. Dice factory programming example 1

At each round students could rethink their strategies, evaluate the effect of race condition, critical section and mutex in their production line. Students should also evaluate in each the “computational effort” for each order when launching several threads and evaluate the effect in the production time and amount of dices produced.

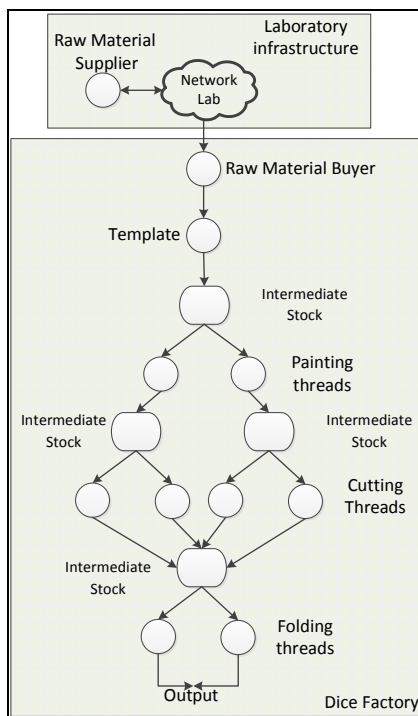


Fig. 4. Dice factory programming example 2

III. RESULTS

A survey has been conducted trying to measure if the simulation can reduce students' learning inhibitors. The questionnaire has been conducted in class, before and after doing the game. The questionnaire asks how much each factor affected students' learning with traditional speech classes (before the game) and with the use of the game to teach (after

the game and it discussion). The student have to answer with "1" if he/she considers that the factor affects very few on his learning; "2" if it affects few, "3" if it affects moderately, "4" if it affects a lot, and "5" if it affects extremely.

The topics measured are (number indicates the question number):

- 1 - Tiresome topic;
- 2 – Topics are difficult;
- 3 - Boring teacher;
- 4 - Boring lecture material;
- 5 - Teacher not been clear in his explanations;
- 6 - Student doesn't realize the practical utility of the topic;
- 7 - Student doesn't remember the content of previous lessons;
- 8 - Student is very tired;
- 9 - Colleagues talking during class disturb learning;
- 10 - Poor conditions of the environment disturb learning;
- 11 - How long do you think you will remember the topic explained? The options for this question are: (a) more than 15 years, (b) between 5 and 10 years, (c) between 3 and 5 years, (d) between 1 and 2 years, (e) less than 1 year.

The results of the survey is depicted in figure 5

An important point is that students have classes at night and in most cases are employees or interns in companies during the day.

The question one indicates that the computer programming classes became more interesting for 73% of students, as the same way the explanations of the teacher were more interesting (question 3) for 81% of them. The class were dynamic (question 8) since at least 36% of the students did not felt tired.

The content of the discipline was complex after doing the game for 18% of the students compared to 36% of them before the game. That indicates the game were useful to better understanding of the topics. One possible reason for such improvement of better understanding of the contents is that game helped teacher in the explanation, since the game was an example for several topics and student could analyze them in the lab. Students also report that could better understand the practical application (91%) of the concepts through the game, which is considered a quite important result since it is possible to estimate that students will be able to apply the studied concepts outside the classroom in related problems.

Question 11 suggests that students can remember the contents for long term using this type of class (9% answered - for more than 15 years, 27% between 5 and 10 years) compared to traditional classes (18% answered that won't remember for longer than one year).

Another important part of the survey measure the students' perception of the learning skills used on the game (the competences). The student have to answer with "1" if he/she considers that the game does not stimulate competences at all; up to "5" if it stimulates the competence very much. Students were invited to answer the competence development the following subjects:

- 12 - Negotiation;
- 13 - Leadership;
- 14 - Communication;
- 15 – Team working;
- 16- Organization

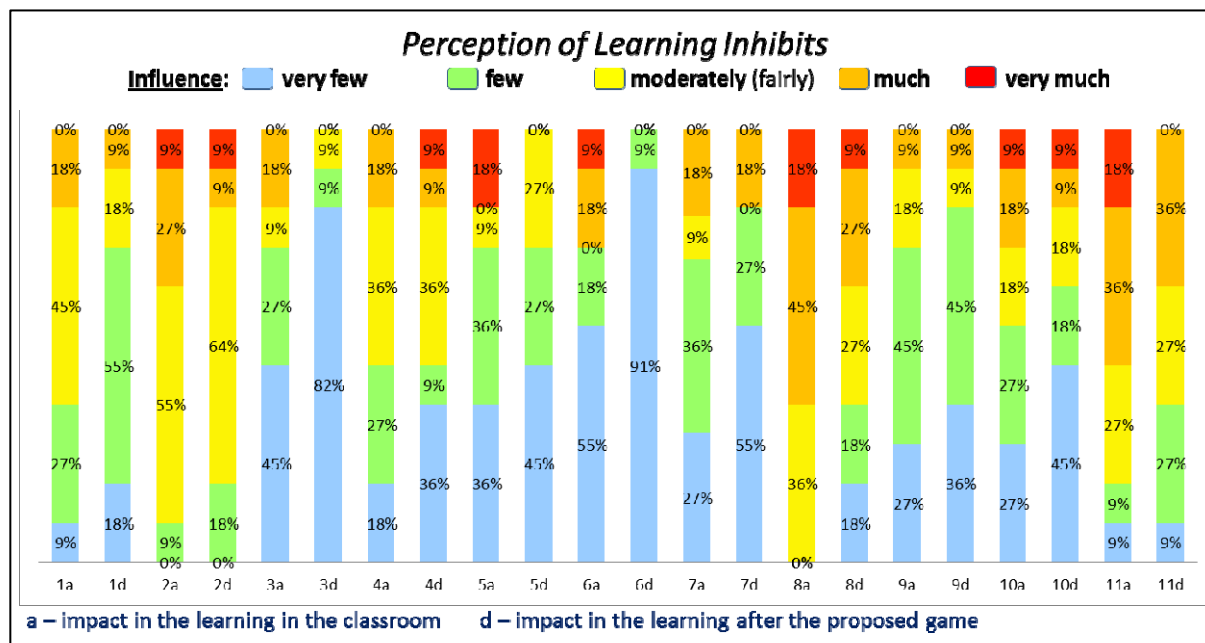


Fig. 5. Students' perception of increasing or decreasing learning inhibits with the game

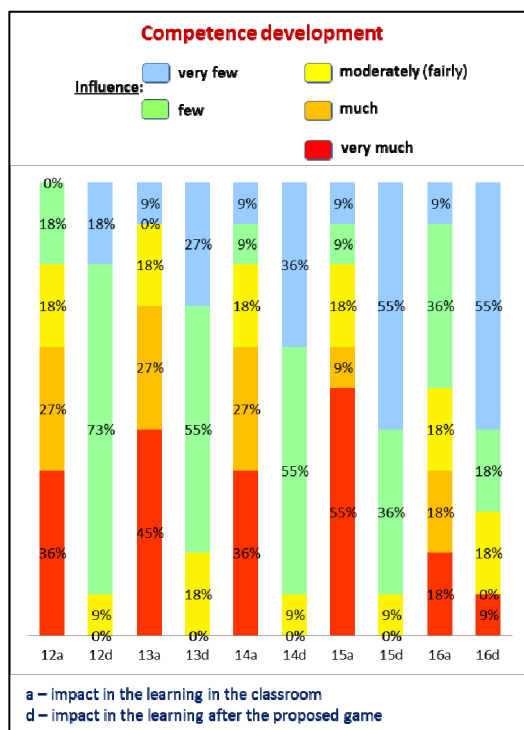


Fig. 6. Students' perception of competences stimulated with the game

The results depicted in figure 6 indicate that the students perceived improvements in all competence through the game compared to classroom. During the game students needed to discuss (negotiate) how the production line should be built on each round, the leadership was developed when the work should be organized, the communication was relevant to better understand the objectives and reach the goals of each round and the organization of work, which means that each student should develop his job to complete the production line.

IV. CONCLUDING REMARKS

Games can enable students to learn in an entertaining and unforgettable way, putting in practice the theory and connecting knowledge. Traditionally, the unstructured problems, the time constrain, working in groups, the competition, the collaboration and other characteristics of the game stimulate the development of entrepreneurship competences on students. This work got evidences that working with games to learn computer-programming techniques is effective and may improve the quality of class and a better understand of the concepts. The game helped to develop skills valuable to students such as teamwork, communication, critical thinking, problem solving, creativity, initiative, holistic view, setting up plans, self-confidence, motivating oneself and others.

The results on the survey revealed that after the simulation game, the students' perception about the negative impact on the learning inhibits usually decrease. Additionally, most students mentioned that using the game to support learning have helped them to retain the knowledge for longer.

The simulation done in class generate worthy discussion about different strategies to develop and organize the code to reach a dice production goal. During the discussions, students could analyze different methods and ideas to model the proposed problem, represented by the production order of each round. The concepts about concurrent programming and their effects became clear in each strategy and as consequence; it became clear why one of the strategy was more feasible for a production order, or specific application scenario.

Discussing the organization of the threads to attend to production strategies adopted by each group, the students demonstrate a deep and mature critical thinking, connecting concepts from different business areas that they studied previously on their engineering courses.

This study contributes to a new approach of teach and learn concurrent programming and offering an initial attempt to measure the impact of gamification on the learning inhibits. The gamification has been helping us to make our teaching task more attractive and effective to the students.

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Towards a Flipped Cyber Classroom to Facilitate Active Learning Strategies

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Abstract—Success within the distance learning paradigm typically requires a strong intrinsic motivation on the part of the learner. This motivation needs to be matched with effective delivery of engaging course content. Developing an active engagement environment for deep learning is a nontrivial task as the instructor is not physically present.

To address the concern in an online/blended delivery model, we had developed and examined our first *cyber classroom*, in which lectures are automatically recorded and posted to a website for subsequent online consumption. The observed limitations of this approach were twofold: (1) online student participation in onground classroom activities was unfeasible; and (2) onground student collaborative activities were severely curtailed by the classroom layout.

In this work in progress we present our revised concept grounded in active learning scientific principles combined with lessons learned from our prior approach. By leveraging classroom spatial layout best practices combined with the apropos technology, we seek to address the aforementioned two concerns. Specifically we present a description of our revised cyber classroom, along with plans for future application involving integrating online learning with the flipped classroom concept.

I. INTRODUCTION

The concept of a classroom has evolved to blur geographic and temporal constraints. Innovations in teaching and learning technologies has facilitated a classroom that extends to the internet, expanding access to education in an unprecedented manner. The progress of these cyber classrooms, however, is not without challenges as we strive towards a merger of technology and pedagogical principles in support of the digital native cohort in a blended environment. Research into these challenges support the existence of a clear disparity between the quality of education available when comparing on-ground and distance-learning (DL) environments [1]–[4]. These studies explored technical solutions to DL problems and collectively support the following as best practices in the design of a active learning online classroom: Internet delivery of audio and video course content; combining real-time student feedback with streaming delivery of audio and video lectures; and the integration of natural handwriting into online slides. With these in mind we sought an approach which would leverage these concepts while infusing an active learning environment for onground students; a best of both worlds solution.

Spurred by a changing student cohort that demanded increasing flexibility, Farmer and Turner [5] described the initial

attempt at a viable solution by repurposing the classroom. This solution combined best practices of interactive distance learning with a traditional classroom experience. Courses in a brick-and-mortar environment are video-captured and delivered via web servers to support both the traditional and online students. The focus was on the technical component that is primarily automated, allowing course instructors to schedule recorded lectures and initiate the recordings with a “one button push”. An underlying pedagogical model being satisfied is that of a *Flipped* classroom whereby traditional lecture and practice components are reversed. Typically students may watch lectures at home and do homework during classroom.

The emerging limitations of this early approach occurred along two primary dimensions. First, the spatial layout of the classroom followed the traditional auditorium design, confining interaction between learners and hindering active learning strategies, such as cooperative learning and peer instruction. The legacy layout, while fitting for passive engagement (typically a lecture), needed to evolve [6]. In terms of the distance learners, the effect was essentially lackluster, as the classroom recording essentially became a video to be endured with great effort.

The second component, which relates to the technology, is that the initial cyber classrooms were not designed to facilitate remote interaction with distance learners. Synchronous interaction could only be accomplished with add-on disparate technologies, which did not lend themselves to smooth integration within the classroom.

These challenges resulted in some frustration within the students and a reluctance of faculty to fully employ all that the classroom had to offer. This meant that any subsequent approaches had to consider as driving classroom design factors:

- An active learning spatial layout capable of peer collaboration.
- Technological infrastructure capable of synchronous communication
- The technologies used should seamlessly integrate and be relatively intuitive to use.

To this end, we redesigned the spatial and technology components based on [7], which proposes a highly cooperative and collaborative environment, along with guidelines for delivery. In this paper we expose our design and overview our

consideration for future application and integration within the current curriculum.

The remainder of the paper is organized as follows: Section II discusses related approaches and Section III describes the classroom in term of spatial layout and supporting technology. We discuss future application and consideration in Section IV and conclude in Section V.

II. RELATED WORK

Related literature suggests that effectively organized distance learning increases learning opportunities and accommodates multiple learning styles [3], [8], [9]. Pedagogically, the cyber classroom allows students who respond to different presentation styles to take advantage of varying content and modalities. Logistically, it has improved the distance learning experience for both our students and instructors; our students have the option of attending class or watching from home/work, and our instructors are able to deliver class without having to substantially adjust their “normal” classroom style of delivery.

The contention that video recordings are effective as a pedagogical tool, as studied in our prior work [5], is supported in a study that examines the use of an online library of video recordings of faculty lectures [10]. Here, the authors came to similar conclusions: students use video recordings as a pedagogical aid, i.e. to review concepts they struggle with and as a back up in case they miss class.

The use of videos have also been explored in the context of flipped classroom pedagogies. Bishop and Verleger [11] explored the use of video lectures coupled with active learning techniques in the classroom. Smit and Goede [12] explored the use of videos to provide supplemental instruction on difficult concepts within a system analysis and design course. In both cases, the authors found that videos are useful as a supplemental instructional aid if properly paired with additional effective instructional techniques.

A study of the use of technologies in the flipped classroom model is presented in [13]. Here, the authors examined the use of video lectures viewed at home, combined with exercises and group activities employed within the classroom. Our approach is similar in that our cyber classroom could support their methodologies, but we intend to extend the pedagogical approaches to include support for distance learning students participating in real-time.

Other work related to distance education paradigm examined the use of virtual laboratory infrastructure [14]–[16]. In these studies, the authors examined mechanisms by which virtual machines are used to deliver laboratory content for use in networking courses. The VMs are coupled with virtual networks built within the VMWare software, allowing our distance students to experience laboratories *equivalent* to in-person.

Active learning strategies are explored extensively by Beichner in the Student-Centered Active Learning Environment with Upside-Down Pedagogies (SCALE-UP) project [6], [7], [17]–[19]. Students learn in spaces designed to facilitate interactions among teams of students, as well as with the instructor. Instead of spending the duration of class in lecture, the goal is

to flip the classroom so that students spend much of their class time engaged collaboratively in a series of short, interesting tasks designed to enhance their learning.

III. THE FLIPPED CYBER CLASSROOM

This cyber classroom consists of two primary systems: the technological component responsible for the recording of lectures and posting them to our department’s web server; and the active learning components based on the SCALE-UP project. Although these concepts are somewhat blended for the purpose of computer science instruction, they primary divide the room into electronic components and physical, architectural features.

A. Spatial Considerations

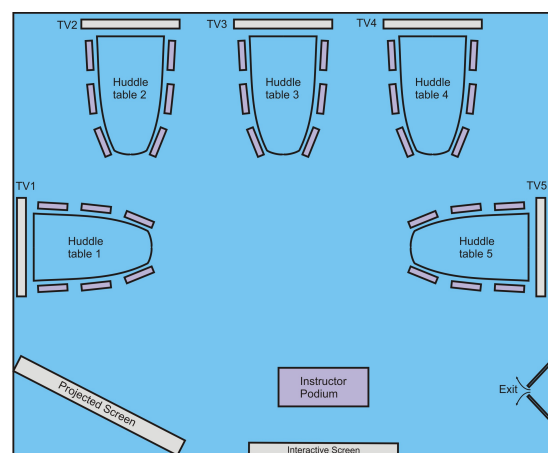


Fig. 1: Active Learning Layout

Figure 1 shows the layout of the classroom. Student huddles of six are capable of collaboration in close proximity. Each table is designed according to the SCALE-UP paradigm, such that students face or nearly face each other with the u-shaped configuration. The huddle size was chosen in accordance with research that suggests optimal group sizes for collaborative learning [20]–[22]. In addition, the instructor is able to easily move about and interact more closely with individuals and groups, a feature sorely lacking within the auditorium style classroom.



Fig. 2: The Cyber Classroom

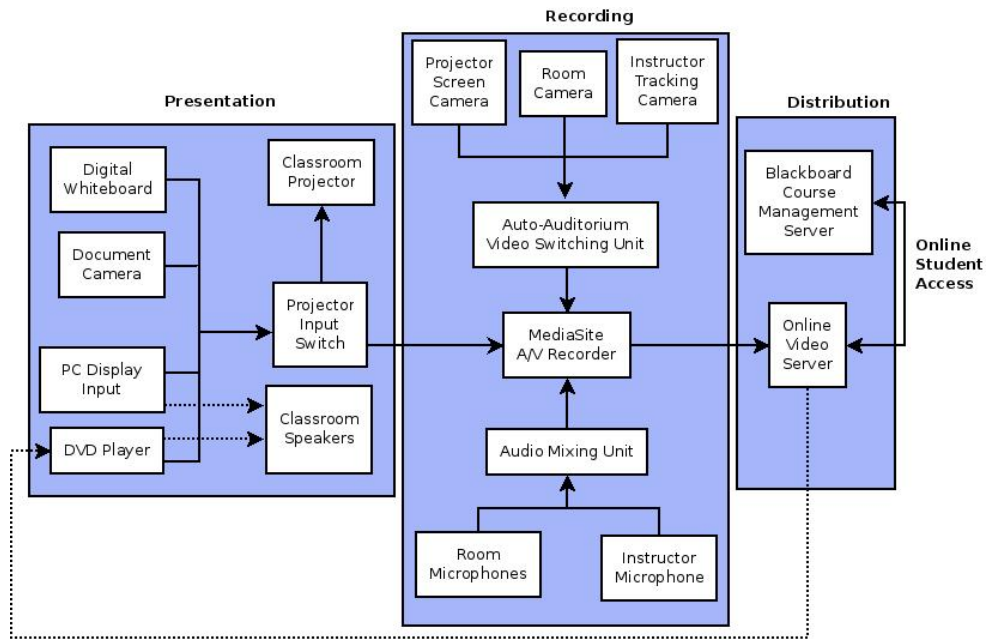


Fig. 3: Supporting Technology Infrastructure

B. Supporting Technologies

The generic technical architecture of the cyber classroom is provided in Figure 3. Here, the system is divided into three general subsystems: (i) presentation, (ii) recording, and (iii) distribution. The system is fully automated, requiring instructors only to schedule a recording, ensure the system power is on at the start of each class, and press the record button on the control screen. The ease of use makes the system suitable for a wider variety of faculty having varying levels of technology comfort.

The automation of the recording mechanism is accomplished by use of MediaSite [23] and AutoAuditorium [24] products. The MediaSite device is responsible for scheduling, recording, and storage of the recorded lectures. The AutoAuditorium acts, using an AI, as a computerized camera operator, determining when to follow the instructor as he/she walks around the room, and determining when to switch among various sources, including a tracking camera, a fixed camera that focuses on the screen, the room camera, and the presentation inputs. Further details of the operations of the subsystems are described in [25].

Figure 4 presents the control screen, used to control operation of the entire room. Note how closely it maps to the actual layout of the classroom. This allows for a more intuitive feel. The controller has the capability of routing feeds among various components, including sending the instructor's video feed to all PCs, routing from one PC to other PCs and/or tables, and controlling feeds to individual tables. As the screen shot shows, there are five *huddle tables* within the room, designed for collaborative activities.

The huddle tables are shown in Figure 2. All PCs on the table are connected together via a local switch such that they can be controlled by an interface local to the table, shown in



Fig. 4: Video Routing Control Interface

Figure 5. Under control of the instructor, individual tables can be independently operated to facilitate close group interaction among students. Outside interaction through Skype or similar real-time communication software, is fully supported.



Fig. 5: The Table Controller Interface

IV. FUTURE APPLICATION

Our intended future uses of this cyber classroom are to further combine the inquiry-based learning techniques advocated in the SCALE-UP project with the best aspects of our video course delivery capabilities. The initial use of the classroom was to teach computer architecture using project based learning as the pedagogical backbone. Our initial results are very promising, as students and instructor alike seemed to take to the technology. We will endeavor to seek a more empirical analysis as to the effectiveness of the classroom in the short term using qualitative methods.

We intend to expand our use of the classroom to teach software engineering as the small collaborative group requirement for agile purposes is a very close fit. In addition, the practice of *pair programming*, which was not easily implementable in our prior cyber classroom, is now an option for learners.

As we expand offering, we intend not only to produce a quick start guide for faculty but guidelines on integrating a syllabus to maximize learning.

V. CONCLUSION

The construction of this room was initiated due to needs within our program to revisit our cyber classroom space design. We used it as an opportunity to add features conducive to Computer Science related coursework. In this paper we exposed our preliminary implementation and consideration for future considerations.

This concept demonstrates promise for teaching and learning augmentation and expansion into other disciplines being taught within our institution.

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Evaluating the effect of thoughtful design of in-class time for a flipped classroom

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Abstract— A lot of attention has been given to the pedagogical method referred to as "flipping" the classroom. Many previous studies and conference presentations have shown that while students do not perform any worse in flipped classrooms than in a traditional format. However, a thoughtful design of the time spent in class can improve performance. This work-in-progress paper is a narrative of one course's journey over several semesters from traditional lecture to flipped classroom, and the observations of the impact that in-class and out of class activities had on overall performance of students. Brief descriptions of many course assignments and activities are included. In addition, the preliminary plan for evaluating how to create an inverted classroom that can support building lifelong learning skills is presented.

Keywords— engineering education; flipped classroom; active learning; effectiveness

I. INTRODUCTION

Inverted, or Flipped, classrooms have been gaining popularity in both K-12 and higher education. Inverted classrooms are a pedagogical method that allows for the combination of behaviorist and constructivist learning theories that were once considered incompatible with each other [1]. In this method, pre-recorded video lectures and individual activities are assigned before class, reducing or eliminating the amount of time spent in lecture during class. As a result, time can be spent in class employing active, open-ended, and group activities. More simply, Lage, Platt, and Teglia explain the flipped classroom by stating, "...events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa" [2].

Many studies that have tried to gauge the performance of achieving course outcomes in flipped courses have found that there is either inconsistent or no significant differences between the performance of students in flipped courses versus students in lecture-based courses [3,4]. In general, studies have shown that students typically like this method, with there always being a few who would prefer a more traditionally structured class [1, 2, 5, 6]. Instructors, including the author, also are satisfied with the flipped classroom format. Faculty can provide more instructional opportunities (such as guest speakers, field trips, deeper discussions) and interact more

with the students [7], and many students are better prepared for class [2].

Because it has been shown to be at least as effective as lecture-based courses, and students and instructors are satisfied with it, the inverted classroom is a pedagogical method that will continue to be used. In addition, it has great potential to be a highly effective pedagogy. Therefore, it warrants further use, experimentation, and refinement. There needs to be more work showing how this pedagogical method can be consistently highly effective and help students achieve outcomes in ways that are supported by educational science. There also needs to be more information provided in publications that share details and descriptions of the assignments and activities used for the inverted courses [1].

This work-in-progress paper aims to help meet these needs, and outlines how one course has progressed from a lecture-based-turned-inverted course to a thoughtfully designed course that aims to support students' learning. Brief descriptions of many course assignments and activities are included, along with a qualitative evaluation of the effectiveness of the course overall and specific assignments and activities.

II. PROGRESSION OF AN INVERTED COURSE

A. The Original Study that is the Basis of this Narrative

In 2012, a high-enrollment (n=146) fluid mechanics course was converted by the author to an inverted classroom format. The impetus for this change centered on the desire to create a course that helped students to learn the course content more effectively while also acquiring some skills to become lifelong learners. After the initial semester, performance on the final exam (which was common between the two semesters) was compared between the inverted classroom in 2012 and a lecture-based section taught by the same instructor the previous year. The results of the comparison showed that the lecture based course had a statistically significant higher final exam score than the inverted classroom section for the overall grade and two course topics. What this analysis does not consider is the gap in the depth of content coverage for one of

those topics, which resulted in a very large difference in scores on the common final exam.[8]

B. Many Course Design Iterations - Striving for Effectiveness

After that first semester of the inverted course, despite the difference in performance, I chose to continue using the flipped format. The potential for “deeper” learning is great, and the extra time spent interacting with the students is invaluable for developing relationships with students when enrollment is high. In addition, educational research has concluded so much that can be supported by having an inverted classroom. For example, the levels of Bloom’s Taxonomy of Learning [9] are addressed by structuring course work such that the lower order thinking and tasks are accomplished by the student outside of class. Doing so leaves time for the instructor to facilitate the higher order thinking and activities in class. Vygotsky’s Zone of Proximal Development [10] is accounted for by designing assignments and activities that will support students learning and help them to learn more than what would have been possible without that support. The extra in-class time that an inverted classroom affords is essential for this. In order to address students who are both intrinsically and extrinsically motivated [11] there needs to be activities that offer choice, and also activities that result in a grade that applies to the final course grade. Providing a wide assortment of activities allows for the many learning preferences [12] of students to be addressed and all students have offerings that will help them to be successful. Time to reflect on the material and then engage with it again is also necessary. These considerations were applied in conjunction with the instructor’s objectives, which are as follows:

- Ensure that students meet the course outcomes and learn the technical concepts necessary to succeed in future courses and their careers
- Develop student ability to use the course concepts as they solve problems and apply them to their chosen careers
- Help students learn how to learn and eventually be lifelong learners
- Provide time for students to have interpersonal interactions and develop teamwork skills
- Have students enjoy learning the course material

Over the 5 semesters that the course was taught after the study discussed above [8], the desired outcomes, assignments and activities have been incrementally changed, integrating aspects of other pedagogies that have been successful. For example, some components of the Team-Based Learning model [13] are incorporated, along with computer simulations and other active learning activities. When the course was first inverted, it followed a regular schedule of student preparation using videos and the text before class, and working problems in class with a few spurratic mini-lectures and demonstrations. More structured in-class activities were needed in order to help make the course more effective.

C. Second and Third Offering of the Course

The following two semesters after the first study, a few in class “labs” using computer simulations were assigned, and team quizzes and multiple choice exams were given using the IF-AT scratch cards first made popular for the Team-Based Learning [13] pedagogy. The computer simulation “labs” were quite effective for letting students “play” with the major concepts involved and were well-received by the students. The scratch card exams gave a lot of people anxiety, and the test was too long if the students didn’t get most of the answers correct on the multiple choice exam the first time around. As a result, the average on the final exams, which used many of the same questions and covered the same topics, was a 72%, which is a letter grade lower than the averages from the lecture based course and the first iteration of the flipped course. In addition to the anxiety that the scratch cards caused, upon self-reflection, the lower performance may also be due to the difficulty of the exams, which have been getting progressively more difficult as I mature as an instructor.

D. Fourth and Fifth Iterations of the Course

Over the next couple of semesters, small changes were made with the intention of improving the learning experience. More computer simulation “labs” and demonstrations were added, and more time was spent working examples together to help model problem solving skills. In addition, many of the students were not comfortable with the small quantity of graded homework, so some graded homework problems were added.

E. Sixth Time is a Charm?

By the time the inverted format had been taught for six semesters, the class was structured around seven key groups of concepts. Each group of concepts went through at least one iteration of the following sequence of carefully sequenced assignments and activities to allow multiple opportunities for students to interact with the course material at steadily increasing levels of difficulty.

- Exposure Level 1 – Introduction and low stakes exploration
 - Online lectures – introduce to topics, give initial chance to organize information, form questions, begin to practice with simple problems and examples
 - Reading quizzes online before class – self-assess whether basic level of understanding has been attained – very low stakes
 - In class demonstrations to illustrate concepts
- Exposure Level 2 – Practice
 - Think aloud examples presented illustrating how to do more complex problems
 - In class “labs” using online physics simulations

- Practice problems – (not for credit) answers given but no solutions. Hints and Steps provided after a week to help with review and build confidence that they are working problems correctly
- “Teach your Team” – students are assigned a practice problem that they work out, write a script explaining the solution, and then teach to a small group of other students.
- Exposure Level 3 – The stakes get higher
 - Homework problems assigned for credit
 - Group Quizzes –
 - in class multiple choice quiz using IF-AT scratch cards [13]
 - Students work together to answer questions
 - Must work until correct answer is determined
 - Credit awarded decreases with each incorrect answer
- Exposure Level 4 – Individual high stakes exam – written, open answer problems; conceptual questions

The final exam given to this sixth group of students was similar to that given to the first inverted section and the lecture based section (final exams are not handed back), with some questions being of higher difficulty. The student performance on this exam was higher than both the original lecture-based section and the first inverted section, for the total score and several topics. This may indicate that the structure of the course contributed to improved outcomes for the students. However, no controlled study was conducted to support this claim.

F. *The Not-So-Lucky Number Seven*

Encouraged by the results in the sixth semester, a similar course design was used again the following (7th) semester, with a few key differences. The number of students increased from 50 to 205. More “labs” were added, and at the request of the students, the amount of graded homework problems from the textbook was increased dramatically. However, contrary to my expectations, the average on the final exam was seven percentage points lower than the previous semester. Upon reflection, these are the reasons that performance was lower for this particular iteration of the course:

- The departure from mainly practice problems and switching to mostly graded problems had a seriously negative effect on the quality of learning. Because the assigned problems were from the textbook (even though it was the first semester of a first edition), the solutions were easily accessed and widely used by the students. As a result, many replicas of the solutions manual were turned in and the quality of engagement with the course material was very low. This is an illustration of how much more this group

of students was motivated by grades instead of having the desire, or motivation, to learn.

- The prolific use of the solutions manual also led to bi-modal exam score distributions. Typically, those who did not engage with the material earned below a 70% of the exams. Those who watched the videos, prepared for quizzes and classes, did the practice problems and truly worked the homework problems performed higher, usually above an 80%. There were very few traditionally average C’s.
- The “personality” of this class was notable in the respect that they were the least self-directed group of students that I have had to date. In addition, many did not have the necessary study skills and or self-reflection skills. The main concern of most was knowing what was going to be covered on the exams. In response to this observation, I added some activities and assignments to help students acquire these skills while working within the confines of the actual course material [14]. These included learner-centered activities such as a participatory exam review [14], a self-evaluation of performance on exams [14], determining individual learning preferences [12], providing instruction on various note-taking techniques, and providing an overview of many sources of course-related information. Many students appreciated these additional activities and commented that no one had ever taught them those aspects of learning before.

III. FUTURE IMPROVEMENTS AND PLANS

In the next offering of this course, a structure similar to the sixth offering is planned, along with integrating the learner-centered material and assignments used in the seventh semester. There will be a return to having more ungraded practice problems and fewer problems turned in for a grade. This is to encourage students to work toward getting a correct answer instead of working to meet a deadline. To help encourage more students to come prepared to class, the reading quizzes will be converted to a take home version of the individual readiness quiz that is part of the Team-Based Learning system [13].

In addition, one of the key outcomes identified for the fluid mechanics course discussed in this paper is to help students attain the skills necessary to be lifelong learners. The structure of an inverted course makes it a great forum for helping students become lifelong learners. Students must be able to acquire knowledge outside of the classroom in order to arrive prepared. They also must be aware of what they know and what they still need to learn in order to be successful. Thus, future iterations of this course will also include more aspects that are structured to directly support developing lifelong learning skills. One such way to accomplish this may be to offer multiple sources and have students be responsible for finding the applicable information, rather than assigning

readings. This may be too much to ask of sophomores, however.

There may even be an opportunity to add to the body of research on the effectiveness of the inverted classroom by evaluating how the pedagogical method contributes to attaining life-long learning skills. A possible design for one such study would be to use in class assignments, surveys, and possibly a validated survey to assess the effectiveness of the course formats and particular activities and assignments. Select participants could also be interviewed either individually or as part of focus groups to learn about their impressions both before the course and after it was completed. Additionally, anonymous comments that are part of the university faculty evaluation system can be used when possible.

For a study such as this, comparisons can be made between at least five cohorts. The first cohort has already finished the course, but is still at the university as seniors. These students

had fluid mechanics as an inverted course, but received no specific instruction regarding lifelong learning skills. The second and third cohorts are groups of alumni who received no related training or assignments as part of their fluid mechanics course: one completed fluid mechanics as a lecture-based course, and one completed the course as an inverted course. The fourth cohort consists of juniors who had the inverted course with some learner-centered activities incorporated into the curriculum. The final (fifth) cohort could be next year's sophomores who will have the inverted course with the learner-centered activities and some additional skills training and assignments. These cohorts are composed of students who are part of a specific department who all aspire to the same profession and have entered the course having completed the same core courses. In addition, the fluid mechanics course is taught by the same professor. Therefore, they are similar even though the experiences of these cohorts have been spread over many semesters and years. The difference between the cohorts is summarized in Table 1.

Table 1. Division of Cohorts for possible study

Characteristic of Cohort	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5
Completed lecture-based course		x			
Completed inverted classroom course	x		x	x	x
Completed learner-centered assignments focused on meta-cognition, study skills, and skills assessment				x	x
Completed assignments with lifelong learning skills acquisition embedded					x
Interviews, Focus groups, and/or Survey	x	x	x	x	x
Interviews, Focus groups, and/or Survey as seniors	x			x	x
Interviews, Focus groups, and/or Survey as juniors				x	x
Interviews, Focus groups, and/or Survey at the beginning of term					x
Interviews, Focus groups, and/or Survey at end of course					x

IV. CONCLUSION

Inverted classrooms provide many opportunities to support student learning beyond what most lecture-based courses can. Many studies have shown that students perform comparatively well despite the format. However, the method offers the opportunity to be more effective for learning both content and professional skills. This paper outlined the progression of how this course was designed in pursuit of an inverted course that is more effective than a lecture-based course, which also offers the additional benefit of going beyond course content and to help students be lifelong learners and members of a team. Careful structuring of the time both in and out of the classroom can lead to an effective educational experience for students that will serve them well both during their time in school and as professionals.

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Adapting a Concept of Framing to Understand How Students Learn in Problem-Centered Group Learning in Flipped Engineering Classrooms

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Abstract—A concept of framing is adapted for analyzing how students learn in problem-centered group learning. Students' contributions to discourse are analyzed and associated with their conceptual understanding and growth. Characteristics indicating conceptual understanding, along with factors influencing classroom interactions for conceptual growth are reported. Resources that support designing and conducting learning activities in “flipped classrooms” are discussed.

Keywords—group problem solving; positioning; cognitive development; conceptual understanding

I. INTRODUCTION

We have applied the Four-Practice Model in flipped engineering classrooms for the past three years and found that problem-centered collaborative learning has been effective in supporting quality teaching for flipped classrooms [1-3]. The four-practice model, shown in Table I, emphasizes the redefined roles of instructors as well as accountability for students in learning. These studies were conducted in an upper-level undergraduate electrical engineering course offered once a year. By problematizing content, we have engaged students in group problem solving that has improved students' learning of content knowledge and development of problem solving skills. Other positive influences, including better understanding of what knowledge is counted toward learning, as well as improved learning habits have been observed [2, 3]. Discourse in group discussions influenced conceptual growth through peer interactions during small group discussions. Many students commented that replacing traditional lectures with problem-centered learning provided them with exciting and authentic learning opportunities. They wished that more engineering classes would make similar changes. Some students reported that the instructor influenced areas of growth, specifically the ability to ask quality questions.

Despite many positive changes in teaching and learning in flipped engineering classrooms, we continue to encounter teaching and learning challenges while integrating collaborative learning with cognitive development. Many factors, including group discussions, classroom discourse,

learning materials, and others influence collaborative learning. These factors can be multi-faceted due to the complex nature of learning. To ensure that the instructional model in a flipped classroom, particularly group problem solving, significantly improves learning outcomes, it is critical that we understand how students learn in groups and how we can best support students to achieve conceptual understanding and growth in the subject domain. Given the reliance on group activities, it is crucial that we assess what aspects of peer-to-peer dialogues facilitate or hinder learning.

In this study, we adapted a concept of framing to explain two cases of small group problem solving, and expanded verbal discourse analysis to include “Big D” Discourse analysis for language and other artifacts used in flipped classrooms. We analyzed students' conversations during a group problem-solving exercise. The content of the group talks was analyzed using a developed scheme supported by the revised 2-D taxonomy [2, 4]. We then applied a general situative framework of framing proposed by Greeno and others [5-7]. We found that the way students position themselves throughout a conversation, as either a source or receiver of information, influences the development of conceptual knowledge.

TABLE I. THE FOUR-PRACTICE MODEL FOR PROBLEM-CENTERED LEARNING IN “FLIPPED CLASSROOMS” [1]

Instructional Practice	Description
Anticipating	<ul style="list-style-type: none">• Select content topics that are important for learning the course in coherent ways• Anticipate demands and possible responses to learning tasks
Monitoring	<ul style="list-style-type: none">• Probe students' responses• Engage in conversations with students• Keep group discussions on track by providing probing and driving questions and hints
Connecting & Contrasting	<ul style="list-style-type: none">• Contrast students' views to discipline norms• Elicit questions and encourage “dialogic inquiries” targeting key concepts• Q & A in a big group
Contextualized Lecturing	<ul style="list-style-type: none">• Lecture based on students' responses

II. BACKGROUND

A. “Big D” Discourse in Flipped Classrooms

“Big D” Discourse, termed Discourse in this report, is a distinctive way of saying, doing, and being, because Discourses are always language plus ancillary material and effects [8]. Applying Discourse analysis combines and integrates languages, actions, interactions, ways of thinking, believing, valuing, and the use of various representational tools to evaluate learning activities. Decades of research on discourse has supported the fundamental role of classroom talks in education. As Halliday puts it, “language is the essential condition of knowing, the process by which experience becomes knowledge” [9]. Much research, for example the study by Chin and Osborne, discusses the potential of students’ “utterances” as an epistemic probe and a heuristic for how students are constructing knowledge collaboratively in classrooms. Other studies indicate that the nature and the quality of the classroom talks are central to whether and how learning occurs [10].

Our previous studies on students’ verbal utterances in group discussions consistently showed evidence that supports these findings [3]. Drawing on the revised 2-D taxonomy for science and engineering instruction, we developed a scheme to analyze content of group talks along the dimensions of “knowledge type” and “cognitive ability” [2, 4]. The coding scheme shown in Table II for discourse analysis allowed us to characterize the nature of group talks and provided indicators of student engagement in learning. We found that students’ group talks shifted from factual knowledge to conceptual and procedural knowledge when deep learning and critical thinking took place. We have also found that some problems posed by the instructor engaged students well while others failed to do so [3]. Building on this first step, we expand to include Discourse analysis to connect saying with doing and being in cognitive development.

TABLE II. KNOWLEDGE DIMENSION OF CODING SCHEME [2]

Knowledge Type	Sample Verbal Data
Factual (F): Terminology; Specific details and elements.	<i>“Isn’t P mechanical tau times omega?”</i>
Conceptual (C): Classifications and categories; Principles and generalization; Theories, models, and structures.	<i>“So, what if we assume the total power we get is some torque times speed. So that torque is going to be applied by the motor no matter what.”</i>
Procedural (P): Subject-specific skills and algorithms; Subject-specific techniques and methods; Criteria for determining when to use appropriate procedures.	<i>“We’re trying to find mechanical power; we have to use mechanical speed.”</i>
Metacognitive (M): Strategic; Cognitive tasks including appropriate contextual and conditional knowledge; Self-knowledge.	<i>“I first did it using P(power) and then added it to the answer and had it wrong.” “Oh! That’s where I got mixed up. It’s not omega synchronous. If you just say omega...”</i>

B. Concept of Framing

Framing generally refers to the way in which participants understand the activity in which they are engaged. Three interrelated aspects of framing, i.e. positional, epistemological, and conceptual framing have been described [6]. Positional framing refers to the way in which participants understand themselves, their relationship to others, and their contributions to group activities. Epistemological and conceptual framings are two parts of cognitive framing. Epistemological framing refers to participants’ understanding of kinds of knowledge that are counted while conceptual framing refers to participants’ understanding of information structure and organization pertaining to domain content knowledge. In general, cognitive framing refers to how different aspects of the information are recognized and organized during group discussions. It is used to consider “knowing, understanding, and learning concepts and conceptions as processes that occur in individual minds” [5].

The current study stresses how students’ interactions influence their learning by connecting positional framing to cognitive framing. The goal is to study ways in which students’ mental processes are supported, facilitated, or hindered by conditions of social interaction described by positional framing in group discussions.

III. RESEARCH QUESTIONS AND DATA COLLECTION

A. Research Questions

The study focused on two research questions: (1) What are the factors that influence students’ interactions with assigned problems as a group? (2) What are the resources in facilitating students to reach common understanding during group discussions?

B. Data Collection

The study was conducted in Electric Drives, one of the three core courses in the curriculum of electrical energy systems. Data collected in spring 2014 included

- (1) students’ verbal discourse while working within a small group on problems posed by the instructor. Student talks were observed by researchers and audio recorded weekly. The recorded voice data were transcribed, coded, and analyzed using the developed scheme (Table II). The coded verbal discourse was quantified to facilitate data analyses.
- (2) students’ team worksheets in group discussion during in-class lecture periods, and for three “mock test” group problem-solving exercises right before midterm exams.
- (3) copies of students’ midterm exams. These were analyzed and referenced in conjunction with the data described above.
- (4) two online surveys. One conducted at the beginning of the semester and one at the end of the semester. Two focus group meetings were conducted at the end of the semester.

For the current study, we analyzed the verbal discourse and written work from two student groups (OR and MN) while they worked on the problem presented in Fig 1. The

problem was one of two problems that were part of a closed-book and closed-notes “mock-test” group problem-solving exercise. Students were asked by the instructor to work in groups to solve the problem. The intended conceptual framing, equations (1) and (2) for steady state, is also shown in Fig 1.

C. Data Analyses

- Using the coding scheme in Table II to identify group talk content;
- Applying positional framing to analyze how students interact with each other in problem solving group activities;
- Employing the extended cognitive framing to examine students’ learning outcomes in conceptual understanding of content knowledge.

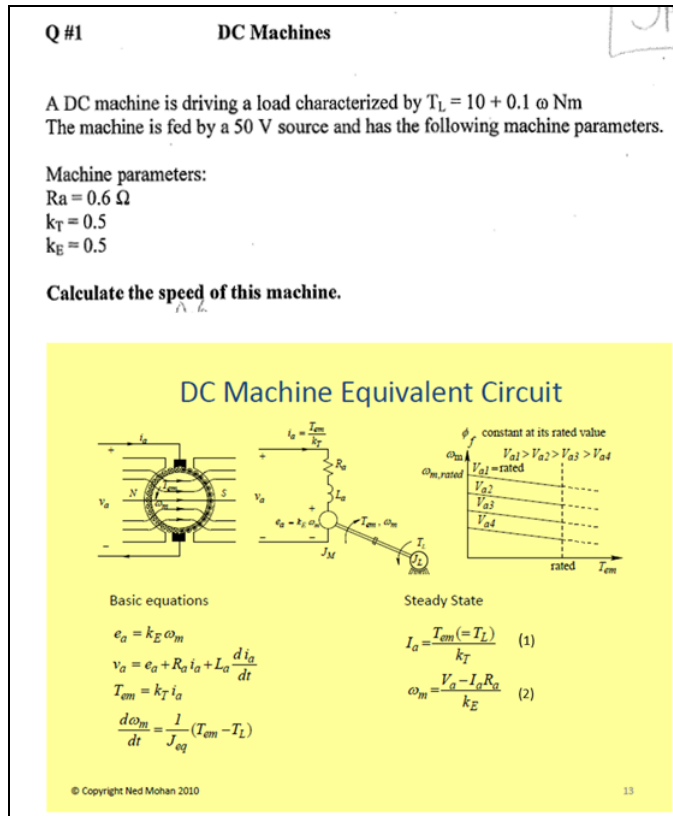


Fig. 1. Problem 1 in the “mock test” and intended conceptual framing [11].

IV. RESULTS AND FINDINGS

A. Positional Framing

Table III displays verbal utterances from Group OR. Four students participated in the group problem-solving exercise. Their conversations were coded using the knowledge dimension coding scheme (Table II). The progression of talks is displayed in Fig. 2.

Patterns of group talks observed are consistent with positional framing, namely that the dialogue progressed involving joint efforts from group members. Multiple students engaged in problem solving by sharing understanding, asking

questions, providing explanations, and reviewing their own and others’ opinions publicly. Prolific dialogues during learning activities such as problem solving often involve negotiations. It requires that two or more participants play roles more than simple “presentation-acceptance” pairs. Because students brought different perspectives into the activity, they were expected to take turns to initiate topics and contribute to dialogues differentially in productive discussions. Participants need to listen critically as well as act as a source of information to achieve mutual understanding for communicative purposes.

Changes in the positioning of each participant in Group OR were observed, which resulted in unique and inhomogeneous contributions from each member. For example, while discussing the proposal “if ω is a constant”, three students repeatedly alternated their roles as critical listeners with their roles as a source of information. Eventually, one idea was accepted after a lengthy discussion. Characteristics in the discussion for Group OR included uneven contributions from members of the group over the course of the conversation due to different positioning. This likely supported their cognitive development in significant ways, which will be discussed in the following.

B. Cognitive Framing: Epistemological and Conceptual

Students in Group OR considered the activity of problem solving to be an opportunity to test their understanding and capability to apply relevant formulas under study. One student, student P1, who initially focused on identifying an equation, ultimately came to understand the meaning and structure of the problem by working with others. The alignment of epistemological framing, i.e. understanding what kind of information and knowledge is needed and counted toward learning is the foundation of conceptual framing, in which students organize the solution activity around the structure of the problem.

Tables included in Fig. 3 provide detailed accounts of students’ conceptual framing and reveal how knowledge is distributed across group members and its resources, and how group communication and collaboration leads to the development of conceptual understanding. We divided the group talk into four episodes to explain what conceptual framing and reframing mean and how they contribute to improved learning. Following [6], we focused primarily on two items: “foreground components” and “relations between these components”. Students’ misconceptions were indicated.

1) Episode 1 (Lines 1-12, Table III)

In the initial framing, it was clear that students knew that finding ω was the goal of the task. Student P1 initiated the discussion and put some components, such as k_T , ω , and T_L , into the foreground. He did not attend to the meanings of these components. Student P2 responded and acted as a source with some explanations and immediately suggested that “the motor is in steady state.” Student P3 joined the conversation with the idea of “finding ω ” in mind. Each participant identified some required components, but none was able to connect these pieces. The left columns in the top table in Fig. 3 show

students' framing in Episode 1. There are gaps in their understanding of content.

2) Episode 2 (Lines 13-27, Table III)

The focus of the discussion in Episode 2 was on "if ω is a constant" and its implication. Student P3 visited and revisited the idea three times and stressed that acceleration was zero as a result of constant ω . While student P2 was uncertain about the claim, because it was not explicitly stated in the problem, he eventually accepted the idea. These utterances revealed that an initially missed connection between "steady state" and "constant ω " was repaired through dialogues. Students P2 and P3 achieved mutual understanding and foregrounded a few more components and their relationships. As illustrated in the right columns of the top table in Fig. 3, they aligned their conceptual framing and were able to bring information into the common ground. Although, student P1 was not yet in agreement, he followed and was involved.

3) Episode 3 (Lines 28-47, Table III)

This part of the discussion showed that students P1 and P4 were able to communicate between themselves and with others after they reframed their conceptual understanding. The component T_{em} along with V_R and e_a was in the foreground, and relations for all foregrounded components became explicit to all in the group. Students evaluated their own work and compared it with works of their peers. As shown in the left columns of the lower table in Fig. 3, after adding two equations, students' conceptual framing was in line with the framing intended by the instructor, Equations (1) and (2). Students were also able to provide explanations for why these equations were applicable in their conversation.

4) Episode 4 (Lines 48-83, Table III)

The group continued to refine their conceptual understanding while evaluating and comparing their work. Because they aligned their conceptual framing, they were able to communicate effectively, and helped each other correct mistakes and consolidate understanding while applying formulas that they identified together. See the right columns of the lower table in Fig. 3. We followed [6] and used refining instead of reframing to infer that discussions at this stage did not change their conceptual understanding. Student P4 misused the equation for I_A , but was able to communicate with his peers. The episode showed that students were able to reflect on the process while strengthening their conceptual and procedural knowledge. As shown in Fig. 2, it is important to offer students time and space that allows them to gain metacognitive knowledge.

TABLE III. EXCERPTS OF GROUP DISCUSSION VERBAL DATA

Line No.	Verbal discourse (Group OR, 4 students)	Code
1	P1: k_T is K Omega, right?	F
2	P2: Yeah. Yes, it is.	F
3	P1: Omega equals T_L minus... (mumbling)... is it 10? It has something to do with current.	F/C/P
4	P2: The motor is in a steady state.	C
5	P1: Right.	C

6	P2: It doesn't say. Oh, wait, it's $10 + 0.1 \Omega$.	C
7	P3: From that can't you figure out the frequency?	P
8	P2: No, you're actually better than most of us at torque stuff.	P
9	P1: Well, because we have that Omega wouldn't we be able to figure out the beginning?	F/P
10	P2: Right, so the beginning DC?	F/C/P
11	P1: Yeah, that's what I mean.	C/P
12	P2: We're trying to find Omega from DC?	C/P
13	P3: If the acceleration is 0, meaning the speed is constant, right?	C
14	P2: Right. Omega equals 10 times T_L ... (mumbled at 1:42)	C/P
15	P3: If the speed is a constant, does that imply that?	C
16	P2: I don't even think it's a constant.	C
17	P3: If it's a constant we can say acceleration is 0.	C
18	P1: Do you guys know how to get an actual number?	P
19	P2: It's the other K , k_T .	P
20	P2: You can make that assumption if acceleration is 0.	C
21	P3: Okay, so let's assume acceleration is 0.	C
22	P2: If acceleration is 0 then T_L equals $k_T I_A$. So, that would mean T over I_A or T over .5 is I_A .	C/P
23	P1: I_A equals T_L over 0.5. Alright.	P
24	P2: Then V_R is that times...	P
...		
28	P2: Oh. We don't have I_A though, right?	P
29	P4: You have T_{em} .	P
30	P2: Oh! Because T_L is in the variant.	C/P
31	P4: Do you agree with that?	C/P
32	P1: Yeah, because it's in a series. Or because we are in steady state.	C/P
33	P3: V_A equals V_R plus e_a , right?	P
34	P1: Yeah.	P
35	P1: $V_R V_L$.	P
36	P2: Let's go back. 50 minus 0.6.	P
37	P3: Oh, okay! 0.6.	P
38	P4: So, you have an equation in terms of ω_m .	C/P
...		
46	P2: That's really easy! When you multiply this you'll have .6 times .05 and subtract that from here and you will just divide it. We have Omega! Well we do anyway.	P/M
47	P4: What did you get? I got 100 radians per second.	P
48	P3: I don't think we did it right.	P/M
49	P4: Here's what I did.	P
50	P1: Here's what I did.	P
51	P4: 100 minus 0.6 minus 5. But I_A is not e_a over Omega.	C/P
52	P1: Hm?	P
53	P4: This isn't right.	P/M
54	P1: Why not?	M
55	P4: Isn't that e_a over Omega?	P/M
56	P2: No, it's not equal to it. That's I_A .	C/P/M
...		
60	P2: Yes, yes. T_L equals T_{em} , yes. I_A equals... that divided by that. Yes.	C/P
...		P
65	P1: I don't know. I'm getting 94. It's probably a calculation error	P/M
66	P4: I'm sorry, what are you trying to do?	p
...		
70	P4: What did I do mathematically wrong?	P
71	P1: I'm saying one of us did something mathematically wrong.	P/M
...		

77	P3: We don't know what V_R is, right?	C/M
78	P1: Well, kind of. We have to solve for I_A and then we get V_R .	P/M
79	P2: I don't like this problem.	M
82	P4: Yeah, but my idea was... (mumbled)...	M
83	P2: You can try that. Okay, I think I just got rid of I_A in the first place.	P/M

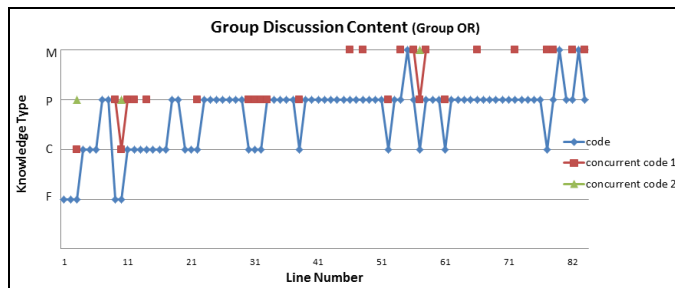


Fig. 2. Group OR discussion content and progression. “Concurrent code” refers to coding with more than one type of knowledge shown in Table III.

C. “Big D” Discourse Analysis

Fig. 4 shows the written work from Group OR. Although they did not show a final numerical solution explicitly, the problem-solving worksheet includes their reconciled and improved understanding about the steady state of DC machines. Fig. 5 displays samples of work by individuals in Group OR in the exam right after the mock team test. The problem is included. The four Group OR students displayed their ability to apply appropriate equations with understanding of the steady state that they co-constructed and strengthened in their team discussions.

Conceptual framing for Episodes 1 and 2								
Framing	Episode 1 (Lines 1-12, Table III)			Episode 2 (Lines 13-27, Table III)				
	OR1	OR2	OR3	OR1	OR2	OR3		
Components in foreground	$V_\phi, T_\phi, \omega, K_T$	$V_\phi, T_\phi, \omega, K_T$	T_ϕ, ω	$V_\phi, T_\phi, \omega, I_\phi, K_\phi, R_\phi$	$d\omega/dt, V_\phi, T_\phi, \omega, I_\phi, K_\phi, R_\phi, V_R$	$d\omega/dt, T_\phi, \omega$		
Relationships between components		In a steady state		$V_R = I_A R_A$	$T_L = k_T I_A, V_R = I_A R_A, d\omega/dt=0$, in a steady state			

Conceptual framing for Episodes 3 and 4								
Framing	Episode 3 (Lines 28-47, Table III)				Episode 4 (Lines 48-83, Table III)			
	OR1	OR2	OR3	OR4	OR1	OR2	OR3	OR4
Components in foreground	$V_\phi, T_\phi, \omega, R_\phi, I_\phi, K_T, d\omega/dt, T_{em}, e_a$				$V_\phi, T_\phi, \omega, R_\phi, I_\phi, K_T, d\omega/dt, T_{em}, e_a, K_E$			
Relationships between components	$T_L = k_T I_A, V_R = I_A R_A, d\omega/dt=0, T_L = T_{em}, V_A = I_A R_A + e_a$, in a series connection, in equations for ω				$T_L = k_T I_A, V_R = I_A R_A, d\omega/dt=0, T_L = T_{em}, V_A = I_A R_A + e_a, e_a = k_E \omega$, in a series connection, in equations for ω			

Fig. 3. Conceptual framing for Episodes 1&2 (top) and 3&4 (lower).

D. A Case of Group Discussion That Hindered Learning

The majority of the class (more than 90%) showed conceptual understanding of “steady state for DC machines” in their work for the midterm exam. Yet, a few were not able to apply the concept. Even though factors that negatively influenced their learning are expected to be complicated, we were able to identify a few from their dialogues during group problem-solving. Fig. 6 displays Group MN’s work in the same exercise and midterm test. Fig. 6(a) shows the written worksheet; (b) and (c) show individuals’ work in the midterm. The group discussion utterances are shown in Table IV, and the progression is shown in Fig. 7. Patterns displayed for Group MN are in sharp contrast to what are shown in Table III and Figs 2 and 3 for Group OR. Contributions to group discussions in group MN were short, linear, and straightforward. Two main participants, students P1 and P2 had fixed roles of “presenting” and “accepting” respectively throughout the discussion. Because the concept of framing recognizes several important aspects of discourse practice including positioning of individuals, joint efforts of the group, and conceptual resources from individuals, it is problematic that student P2 did not question any proposals that student P1 presented. In addition, student P2 never presented his own conceptual framing, i.e., relationships for foregrounded components. As shown in Fig. 8, student P2 (Mn2) did not get an answer to the question of what I_A is. By positioning himself as a passive information receiver, student P2 failed to show learning gains. This is evidenced by his poor performance in the individual work for the midterm (shown in Fig. 6(c)).

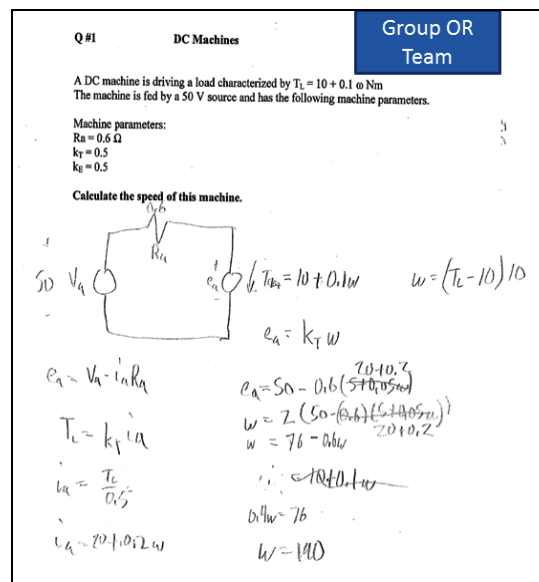


Fig. 4. Team written work of Group OR.

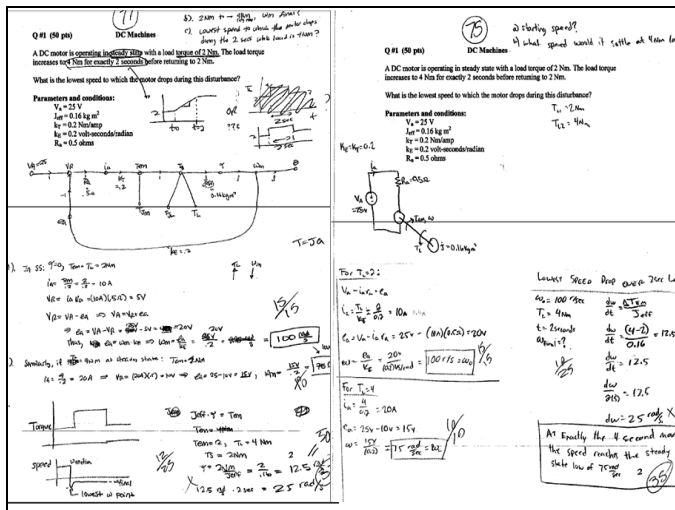


Fig. 5. Samples of individuals' work in the midterm. (Group OR).

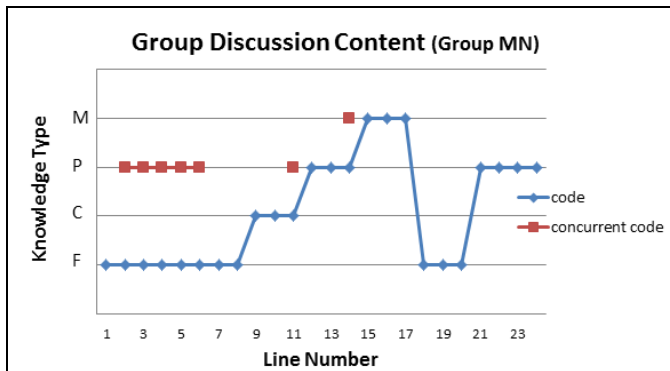


Fig. 6. Group MN discussion content and progression. "Concurrent code" refers to coding with more than one type of knowledge shown in Table IV.

TABLE IV. EXCERPTS OF GROUP DISCUSSION VERBAL DATA

Line No.	Verbal discourse (Group MN, 3 students)	Code
1	P1: I would kind of like to start with this one. T_L equals 10 plus I_A is $V_A R_A$?	F
2	P2: I_A ? Or V_A over R_A , I_A .	F/P
3	P1: Well, you just confused me. Oh!	F/P
4	P2: Well, is that I_A ? Is that the equation? I'm not sure if that's how it works.	F/P
5	P1: Well, it's $e_a + R I$, so here's R .	F/P
6	P2: Yep.	F/P
7	P1: And I is $-T_{EM}$ over k_T over 5.	F
8	P2: T_{EM} equal k_T ...	F
9	P1: I think if we're at a constant speed then T_L is equal to T_M . I think.	C
10	P2: Sure.	C
11	P1: So, we have the total voltage, --- is the total voltage, which is the voltage across the resistor, plus that thing (e_a), which is .5 Omega. Well, then we just have one variable.	C/P
12	P2: Yeah, we can solve already! Oh wait, no we do because T_{EM} equals 6.	P
13	P1: There it is.	P
14	P2: Awesome. Do you think that's right? I don't see any other way to do it.	P/M
15	P1: Seems reasonable.	M
16	P2: Sure.	M

17	P3: Is that right?	F
18	P1: Yeah.	F
19	P3: Alright.	F
20	P1: 38 divided by .17.	F
---		P
24	P2: Is it .5?	P

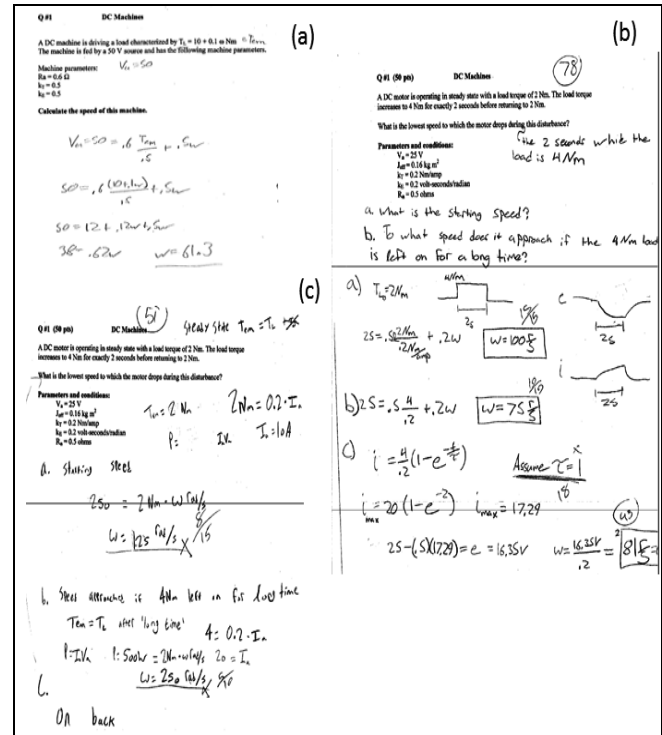


Fig. 7. (a) Group MN written team work for the mock test; (b) Individual work in the midterm by student P1; (c) Individual work of student P2.

Framing	Mn1	Mn2	Notes
Components in foreground	V_a , e_a , T_L , ω , R_a , I_a , T_{EM} , k_T	V_a , R_a , I_a , T_{EM}	
Relationships between components	$V_a = I_a R_a + e_a$; $\omega = \text{constant}$; $T_L = T_{EM}$	None was stated explicitly	Mn2 never stated clearly what I_a was, and only mentioned if $\frac{V_a}{R_a} = I_a$ (?)

Fig. 8. Conceptual framing for Group MN discussions.

V. CONCLUSIONS AND IMPLICATIONS

We introduced two case studies of group discussions and used the adapted concept of framing to analyze students' discourse and written work. The study revealed processes with which students created solutions and provided insights into how students interact in ways that facilitate learning. The study also suggested several factors that hindered productive

group learning. The two main factors that influence productive interactions, indicated by this study, include (i) if an individual and his/hers peers recognize gaps/discrepancies in views toward the subject under study; (ii) if an individual and his/hers peers are able to reconcile the revealed differences in understanding through conceptual framing and reframing. The quality of classroom discourse while solving problems within a small group is critical for effective learning in problem-centered flipped classrooms. Applying the concept of framing allowed us to analyze students' verbal utterances along with other artifacts such as written work, etc. from two dimensions of social interactions and cognitive development. The two dimensions are combined through Discourse analyses, which revealed whether students' interactions support or hinder their learning. We observed characteristics indicating cognitive growth and learning gains for an individual: (1) changes in his/her contribution to discourse practice; (2) changes in his/her ways of defining goals of the task; (3) changes in understanding of the nature of knowledge; and (4) changes in understanding of information structure and organization.

Because knowledge and cognition in general is distributed across members of the group, group talks involve levels of information that is "expected or required for mutual understanding, and for the kinds of questions or challenges that are appropriate" [5]. Variations in an alignment imply that it is significant to provide resources that support students to place their framings, including both positioning and cognition, in line with others.

There are two implications for directing resources to designing and conducting group learning activities in student-centered classrooms such as flipped classrooms. First, it can be useful to support students' positioning themselves in multiple ways during group conversation. Although it is often difficult to anticipate the ways students will engage in conversations that involve turn taking, one resource for encouraging turn taking in group discussions is to formulate a set of sub-goals for students. These sub-goals should be defined in ways leading to an ultimate goal. They should help to highlight misconceptions thus motivate each participant to contribute by rotating roles with others during group discussions. Working on a large overall goal at the front end is sometimes to the disadvantage of student groups who are not able to identify gaps in understanding within the group. In these situations, participants often do not know how to make inquiries or to initiate dialogues, and cannot sense if one or more group members lack understanding. Participants will unsurprisingly place themselves at a fixed position, either as a presenter or a follower, due to a lack of negotiation and opportunity to pause the conversation. It is difficult for participants to improve their contributions to discourse practice unless they improve their understanding. What happened in Group MN illustrated the situation. Two participants, students P1 and P2, seemed to work and solve the problem together. Yet, student P1 never recognized that student P2 lacked a significant level of understanding. Student P2 did not show improved comprehension, and his simple acceptance was merely for communication purposes. For both

students, there was no need or context for negotiation. It is essential that instructors develop pedagogical strategies to help students recognize their misaligned framings in group activities. It is also important that students are provided with time, space, and opportunity to notice misalignments and to negotiate before they establish a common ground.

Second, it is important to support processes by which students come to understand concurrent limitations and reasonable information structures when one and more group members have not developed sufficient strategies such as the application of relevant formulas. Instructors should provide guidelines to help students connect "knowledge pieces" and repair misconceptions during the process. For example, during Group OR discussions, students took turns making inquiries, providing explanations, and critically reviewing their own and others' opinions. The students improved their understanding of content knowledge while negotiating the proposal "the motor is in steady state". Together they created an appropriate equation for the target quantity ω . The problem posed by the instructor provided resources that helped the group and individuals to pay attention to limitations and resources for information organization, i.e. an equation for ω in a steady state. Because the problem did not explicitly state the condition and required students to make assumptions, it did not undercut learning. Instead, it confronted individuals' misconceptions and engaged students in discourse practice. It improved their learning through constructing understanding that was situated in group problem solving and was supported by the domain concept knowledge.

We believe that results from the current study have contributed to general understandings of how students gain conceptual understanding through productive interactions in classrooms. Two factors that influence group problem solving discourse are identified by adapting the concept of positional and conceptual framing. Resources that engage students in group discussions to facilitate learning include instructional interventions, helping students confront misconceptions, and, if needed, providing a set of sub-goals for a designated learning task.

ACKNOWLEDGMENT

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Evaluating Flipped Classrooms with respect to Threshold Concepts Learning in Undergraduate Engineering

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Abstract—This paper reports on the initial findings from a two year (2015-2016) investigation of the impact of the flipped classroom on student learning of threshold concepts (TCs) in a large introductory undergraduate engineering course at a New Zealand university. As part of the flipped class intervention trialed over a three-week period, a series of short themed video lectures were developed as a replacement for the traditional weekly lectures. The weekly practical lab session were redesigned to incorporate small-group problem solving tasks and assessment. Data from student surveys, interviews, class observations, and video analytics were collected and analyzed. Findings revealed that students were familiar with online videos as a learning resource; they had positive past experiences with using them and were willing to participate in a flipped classroom. However, most students did not watch all assigned weekly videos, including ones crucial to their TC learning. There is indication they thought learning strategies involving interactions with real persons to be more useful to their learning. This suggests that current strategies for motivating students to access and engage with the prepared videos need to be revised to maximize students' learning opportunities.

Keywords—engineering education; threshold concepts; flipped classrooms; university students; electronics engineering

I. INTRODUCTION

This paper reports on the initial findings of a two-year (2015-2016) longitudinal case study exploring whether and to what extent a flipped classroom model of teaching and learning enhances student learning of hard to master threshold concepts (TCs). TCs are concepts students need to master in order to think like a subject specialist [1] and have been evidenced as an effective theoretical framework in facilitating student learning [2, 3].

The flipped classroom is a variant of student-centred learning where lecture materials are assigned as take-home tasks, typically in the form of online videos [4]. By freeing up class time for instructor-student class contact a flipped class provides more flexibility for instructors and students to partake in discussions, collaborative and guided problem solving

activities to address student misconceptions, and, is claimed to support the mastery of TCs and the development of the skills needed for 21st century graduates [5]. We postulate that a TC-based flipped-class pedagogical approach to teaching and learning can enhance first year students' learning of TC content in an undergraduate engineering course which had a large enrolment and a strong lab component.

II. RESEARCH CONTEXT

The "Introduction to Electronics" course is a core undergraduate engineering paper compulsory for EE and ME students. In 2015 approximately 150 students were enrolled in the course and about 30% of the students were from Software Engineering, Computer Science, Education, and other disciplines. The organizational model for this paper has traditionally consisted of three one-hour long lectures, an hour-long tutorial session, and one three-hour laboratory session each week of the semester. It is expected that all students would attend all lectures. Each student is expected to attend one of 5 parallel laboratory streams which run once a day on each day of the week. The laboratory space is set up for pairs of students to work at one of 18 identical benches, each bench equipped with a PC, oscilloscope, function generator, power supply, soldering iron and DMM (Digital Multimeter).

The Introduction to Electronics class differs from many university classes in its "engineering" style predominance of laboratory learning time. Much of the learning revolves around tacit knowledge and practical skills that are picked up in the lab sessions. Notably the paper differs in having a high level of conceptual difficulty, representing a relatively heavy conceptual load. It is regarded by many students as the most challenging paper of the semester.

Our project team had investigated ways to enhance the pedagogical approach for teaching this course since 2011. In 2011, the course syllabus was rigorously analyzed to identify TCs that it seeks to teach [6, 7, 8] which led to a refinement of the course curriculum and assessment to emphasize student understanding of TCs [9]. In 2013, the face-to-face tutorials were replaced by an online system which was well received by students and credited with an increase in learning [10, 11]. Student achievement data showed that the 2013 student cohort did significantly better than previous cohorts, and students

reported liking the flexibility and accessibility of the e-tutorials. This affirmed the value of incorporating online resources in support of student learning in the course. During these changes the cohort was observed extensively and student performance was carefully benchmarked.

A problem inherent in the lecture-plus-lab model is what we term "the phase problem". Typically, students attend lectures spread throughout the week. All students also attend one (out of five parallel) lab streams during the week. Some students have their lab on Mondays—the last group of students has it on Fridays. This means that the theoretical material is covered in lectures from 3 up to 11 days before a student may put it into practice in a corresponding lab (i.e., Friday group). This delay is undesirable. We realized that this delay could be eliminated if the material presented in lectures was made available through instructional videos. The question that arises is: Would the same flexibility and availability that enhanced e-tutorials be as welcomed and as effective in the case of making the instructional materials available in video format?

Currently in 2015, we are trialing a flipped-classroom model for 3-weeks (Weeks 2 to 4 out of the 12-week semester) by replacing the three 50-minute weekly lectures with a suite of short videos which are accessible from the course Moodle website (Moodle is our university online learning management system). The videos, each between 4 to 13 minutes long were created with careful reference to recommendations from cognitive models shown to be effective in online learning [12] and strongly resembled the style found in Sal Khan's work on khanacademy.org. The videos targeted the teaching of two key TCs in the course (i.e., Thevenin's theorem and dynamic resistance). As these TCs are mostly taught using circuit diagrams and solving equations, the videos allowed the lecturer the flexibility to draw, modify and elaborate on circuit diagrams using a drawing tablet to replicate the way he usually teaches in his face-to-face class. Smoothdraw and Quicktime were used for the video screen capture of the lecturer's explanation and illustrations. There is evidence that interactive online instructional videos can be effective in fostering university student learning [13], including in the Engineering discipline [14, 15] and even in the learning of TCs [16].

Students were expected to watch the assigned videos in preparation for each week's practical activities. We anticipated that the video materials would allow students more flexibility in viewing and reviewing the course material before the lab sessions in which the learning would be put into practice. The three-hour laboratory sessions were extended to four hours to allow for small-group problem solving activities and more personal interaction with the instructor and demonstrators.

III. DATA COLLECTION AND ANALYSIS

In the project, a design-based research approach [17] with practitioner-led cyclical processes of planning, design, and implementation is used to refine the pedagogical tasks. Multiple data are currently collected from: (1) instructor and student interviews, (2) student surveys, (3) class observations, (5) video analytics, (6) student online usage logs, and (7) student achievement data. The research project received formal university-level human research ethics approval. All

participants participated in the project on a strictly voluntary basis.

As data collection is still underway, we will report only on results from the student pre-intervention survey, and, weekly surveys and video analytics of student viewing patterns during the final week of the flipped class (Week 4). Week 4 was selected for analysis because the TC, Thevenin's equivalent circuit theorem, was introduced in this week. Students were expected to watch 11 videos (9 created by the instructor and 2 were from YouTube) related to Thevenin's theorem before attending the lab. Of these videos, we identified and analyzed three that were crucial for student learning of this TC. The pre-intervention survey and Week 4 student evaluation of the intervention quantitative data are analyzed using the SPSS software while qualitative data are coded and categorized to identify emerging themes.

IV. FINDINGS

One hundred and fifteen students completed the pre-intervention survey voluntarily. The survey was distributed during the first week of lectures prior to the flipped class intervention. A majority of the student respondents were 18 years old (64%); most were males (90%); 15% were international students, and 17% were second language speakers of English.

As can be seen in Figure 1, when asked about their preferred ('useful' and 'very useful') learning strategies when learning for formal qualifications, students reported asking the teacher as the most frequent option (95%), followed by watching live demonstrations (93%), referring to the laboratory notes (86%), asking their friends (79%), watching Internet-based videos (76%), learning through trial-and-error (74%), and reading Internet-based text (73%). Reading a textbook was the least favoured strategy (59%). It is noteworthy that students prefer learning strategies in which they can interact with a real/live person be it a teacher, demonstrator or a friend.

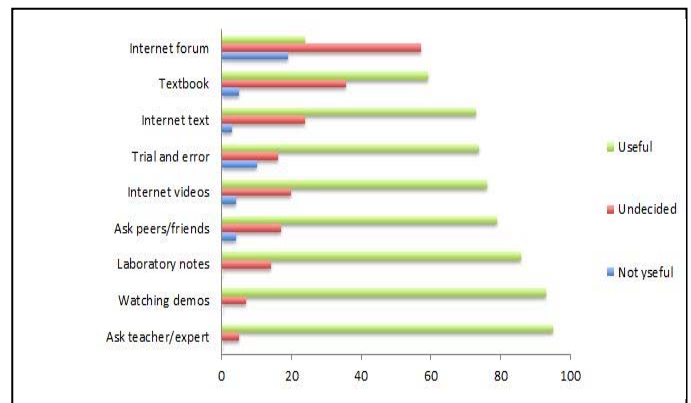


Fig. 1. Strategies students considered when learning for formal qualifications (collated 'useful' and 'very useful')

A majority of students (79%) had used online videos as a learning resource and had positive experiences when using them. Another 14% had also used online videos in the past but did not like the experience. This indicates most of the class are

familiar with online videos as a learning resource and had positive experiences with using them.

Most students, 86%, were not familiar with a flipped classroom prior to enrolling in the course, 9% have had some experience with flipped classes, while 3% had only heard about it. Since most students were unaware of the flipped class concept, it was no surprise that when asked if they thought a flipped class could help them learn better in the course, 70% were not sure, 17% thought it would, while another 14% did not think so. However, 93% of students were willing to participate in and experience a flipped class. General themes from the open-ended survey question support this broad trend to reveal students generally lacked prior experience with a flipped class (36 responses), were open to the potential a flipped class could offer to enhance learning (16 responses) but were reluctant to lose the structure that regular lectures offered (8 responses), and, a (mis)assumption about losing the human interaction factor found in traditional lectures (6 responses). Some key illustrative quotes include; ‘I am new and adapting to the new environment, so I have no relative intention on what it takes to learn’, ‘Its (Flipped class) very self-directed. If you put in the work it should be very beneficial’, ‘It kind off becomes me delaying watching the videos till the last minute because I have other assignments to work on’, and, ‘I believe flipped classwork would result in slightly less success due to the lack of commitment to lectures and inability to ask the lecturer questions’.

During the final week of the flipped class (Week 4), 141 students completed a weekly survey on their learning experiences. Less than half of the class (44%) reported watching a few videos assigned for the week, 39% had watched most, 10% had watched all videos, while 7% did not watch any. Overall, 93% of students had watched the assigned videos albeit to different extents.

A majority of students (74%) thought the length of the videos were just right, 24% thought they were too long while only 3% thought they were too short.

As can be seen in Fig. 2, over half of the students did not watch all of the three key videos related to Thevenin theorem (e.g., 61% did not watch ‘Finding Thevenin Equivalent Circuit’, 54% did not watch ‘Thevenin Equivalent Circuit Example’). Interestingly, almost all students (97%) watched the video titled ‘Thevenin Equivalent Circuit and Measuring It’. Remarkably, 41% of students watched this video once, almost 30% watched it twice, and 2% of students viewed it up to eight times compared to the other videos.

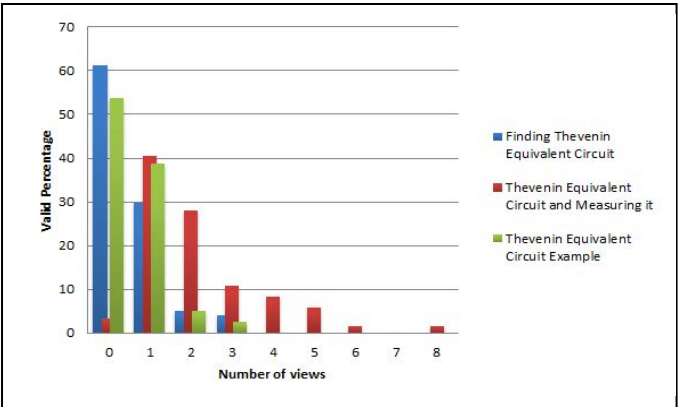


Fig. 2. Student viewing patterns of the three key videos for TC learning in Week 4.

The high student regard for this particular video was corroborated by the fact that over half of students (57%) thought this video to be the most engaging for their learning (Fig. 3). Conversely, the other two key videos associated with TC learning (‘Thevenin Car Battery Equivalent Circuit Example’ and ‘Finding Thevenin Equivalent Circuit of a Network’) had less than 40% of the class watching them at least once (Fig. 2) and were rated to be engaging by only 30% and 20% of students respectively (Fig 3).

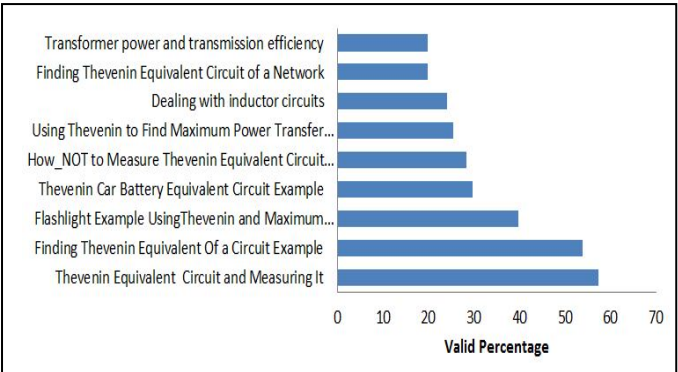


Fig. 3. Videos reported to be most engaging for TC learning in Week 4

Further examining of the characteristics of this "most engaging of the videos" (‘Thevenin Equivalent Circuit and Measuring It’) revealed it importantly contained footage of practical ideas—making measurements in the lab, which was integrated into a lecture of the theoretical concepts. Students probably found the practical demonstration helped to exemplify the conceptual ideas in a manner that was useful and engaging to their learning which the other videos did not.

When asked about the extent they thought the instructor prepared videos had helped them learn about Thevenin's equivalent circuit, 96% of students reported ‘somewhat’ or ‘very much so’, while only 4% thought the videos did not help them learn; this responses included students who did not watch the prescribed videos. This finding suggests that when students watch the videos, almost all of them find them to be helpful to their learning of the TC. Future analysis of the student achievement data may provide further evidence of the effect of (timely) video watching on learning the TC.

V. DISCUSSION AND CONCLUSION

In our study we integrated a TC-based curriculum with a flipped class model of teaching and learning in an engineering course to investigate if and how a TC-inspired flipped class can facilitate student learning. It is novel as no other studies have attempted to integrate a TC-based flipped class approach in engineering education. The results thus far show that students report to prefer learning from a real person (teachers, demonstrators, peers). The video analytics data reveal that students are not fully engaging with the assigned weekly videos. Importantly, when students do watch the videos, they find them to be useful to their learning of the TC.

From past experience, we observed that students generally find learning TCs to be more difficult than non-TCs and we assumed this would still be the case even if the form of course delivery had changed to online videos instead of lectures. The fact that over half of the class did not watch two of the three key videos relevant to TC learning prior to the practical lab session leaves us in doubt as to whether students had understood the TC. This poses a question about when and if students will have a chance to learn the TC. Students' hesitancy/failure to watch the videos (on time), despite their familiarity and past positive experiences with learning from online videos and their being open to the notion of a flipped class, may point to a limitation of a flipped class approach designed for the first semester of a large undergraduate course. We had also foreseen the possible loss of pedagogical responsiveness and group momentum without any scheduled course event that brings the whole class together (such as lectures) as another potential limitation of our intervention. This suggests a need to look into possible revision of current strategies for motivating students to watch the videos and come to the face-to-face class sessions prepared to participate in active learning tasks and ask questions. Another possible way forward is to closely examine the characteristics and content of the instructor prepared videos that students found particularly engaging and useful to their learning to inform our (re)design of future teaching videos.

In conclusion, as universities continue to explore and adopt e-learning platforms including Web 2.0 and mobile applications to provide for more flexible and innovative teaching and learning approaches, our study highlights the need for further investigation into the learner perspective to maximize their learning opportunities and outcomes.

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A Letter to the Future Engineer: Exploring cross-cultural engineering identities through practitioners' letters of advice

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Abstract— Engineering education researchers have been trying to improve the quality of engineering education. Related to these efforts, it is important to revisit and better understand the definition of engineering education. As part of our PhD coursework, we were required to create a short video depicting our understanding of the definition of engineering education. For this purpose, we created “*a letter to the future engineer*” that presented a holistic view of the challenges and opportunities involved in the professional practice of engineering. To write our letter, we collected real letters of advice from practicing engineers with varying demographic characteristics and experiences. Thematic analysis of the letters uncovered some country-level differences in terms of priorities, perceptions, and the professional life of the contributing engineers. The aim of this work-in-progress paper is to describe our experience of generating this letter of advice and to comment on the patterns we identified during this process. This idea calls for more in-depth studies to reveal the influence of culture and geographic regions on the engineers' perceptions of their profession.

Keywords—*engineering practice; ontology; cross-national; engineering identity; global engineering; letter; advice*

I. INTRODUCTION

This work-in-progress paper came into being as a class project for a graduate-level engineering education course, ENE 502: “History and Philosophy of Engineering Education” [1]. For this project, students were required to depict their understanding of and inquiry into the definition of engineering education in the form of a short video. Some of the guiding questions that shaped both the class in general and this assignment in particular were: “*What is (and should be) engineering?, what is (and should be) the purpose and process of engineering education?, who gets to be an engineer (and who should get to be)?...*” As our project group comprised people from multiple cultures and ethnicities, we decided to portray our vision of this task within a global framework. Rather than focusing on descriptive or normative definitions of engineering education, we preferred to focus on sending a positive message, one full of hope in the future of engineering practice. To make our vision a reality, we decided to create a video for the future generation of engineers which could serve to advise them during their learning process and future

practice. Without ignoring requirements by different national accreditation bodies [2], [3], we opted to capture the messages that current practicing engineers would like to send to their successors. Moreover, to make the content of the video as realistic as possible, we decided to ground the video in the perspectives and experiences of practicing engineers.

In order to make the letter more personal, we asked practicing engineers to write letters to someone who was close to them (a son or a daughter, a niece or a nephew, a younger friend, etc). We asked them to assume that the intended recipient of the letter would be starting their engineering training soon and that this letter would serve as a means to guide them throughout their journey. A variety of prompts were given to the letter writers, the intent of which was to capture the following questions:

1. What advice can an experienced engineer give to an incoming generation of students?
2. What aspects of their training and practice should they pay special attention to?
3. According to their perception, what facets were missing in their own training, which they wished these new generation of engineers to experience?

We collected 21 letters from practicing engineers located in U.S., México, Pakistan, Canada and Brazil. We analyzed these letters to identify themes and topics which were then used to create a unified letter of advice to the future engineers. During this process, we had some interesting and meaningful insights, which motivated us to write this paper. Since this endeavor was initiated as a class project, our motivation was merely exploratory and was not supported by an extensive literature review. Similarly, there was no theoretical framework shaping this work. However, the next sections will discuss the process of letter development and our resulting insights, including some suggestions for future research that can potentially be derived from this preliminary effort.

II. LETTER DEVELOPMENT

The first four authors independently sent an open invitation to their personal network of engineers. This

network consisted of parents, siblings, friends, cousins, colleagues and acquaintances in general. As one of the instructors of this course, Dr. Jesiek provided support and feedback about the original idea and venues of letter collection and analysis.

From the 21 engineers replying to the invitation, only three were women. Respondents ranged in ages broadly, from early 20's to late 70's, implying all levels of experience. They had experience in industry, academia or both. Many of these engineers had international working experiences in addition to working in their home countries. Others were working or conducting graduate studies outside of their home country.

Letter writing as our method of data collection gave the engineers freedom to express their views without any constraints, the intention of which was to ground the letter in realistic, practical, and meaningful experiences.

The thematic analysis of letters resulted in four broad themes that are summarized in Table 1. The columns denote two main phases of engineering life as mentioned by the writers: 1) college experience/training, and 2) professional practice. The rows denote themes corresponding to their academic and personal life. During analysis, we identified some themes that emerged consistently from engineers practicing in the United States and those practicing outside the U.S.

From Table 1, it can be seen that the most common themes across countries were those related to academic college experiences. Letter writers suggested future engineers not get frustrated by courses if they could not make sense of or connect with them initially. They encouraged students to acquire communication, teamwork and critical thinking skills, which they found more useful than pure academic skills. A recurring theme was advice on understanding that engineering training should be focused more on 'learning how to learn' rather than preparation of specific skill areas. In terms of personal life, letter writers from all locations suggested that future engineers should proactively get involved in extracurricular activities.

In the professional realm, engineers based in the U.S. offered more advice in terms of how to get a good job and being prepared for it. Engineers from other countries were focused more on continuous learning and ethical considerations in engineering practice. However, both groups were aware of the variety of possibilities that a future engineer could possibly pursue, e.g., in industry, academia, and research. Some advice provided for the personal life by U.S. engineers was to keep a work-life balance, while non-U.S. engineers suggested a more holistic growth, ego control, and caution against discrimination. The following section will consider the value found in this letter writing process and how this effort is envisioned to generate valuable new inquiries to identify trends in different identities of engineering across countries and cultures.

TABLE I. THEMES IDENTIFIED IN LETTERS WRITTEN BY PRACTICING ENGINEERS

	College Experience/Training	Professional Practice
Academic	<u>U.S.</u> <ul style="list-style-type: none"> seek networking <u>U.S. and non-U.S.</u> <ul style="list-style-type: none"> persevere through nonsensical, hard or, disconnected course content acquire communication and critical thinking skills look for internships learn how to learn <u>non-U.S.</u> <ul style="list-style-type: none"> don't focus only on grades 	<u>U.S.</u> <ul style="list-style-type: none"> getting a good job will mostly depend on non-technical abilities ("soft skills") look for mentors your engineering degree will open doors <u>U.S. and non-U.S.</u> <ul style="list-style-type: none"> career paths for engineers are varied <u>non-U.S.</u> <ul style="list-style-type: none"> keep your ethical and moral values aligned with your work remain abreast of technological developments ensure your solutions are within a human framework
Personal life	<u>U.S.</u> <ul style="list-style-type: none"> connect your hobbies to engineering learn to manage your free time <u>U.S. and non-U.S.</u> <ul style="list-style-type: none"> seek extracurricular activities 	<u>U.S.</u> <ul style="list-style-type: none"> maintain a healthy work-life balance <u>non-U.S.</u> <ul style="list-style-type: none"> read diverse topics outside engineering for a holistic development keep your ego under control avoid stereotypes and discrimination against others

III. INITIAL INSIGHTS

A. Value of a personal letter

Although Creswell cites the use of letters as a way to collect research data [4], their use is very limited due to logistical issues related to time elapsed between prompts and answers provided using conventional mail. However, technology now makes this process easier. In a few seconds we can reach thousands of people from all over the world through electronic communications [5]. Additionally, the use of letters may allow a deeper understanding of the individuals' perceptions of engineering. Since writing normally involves a deeper, organized, and more purposeful thinking and reflection process, it may reveal deeper thoughts in terms of facts, opinions and ideas [6]. Some of our letter writers reported seeing value in the writing process of the letter; some of them even considered it as a venue to expose hidden feelings towards their experiences, which further supports our argument.

B. Value of a global perspective

Another important aspect of this novel approach is the diversity of our sample. In fact, using letters, we can reach engineers in the most diverse cultures and countries, not only those already engaged in engineering education research, but also those most likely to be affected by cross-cultural aspects of engineering. Lucena et al. conducted rigorous research about the re-organization of engineering education in US, Europe and Latin America [7]. They collected data from different sources such as international conferences, workshops, meetings and interviews with people already engaged in engineering research. In this sense, our work complements this research by bringing information from engineers who are engaged in the day-to-day rigor of the profession, and more likely will reflect the common culture that pervades the engineering profession of a certain country. One of our future goals would be to further analyze how engineering identities reflect the historic and socio-cultural processes that shape them within countries, and also evaluate the impacts of globalization on such identities all over the world.

Our results so far are in consonance with the findings from other studies. Downey and Lucena [8] show us how historical and cultural factors have shaped different engineering identities in France, U.S., Germany and England, defining or influencing values, beliefs and metrics of progress. According to the authors, for U.S. engineers, the metrics of success were associated to the corporate and industrial world. Lucena [9] described the process of construction of engineers' identities in Mexico and revealed that at least part of the engineering community has a great concern with societal issues other than the corporate world.

IV. DISCUSSION AND FUTURE WORK

Even though the insights from this exercise are limited, they prompt a variety of questions that would be interesting to keep exploring such as: 1) By means of the advice given to the future engineers, how can we investigate the engineering

identities in different cultures?, 2) How do cultural differences of practicing engineers influence the advice given to future engineers?, 3) What would be an effective way to deliver a concise yet powerful message to future generations of engineers worldwide?

We see value in the use of letters as our primary source of qualitative data in order to build a cohesive, unified letter. This approach offers a way to portray real feelings and experiences in a more authentic way. The method we used to invite the professionals to write the letters could be improved through the development of a uniform protocol that gives the same prompts to all the potential writers. This uniformity could result in stronger conclusions when comparing letters from different countries and drawing conclusions about their differences regarding the engineering profession in a qualitative way.

The original letters can also be used as a starting point for a potential longitudinal study where the professionals project their thoughts at a point in time, and after some time they can be monitored through this or other venues of data collection to detect their evolution of thinking. Additionally, we can investigate engineering identities within the same country. Other inquiries could involve identifying the level of development of communities of practice of engineers among and across countries. This methodology can be a powerful way of assessing engineering identities over time.

It is envisioned that the effort of building a strong holistic message can open conversations about how different factors interact with the advice experienced engineers want to give to novices. In an educational setting, the letter has the potential to promote awareness of the multifaceted nature of engineering as well as to motivate the persistence and success of those aiming to join the field.

The appendix contains the final letter we composed from those we received, which was finally used in our video. The corresponding video can be accessed from the following URL: <https://www.youtube.com/watch?v=R3XBclouVxI>.

V. APPENDIX: "DEAR FUTURE ENGINEER"

Congratulations on your admission to your engineering program! I am honored by your decision to join the profession I have devoted my life to. Because of my experience, I will offer you some advice for your journey to begin.

First of all, engineering education is composed of all the different aspects that aim to build the knowledge, skills, and attitudes required to execute the possible roles of engineers in a society. It comprises a lifelong process that you may have already started in your experiences during your basic education. This process won't end with obtaining your degree but will keep going as you mature professionally.

As you start this new journey, be aware that you will be challenged. This is not meant to scare you off, but rather to ground you so that you remain motivated and enjoy the experience you are about to embark on. Smile, keep your head up and enjoy the challenges that come your way. Know that

you will be able to resolve those challenges only with conviction and interest. Problem solving in Engineering is not about knowing the solution, it's about having the confidence that there is a solution, and knowing where to start looking for one. Getting good grades is important, but focusing solely on them can take away the joy from the learning experience. Do not become a slave to grades. Learning combined with hard work will result in success.

When you start college, you will take courses you may not consider relevant. Researchers, professors, and even industry members are aware of this, and they are working on making the engineering education experience more meaningful. I would urge you to be patient, see math and science as tools in a holistic problem solving strategy. Keep on growing your toolbox, and be rest assured that you will find all of these tools handy somewhere down your journey.

As you get through the courses involving problem solving and design skills, you will be expected to develop critical thinking skills. Problem solving and designing for others and with others is important in creating meaningful and impactful solutions. In order to make the most of your precious time and effort while solving a problem do not try to "reinvent the wheel", we are standing on the shoulders of giant; take advantage of this.

The importance of good written and verbal communication skills cannot be ignored. You will have opportunities to develop these skills in part through engineering coursework. However, you must strive to take courses outside of your area. These courses will help you broaden your perspective and will help you build intellectual connections required to translate engineering to the outside world.

Teamwork skills are essential to engineering. Find opportunities to practice these skills, be a good team member, and do not shy away from opportunities to work with difficult people. These experiences can cultivate sound professional connections and in some cases long-term friendships.

You will be working in a community of people with diverse backgrounds and cultures. Be aware that engineers are trained differently in different countries. As part of society, engineers should appreciate differences and avoid segregation and discrimination at all levels. Value the contributions of others, regardless of their gender identity, sexual orientations, culture, ethnicity, religion, language, nationality or any other difference. Diversity brings with it tremendous value. Developing these skills will enrich you and help you become a more competent global engineer.

Balance is essential in all stages of your life. While in college make time for yourself and the rigorous demands of school. Carry this trend forward after graduation so you are able to live a happy and healthy professional life.

"Scientists discover the world that exists; engineers create the world that never was." As an engineer you will be responsible for creating this new world in a sustainable way and you must be conscious of social, ethical and moral issues. Avoid unethical decisions as they discourage the ingenuity of

a solution. The value of your contributions will not be measured by money but by the betterment of society.

Your engineering education will teach you a way of thinking - a way of approaching problems. You will need to find ways of connecting course content with real world applications. The skills you acquire along your journey are just as important as the content itself. By virtue of our educational journey, as Engineers we are meant to become life-long learners.

The community of Engineers you will belong to is constantly innovating and developing new technology. You must keep abreast of these newest developments as well as ways to use them by participating in communities of practice.

Again, I would like to conclude by congratulating you on picking such a rich, challenging and fulfilling field. Engineering offers limitless opportunities. Engineering plays a big role in society and on the shoulder of an engineer lays the responsibility and consequences of all their decisions.

Your journey into engineering education is sure to be filled with challenging, rewarding, and enjoyable experiences. These experiences will be what you make of them. Now it's time for you to start thinking about what you will do with your engineering education.

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Collaboration in the development of a Precision Engineering Programme at Limerick Institute of Technology in response to a call from Industry

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Abstract— A Bachelor of Engineering in Precision Engineering programme at Limerick Institute of Technology (LIT) has been created in a collaborative response to the needs of the industry. This new one year duration add-on programme was developed and implemented in an eight month period. The programme differs from the norm in the nature of its development, the integration of industry requirements and the balance of academic requirements. This unique programme offers a flexible mode of delivery where a key attraction for industry is that student may attend two consecutive days per week and work three days per week. Students choosing this option take two years to complete one academic year while gaining professional experience in a world class manufacturing environment. Students not employed in industry may attend on a full time basis. As a result of this collaboration, industry has committed to provide €100,000 to assist LIT in equipping the programme. This coming together of industry and academia has resulted in forming the greater ambition of creating a National Precision Engineering Centre of Excellence to address the long term goals of Ireland's manufacturing industry to develop a constant stream of competent, technical and practically orientated engineers.

Keywords—*component; precision engineering, industry collaboration, engineering education, training, curriculum development.*

I. INTRODUCTION

Collaboration with industry in the development of curricula is encouraged to ensure excellence and relevance is achieved in third level programmes. The need to develop engineering graduates that are ready for employment upon graduation is a key focus for industry. However, balancing the educational and training needs of students and the specific requirements for employers creates a need for the development of trust and understanding between academia and industry. A shortage of skilled, educated engineers in the precision manufacturing sector in Ireland was identified by the Precision Turned parts Manufacturing Association (PTMA) and an expert industry focus group brought together by the Department of Jobs, Enterprise and Innovation in response to a report from Forfás. Forfás is Ireland's policy advisory board for enterprise, trade, science, technology and innovation. A serious deficit in the

availability of human resources in the precision manufacturing sector and the potential to meet current demand and the future expansion of business in Ireland was highlighted as a serious problem. Limerick Institute of Technology (LIT) was selected by the Industry focus group and the PTMA as a possible partner to collaborate with in the development of a new Precision Engineering programme in Ireland.

II. ECONOMIC BACKGROUND

Ireland as a small open economy on the west of Europe depends greatly upon the ability to satisfy an international market with products, systems and services that are in demand. As a country emerging from an economic crises, with a relatively high but decreasing unemployment rate, it is essential for the future development of the economy that existing areas of excellence and new areas to be explored to remove the past reliance on one major economic sector.

Manufacturing plays a crucial part in the Irish economy and is a driver of innovation and technical advances with a broad range of employment and skill levels. Associated with these activities are a range of additional indirectly related jobs in the economy [1]. In 2012 manufacturing contributed significantly to Ireland's exports at €78.5 billion [2]. In Ireland, manufacturing can be divided into two main categories; Irish owned manufacturing and service companies which in 2012 were responsible for €27.59 billion in sales and secondly, foreign-owned agency assisted manufacturing companies were responsible for €68 billion in sales. Within the export sector, traditional manufacturing represented €5.3 billion in sales from foreign owned agency assisted operations, yet €5.7 billion was also achieved from Irish-owned agency clients.

One of the major concerns of the manufacturing sector was the need for a detailed assessment of the skills required industry up to 2020. This need was articulated in the 2012 Government "Action Plan for Jobs in 2012". This report highlighted that manufacturing accounts for less than 10% of total employment but it accounts for over 30% of GDP and remains a fundamental 'engine' of the Irish economy [3]. The challenges for manufacturing in Ireland are, for example reducing costs and moving to sophisticated knowledge based systems with

economies of scale in a globally competitive market. The need for upskilling across the manufacturing sector so that workers are proficient in the most up to date tools, technologies and systems within their specific sector is a clear requirement. A further need to develop the capacity of indigenous and multinational manufacturers for research and innovation from publically funded research in universities and colleges is also stated.

III. INDUSTRY DEMAND

Enterprise Ireland (EI) was tasked with determining the needs of the indigenous Irish manufacturing sector. In June 2013, an EI Manufacturing Focus group met to determine the challenges facing the industry. The key challenge facing industry identified by this grouping was a lack of qualified, competent and skilled personnel to drive business forward. An unpublished report [4] identified the need to collaborate with a third level partner to develop a programme to meet the specific needs of the precision manufacturing sector in Ireland. A parallel discussion within the PTMA had also been ongoing. Both the PTMA and EI focus groups share common membership and this led to discussions around the development of a degree programme in Precision Engineering. LIT was identified as producing quality graduates that are close to meeting the requirements of industry due to the fusion of theory and practice through applied active learning that LIT promotes [5]. Both groupings expressed their interest in developing a programme with emphasis on the mid-west of Ireland region and specifically LIT as a centre of excellence in precision engineering

The EI Manufacturing Focus grouping had access to an out of date version of the Bachelor of Engineering Mechanical Level 7 Degree Programme in LIT. This formed the basis for the development of a new programme by highlighting the following:

- Areas that are relevant and should be retained.
- Areas that are not relevant and should be replaced by new content.
- Content that should be included in a new programme

IV. COLLABORATION WITH LIT

Collaboration between the PTMA, the EI Manufacturing Focus group and LIT was initiated through a series of meetings to establish common ground. It was evident through these discussions that the industry understanding of qualifications levels was very poor. For example, Quality and Qualifications Ireland (QQI) has 10 levels on the National Framework of Qualification (NFQ) [6] with overlapping levels at Level 6 as shown in Figure 1. Level 6 to Level 10 are regarded as higher or third level education. The structure of the NQF in Ireland needed explanation to the industry representatives to ensure a clear understanding and direction on the level of qualification that was required. Apprenticeship and Higher certificates share level 6 but with differing levels of Mathematics and Science being one major differentiating factor.

Clarification of the difference between training and education was also required. In the Irish context Garavan [7] utilises the definition of training as a practical education in a profession, art or craft.

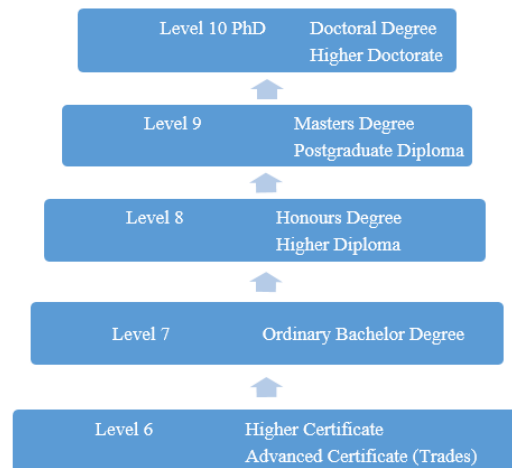


Figure 1 National Framework of Qualifications Ireland [6]

Garavan regards training as a planned and systematic effort to modify through learning experiences to achieve effective performance. In human resource development education is regarded as teaching general skills and knowledge for the sake of field or discipline rather than having a specific job focus. This difference between training and education is an area of continuing discussion with industry. A long discussion and exchange of knowledge/views relating to the current programme provision and the needs of industry to meet a skills shortage/education gap and how this could be accommodated was held [8]. The outcomes of this discussion were that;

- A Level 6 and 7 programme with shared/common modules with the mechanical engineering be developed
- The level 7 programme would be populated by students selected by industry as programme partners and the modules would be delivered on-site in LIT.
- A level 7 add-on programme where students could work for three days per week in the sponsoring company and attend college two days per week.
 - This would allow a student to complete a level 7 one year add-on Ordinary degree over two years.
- A part-time work-learn model mode of delivery was viewed favourably by industry as a where engineers are graduating with real experience.
- Entry to the level 6 or 7 programme could be from any relevant third level programme subject to the programme prerequisites being met.
- A student may have to take qualifying modules to gain entry if they have not met prerequisites.
- Industry to directly support this programme for the first five years in a variety of ways i.e. sponsoring students travel and subsistence, seeking tax breaks for students.
- Electives could be offered where there is a need from a particular sector in engineering .

- Equipping the programme could be achieved by working with suppliers and perhaps the sponsoring of equipment.
- Infrastructure and capital equipment will be required to meet the shortfall in equipment/resources available.

As part of this process a request was made to industry by LIT for evidence of demand for the programme. Over 40 letters of support from industry were received thereby reinforcing to LIT management that the base of support that would lead to student registrations on the programme.

V. ACADEMIC PROGRAMME DEVELOPMENT

In October 2013 a collaborative process was set in motion between the Industry representatives and LIT as the educational provider. The need for a rapid response to the requirements of industry was clearly stated and this led to the unusual step of developing a one year duration Level 7 add-on degree programme first. Putting in place the third year of a degree programme before the first two years are in place appears to counter intuitive but the need to convert existing trade staff, technicians or degree students as specialist engineers in the precision sector to address the needs expressed in government policy was a key deciding factor. A time frame of eight months was deemed achievable for this response. A level 6 programme of two years duration would be added in the 2015/16 academic year with wider consultation on content. A level 8 Programme to follow in the 2016/17 academic year.

In November 2013 an Industry/Academic brainstorming session was held to determine the curriculum content of the one year duration Level 7 Add-on programme. A clear direction emerged from the discussions and preferred content was listed under various headings. The brainstorming meetings followed this process firstly by determining the type of role that the graduate would grow into, the second step was to determine the types of activities undertaken in industry and thirdly the skills and knowledge deficits identified need to address the shortcomings.

The danger of this approach is similar to that of a teacher-centred approach highlighted by Kennedy [9] where teachers decide on content of a programme, plans how to teach this content and then assesses the content. In this case, the concern was the creation of a narrow outcomes-based industry centred programme, with industry deciding the content, and deciding how the content was to be taught and assessed. A balanced programme is needed to ensure the students achieve verifiable learning at the end of a programme or module to an appropriate educational standard. The outcomes-based approach needed in third level programmes must also incorporate a variety of outcomes including the higher level skill, knowledge and understanding outlined by Gosling and Moon [10] and in this case to address more than just a skills shortage.

In December 2013 Academic staff in LIT then undertook address these issues by differentiating, organising and developing the industry led content into programme learning outcomes (PLOs) and coherent modules. Under the European Credit Transfer and Accumulation System (ECTS) Learning Outcomes (LOs) are defined as statements of what the individual knows, understands and is able to do on completion of a learning

process [11]. Balancing industry requirements against this was crucial, Gosling and Moon present an ideal sequence for module development but acknowledge that although it is rarely followed, it does provide a basis for a quality assurance process. The main components of this are:

- level descriptors
- learning outcomes
- assessment criteria
- assessment procedures
- teaching strategies.

The programme development followed the frameworks and regulations required by LIT's Academic Council Regulations and Procedures for Taught Programmes [12] which generally follows this ideal process. In reality programme development, while controlled by frameworks, is a much more dynamic process. The need to develop students beyond the short terms skills deficit urgently required by industry and the longer term need for knowledgeable intelligent engineers is the responsibility of the academic staff. It was agreed to meet industry in January 2014 to present the PLO's, the modular structure and content to industry for consideration.

During the period between the industry meetings, an evaluation of the balance between training needs of the employers and the education needs of the students was undertaken Using the experience and knowledge acquired from industry, a process similar to the three-circle method used by Harden et al. [13]. The focus being to determine the:

1. Role the engineer is expected undertake.
2. Tasks to be achieved by the engineer
3. Attributes of the individual being trained/educated and registered on the programme.

The programme was subjected to an internal review and an external review before being approved in June 2014 and the first cohort of students were enrolled in September 2014.

VI. PROGRAMME STRUCTURE

The outcome of the collaborative process led to a clear direction for the academic development of the programme. This led to the development PLOs utilising the QQI Awards Standards for Engineering [14] and from these outcomes a set of modules were developed.

Three modules currently offered in LIT's Level 7 Mechanical Engineering programme are included in this programme. These modules form a broader base to the learner's education giving a strong academic aspect to the programme. The existing modules to be utilised are:

- Mechanics and Materials,
- Mathematics and Statistics
- Project

Three new modules were developed to respond to the need for high level graduates that are not currently available. These modules enable graduates to work safely with mechanical, electrical, control and automation systems with a special

emphasis on manufacturing with CNC equipment. These new modules are;

- Metrology and Statistical Process Control
- Advanced CAD/CAM
- Advanced Engineering Technology and Process Planning

Figure 2 was created to illustrate to industry the structure and focus of the programmes. A project based module was not listed in this graphic as it is expected that the students will utilise elements from each module as part of the project based work.

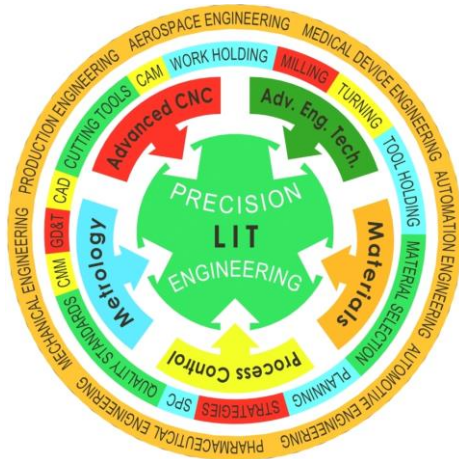


Figure 2: Programme focus and content.

VII. PROGRAMME IMPLEMENTATION

The programme was created as one year add-on Level 7 programme on a full time basis. This is equivalent to the third year of a four year ab-initio degree programme with an exit award. Access to the programme is available to those with a minimum NFQ Level 6 award at Technician level in a related cognate area or those with a trade qualification who have also improved their mathematical and science qualifications sufficiently to move to Level 7.

As a result of the rapid programme development it was not possible to have the all resources, including staffing, in place to deliver all six modules for the September 2014 deadline. It was decided to offer the programme on a part-time basis initially with three modules being offered utilising existing resources and the purchase of additional equipment. In the 2014-15 academic year the following were offered;

- Mechanics and Materials,
- Mathematics and Statistics
- Metrology and Statistical Process Control

From September 2015, all six modules will be on offer allowing both part-time and full time students to register on the programme.

- Advanced CAD/CAM
- Advanced Engineering Technology and Process Planning
- Project

As the programme was offered part-time, a small cohort of eight students from industry were registered thereby allowing the programme to become established and credibility gained with industry. All of the students are working in industry three days per week and attending LIT on two consecutive days per week.

A Level 6 programme has now been developed that will provide graduates to industry not currently available. The development of a Level 6 Higher certificate programme would normally precede a Level 7 programme but in this case the need from industry required the opposite approach be taken. A Level 8 Honours degree programme will be added in 2016 as shown in Figure 3.

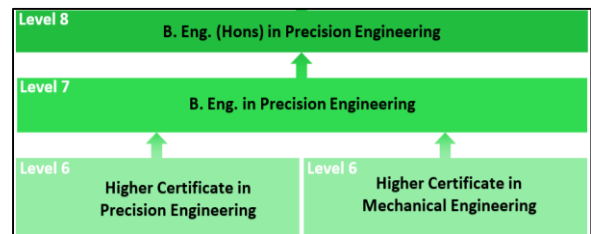


Figure 3 Academic Progression Ladder

VIII. INDUSTRY SUPPORT AND SUPPORT TO INDUSTRY

In response to the development of the programme four companies were approached to make a charitable donation to help fund the programme. Approximately €100,000 over a five year period has been pledged to LIT to support the development of the programme. Equipment suppliers from industry have also committed to supply equipment to the programme. As a result of this unique level of collaborative engagement, LIT are in the process of developing a Precision Engineering Hub with the aim of become the National Centre of Excellence in Precision Engineering and Manufacturing Technology.

IX. CONCLUSIONS:

The development of a Precision Engineering programme at LIT has been created by a unique Industry-Academic collaboration and an innovative response to the needs of industry. The PTMA, EI Manufacturing Focus group, LIT academic staff and management successfully implemented a common approach to programme development. This approach proved successful, even though a little unusual, by creating one Year Level 7 add-on programme before a Level 6 programme and Level 8 had been created. The rapid and successful development of the programme could only occur where a clear meeting of minds had occurred and a balanced approach to the immediate training needs of industry against the long term desire to educate engineers to drive the industry was achieved. The work-learn model where a student may attend LIT two days per week on a part-time basis while working at the same time has also proved innovative in an Irish context. The financial investment by industry into the programme has also been a new development and is also seen as a key factor in the proposed development of a new dedicated Precision Engineering Centre of Excellence at LIT. The plans for this new facility are evolving rapidly with a predicted opening date for September 2016.

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Localized Open Source Collaboration in Software Engineering Education

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Abstract—Involving computer science students in open source software projects provides opportunities for them to contribute to real products with more authentic scope than typical computer science assignments. However, the environment of collaborating with external, distributed teams also poses unique challenges and may distance students from the potential for valuable, direct contact and mentorship from software professionals.

In addition, while the technology industry continues to grow, smaller communities have a vested interest in growing a culture for collaboration between students and local software developers. We formed a local open source organization to collaborate on a product by combining efforts from students and professionals. This paper describes the localized free and open source software (LFOSS) organization and reports initial findings from software engineering students' involvement.

Keywords—computer science education; software engineering; industry collaboration; free and open source software (FOSS); humanitarian free and open source software (HFOSS); team projects.

I. INTRODUCTION

Teaching software engineering in traditional educational settings poses the challenge of teaching principles and practices with limitations imposed by academic calendars and budgets. In particular, common fifteen (or fewer) week academic terms restrict students from producing large-scale projects from scratch even when an entire term is dedicated to a single project. Consequently, students in computing disciplines may not be exposed to projects with long enough lifespans nor large enough scale to appreciate software qualities such as maintainability and reusability. Meanwhile, learning software development methods and conventions in a classroom setting alone may feel contrived and detached from actual professional applications.

A hindrance of contemporary computing education is that programming projects usually produce “toy applications”—those with little practical use outside of the classroom and whose lifespans rarely extend past the academic term in which they are assigned. However, in an effort to mature from “toy” to extensible and useful software projects, some software engineering instructors advocate incorporating Free and Open Source Software (FOSS) projects [1]. These projects offer publicly available code where students can often contribute to software products that aim to solve real problems and will

continue to be used and maintained beyond the completion of school calendars. The following *Background* section discusses general advantages and challenges to integrating FOSS projects in the classroom.

In Chico, California—a city with a population of approximately 100,000 and with no *Fortune 500* software companies [2]—we organized Chico Open Source Consortium (COSC) to help bridge a disconnection between the university students and the local software professionals. Independently, both students and professionals had expressed frustration of a missing “technology culture” or “software community” despite the resources available.

COSC formed as a localized FOSS organization comprised of a professor and eleven software professionals who worked at three different companies within the city; its mission is “fostering a collaboration between CSU Chico students and Chico, CA software companies on open source projects” [3]. Students in an upper-division software engineering class were given the option to use this project as their semester-long team assignment. However, students in the class were provided leniency and agency to choose their team projects, including options to contribute to remote FOSS projects or to propose their own products.

We used surveys to gauge students' experiences with their respective projects at the end of the term. In this paper, we compare student experiences and opinions from a variety of projects and discuss implications of local and remote FOSS collaboration. Lastly, we identify other benefits and lessons-learned from the first semester of student collaboration with a localized FOSS organization.

II. BACKGROUND

Thanks to the contributions of worldwide software developers, many Free and Open Source Software (FOSS) products have gained popularity, including Mozilla Firefox web browser [4]. Just like the commercial software it often competes against, FOSS products require software design, development, validation, and maintenance with care not normally afforded to traditional educational computer science assignments. Consequently, introducing FOSS projects to software engineering students exposes them to challenges like those they will face as professional software developers. In

addition, by collaborating with the FOSS community, students potentially gain insight and mentoring from more experienced developers.

Nevertheless, involving students in FOSS projects also introduces new challenges, such as working with geographically remote (non-classmate) collaborators whose active participation and communication in the project may be unpredictable. However, despite its challenges, there are strong pedagogical and curricular rationales for using FOSS projects in software engineering courses.

Auer, Juntunen, and Ojala describe FOSS projects as a viable application of constructivism learning theory. Constructivism explains learning as a processes of building (or *constructing*) new knowledge based on connecting new information to learners' prior knowledge. Additionally, project-based learning contextualizes learning new skills by directing students to solve real-life problems. Experts (i.e. experienced software developers) may scaffold students' learning by following an apprenticeship model whereby the novice students gradually develop and adopt the experts' skills through mentorship [5].

However, Auer, Juntunen, and Ojala acknowledge that connecting suitable projects with experienced software developers can be challenging. Meanwhile, In an effort to connect students with "education-friendly open-source projects," the Repository for Open Software Education (ROSE) collects a list of projects that may be suited for classroom use [6].

Moreover, the Humanitarian Free and Open Source Software (HFOSS) Project advocates contributions to humanitarian projects that "intrinsically benefit a non-profit organization pursuing some kind of public-service mission" [7]. As an example, they submit Sahana, an application to help manage disaster relief. However, the potential benefits of HFOSS extend beyond the altruistic nature of the projects.

ABET accreditation criteria specify that student outcomes include "an ability to analyze the local and global impact of computing on individuals, organizations, and society" [8] and involvement in HFOSS certainly lends itself to analyzing its social benefit. In addition, the HFOSS Project reports that experience with their projects influences positive perspectives of computing majors and careers, particularly among students with less programming experience [9].

A preliminary experience report also suggests that HFOSS Projects could help recruit underrepresented minorities in computing who may have a stronger interest in "applications that benefit society" [10]. If true, integration of HFOSS in computer science curricula could begin to address the lack of diversity in the discipline, particularly concerning the disproportionately few women.

III. METHOD

A. Localized Free and Open Source Group

After talking and identifying a mutual desire to organize collaboration between software engineering students and professionals in the local area, a group of twelve individuals formed through existing professional and personal networks.

The group comprised of the software engineering professor and eleven professional software professionals who worked for three different employers in Chico, California and named itself the *Chico Open Source Consortium* (COSC).

Over the summer, COSC met and discussed project ideas that we thought would be useful to their respective companies as well as to the general software developer population. Together, COSC brainstormed the idea for *BossyUI*, a web toolkit that would include a collection of widgets (common components used on websites, such as calendars and data grids) that could be reused and adapted for different web pages with adaptable visual styling and automatic data binding. The idea for *BossyUI* developed from a common appreciation for existing web toolkits like Bootstrap [11] and jQuery [12] while avoiding frustrations and limitations that the team found with existing products.

In addition to identifying *BossyUI* as its first FOSS project, COSC set expectations for the core members of the team. COSC scheduled a weekly one hour meeting at which the members would share updates and discuss issues with the project. In addition, each member agreed to devote two hours per week to the project. In recognizing the value of the project, two of the three employers agreed to donate their employees' two hours per week workload so that they could support the project. Once the product had been identified and the COSC team solidified, the next task was to find software engineering students who wanted to collaborate.

B. Student Teams

In an upper-level, undergraduate software engineering course, teams of students were assigned a semester-long project to practice and demonstrate the software development techniques taught in lecture. According to the suggestion that ideally, students' involvement in FOSS should be voluntary [5], we gave the teams the option to choose their own projects. Although HFOSS shows promise of attracting new audiences, we recognize that different students may have different motivations. In particular, a student with an entrepreneurial motivations may be more interested in creating a commercial product that is not freely-available to the public.

Accordingly, we allowed teams to either identify an existing FOSS project or propose an original product to maintain on an either public or private repository. During the first week of the semester, students formed groups of 3-7 members based on the projects and technologies that interested them the most.

Altogether, there were 75 students divided into 15 teams. Three of the teams (n=17 students) chose to pursue original commercial products in which they could keep their code private within the team (and overseen by the professor). Nine teams (n=41) also identified unique products that they wanted to develop but without aspirations to profit from them and consequently chose to make their products free and open source.

One team (n=4) chose to contribute to Spyral, a library specific to the XO "One Laptop Per Child" non-profit initiative [13]. Spyral was an existing library but its original authors had

identified new features that the software engineering students could add to it.

Finally, three teams (n=13) chose to contribute to *BossyUI*, the COSC project. Each of the three teams needed to produce independent deliverables for the class (since teams belonged to different sections of the software engineering course). Consequently, with some guidance from COSC, each team identified a subset of the *BossyUI* widgets that they would work on. Once the semester began, the student teams were given prominent roles in developing the widgets, while the COSC team agreed to mentor the teams and to help provide specifications. Effectively, the COSC team became both clients and technical supervisors for the student teams who assumed the lead in development.

C. Course Overview

The software engineering class used for this project is a upper-division class for computer science majors after they have completed the three-course sequence of Introduction to Programming, Programming 2, and Algorithms and Data Structures. Software engineering concentrates on students learning Agile software development methods, version control, testing, software quality metrics, and design patterns. Teams were required to have (at least) weekly meetings. The project grade specifically required teams to demonstrate that their software was ethical, well-designed for maintainability and extensibility, and was tested thoroughly with software tests. However, since students chose their own projects, the programming languages, platforms, and libraries used varied considerably, including mobile development in Java, full stack web development, and lower level C programming for breadboard hardware.

The teams presented their product at the end of the term and were assigned team grades (with adjustments made when the instructor deems necessary due to imbalanced contributions and peer-reviewed ratings). Every team's code was maintained in their own GitHub [14] repository, which tracks each individual members' code contributions through version control. Most groups' repositories were public but two teams (both with commercially aspired projects) chose private repositories to keep their code proprietary. The instructor was a member of the private repositories for grading purposes and classmates were sometimes added temporarily as members to private repositories during peer-review class activities. At the end of the term, there was also a project showcase on campus that was open to the public so teams could demonstrate what they contributed.

D. End-of-Term Survey

At the conclusion of the semester, students were asked to complete a survey to summarize their opinions, expectations, and experiences with their team projects. The survey included the following questions:

- Outside of lecture and lab, estimate how many hours you spent per week on your team project.
- (T/F) I plan on continuing to contribute to my team project after this semester is over

Rate the following from 1 (Strongly Agree) to 5 (Strongly Disagree)

- After the end of the semester, I expect other programmers (besides my team and instructor) to use my project's code
- After the end of the semester, I expect my project to become a commercial (for sale) product
- I believe my project can help serve my school (and/or affiliated groups)
- I believe my project can help serve the local community
- I believe my project can help serve national or international communities
- (T/F) What I have done in Computer Science and Software Engineering has made a positive impact on the world.

The survey had 66 (88% of 75 students) responses and students identified to which team they belonged so their responses could be associated with what type of project they worked on.

IV. FINDINGS

The team projects were grouped into four categories: commercial, HFOSS (Spyral project only), LFOSS (localized FOSS BossyUI project only), and FOSS (open source projects started from scratch not categorized as HFOSS nor LFOSS) and survey responses were aggregated accordingly. First, we investigated the responses for the estimated amount of time spent per week and the true/false questions, as shown in Table I:

TABLE I. REPORTED HOURS PER WEEK, EXPECTATION TO CONTINUE, AND POSITIVE IMPACT

Category	Hr/Wk	Continue	Pos. Impact
Commercial	M=6.86 sd=4.30	64%	93%
FOSS	M=8.17 sd=7.39	36%	72%
HFOSS	M=3.63 sd=1.60	100%	50%
LFOSS	M=4.04 sd=2.57	75%	83%

In Table II, we summarize the Likert scale responses (1 strongly agree to 5 strongly disagree) by category for each question: expectations for other programmers to use the code, expectations to become commercial product, and serving school, local, and international communities.

TABLE II. LIKERT SCALE RATINGS AGGREGATED BY CATEGORY

Category (M, <i>sd</i>)	Other Prog	Comm	Serve School	Serve Local	Serve Intn'l
Commercial	3.57, 1.34	2.43, 1.45	3.21, 1.47	2.36, 0.93	2.50, 1.22
FOSS	3.58, 1.02	3.78, 1.24	3.11, 1.24	3.11, 1.19	3.22, 1.27
HFOSS	3.00, 1.41	4.50, 1.00	4.00, 0.82	4.25, 0.50	2.25, 0.50
LFOSS	1.50, 1.00	3.58, 1.68	2.25, 1.14	1.83, 0.94	2.25, 1.06

When analyzing these findings, one must keep in mind that this study was *exploratory* and *not* intended to explicitly test hypotheses. There are several limitations and confounds that would make any attempt to generalizable conclusions inappropriate from this data alone. First, the sample size for the Commercial, HFOSS, and LFOSS categories were very small and consequently, the aggregated data could be dramatically skewed by even just a single student's response.

Perhaps even more importantly, one should keep in mind that the students chose their own projects so the results are confounded by any personal characteristics that may accompany the selection bias. In particular, we anecdotally observed that in general, the students who chose either Commercial or LFOSS projects tended to be stronger self-starters and generally higher-motivated (to either create a profitable product or contribute to a FOSS project while networking with professionals). While these confounds hinder the experimental design of comparing end-of-term attitudes, they also illustrate the attraction that both commercial and LFOSS projects have to students.

While we will continue to monitor the lifespan and activity of these projects for future longitudinal studies, it is also worth noting that two of the three commercial projects have publically released their products (one as a mobile phone application [15] and the other as a website [16]) and that BossyUI (the LFOSS Chico Open Source Consortium product) [3] is preparing its initial release for Summer 2015. Unfortunately, Spyral (the HFOSS project) [13] was trumped by a similar product that rendered it obsolete for all practical purposes. Although the HFOSS team met their goals for the semester, the parent product itself was unexpectedly abandoned approximately at the same time the semester was concluding. The exact timing and communication to the HFOSS student team is imprecise so we do not know if it influenced their survey results.

We also observed several valuable outcomes from the LFOSS project. Foremost, one of the students from an LFOSS team was recruited and hired as a paid intern as a direct result of his interaction with the professional developers on the COSC team. That networking and mentoring between the LFOSS students and the COSC was very positively received by both sides. Although the HFOSS students had mentors to guide their project, the weekly in-person interaction between

the LFOSS students and COSC seemed invaluable and unmatched. Anecdotally, we noticed the LFOSS students mature most distinctively as software developers as they adopted the habits and the language of their professional mentors. From the first semester of this study, we are inclined to believe that the in-person interaction of LFOSS projects may offer more impactful learning experiences than collaborating with a distributed team can. These promising anecdotal observations give us reason to continue studying the impact of LFOSS projects.

Although the preliminary data must be accompanied with caveats of multiple confounds, the general trends seem to suggest that options to pursue both commercial and LFOSS may compliment HFOSS opportunities for students with different motivations.

Nurkkala and Brandle identified the lack of software maintenance and lack of customers as vital limitations of traditional ("toy application") software engineering projects [17]. Any projects that start from scratch at the beginning of the semester will suffer from the former. In that regard, existing and active open source projects (of any variety) will have a distinct advantage over students who begin development of a new product regardless of whether it is intended to be commercial or not. In this study, the *new* FOSS (but not HFOSS nor LFOSS) projects lacked both maintenance and a customer. Many of these new FOSS projects could be considered "toy applications." Consequently, we discourage allowing students to pursue *new* FOSS products as they tend not to bridge the gap between education and industry.

Both HFOSS and LFOSS types of projects appeared to particularly benefit from interaction with external, professional software developers. Consequently, the students were held to high standards and received quicker feedback than instructors can achieve reasonably at scale. For these projects, the teams followed a "fork & pull" model of committing their code to the repositories—that is, they created copies of the existing repositories in their own space (forks) and created "pull requests" for their customers to review before their work was merged with the main repository (when deemed satisfactory). As the students were learning Agile development methods in the software engineering class, it took some practice for some students to adapt to getting quick (and occasionally negative) feedback. However, the experience is useful in preparing students for working in real project environments.

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Teaching Digital TV Programming for Engineering Students

An Industry Oriented Proposal

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Abstract— One of the most important problems of the engineering courses in Brazil is that they do not cover subjects related to computer science deeply enough to attend the needs of the modern industry. It is uncommon to find young electrical engineers able to deal with programming techniques for applications like web engineering, embedded systems, mobile devices, or new digital TV systems. Indeed, that is a new problem for engineering educators, to keep teaching the classical approaches as well as to keep path with new technologies. One of these actual hot topics in Brazil is the programming for Digital TV Systems. The goal is not only to produce basic software but also applications that may be used in new smart TV devices. In fact, we need a novel academic program that could introduce new subjects without changing the official curriculum. This kind of program would help to keep the students aligned with novel themes and help them understand the linkage of fundamental topics with new technological trends. Moreover, this program also helps to bring the industry closer to the university. Complete analyses of the adopted curriculum as well as the activities done are going to be presented in this paper. We will also present some examples of the developed software.

Keywords –University and Industry Collaboration; Extra-Curricular Programs; Educational Experience.

I. INTRODUCTION

In Brazil, the curricula of engineering courses are defined following strict rules from the ministry of education. There are some mandatory points that must be obeyed prior to the accreditation of any engineering course. In one hand, curricular modifications must be submitted for evaluation what starts a long administrative process that may takes years to be concluded. On the other hand, many modern industries need to hire engineers with knowledge of new technological trends [1], which demands the introduction of new curricular components in the existing engineering courses in a very quick way. Most of these curricular modifications could not be implemented or, sometimes, take too much time to be integrated to the official curriculum, what reduces the possibility to start any profitable cooperation between the local industry and the universities. Moreover, the universities have been facing many problems to keep up-to-dated with the even faster technological changes, for example, it is not easy to construct and maintain laboratories in areas like embedded systems, digital TV, or

related topics. The contents of the classical engineering majors are not capable to attend these new demands.

Trying to solve these problems, some lecturers from UFAM proposed a flexible extra-curricular program (extension) for electrical and computer engineering students [2]. The whole program, its subjects, duration, and topics of each particular course were discussed previously with the industry partners in order to attend their actual needs. The extension programs contain two mandatory parts: one that covers the most significant theoretical concepts, and another one that focuses on the practical aspects of the technologies being taught, that is where the students are supposed to solve real problems. This concept is flexible enough to cover any new trend in electrical engineering and computer engineering and to be adapted to the needs of the companies installed in the local industrial pole.

Particularly, in this work in progress paper we are going to present a specific program demanded from Samsung Company. They have a huge production plant installed in Manaus that assembles television-sets, mobile phones, and other consumer electronics devices. In order to keep the production running they need qualified people and their demand is still growing. Many of the particular desired skills for the engineers being hired by the company are not discussed during the college period and therefore they asked UFAM to develop a specific training for these people.

Despite the inflexible curricula, we decided to propose an alternative way to insert those new interesting topics on the undergraduate studies path. It was possible by the offer of extra-curricular modules taught after the official class hours. This are the so-called extension programs and the choice of their content was done in a close cooperation with the industry.

One of the demanded topics dealt with software development for Digital TV. Indeed, the technology used to construct digital TV systems is already covered in the traditional engineering curriculum of any classical electrical engineering program. However, those topics are distributed in many disciplines all over the undergraduate course. In the next paragraphs we will describe particularities of the educational program developed by UFAM in cooperation with Samsung, we believe this model may contribute to other similar experiences.

Some of the results presented here were obtained through the research and training of human resources project, at the undergraduate and graduate level in the areas of industrial automation, software for mobile devices and digital TV, funded by Samsung Electronics Amazon Ltda. under the Law. 8387 (art. 2) / 91.

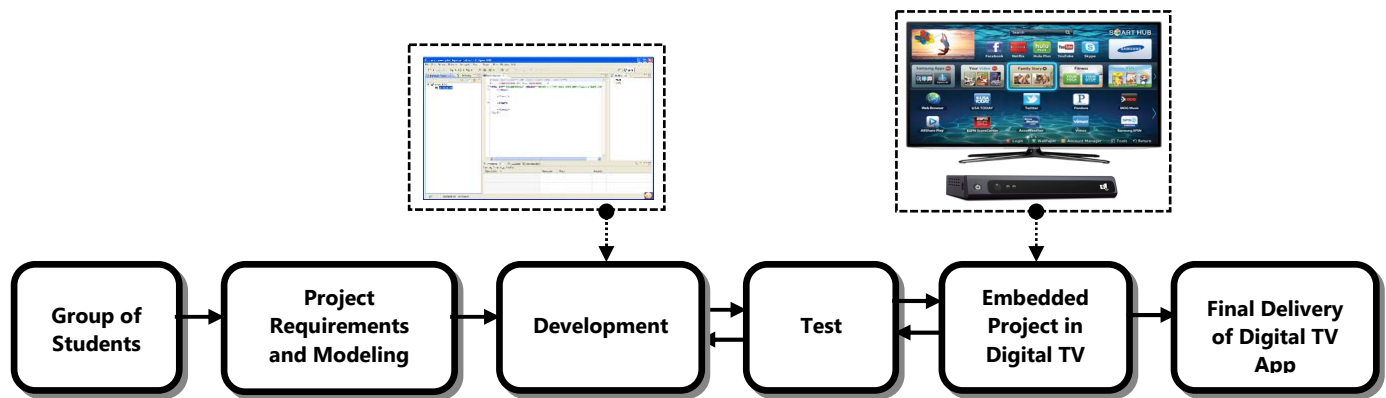


Fig. 2: Block diagram of the project phases.



Fig. 1: Block diagram of the Digital TV Technologies program.

II. PROGRAM DESCRIPTION AND METHODOLOGY

The program follows the steps presented in Fig. 1, where we can observe all its stages in a macro way. In general, according to the block diagram, the project starts with the planning of the desired topics. In this case, the chosen theme was Digital TV Technologies, specifically the programming for this kind of system. Professors from the Federal University of Amazonas together with the researchers and technical staff from the company developed the whole program. In this planning, the following points were established:

- Objectives and milestones of the complete program.
- Common technologies from the industry that could be used in the program.
- Program organization in two different sub-phases called *training* and *project*.
- Definition of the desired modules of the *training* phase and the requirements of the digital TV applications in the *project* phase.
- Workshop with the participating students presenting their final work to researchers and managers.

After concluding the planning phase, we started the selection of students. In this step, students from different institutions of the State of Amazonas (in Brazil) were enrolled. The criteria for selection were: (1) current semester in the University; (2) scholar performance (cumulative grade); (3) overall academic performance; and (4) available time to dedicate of the program. At the end of this process, twenty students were selected to take part in the project.

Another important aspect of this project is that the instructors are not necessarily the same lecturers that work in the University. Indeed, it is more interesting if the instructors come from the industry in order to pass for the students another point of view on the topics being studied. In this project, we could select five industry researchers that agreed to work as lecturers for the selected topics. The selection criteria were: (1) practical experience in Digital TV; (2) academic experience in the Digital TV; and (3) provided training experience in general.

As soon as the project started, two meetings were held with students together with the researchers and with the professors in order to present the whole program objectives. The specific goals in respect to the training, the use of laboratory infrastructure, a detailed description of the modules, the period and duration of the modules, and other general information about the program were also discussed. Additional subjects discussed at these meetings were the classroom place, time schedule of modules, delivery of software artifacts, and program approval criteria.

In the training phase, five modules were defined with twenty/thirty hours each, the total duration of this phase was 110 hours (see Table I). The topics covered the most important aspects of programming for Digital TV systems [3, 4, 5, 6]. The selected industry researchers taught the modules, whose took in consideration theoretical and practical aspects of the art. The practical classes occurred in an appropriate laboratory that hosted all students at one time containing appropriated Digital TV equipment. During the theoretical and practical classes, students worked out several assignments in order to exercise the taught content. Details of each module are presented in Table I.

TABLE I. MODULES OF THE TRAINING PHASE OF THE DIGITAL TV TECHNOLOGIES PROGRAM.

Module Title	Duration (h)
Fundamentals of Digital TV and Software Development	20
Java and Java TV	30
Software Development using Digital TV Middleware	20
C/C++ Programming	20
Embedded Systems Programming and Embedded Linux to Digital TV	20
Total amount of hours	110

The topics covered in each module were previously discussed among the professionals from the company and the university staff. As said before the choice of the person in charge for teaching each module were based on the academic competence and on the practical experience in solving real problems. The following subjects were covered in each module:

- **Fundamentals of Digital TV and Software Development** - Digital TV Fundamentals. Concepts of video systems. Analog television systems. Video scanning. Decoding techniques used in Digital TV. Components of Digital TV systems. System Block Diagram. Software Environments. Hardware and Application. The context of Interactive TV. The Set-top Box. Constitution of the Set-top Box. Introduction to software engineering. Life cycle of software development. Software Quality. Techniques and methods for design and software testing.
- **Java and Java TV** – Introduction to object-oriented programming languages. Java virtual machine. Data types. Control structures. Object orientation. Classes and interfaces. Java class libraries. Packages of the Java language. AWT. Creating Java applications. Exception handling. Events and Threads. Java TV programming. Paradigms of implementation. Software emulation and authoring. Xlets and NCL: presentation engine. NCL formatter. Objects and media players. Structure of an NCL document. LUA execution engine. NCL-LUA integration.
- **Software Development using Digital TV Middleware** - Interactivity concept and interactive content for DTV. Definition of Middleware. Existing middleware standards. Typical architecture of a middleware and types (declarative and procedural). Carousel of objects. Hardware architecture and software of a Set-Top-Box. Definition of a transport stream and tables. Conventional Broadcast. Broadcast of Interactive applications and the Internet. Introduction to the concept of interactive applications. Software Emulation. Concept of graphical interface and usability design. Interactive applications based on Java for TVD. Interactive applications based on NCL-LUA.

- **C/C++ Programming** – History of the C language. C compilers. Program Structure in C. Data Types. Logical Data, Variables and Constants. Operators and Arithmetic Expressions. Relational and Logical Operators. Repetition structures. Structure of Matrix. Functions and Procedures. Using Libraries. Functions of application. Parameter Pass, Pointers, Vector Pointers, File Pointers. Introduction to C++ programming. Algorithms of structures. Functions and Recursion. Operator overloading. Object-oriented programming in C++. Objects, Classes, and Polymorphism. Templates. I / O Stream. Exception handling in C++.
- **Embedded Systems Programming and Embedded Linux to Digital TV** - Hardware and software architectures of embedded systems. Operating Systems for embedded platforms. Understanding of design methodologies and programming languages for minimal systems. Hardware synthesis application. Software and communication. Validation of mixed hardware-software systems. Design based on platforms and low power system design. Introduction to Linux. Process model and overview of the kernel. Real-time scheduling. Linux boot process. Interrupt process on Linux, device drivers. Kernel modules and boot sequence. File system. Shared and static libraries. Graphical environments for Linux embedded systems. Real-time Linux. Business solutions for embedded Linux.

After completing the modules, those students that obtained the minimal average grade were admitted to start the project phase. The planned workflow of this phase is presented in the block diagram shown in Fig. 2, and it has six different steps. First, the students are supposed to create working groups with six/seven members each and establish their own responsibilities. One of them plays the role of the leader; the others will work as developers and testers. Each group is responsible to define the project requirements and to submit their proposal to the supervisors. After the approval, the students start modeling and developing the software.

Here is the point where the students begin to exercise their professionalism, one of the most important characteristic of an engineer. In the steps *Development*, *Test* and *Embedded Project in Digital TV*, we used the Scrum development methodology with weekly sprints [7]. This methodology is very popular among software developers now a day and wide spread among mobile developers. It also proved to be effective for the development of software for Digital TV systems.

Every week, the groups must deliver a set of document reporting their progress, as well as, the faced difficulties. One of these deliveries must be made directly on the set-top box device (see in Fig. 2, on top of the box *Embedded Project in Digital TV*) which allows real monitoring of what has been developed. In these three steps, we used several tools like Ginga NCL [8], Eclipse [9], and Git [10] to develop the proposed work. In fact, the students should start the implementation by using a simulation tool and afterwards they should move their applications to the real Digital TV device.

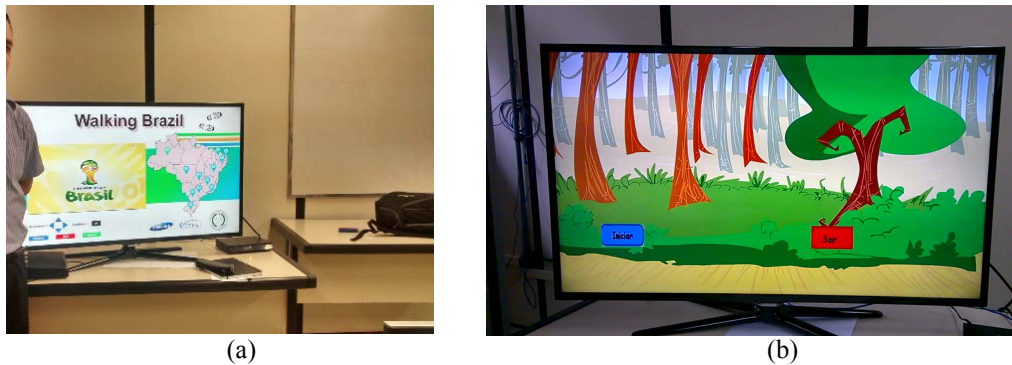


Fig. 3: Screen inside of a Digital TV, in the digital TV laboratory, of the groups that are developing the project Interactive Application of Points of Interest of Brazilian Cities (Fig.3(a)) and the project Interactive Educational Game: Search the Treasury (Fig.3(b)).

III. PARTIAL RESULTS

The results obtained in our last execution of this project (December 2014) were very interesting. After the last phase, the groups could deliver three functional digital TV applications. The title of the developed applications were:

- a) Interactive Application of Points of Interest of Brazilian Cities. This software searches in a database the most relevant touristic points of a specific city and present them on a TV screen. Particular interest was given to the 12 host cities of the 2014 Soccer World Cup.
- b) Digital TV Interactive Application for the Soccer World Cup. The goal of this application was to display the information about the status of the Soccer World Cup. Games scores, best players, national teams' classification, and other relevant information were presented on-line.
- c) Interactive Educational Game: Search the Treasury. That was a quiz game developed for the Ginga Middleware. The questions were presented in a very attractive way and the difficulties increased as the number of correct answers grew.

All those projects were successfully developed in a simulation environment inside of a digital TV laboratory. After a long period of tests, they were embedded in the digital TV set-top-boxes. That means that all groups were able to reproduce a development environment commonly used in the local research and development companies. Fig. 3 shows two examples of the developed software applications.

IV. CONCLUSIONS

At the end of the project, the students presented their work in an open workshop at the University. All applications worked well and proved to be good experiments for demonstrating the importance of Digital TV technology. The student groups were supposed to present their products as real professionals trying to impress customers or investors. The company's staff took part in their presentations; they judged the quality of each application, and choose the most interesting which won a prize given by the company.

The most important result was that the totality of the students was able to conclude successfully the training. The teaching model proved to be a good extra-curricular approach. In fact, the students learned a lot about topics related to Digital

TV and learned how to develop software in a real world approach.

From the professor's point of view, we had to manage many new pedagogical situations. For example, teaching at the evening is quite different from doing the same job during the day. We needed to supervise the students in a very closer way keeping their progress under constant attention. Another challenge was to work with students having quite different backgrounds; in fact, we received students from other universities and in different stages (seniors and fresh man) that needed to work together.

Finally, we may affirm that we have learned a lot by working closer to the industry professionals. The practical aspects and the industrial way of doing could be taught not only to the participating students but also to the professors coordinating the whole program.

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Tendencies Towards DEEP or SURFACE Learning for Participants Taking a Large Massive Open Online Course (MOOC)

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Abstract— *In this report we will describe our first steps in understanding the characteristics of individuals enrolling and completing MOOCs. The learner characteristic we focus on is the deep versus shallow learning dimension. We will use the revised two-factor study process questionnaire of Biggs in our study [1]. To our knowledge, there is no comparable research either reported in the literature or currently under way. Our focus is on Learning How to Learn (LHTL), currently the most heavily subscribed course on the Coursera platform. The last offering of LHTL, completed in January, 2015, attracted just under a quarter million learners. In the fourth and final week of the course, the R-SPQ-2F survey instrument was made available to all students on the LHTL site. Approximately 1,600 students completed the survey. We believe our research to be of interest widely because of the confluence in our research of (a) MOOCs, (b) the deep versus surface learning dimension, and (c) a methodology that can lead to better understanding of MOOCs.*

Keywords—MOOC; online learning; deep learning; surface learning

I. INTRODUCTION

Massive open online courses (MOOCs) have been a rapidly growing part of the educational space since 2008. MOOCs have been saddled by both overly optimistic expectations and overly pessimistic warnings. On the optimistic side, MOOCs have been touted as a vehicle for democratization of educational opportunities on a global scale. On the pessimistic side, some have pointed to the current very low “graduation rate” of students. The ground truth about MOOCs is dependent on the factors distinguishing a given MOOC. This is where serious research about MOOCs and the learning potential they may offer should start. Analyzing MOOCs as a whole is difficult without first coming to an agreement on the dimensions they will cover. At that point we will begin to understand strengths and weaknesses of each type of MOOC. What draws individuals to enroll in a given

MOOC? What holds a learner’s attention over the duration of the course? The subject matter of the MOOC and the pedagogical approach underlying the MOOC are part of the story. But part of the story must be in the characteristics of the learners and this study focuses on that aspect.

As part of our investigation, we will be looking at students enrolled in Learning How to Learn (LHTL), a MOOC offered on Coursera by Drs. Barbara Oakley and Terrence Sejnowski. LHTL consists of a series of 41 brief videos, each with a clear and concise focus on one learning “principle.” Students who take LHTL in a session-based platform view these videos over a one month period. Although like all massive open online courses, the LHTL MOOC has a lower completion rate than would be desirable, statistics from Coursera indicate that the offerings of LHTL have attracted hundreds of thousands of “students” and that the participation rate for LHTL is high.

While most students become more efficient learners as they mature and progress through school, “most college students have not developed a systematic approach to study skills” [2]. According to the most recent Noel-Levitz report, approximately 60% of incoming first-year students nationwide report positive study habits used in high school [3]. While students with better study skills, attitudes, and time management skills tend to achieve higher academic results, the converse is also true [2]. There is evidence to suggest that students will not learn study skills unless those skills are explicitly taught [4]. However, such training can significantly improve academic performance in at risk college students by changing students’ academic behaviors [2]. Bender et. al., suggests that “the at-risk student may be more successful in college than in high school if academic behaviors that contribute to college achievement are acquired, whatever the reason for poor performance in the past” [5].

While the students enrolled in LHTL, may or may not be college students, the course emphasizes techniques that can be applied to any learning environment. The course description states: “We’ll learn about the how the brain uses two very different learning modes and how it encapsulates (“chunks”) information. We’ll also cover illusions of learning, memory techniques, dealing with procrastination, and best practices shown by research to be most effective in helping you master tough subjects” [6].

At the end of their course sequence students were asked to complete a 20 question survey, The Revised Study Process Questionnaire (R-SPQ-2F) to assess deep and surface approaches to learning to determine which learning styles the students are using at the end of the course [1, 7]. In addition to the R-SPQ-2F data, also available to this research team are the results from a preliminary survey which explores the student’s intentions of course participation and expectations in LHTL. Our primary result presented here is the scoring on the deep versus surface learning dimension for those who completed the survey. While extrapolation to the entire population will be difficult, we will attempt to characterize the similarities and differences between the population taking the survey and the general population taking LHTL on the preliminary survey results. Finally we will examine correlations among the preliminary survey and the results of the R-SPQ-2F survey.

II. SURVEY INSTRUMENTS

The preliminary survey begins by asking about the student’s personal participation expectations in the course. They are asked how many lectures they intend to watch and how many assessment activities they intend to complete. They are also asked to rank the importance of the course topics on a 5 point Likert type scale (5 = very valuable, 1= not valuable). Finally, students are asked to describe their common study techniques and approaches and explain why they are taking the course.

The R-SPQ-2F survey is broken down into 6 measures. *Deep Approach: Method, and Strategy*; and *Surface Approach, Method, and Strategy*. Each of the subscales is a set of 5 questions. The *Approach* measure is the sum of the *Method* and *Strategy* scores as shown below [1]:

A. Deep Method

- I find that at times studying gives me a feeling of deep personal satisfaction.
- I feel that virtually any topic can be highly interesting once I get into it.
- I find that studying academic topics can at times be as exciting as a good novel or movie.
- I work hard at my studies because I find the material interesting.
- I come to most classes with questions in mind that I want answering.

B. Deep Strategy

- I find that I have to do enough work on a topic so that I can form my own conclusions before I am satisfied.
- I find most new topics interesting and often spend extra time trying to obtain more information about them.
- I test myself on important topics until I understand them completely.
- I spend a lot of my free time finding out more about interesting topics which have been discussed in different classes.
- I make a point of looking at most of the suggested readings that go with the lectures.

C. Surface Method

- My aim is to pass the course while doing as little work as possible.
- I do not find my course very interesting so I keep my work to the minimum.
- I find I can get by in most assessments by memorizing key sections rather than trying to understand them.
- I find it is not helpful to study topics in depth. It confuses and wastes time, when all you need is a passing acquaintance with topics.
- I see no point in learning material which is not likely to be in the examination.

D. Surface Strategy

- I only study seriously what’s given out in class or in the course outlines.
- I learn some things by rote, going over and over them until I know them by heart even if I do not understand them.
- I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra.
- I believe that lecturers shouldn’t expect students to spend significant amounts of time studying material everyone knows won’t be examined.
- I find the best way to pass examinations is to try to remember answers to likely questions.

The R-SPQ-2F rates the items on a 5 point scale where A = this item is never or rarely true of me (1 point) to E = this item is always or almost always true of me (5 points) [1]. Therefore, within each subscale there is the possibility of 25 points and within each main scale, the possibility of 50 points.

III. ANALYSIS AND RESULTS

A total of 2,081 students completed the preliminary survey out of 223,428 participants (0.9%). From the preliminary survey, we can see that the students enrolled in LHTL for a variety of reasons (Table I) and have an affinity for various professional areas (Table II). For both of these questions, students could select more than one answer. According to our

survey results, it would appear that the top two reasons to enroll in LHTL are to assist with personal and professional development. It also seems that STEM fields as well as the humanities and education are the most popular affinity areas for students. In terms of expected participation, approximately 78% of students (N = 1648) planned to participate in the course discussions, with only 48% (N=1002) planning to complete the course assessments and 22% (N = 365) planning to watch most of the course videos.

TABLE I. REASONS FOR ENROLLMENT IN LHTL MOOC (N = 2081)

To assist with personal development	85.6%
To assist with professional development	60.9%
Curiosity about the course materials	55.6%
To improve my academic performance	52.0%
Other	12.2%

TABLE II. WHICH OF THE FOLLOWING AREAS DO YOU FEEL YOU HAVE A "NATURAL AFFINITY" FOR? (N = 2081)

Math, science, engineering	55.0%
The social sciences (psychology, sociology, anthropology, etc.)	45.6%
The humanities (art, music, literature, history, etc.)	44.4%
Athletics/sports	20.4%
Business/entrepreneurship	28.2%
Education/teaching	40.8%
Medicine/health sciences	19.9%
Other	12.3%
None	2.60%

While only 48% of students who completed the preliminary survey stated they would complete both course assessments, 77.4% (N =1,638) actually completed the R-SPQ-2F survey as well (0.7% response rate). For analysis and classification purposes of the R-SPQ-2F survey results, those students with a Deep Approach score greater than 35 (average 3.5 on methods and strategy questions = items true more than half the time) and a Surface Approach score less than 25 (items true less than half the time) were classified as learners who applied a primarily Deep Approach. The opposite is true for learners applying a primarily Surface Approach. Students with both a Deep and Surface Approach score greater than 35 were classified as Mixed. Students who scored below 25 on both were classified as using Neither Deep or Surface Approaches.

Shown below in Fig.1, 44.6% (731) of the 1638 students were classified as using a Deep Approach to learning, 54.5% (892) are not readily classifiable as using either Deep or Surface Approaches, so were designated Mixed, only 0.4% (7 students) would classify as using primarily Surface Approaches and 3.5% (58) used neither approach.

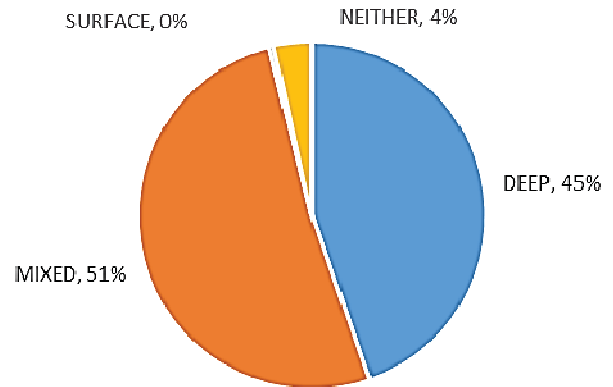


Fig. 1. Learning Approach Profile

Each Approach Scale has a total of 50 points that can be earned. To classify students in the subscales, we used a similar rating as with the approach scales. An average of 3.5 or higher on the subscale questions meant that the student used this more than half the time. These students were classified as using a Deep Method, Deep Strategy or a combination of both depending on their scores on these scales. For example, students who scored higher than a 3.5 on the Deep Method scale, but not the Deep Strategy scale were classified as using Deep Methods. Those students who averaged 3.5 or higher on both scales were classified as using both Deep Methods and Strategies.

An average of 2.5 or lower on the subscales meant that students used the method or strategy less than half the time. Students who scored in this group were classified as not using deep strategies or methods. Between these two groupings, greater than 2.5 average and less than a 3.5 average, students were classified as Mixed Deep which meant they used either Deep Methods and/or Strategies about half the time. An identical classification scheme was used to classify students according to the Surface Approach subscales.

Looking at the Deep subscales in Fig. 2, 71.2% (1166) strongly use deep methods and/or strategies. This total includes all those classified as deep learners (731) as well as 96.6% (435) of those students who use mixed learning approaches. An additional 24.4% (399) employ some deep method and/or strategies. Only 4.5% (73) use no deep methods or strategies. The Surface subscales, shown in Fig. 3, are almost a complete reflection of the Deep subscales. Fig. 3 shows that only 4.6% (75) use surface methods and/or strategies, while 69.1% (1132) use no surface methods or strategies and 26.3% (431) use mixed surface methods.

These results seem to imply that those student who are classified as Mixed Surface or Mixed Deep are truly using both equally. However, looking closer at the data, only 146 students (34%) are common to both groups. Therefore it seems that most of those classified as Mixed Surface or Mixed Deep are still more one than the other and we may need to update our classification scheme.

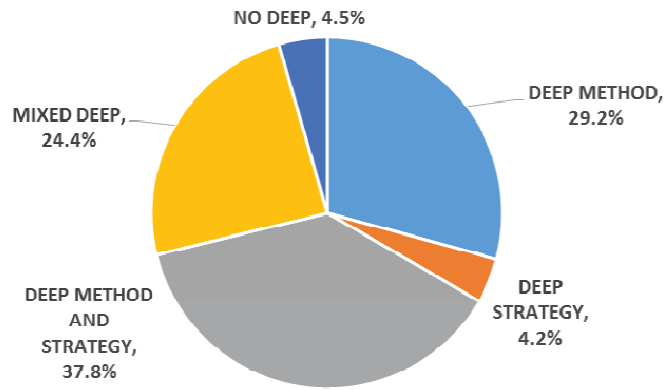


Fig. 2. Deep Approach Usage

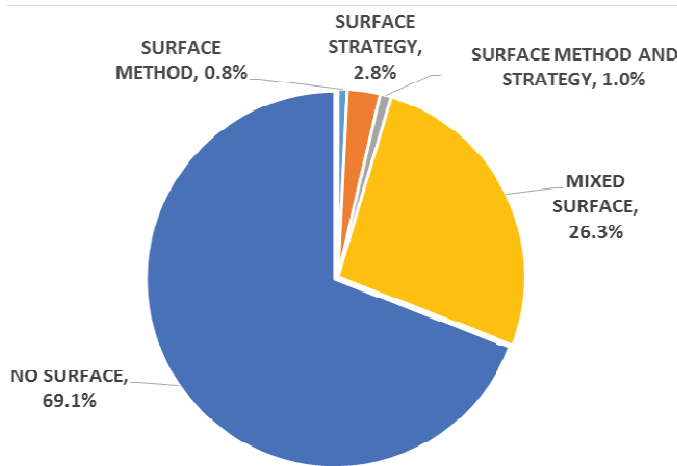


Fig. 3. Surface Approach Usage

One option available for those students who enroll in LHTL is to earn a course grade or certificate. In order to pass the course, a 70% average must be obtained. In order to earn a certificate, an 85% average must be earned. Looking at the entire set of data, only 5% of those students enrolled in the class passed the course (11,229), while only 1.8% (4,008) passed with distinction. A substantial group (81.5% or 182,088 students, did not take quizzes or earn a score in the class. Within our survey group, 22.7% (372) scored a passing grade in the class and 47.6% (177) were deep learners. 70.6% (1157) of students did not complete any graded work in the class.

Table III below shows the correlation between overall grade in LHTL and the overall scale and subscale scores for the R-SPQ-2F survey. As shown, only the Deep Method subscale seems to be a significant predictor of final course grade ($p < 0.05$). The Deep Approach approaches significance, but the other measures (Deep Strategy and Surface Approach, Method, and Strategy) do not appear to be significant predictors of success in this course. Although, as always with such a small sample size from this population it is difficult to draw meaningful conclusions.

TABLE III. CORRELATION OF LEARNING APPROACH WITH LHTL GRADE

Learning Approaches	Passing Score Correlation(p-value)	Distinction Score Correlation(p-value)
Deep Approach	0.047 (0.059)	0.048 (0.066)
Deep Method	0.063 (0.011) ^a	0.067 (0.009) ^b
Deep Strategy	0.023 (0.358)	0.021 (0.426)
Surface Approach	-0.034 (0.171)	-0.04 (0.118)
Surface Method	-0.037 (0.138)	-0.039 (0.134)
Surface Strategy	-0.026(0.300)	-0.035 (0.171)

^a Significant to $p < 0.05$

^b Significant to $p < 0.01$

IV. CONCLUSIONS AND FUTURE WORK

This paper investigated the different learning approaches used by students completing the Learning how to Learn (LHTL) MOOC offered through Coursera. While survey responses are low, they do offer an interesting snapshot of the students enrolled in this course. The majority of students are enrolled in this course to develop their personal and/or professional skill set. Course participation through assignments and discussion are low, however within the students that did participate in our survey, about half seem to be employing a Deep Approach to learning, while the majority of the remainder are using mixed methods in their learning approach. Very few students apply a purely Surface Approach to their learning. With regards to grades, it appears that very few students are completing the course for a grade, but of those that do, using a Deep Method for learning was significant predictor of student's success or final course grade in this measure.

In the future, the authors plan to investigate the learning approaches used by students in the LHTL course and the effect the course has on these approaches. Using a simple pre-post-test, we can get a better understanding of individual changes.

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Scaling Youth Development Training in IT Using an xMOOC Platform

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Abstract—The paper at hand evaluates the Massive Open Online Course (MOOC) *Spielend Programmieren Lernen (Playfully learning to program)*, an effort to scale the youth development program at the Hasso Plattner Institute (HPI) for a larger audience. The HPI has a strong tradition in attracting children and adolescents to take their first steps towards a career in IT at an early age. The *Schülerakademie*, the *Schülerkolleg*, the *Schülerklub*, and the support for the *CoderDojo* in Potsdam are some of the regular activities in this context to take youngsters by the hand and supply them with material and guidance in their mother tongue. With the emergence of MOOCs and the success of HPI's own MOOC Platform—openHPI—it was a natural step to develop a course to address an audience that is only marginally represented in openHPI's regular courses: school children and adolescents. A further novelty for openHPI in this course was the focus on teaching programming with a high percentage of obligatory hands-on tasks. Particularly for this course, a standalone tool allowing participants to write and evaluate code directly in the browser—without the need to install additional software—has been developed. We will compare this tool to a small selection of similar approaches on other platforms. As it will be shown, the course attracted a far more diverse audience than expected, and therefore, also needs to be seen in the context of spreading digital literacy amongst wider parts of society. In this context we also will discuss the significant differences in the usage of the forum between the course *Spielend Programmieren Lernen* and the course *In-Memory Databases*, a more traditional openHPI course.

Keywords—K-12; openHPI; Automated Assessment; E-Learning; Online Learning; Programming; Python; MOOC K-12; openHPI; Automated Assessment; E-Learning; Online Learning; Programming; Python; MOOC ;

I. INTRODUCTION

The Hasso Plattner Institute (HPI) in Potsdam, Germany is a university-level institute offering study programs in IT-Systems Engineering. Since its early days, youth development training has been a strong focus of the HPI. In order to raise IT-skills and interest of (junior-)high school students in programming subjects, the Hasso Plattner Institute has established the *Schülerakademie* (lit. "academy for pupils") offering various activities in this area. Part of these activities are organized by the *Schülerklub* ("pupils' club"). Bachelor and master students at the HPI are encouraged to participate in so called *Klubs*, which are self-organized by the students, alongside their regular studies, as a part of their socio-emphatical education

at the Institute. The *Schülerklub* is one of those. The members of this Klub are working with school children to raise the enthusiasm for computer science amongst this clientele. They organize events and activities for children and adolescents who are interested in getting first hand information about studying IT Systems Engineering at the HPI. These events include e.g. a summer camp of several days' duration for girls and boys from all over Germany and the HPI CodeNight. The HPI also sponsors third party events, such as the CoderDojo, with locations and support. The *Schülerkolleg* is a special program for school children from 7th to 12th grade, who are particularly interested in computer science and mathematics. For one year, every Tuesday afternoon, the participants of the program meet to experiment with new information technologies and their foundations. They are supported by faculty and students of the HPI as well as four teachers who are sent by the school authority of Brandenburg. Even though the HPI facilitates those numerous activities for high-school students, they are limited by given capacities, such as staff, room size, and number of available computers.

openHPI started in 2012 and, thereby, is one of the first platforms that transferred the idea of MOOCs to Europe and Germany. Run by the HPI, it has offered about 20 self produced courses on various ICT topics since September 2012—hosting between 5,000 and 17,000 enrolled users per course. Typical openHPI courses follow a classical xMOOC schema of a six-week course with several ungraded self-tests and one graded assignment per week. The courses are concluded with a final exam, which also is graded. For each of these graded assignments, the participants can achieve a certain amount of points. To be eligible for a graded record of achievement, a participant has to achieve at least 50% of the overall maximum course score [1]. In this specific course (Python2014), the setting was a little different as the focus was moved to hands-on exercises. The only way to gain grade relevant points was by solving practical programming exercises. Weekly assignments and a final exam have not been offered, ungraded self-tests were available, however.

A number of improvements on the platform enabled us to implement a new course model with a focus on hands-on tasks and practical exercises. A standalone tool has been developed that allows the participants to write, run, and evaluate Python code in the browser. The tool stores the submitted code for each user and automatically grades the submissions.

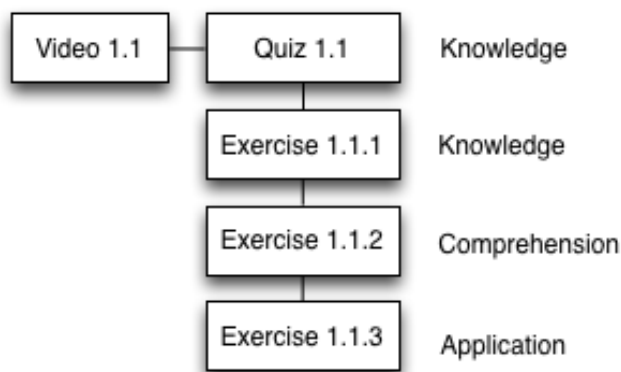


Fig. 1. Exemplary structure a *building block*. Each week contained four of these blocks following the same structure.

The remainder of the paper is structured as follows: The first section will give some information about the course itself and its participants. The second section will give more information about the programming tool, the experiences with it throughout the course, and how it has been connected to the openHPI platform. Furthermore, similar solutions offered on other MOOC platforms will be compared to our approach. The third section will deal with a non-technology-related scaling issue that has been encountered while the course was running: The participation in the forums and the usage of the help-desk, which was noticeably higher than in regular openHPI courses. The final sections will discuss some of the steps we are going to take next and conclude our findings.

II. COURSE STRUCTURE

To scale the HPI's activities in the area of youth development training, a prototypical MOOC to teach children and adolescents the basics of Python programming has been designed throughout summer 2014 and was realized on openHPI in October 2014. The 4-week course consisted of teaching videos, self-tests in quiz-format, and graded hands-on programming exercises. For each week, four videos were offered. Linked to each video were one ungraded self-test and three graded exercises in different levels of difficulty. According to Bloom's

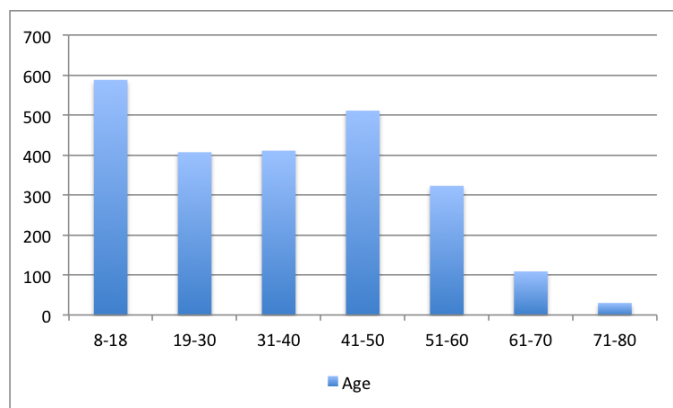


Fig. 2. Total user distribution (8-80).

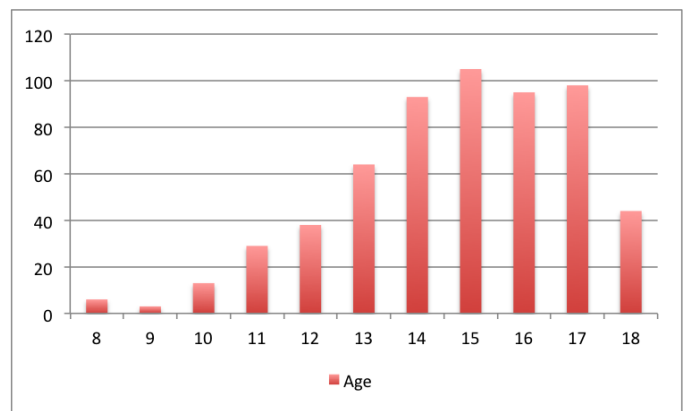


Fig. 3. User distribution of the actual target group (8-18).

taxonomy [2] the exercises can be classified in the categories: knowledge, comprehension, and application. Figure 1 shows such a building block—exemplary for the first video in week one. All others followed the same structure. The deadline for the graded exercises of each week was at 10:00pm(CEST) on the following week's Monday.

The course had about 7400 enrolled participants. The specified target group were children from the age of 11 to 17, but the course attracted users from a wider range of ages. Some parents enrolled in the course together with their children, also teachers enrolled with their classes. Additionally, the course attracted a vast variety of programming beginners of all ages. Many of them have expressed in the forum, that the promise of understanding basic computer programming, persuaded them to join this course. Figures 2 and 3 show the distribution of the participants age, as far as it is known. The participants are not obliged to enter their age—in the case of Python2014 we have this information for 2379 participants (32%). This course provided the users with a tool to write, run, and evaluate programs in the browser. From here on we will refer to this tool as WebPython. It was very well accepted amongst the participants. Table I shows some of the numbers in the context of user activity with regard to this tool. In the context of our regular courses, active participants are defined as those users, who have submitted at least one discussion post or one assignment [3]. In previous courses the percentage of active participants during the first week was about 40% (see e.g. [4]). In Python2014, due to the different setting, we defined an active participant as a user that at least has started one exercise in the respective week. According to this definition, Python2014 sported 68.73% of active users during the first week (derived from the number of registered users (Table III) and active users (Table I).)

	Users	Started	Submitted
Week 1	4961	51209	48764
Week 2	3696	37597	34115
Week 3	3078	28862	26118
Week 4	2392	23780	21725
RoA	2523	-	-

TABLE I. ACTIVE USERS, STARTED EXERCISES, AND EXERCISES WITH SUBMITTED (NOT NECESSARILY CORRECT) SOLUTIONS PER WEEK. THE LAST ROW SHOWS THE NUMBER OF ISSUED RECORDS OF ACHIEVEMENT.

	Total	Active
Average openHPI courses	18.3%	51.11%
Python2014	34.22%	50.86%

TABLE II. COMPLETION RATES IN RELATION TO THE TOTAL OF REGISTERED USERS AND THE NUMBER OF ACTIVE PARTICIPANTS DURING WEEK ONE

Figure 4 shows the decrease of the number of active participants over time. High dropout rates are a common issue that is shared by most MOOCs. Courses on openHPI have generally rather low dropout rates compared to other MOOCs [3]. To compare Python2014 to other courses on openHPI, we employed the same methodology as Meinel et al [3]. They observed the participants' engagement throughout the course and took the number of submitted homework assignments as measured value. The submission number for the first week's homework is taken as a reference (100%) [3]. In this course multiple submissions per participant and exercise were possible. We, therefore, normalized the number of submissions by counting only one submission per participant. We calculated the average value of the courses Meinel et al have listed and compared this average to the number of active participants in Python2014 based on their methodology. The dropout rates of Python2014 seem to be a little higher than in the average openHPI courses especially in week four (see Figure 5).

Comparing the completion rates of the average, regular openHPI course and Python2014 shows a different image: The completion rate in relation to those users that have been active in week one is almost the same as for the average openHPI course. The completion rate in relation to the total of registered users is even better (see Table II.) At the end of the course we also conducted a survey amongst the participants. The results of this survey indicate two explanations for this phenomenon:

- 1) A substantial amount of participants took the course with their school class, some of them not by choice. Teachers required a Record of Achievement to pass the class. So, as soon as those students had achieved 50% of the points, they quit.
- 2) The workload of the course was perceived as getting increasingly higher from week to week. More details will be discussed in one of the following sections.

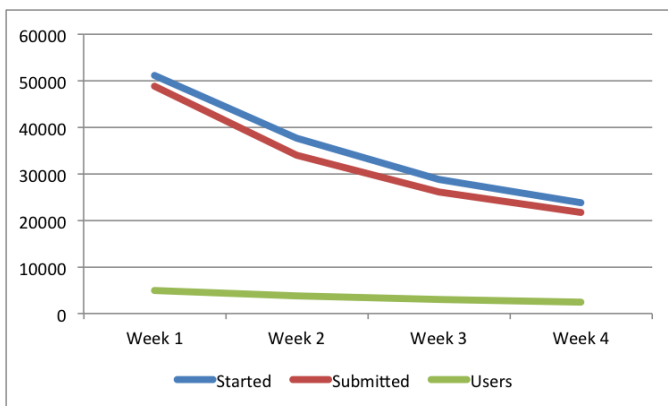


Fig. 4. Decrease of active participants from week one to week four.

III. SCALING THE TECHNOLOGY

As participants kept dropping in during week one, we decided to extend the deadline for the exercises of this week until the end of week two. During week two, we faced increasing load problems, culminating into a tightened version of another common problem that we are facing at openHPI: load peaks before deadlines. In this case the participants had to hand in the exercises for two weeks instead of one, additionally they did not have to hand-in simple multiple choice tests but running code. Particularly, in week two—the *loop* week—this caused technical problems, which forced us to extend the deadline for the first two weeks for another day until Tuesday. Figure 6 shows the load peaks on that particular Tuesday. At some point we had a CPU outage but could take measures to recover before the end of the deadline.

Figure 7 compares the number of started exercises, submitted solutions, and active users before and after the deadline of week three. The numbers on the left have been extracted a day before the exercises' deadline. The exercises were available

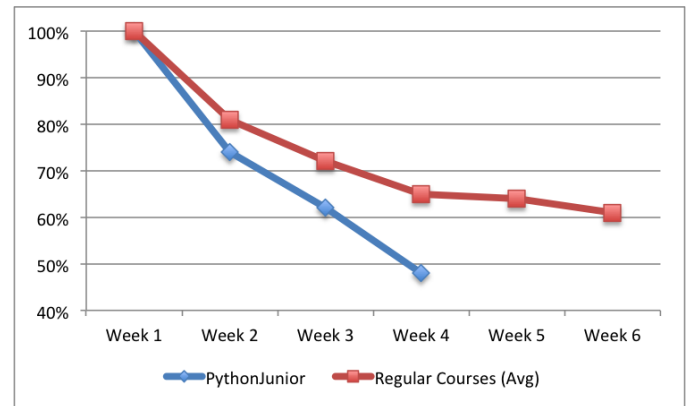


Fig. 5. Active participants in Python2014 compared to average openHPI courses.

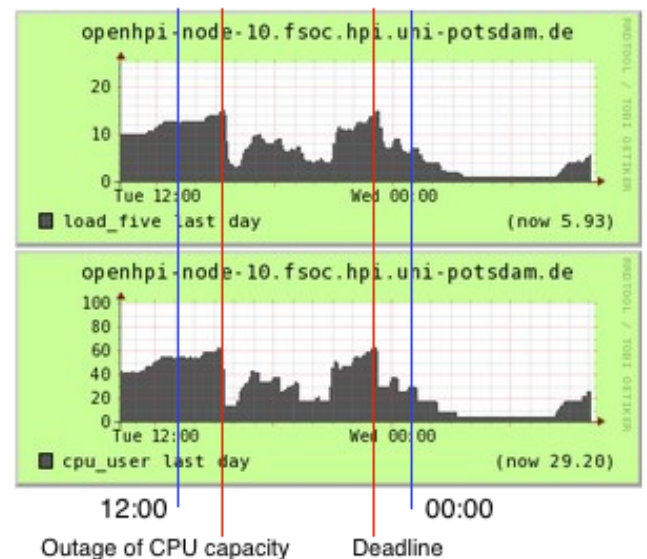


Fig. 6. CPU usage and load on a node shortly on the day of the deadline.

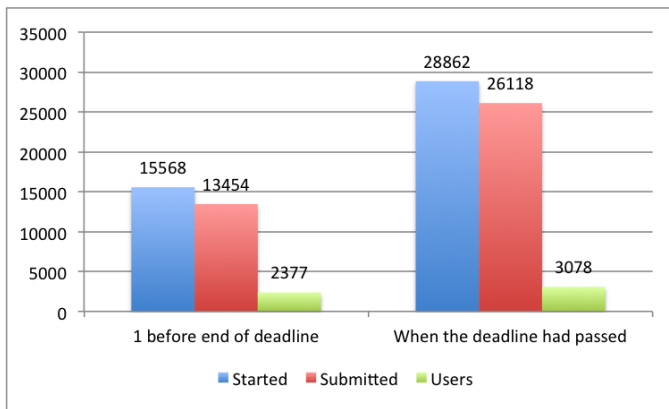


Fig. 7. Submission peak before deadline (week three, Python2014).

for exactly one week. During the remaining last day before the exercise's deadline the number of submissions almost doubled, which increased the load on the system remarkably. Unfortunately, we do not have these numbers for the first two weeks, but the trend would undoubtedly be the same there.

A. Python Programming Tool

The course objective was to teach programming with Python to people with no prior programming experience. As programming is learned primarily by exercise, we set a list of requirements for the infrastructure:

- There should be practical exercises along with the video teaching material.
- Participants should not be required to install additional software on their systems, to avoid hassle with broken software installations.
- There should be support for graphical output, following the turtle graphics programming model.
- There should be fully automated assessment of the programming exercises.

The second requirement resulted in the necessity to offer Python programming in the web browser. Our system features a web server that allows to edit Python source code in a programming editor, based on the CodeMirror¹ package. In

¹CodeMirror: <http://codemirror.net>

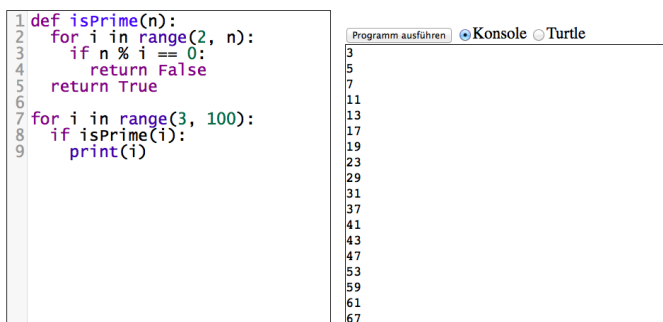


Fig. 8. WebPython in console mode.

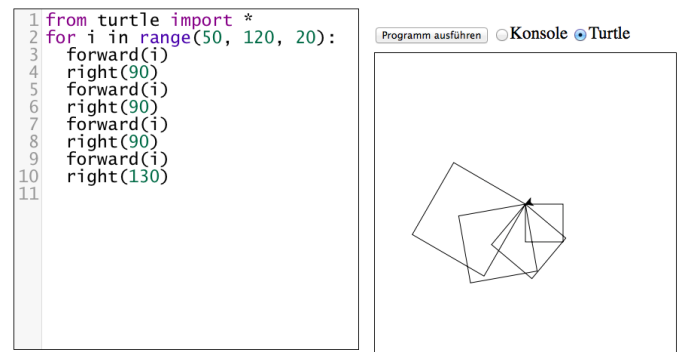


Fig. 9. WebPython in turtle mode.

order to test their programs, users can submit their source code to the server for execution and view the results in a console output window (see Figure 8). After completing the exercise, users can submit the code for assessment, resulting in a grade for the exercise. To allow for long-running Python processes that produce output in an ongoing manner, while also consuming user input of their own, a web socket connection is established between the web browser and the Python process.

As the course title and the target group suggest, we intend to attenuate prejudices against computer science amongst children. Therefore, we designed exercises with visual—and not only numerical or string—output. Turtle graphics [5] is a programming model developed by Seymour Papert in the 1970s, which targets this goal. Various projects have demonstrated its practicability in teaching programming to children (see e.g. [6] and [7]). Turtle graphics is a core part of the Python standard library and Python programming literature for children typically leverages this support [8] [9]. An exemplary output of a turtle script is shown in Figure 9.

Automated assessment of programming exercises is the most challenging aspect of this project, and previous work has demonstrated inherent limitations of automated assessment when compared to a human teacher's assessment [10]. On the other hand, automated assessment also has advantages over human assessment, such as instantaneous feedback, scalability to a large number of participants, and objectiveness.

We decided to allow participants to submit each exercise as often as they want, grading each attempt, and finally taking the best result into account. The assessment code is written in Python as well, running it, and then evaluating the output (not just the printed output, but also side effects on variables, function definitions, and other changes that were expected from running the program). In addition, for a few exercises, the source code was analyzed, primarily to determine whether the solution was using an undesired shortcut.

Running the Python script either for the user's testing purposes or for assessment requires a working Python implementation. For that purpose, several implementations of Python that allow to run code in the web browser itself are available. Unfortunately, none of them is production-ready in the sense that it provides sufficient compatibility with the *official* Python (aka CPython) installation. Therefore, we opted to provide a server-side installation of CPython.

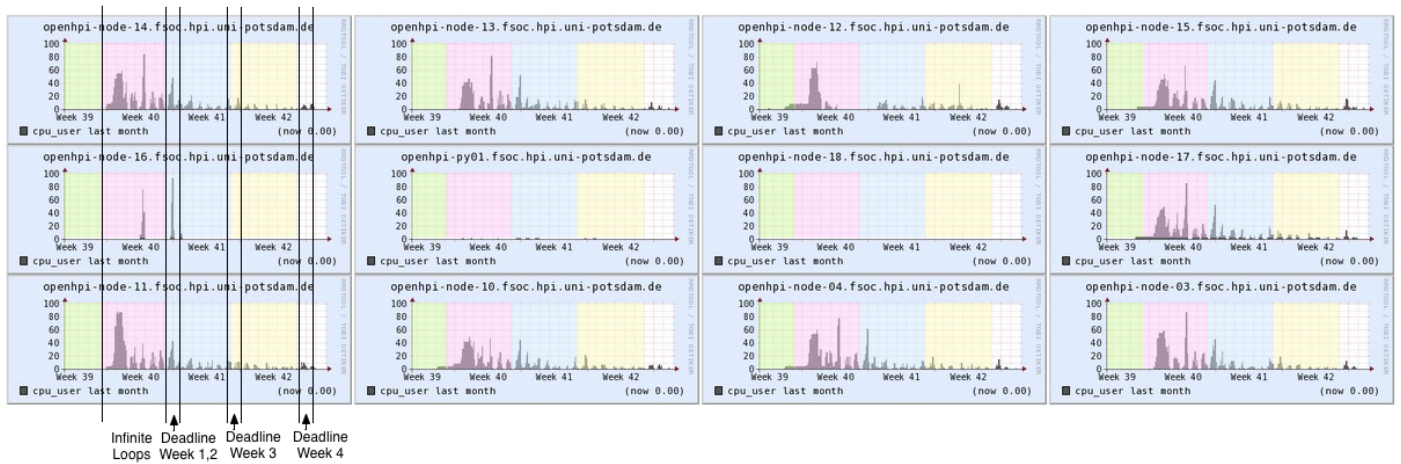


Fig. 10. Load on some of the nodes in our private cloud at the Future SOC Lab during the course. There are two nodes in the middle of the figure that have no or only very little load. The one on the left is the head-node that only runs the web-server. The one on the right did not want to join for unknown reasons.

B. FutureSOC

Providing a server-side CPython installation produces two challenges: first, it is necessary to provide sufficient CPU and memory resources to accommodate a large number of concurrent users. Second, the system must be protected against abuse and user mistakes.

To allow for a large number of participants, we set up a private cloud in the HPI's Future SOC Lab².

The Future SOC Lab is a cooperation of the HPI and a couple of industrial partners. It provides a complete infrastructure of state of the art hard- and software to researchers—free of charge—for a certain period of time. Python2014 was running in between two lab periods, and therefore, we had the chance to use some of its computing power. The code submission system consists of several server processes as shown in Figure 11. The head node runs the nginx web server, to provide for static files and TLS encryption. It delegates to a number of Python servers written with the Twisted framework³ which perform user authentication, templating of the exercise descriptions, and delegation to worker processes running on the cluster. Each node in the cluster runs a Twisted Python server, which in turn launches a Docker⁴ container that ultimately runs the Python process.

²<http://hpi.de/en/research/future-soc-lab.html>

³<https://twistedmatrix.com/trac/>

⁴<https://www.docker.com>

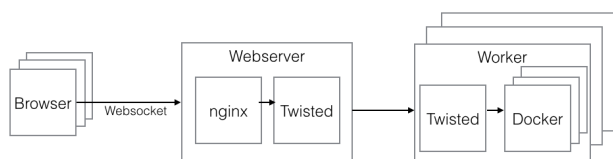


Fig. 11. WebPython's architecture.

The cloud consists of 18 machines in the HPI FutureSOC Lab infrastructure. Each machine has 24 CPU cores and 64GiB of memory.

As kind of a coarse-grained load balancing, we initially had set a limit of 10 processes to be run per core. This arbitrary limit caused a shortage on available process slots within week two, where we dealt with the concept of loops. As expected, several users created infinite loops by error, which blocked a process slot for the maximum allowed runtime of 10 minutes per process. This issue could luckily be solved by setting the limit to 50 processes per core, resulting in a more efficient scheduling, capable of enduring some infinite loops without running out of available process slots. We have not gotten any CPU or main memory outage since this increase. This overload situation can be seen in Figure 10 as the block of higher CPU usage in week two and the pike at the beginning of week three. Afterwards, only minor peaks show up—also due to decreasing numbers of active users—but no more longer lasting high load situations.

As expected and clearly visible in the peaks, most load always occurred close to the closing dates of the respective exercises. With regard to the different charts, it stands out that some nodes hardly show any load at all. Node 18 seemed to be simply broken, while node *py01* was responsible for rendering the web front-end of the python editor, which was a comparably simple task requiring only little CPU capacity.

The protection against abuse and mistakes is primarily achieved by using Linux containers, and the Docker infrastructure that builds on it. Users are isolated against each other and the system, and state is not persisted across program invocations. Docker also allows to limit the CPU share and memory that a process may consume. However, it currently does not provide sufficient support for setting a maximum process run time, which becomes necessary as programming beginners will inevitably write programs that perform endless loops. External monitoring is used to kill processes that exceed the maximum acceptable run time of 10 minutes.

IV. COMPARISON TO SIMILAR COURSES ON OTHER PLATFORMS

In this chapter, we provide a short description of similar courses. The selection is based on the following criteria: First, we only consider courses on MOOC platforms as most of the issues we are focussing on in this paper are to some extent specific for this format. Second, we focus on Python programming courses and third we focus on courses that claim to be addressing programming novices. Finally, we do not claim that the following list is exhaustive.

Programming for Everybody⁵—A first programming course, teaching Python, applies an open-source, web-based development environment⁶ for writing and assessing practical programming exercises. The tool is based on CodeMirror and Skulpt, an in-browser implementation of Python, providing client-side code execution. Since no request to the server is required, the tool's client-side code evaluation approach has the advantage of short response times. Infinite loops also turned out to be problematic, as they eventually rendered the browser window unresponsive. Affecting the client side only, at least they did not affect the performance of the tool for other users than those that caused the problem. Program errors are reported using native browser alert dialogs. Error messages are reduced to the essential. They neither contain a traceback nor provide additional clues to the error's origin. Whenever code is executed, it is also checked against the exercise specification. The programming tool performs automatic grading, based on I/O matching and basic invocation checks at runtime. The grading approach can only grant full score or zero points. Partial solutions, however, are not awarded. Besides auto-graded programming assignments, the course contains two optional peer-graded essays.

Intro to Computer Science⁷—An introductory Python course aiming to build a basic search engine. The course makes use of a lightweight web-based development tool, which is based on CodeMirror and seamlessly integrates into the Udacity platform. The editor is easy to operate, but it provides no means for editing more than one unit of code. Exercise instructions are provided as comments in the skeleton source code and sometimes in the form of a short introductory video. Learners can restart the exercise from scratch, execute their code for exploration, submit their code for evaluation, or view a sample solution, which is presented in a step-by-step fashion. During program execution, Python's standard traceback is presented in case of an occurring error, which might be too cryptic for beginners. During test execution, basic hints pointing to corrective actions are provided, however. The result of successful test-based code assessment is briefly presented in natural language, which benefits comprehensibility but lacks valuable details, such as expected and actual program behavior.

V. BETA-TESTING THE COURSE DESIGN FOR LEARNING ENVIRONMENTS AT SCALE

As a course of this kind was new terrain for all members of the teaching team, we conducted a beta test with six high-school students, who participated at one of the HPI's on-site

⁵<https://www.coursera.org/course/pythonlearn>

⁶<https://github.com/csev/tsugi>

⁷<https://www.udacity.com/course/cs101>

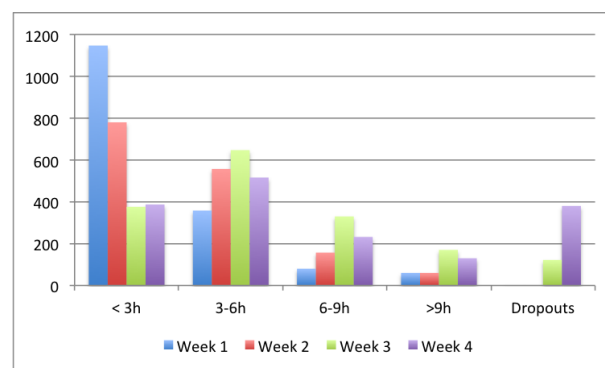


Fig. 12. Workload as perceived by the participants.

youth development activities. The main reason for this effort was to get a feeling about the necessary amount of time that participants would require to cover the workload. The pupils in the beta test were able to work through the exercises of week one in very short time. It took the fastest pupil about ten minutes the slowest had to invest about twenty minutes. Another test was conducted with first semester HPI students. While these students did not notice a higher workload for the following weeks, a survey at the end of the course, and some discussions in the forum, showed that the participants perceived this differently. While in weeks one and two the majority of the users stated that the workload was below three hours, in weeks three and four this shifted towards three to six or even six to nine hours with an increasing dropout rate. See also Figure 12. Therefore, we investigated if our analysis tool⁸ would also reveal that the time that the users have spent on openHPI has increased, which was not the case. See Figure 13. Instead, we can see again the recurring pattern of activity peaks shortly before approaching deadlines.

VI. SCALING THE SUPPORT

At openHPI, the user forum is an important part of scaling the support for the users. The help-desk, openHPI's one-to-one support tool, turns out to be overwhelming the teaching teams, particularly in hands-on courses on beginner's level. Many participants do not realize that personal support is not manageable for a small team facing the massive amount of users. Too often requests cannot be answered during the runtime of a course. Monitoring the forum alone and providing appropriate support is often already taking the teaching teams to their limits. In general, our teaching teams consist of the professor, four to eight research assistants, and one or two

⁸Piwik: <http://piwik.org/>

Returning Visits

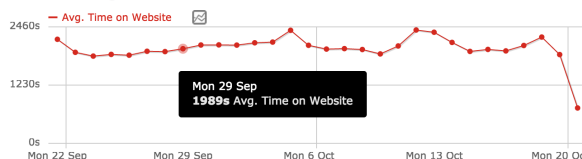


Fig. 13. Average session length during the course.

No. of	Python2014	IMDB2014
Users total	7373	8641
Users active (avg)	about 3700	1191
Users(Q)	700	139
Users(A)	670	56
Users(C)	770	104
Questions	1404 (0.19/2.01)	219 (0.03/1.57)
Answers	2178 (0.30/3.25)	203 (0.02/3.63)
Comments	3571 (0.48/4.64)	385 (0.04/3.70)

TABLE III. COMPARISON OF FORUM AND HELP-DESK USAGE BETWEEN PYTHON2014 AND IN-MEMORY DATA-MANAGEMENT (IMDB2014)—TWO PARALLEL COURSES ON OPENHPI. USERS(Q,A,C): AMOUNT OF USERS THAT POSTED A QUESTION, ANSWER, OR COMMENT. THE NUMBER IN BRACKETS SHOW THE AVERAGE AMOUNT OF POSTS PER USERS TOTAL/POSTING USERS.

students. Participants are encouraged to support each other in the forums. The teaching team only intervenes if discussions get rough, or go down the wrong track. In Python2014 it could be observed that this style of offering support to the course participants has worked very well. Naturally, as the course had way more participants than the on-site youth development activities at HPI, an increased demand for support had already been expected. The factor, however, by which the forum usage of Python2014 has increased in comparison to other openHPI courses really came surprising. Table III compares the forum activity of Python2014 to a IMDB2014, a regular openHPI course that was conducted in parallel. The numbers in brackets show the average amount of forum posts per total participants and the average amount of forum posts per users that actually have posted a question, answer, or comment in the forum.

The forum usage in Python2014 was significantly higher compared to other openHPI courses (exemplary IMDB2014). The average number of questions per participant was six times higher in Python2014, the average amount of answers was even more than fifteen times as much. The amount of comments was about twelve times higher in Python2014. The majority of the questions were about problems with the programming exercises. Often, the participants started with a complaint about the automatic grader while asking for help. Having received an answer enabled them to finally solve their problem. Common complaints were about tests being too restrictive, e.g. being case sensitive.

We came up with a couple of hypotheses for this significant difference between the two courses.

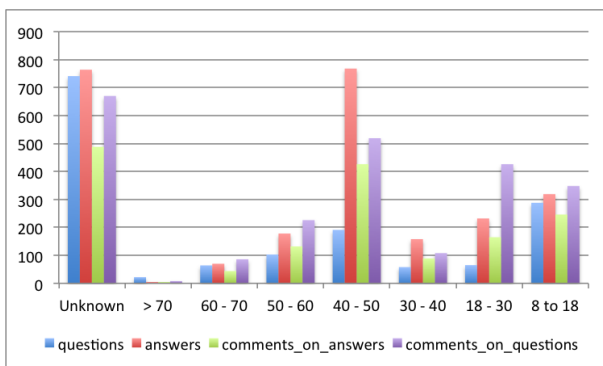


Fig. 14. Age of the participants who were active in the forum

- 1) The age of the participants: Python2014 sported a high percentage of very young participants. Younger users are more used to expose themselves on the internet and therefore have less problems to publicly post in a forum.
- 2) More posts due to "misusage" of the forum, such as duplicated questions due to a "post first, search for similar topics later (or never)" tactic by the less experienced participants, fun posts or irrelevant posts, and user to user communication via the forums.
- 3) Optimized forum usage by the more experienced users of IMDB2014.
- 4) The professional level and background in IT of the participants: IMDB2014 participants are at a higher level of their career and, therefore, have the notion that they have more to lose when they show the gaps in their knowledge by posting.
- 5) The language barrier: Python2014 participants were mostly German native speakers, while IMDB2014 participants come from all over the world.
- 6) The possible benefit that could be achieved by actively taking part in the forums was much higher in Python2014 as graded homework could be done over and over again. Asking for help in the forum was likely to improve the grade. Due to the short and strict time limits for graded assignments in IMDB2014, in this course, it was rather unlikely to find direct help in the forum.
- 7) As the course itself afforded more active participation, the threshold to actively participate in the forums was less high.
- 8) The forum was identified as the second most important learning material, next to the course videos, in the survey at the end of the course. Way in front of books, even relegating the internet to the third position.

We tried to find indicators for these hypotheses in our data. Table IV gives an overview about the socio-demographic

	Python2014	IMDB2014
Background IT		
Beginner	43.8%	14.7%
Advanced	58.7%	49.8%
Expert	18.7%	35.5%
Professional life		
None / not set	81.6 %	61.6%
Up to 5 years	4.7%	10.4%
Up to 10 years	2.9%	8.5%
More than 10 years	10.9%	19.5%
Highest degree		
High school	23.4%	10.4%
Bachelor, Diplom, Master	42.7%	76.0%
PhD	3.7%	4.9%
other	30.1%	8.7%
Gender		
Male	77.2%	87.5%
Female	22.8%	12.5%
Country		
Native German	96.2%	48.8%
Native English	0.8%	14.2%
India	0.3%	14.9%
Other	2.7%	22.1%

TABLE IV. SOCIODEMOGRAPHIC COURSE DATA.

data of the course participants in comparison to a regular course on openHPI. As mentioned before in the context of the participants' age distribution, we only have this data available for those participants who voluntarily entered this information in their profile page (25.6% in Python2014 and 41% in IMDB2014). Generally, those users, which have a longer relation to the platform and have taken more than one course (and, therefore, are not in the actual target group of this course) are more likely to have completed their profile. So the actual circumstances might be a little distorted. Figure 14 shows the age distribution of the active participants in the forum. Most of the posts are from users that have not completed their profile information. Where we have this information, it seems to be the 40 - 50 year olds who were most active. There were some patterns that we observed amongst the younger participants. For instance, we can say that some inappropriate posts that had to be removed, were definitely written by younger participants. After deleting the threads we wrote to the culprits in private and asked them to stop such behavior. They apologized and the number of this kind of posts was reduced remarkably. Technical or performance problems at peak hours generated a lot of forum posts. We could observe, that especially among younger and not as experienced online-learners, the forum mirrored frustrations over-exceptionally. Discussions in IMDB2014 mainly revolved around three topics: general questions and comments concerning the content, seeking for clarification if the participants understood it correct, in-depth questions on applying the presented principles on real-world problems and organizational questions concerning the course. Since technical issues were mainly targeted towards the helpdesk, and organizational questions accounted for only the minority of threads, most discussions were content oriented. The fact that the in-depth questions usually were too specific to be answered by fellow students, such threads typically ended up in a 3-5 post status, with one post asking the question, a teaching team member answering it and the original poster either saying thank you or asking for further clarification of a certain detail and then thanking the team member. Comparing the numbers per active or posting user, the gap becomes noticeable smaller. While the participants of IMDB2014 in average were less likely to be active in the forum, those who did participate did not show a different communication pattern than the participants of Python2014.

A potential reason for the, generally, more reluctant behavior within IMDB2014 is the fact that substantial parts of the audience did not have English as their mother tongue and, therefore, felt uneasy to pose questions potentially exposing them in front of other adults or even professionals and colleagues. Matching our hypotheses to the data presented in Table IV, it becomes apparent that the language hurdle is most likely to be the main reason for the lower post count within IMDB2014. Above 85% of the participants were non native speakers with regard to the course language. Also the second hypothesis, taking the professional career into account, is backed by the data. While the majority of users did not answer this question at all, the fraction of participants with higher progress in their career in IMDB2014 is about twice as high as the corresponding one in Python2014.

VII. FUTURE WORK

Coming up next on openHPI is another hands-on programming tool that will allow to set up courses in a wider variety of programming languages. This tool also allows to define test cases for these languages—in the language's native testing framework, e.g., RSpec for Ruby, JUnit for Java, etc. Courses, such as Python2014 require additional forum support and monitoring. A possible solution might be to involve experienced and active participants. In an earlier survey we had very encouraging results from users that would be willing to mentor in future iterations of a course [11]. Making these people recognizable as mentors could ease the high demand for individual support. Already during the registration phase of Python2014 an opportunity to scale the support for participants in future iterations of this kind of courses evolved. We received many requests from teachers who intended to use the course in a flipped classroom setting and asked if the platform supports mechanisms to enroll whole classes or to monitor the results of the students in their class. Enabling teachers to give optimal support for their pupils seems to be a promising way to relieve openHPI's teaching teams from at least a part of their workload. For this use case enabling teachers to create learning groups, supervise their students within the group, and being able to check their results will be very helpful for both sides. A very important step is to enable users to go on from where they are when the course has ended. Particularly, it is important to enable the users to step forward from the restricted learning environment that has been employed during the course to a more self-determined way of coding. Therefore, we plan to enhance our next programming course with a supplementary course introducing the participants to the world of compilers, interpreters, and IDEs.

VIII. CONCLUSION

The MOOC format certainly offers a valuable means to scale the youth development efforts of an institution such as the HPI. Offering MOOCs for a very young audience—or more general for novices—however comes along with a couple of challenges. Particularly, a significantly increased amount of support needs to be taken into account when planning the human resources for such courses. Despite several technical hiccups at the beginning of the course, we conclude that the course can be considered as successful. It was well received by the participants and had a comparably very high rate of user participation. In the survey at the end of the course, 84.33% of the users stated that they would recommend the course to other people, and 71.10% asked for a sequel of the course. The age distribution turned out to be more widespread than we had intended. Concerns that this could turn out to be problematic did not come true, rather quite the opposite was observed. Participants of all ages worked very well together and supported each other. Particularly, programming courses at a beginner's level should support a tool that liberates the participants from having to install a programming environment of their own to ease the initial pain. Towards the end of the course, the participants need to be introduced to more powerful tools, however, to enable them to transfer the knowledge they gained to real life challenges.

IX. ACKNOWLEDGMENTS

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From Flipped Classroom Theory to the personalized design of learning experiences in MOOCs

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Abstract — The frequent advances in Information and Communication Technologies (ICTs) represent an opportunity to rethink teaching and learning in the context of virtual education. In this perspective, MOOCs (Massive Open Online Courses) have been promoting research in the technological and educational areas, since they serve as an emerging and powerful knowledge-building platform for anyone, anytime and anywhere. However, limitations in the current development of MOOCs have required the search for strategies to support their personalization in order to enhance the users' learning and others skills, such as the ability to self-regulate and to work in a collaborative way, and not just to replicate the content already taught in the traditional classroom, through videos or other passive learning activities. Considering the need for changes in the MOOC's pedagogical model, this research aimed to investigate and promote a reflection about the possibility of using Flipped Classroom Teaching Model principles to design this type of virtual and massive environment. The paper starts with a description of MOOCs, Flipped Classroom and some related works used to support personalized learning in MOOCs. As a result of this investigation, we present some conceptual strategies for educators to design MOOCs from FC ideas and principles. We envisage that adaptation and incorporation of concepts of Flipped Classroom, already applied in face-to-face classroom, can also act as an effective intervention to support personalized learning in MOOCs, helping students to take the active role in their own process acquisition of skills and knowledge construction.

Keywords—Massive Open Online Courses (MOOCs); Flipped Classroom; Personalization; Learning Design.

I. INTRODUCTION AND MOTIVATION

The adoption of Information and Communication Technologies (ICTs) has been highlighted as an important mechanism for improving the quality and learning effectiveness. Among the benefits pointed out, ICTs can also contribute to make students more creative, motivated and

critical, capable of solving problems in a more autonomous and, at the same time, in a collaborative way.

However, there is still little evidence if the isolated use of computational technologies can really change educational practices [3]. Actually, effective learning occurs when computational technologies and teaching methods are applied in an integrated manner, contributing to student's knowledge construction process.

Considering this perspective, some research studies in the Computers and Education field have suggested MOOCs (Massive Open Online Courses) and Flipped Classroom as new trends in order to better achieve the requirements and outcomes of the emerging learning scenarios [5].

MOOCs are characterized as online courses, with unlimited participation of students and open access (e.g., Coursera, edX, Veduca). Although promising, most of the MOOCs produced are still based on traditional classroom formats. Furthermore, the number of students that successfully finish a MOOC is very small, motivating the research for alternative pedagogical designs to deal with the dropout rates.

Flipped Classroom Model [4], in turn, is an inverted version of the traditional learning model. Basically, there is an inversion between in-class and out-of-class activities: firstly, students learn new content by reading texts or watching videos wherever they are, and whenever they want; and then, exercises, group activities, and other active learning strategies are performed in the classroom with instructor mentoring.

Some people are using MOOCs to support out-class Flipped Classroom activities. However, despite of the works already done [31, 33], there is a need for research on mechanisms to support the integrated adoption of these strategies in virtual learning contexts, providing the necessary support for educators to manage their classrooms and for students to develop autonomy and creative skills.

Considering this context, this work fits in this new perspective, investigating how Flipped Classroom ideas can be used as an approach to create personalized learning experiences in MOOCs, in order to achieve initial findings to support an answer for the following research question:

“How the Flipped Classroom teaching model can be incorporated into the MOOCs project in order to contribute to the learning and student’s engagement?”

In a general way, three main factors motivate our research: i) the current model of MOOCs, which basically replicates the traditional classroom; ii) the low completion rates for MOOCs, particularly due to the lack of motivation and student’s engagement; and iii) the large amount of information produced by the interaction among MOOCs and their users. Considering these issues, we propose a preliminary approach based on Flipped Classroom which can be used as an intervention in MOOC project.

This paper is organized as follow: Section II provides information about other projects we have used as motivation to develop the current idea. In Section III, we present some conceptual strategies to be used by educators to describe and design MOOCs from FC ideas and principles. Finally, section IV shows the discussions and future works.

II. THEORETICAL FRAMEWORK

The theoretical framework for this study draws upon three groups of investigations connected by the perspective of learning: i) MOOCs, pedagogical design and its limitations; ii) Flipped Classroom teaching Model, its origin, meaning, characteristics and some experiences on its application in the context of face-to-face classroom; and iii) current personalization approaches in MOOCs. Together, they provide insights to explain an initial conceptual framework for educators to describe and design MOOCs based on Flipped Classroom fundamentals and related theories.

A. Massive Open Online Courses (MOOCs)

As previously discussed, MOOCs have emerged as an important mechanism for democratizing the access to education. In general, the massive and open distribution of learning resources and materials contributes to the dissemination of knowledge and facilitates access to information, benefiting society as a whole.

Nevertheless, despite the enthusiasm raised by MOOCs, there is also much skepticism. In fact, several problems should be addressed to incorporate MOOC as part of formal education [6, 7].

One of the most important challenges in the first generation of MOOCs is how to ensure a minimum participation, avoiding the (relatively) high dropout rates throughout the course [8, 9, and 10]. In general, the dropouts are associated with difficulties in the required autonomy level, the ability to deal with the adopted technological environment and the lack of physical presence of teachers and peers, among others.

Although extremely promising, current MOOCs still reflect traditional class formats with few personalization features and adaptation to their users. For Blanco et al. [11], personalization and content adaptation, assessment and learning strategies, considering the diversity of the audience are gaps that require investigation by researchers.

As highlighted in Guàrdia, Maina and Bleeds [12], the need for the development of new pedagogical approaches that are able to provide consistent support on how should be designed the personalized teaching and learning strategies for this emerging educational setting must be greater than the debate about technological, economic and MOOCs’ institutional aspects.

In general, the presented limitations motivate the search for new ways of understanding the construction of knowledge in virtual learning environments on a large scale. This, in turn, triggers challenges in order to design educational experiences, demanding innovative and appropriate teaching and learning approaches.

B. Support for Personalized Learning in MOOCs

Personalization in learning environments is crucial to the learning of each student being effective, especially in informal education, which requires motivation, determination and users’ self-control [13].

Krafcik, Santos and Apothecary [13] also argue that personalization approaches can be built from different perspectives and applied in various educational contexts, such as face-to-face classroom or virtual environments, formal or informal education, among others.

Personalization in virtual learning environments has been developed for years, and has been evolving as new technological and pedagogical innovations appear. In addition, there is no unique, formal and widely accepted definition. Essalmi et al. [14], for example, highlight some basic principles commonly used in the literature about personalization in e-learning systems, such as personalization parameters, personalization strategies, combining operators, learning scenarios and learning objects.

In this work, the personalization idea is based on Blom [15], which defines it as a process that can change the functionality, user interface, content or the distinctiveness of a system in order to increase its relevance in favor of a certain individual.

Considering these issues, investigations about MOOCs and personalization aspects are still limited. In general, the first generation of MOOCs uses the same content, activities and assessments for all students, ignoring the diversity of learning styles, academic background, learning objectives and cultural/social aspects.

The following strategies change, according to the definition identified above, functional, interface, content, or mainly, the distinctive character of the virtual learning environment. They try to leverage many personal aspects, such as motivation, engagement, self-regulation, effective learning, and

collaboration, among others. In addition, such related works investigated the incorporation of theoretical aspects of collaborative learning, game elements or social aspects in the design of virtual learning environments, including MOOCs.

1) Collaborative Learning

Ronaghi, Saberi and Trumbore [16] presented the MOOC provider called NovoEd¹. His instructional model is supported by many learning theories, such as project-based learning, team-based learning, collaborative learning and social aspects. It is, therefore, a user-centered online environment that attempts to promote the engagement of students, i.e., the focus is not on the content delivery, but on the student's learning. NovoEd supports two types of formation teams: algorithmic and organic. Algorithmic teams are formed automatically, based on criteria defined by instructors. In organic teams, students form their own groups. The Figure 1 highlights the main page of a MOOC available in NovoEd provider. It is aimed at people who have access to a face-to-face classroom where science content and scientific reading are being taught. The MOOC users, which are teachers in the face-to-face class, must complete a series of tasks, such as watching videos, performing tasks embedded in videos, participating in discussion forums, reading research articles and engaging in activities in the classroom where it operates (practical project).

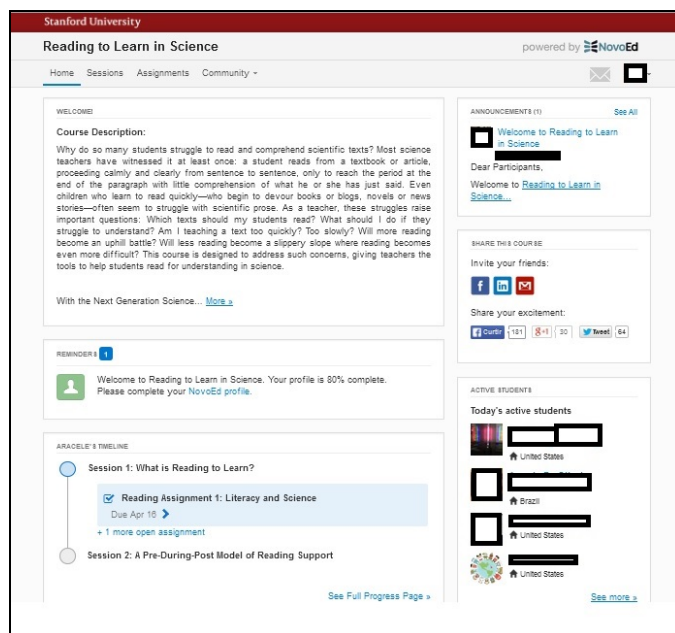


Figure 1 - MOOC “Reading to Learn in Science”, available in NovoEd.

In another strategy, Collazos, Gonzalez and Garcia [17] argue that MOOCs can be understood as an extension of existing online learning approaches, but they also offer an opportunity to think about new models of open online education. Thus, the authors analyzed as collaborative elements should be incorporated into MOOCs, in order to increase students' interest in content related learning. They proposed an

open online course model that integrates collaborative aspects content, activities and assessments, considering the elements highlighted in Figure 2. Teachers are responsible for generate and build contents and activities, but using a collaborative environment. A technology platform supports teachers in the development of collaborative learning activities, defining which task should be performed in order to achieve the rapid and real collaboration among the participants. However, the model has not been validated, and therefore does not measure the level of learning acquired during the collaborative activities.

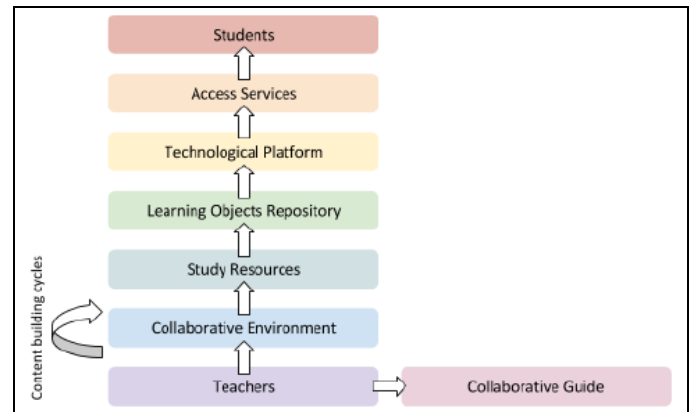


Figure 2 – Collaborative MOOCs supported by a computer model (Collazos, Gonzalez and Garcia [17])

2) Gamification

The addition of game elements in environments that are not related to games, that is, gamification has been used in the design of virtual learning environments in order to enhance some student's personal aspects, such as motivation and engagement.

Considering the high dropout rates in MOOCs, Gené, Núñez and Blanco [18] proposed a model based on gamification to promote students' intrinsic motivation. The model includes an additional layer to MOOC projects, based on game theory and collaborative aspects. This layer includes various elements such as distribution points and ranking, volunteer activities, promote cooperation among peers, information about student' progress, among others.

Additionally, Vaibhav and Gupta [19] conducted an experiment to compare the results obtained from a traditional virtual learning environment and another based on gamification ideas. These results indicated that if the learning platform is based on gamification, not just the subscriber's numbers increase, but also the involvement of users throughout the course.

3) Social Aspects and User Profile

According to Nawrot and Doucet [20], MOOC's platforms, their pedagogical paradigms and business models are still in the early stages of development. This situation and possible connection with low completion rates require different and

¹ <http://novoed.com/>

adapted directions for the construction and use of MOOCs. After investigating the causes of evasion, their results indicated that one of the main motivations and meanings of abandonment is related to bad time management. They presented features that can be incorporated into MOOCs platforms to allow users to optimize their learning process, increasing engagement and reducing the dropout rate. In general, these characteristics should support the prioritization of activities, the development of strategies to achieve the learning objectives, time allocation and schedule. They should provide the user with action plans; activities of driving suggestion, with its priorities and time allocation based on users profile; reports on overall progress in the course, among others. However, the effectiveness of the proposed solutions has not been tested empirically. It is therefore recommendations for MOOCs developers.

Nkuyubwatsi [21] investigated strategies to achieve or incorporate cultural and recontextualization aspects in MOOCs. Using an observation protocol focused on cultural issues, data were collected from videos, quizzes, surveys, discussion forums and five MOOCs descriptions available on Coursera provider. The main practices identified were: i) the translation of courses for certain languages and ii) the creation of local or geographic groups (virtual or face-to-face) to conduct collaborative activities. A small number of MOOCs incorporated activities and projects to encourage students to reflect on the application of the concepts studied in their own environment or work space. The authors consider that project-based activities are important and should be used as a strategy to allow students from different cultures to adjust their learning to their reality of life or work, since they received the opportunity to choose the project theme and which individuals will profit from the implementation of this project. MOOCs designers can use these achieved theoretical results to reflect and build customized interventions to promote diverse and multicultural experiences in MOOCs.

So, developing a personalized learning is one of the most important challenges of the twenty-first century, according to Perry et al. [22]. It is focused on student's success and try to develop in them various skills such as creativity, innovation, critical thinking, problem solving, communication and collaboration. In general, any personalization strategy should consider differing personal characteristics to achieve these skills. The customization in large-scale virtual learning environments must therefore consider different characteristics of learning, such as learning styles, academic background, learning goals, and different social, economic, cultural and media types used by the students.

As the technological evolution happens, different personalization strategies in virtual learning environments appear. In this section were highlighted some studies which incorporate the use of basic fundamentals of collaborative learning theory, games, time management, cultural issues and recontextualization as an intervention in the MOOC pedagogical design. However, these are recent strategies and more investigation about the positive and negative aspects of each of them still need to be performed by the scientific community.

The strategy instigated in this work is based on practices of Flipped Classroom Model already used and investigated in face-to-face classroom teaching. The idea aims at investigating how the principles of Flipped Classroom can be used/adapted to achieve the personalization requirements for MOOCs. The main Flipped Classroom fundamentals are discussed next.

C. Flipped Classroom

Concerns about education reform to provide appropriate subsidies for students to acquire the needed skills for the twenty-first century suggest the adoption of ICTs as an important perspective to improve the quality of education and the search for an effective learning. That is, learning mediated by technologies can significantly contribute to the formation of students more creative, innovative, critical and able to solve problems independently, but in a collaborative way.

Durall et al. [23] investigated the use of emerging technologies to predict their impact on the Latin American context. They compiled a list of pedagogical trends that comprise the main impulsion of technology adoption in Ibero-American education between 2012 and 2017. As stated by the authors, the Flipped Classroom (FC) is the new paradigm of modern pedagogy for both secondary and higher education.

Considering the FC origin, it is likely that this teaching model has been adopted at other times or circumstances, but was not widely used and disclosed in the academic and scientific community [26].

In addition, FC became a popular term [24], mainly from the year 2012. This fact was motivated, in general, from reports about trends in education [23] and by the increased academic interest, noticed by the amount of scientific publications and events that have discussed this subject [25].

With the evolution of mobile devices and the communication media types, since 2012 Bergmann and Sams [4] are constantly referenced in scientific papers of the area as those who popularized the concept of Flipped Classroom. The definition of FC in Bergmann and Sams [4] and Lage et al. [27] establishes the "inversion" of the classroom as the conversion of events that traditionally occur inside the classroom to events that occur outside the classroom and vice versa.

Regarding the concept of FC, according to Bishop and Verleger [25] there is no consensus on a formal and widely accepted definition of Flipped Classroom by the community and, to Bachnak and Maldonado [28] there is no single strategy to apply it.

On the other hand, Bishop and Verleger [25] also argue that such simplistic definitions, in general, can suggest that the Flipped Classroom model is only a re-ordering of the classroom and the activities that are carried out elsewhere. However, as can also be identified in Keengwe [29], FC represents an expansion of the curriculum, rather than a mere re-ordering of activities.

For example, according to Galway [30], the Flipped Classroom model can represents a broader shift in how we think about the learning process. It is based on several theories

about learning and pedagogy. An explicit attention is given to interactive and collaborative learning, based on Piaget's active learning theory, which emphasizes that learning occurs when we act and apply in practice new ideas and learned theoretical concepts.

Galway et al. [30] also points out that, taking into account the influence of (Revised) Bloom's Taxonomy about thinking and learning, the inverted classroom model allows high and low levels of cognitive work. Specifically, students take a lower-order cognitive work, i.e. the acquisition of knowledge, independently and outside of class form; while the higher-order cognitive work, including the application of knowledge, analysis and synthesis, occurs during the class time, with the support of class friends and teachers.

In addition, Flipped Classroom helps instructors or teachers to develop different learning experiences appropriate for each student, considering their regional or local context [4].

The Table 1 highlights some approaches used to achieve the classroom inversion, based on FC general ideas. The main strategies adopted in and out of the classroom, and the main forms of assessment are presented.

TABLE 1 - EXAMPLE OF FLIPPED CLASSROOM EXPERIENCES

Ref	Subject	Out-class activities	In-class activities	Evaluation
30	Master of Public Health	-MOOC -Quizzes	-Short-classes -Active Learning activities -Talks between students-teacher	-Final text -Diary -Online participation -Final project in groups
31	Undergraduate Health. Department of Basic Pharmacy.	-Textbooks -Videos -Virtual Learning Environment Sakai	-Revision Questions -Pairs activities -Discussion mediated by two students. -Quizzes -Short-classes	-Tests -Quizzes -Projects -Engagement
32	Undergraduate Software Engineering. Discipline Introduction to Scrum Methodology.	-Videos (YouTube) -Resolution of some issues before going to class time.	- Group activities - clarification of doubts	- Formative evaluation - Group talks - Summative evaluation
33	Graduation of Teacher Training.	-Sophia Learning Platform -Quizzes -Learning objects interaction	- Project-based learning activities	-Diagnostic evaluation - Sophia learning participation - Project

These and other analyzed works suggest that FC can improve the student's learning and their problem solving skills. FC can also promote engagement and motivation to learn.

Consider and analyze such experiences may be relevant to think over a Flipped Classroom application approach MOOCs project, issue highlighted in this work.

The review also provided a set of findings: i) students can learn at your own pace; ii) the curriculum can be customized; iii) the time in the classroom can be used in an efficiently and creatively way; iv) there is evidence that such model contributes to increase the students levels of interest, engagement and achievement; v) the model supports new strategies and teaching and learning approaches; vi) among others.

This findings were used to support conceptual ideas described in the next section, which can be useful for educators to describe and design MOOCs from FC principles.

III. IDEAS TO ADAPT AND INCORPORATE CONCEPTS OF FLIPPED CLASSROOM IN MOOCs DESIGN

This work argues about the possibility to adapt and incorporate concepts and principles of Flipped Classroom as an intervention in MOOCs design.

Initially, Honeycutt and Glory [34] presented in their blog a reflection about Flipped Classroom model to design more interactive and personalized online learning experiences for virtual learning environments, in general. They suggest that the course project proposal could be planned considering the Flipped Classroom ideas in order to develop learning experiences needed to engage students in theoretical activities or application of concepts, with focus on expected learning outcomes for the related course context.

Based on this first reflection, we present some more explored ideas and new initial strategies to incorporate concepts of Flipped Classroom in MOOC project. The first two descriptions were presented from the perspective of Learning Design (LD). The others could follow the same perspective, but were presented using text model, for reasons of space.

Learning Design (LD) is an approach that aims to support the explicit design of course learning activities with regardless of pedagogical approach [1]. This research field has stimulating the development of useful tools and methods to represent the design process of learning experiences. In this current work, the CompendiumLD tool was used to visually represent guidelines to apply personalized learning activities from the Flipped Classroom perspective. According to Conole [2], Learning Design methods and tools have been shown benefits when employed to design complex learning contexts, as is the case of MOOCs, in which a significant number of resources and stakeholders are involved. However, more investigations about MOOCs and Learning Design are still needed.

For each scenario we highlight i) when the strategy (or idea) could be applied, considering the MOOC outline, ii) some guidelines to apply it, regardless the MOOC platform that will be used, iii) what kind of skills, learning or personal features are stimulated by the strategy, considering the Flipped Classroom related theories, among others.

Scenario 1: In the first week of the MOOC course, or as soon as possible, students (MOOC users) are asked to find important data related with the syllabus, such as material to be learned, course organization, warnings, teaching strategies,

deadlines, among others. Thus, instead of performing a reading of these current features, students have the opportunity to build their own mental or mind map related with the MOOC course (or another kind of conceptual diagram), considering the scenario described (Fig. 3).

According to Willis and Miertschin [36], this kind of strategy is a form of active learning and can be used to engage students in meaningful learning activities, for instance, writing, problem solving, visual thinking, analysis, synthesis, creativity, evaluation, among others, considering the theory related with mind maps.

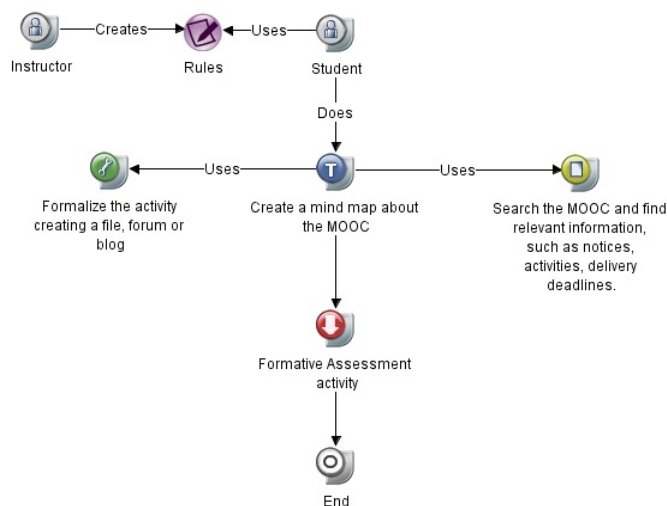


Figure 3 – An application of Flipped Classroom ideas in MOOC project – visual representation from the perspective of Learning Design.

The instructor can also use some final results or shared mind maps to verify and clarify common student's misconceptions early, which could prevent possible high drop-out rates. However, further investigation about this relation needs to be performed.

A way to formalize the activity can be adjusted according to the used MOOC platform, for example, using forum, blog or posting a file. There are many available free and online tools which can be used by the students in order to develop their mind maps, such as the MindMup², what can be used in an integrated way with Google Drive and some browsers.

In addition, the mind map can be changed by a video, text, or audio, considering the student's learning styles, in order to achieve personalization.

About the activity evaluation, benefits can be offered to those who complete the task. In this case, our proposal is a formative assessment activity. However, the instructor can also use a summative assessment with multiple choice test for a more individual and prompt evaluation.

² <https://www.mindmup.com>

Scenario 2: In general, this scenario is related with the use of social media to support learning. There are many ideas or possibilities.

Firstly, the instructor can create an unique hashtag for the MOOC course and share it, before the course start date, in order to promote the upcoming course.

Following on, according to Fig. 4, the instructor can advise the students to use this resource in social media to share interesting materials and stuffs related to the course topics. Many MOOC platforms already provide support for the use of external social tools. In this way, they can feel engaged and motivated for sharing information to their colleagues. It is also important encourage the student to share materials created by himself, such as video tutorials. In this way, a student can act as a teacher to another student.

Finally, the MOOC team can use all the statistics from the hashtag to analyze the results and to take future decisions about the course.

Personalized learning is achieved by enabling students to choose what (video, text, softwares, etc.), when, and where (Facebook, Twitter, etc.) to share, in order to make use of the enrichment resources and undertake the extended learning activities [37].

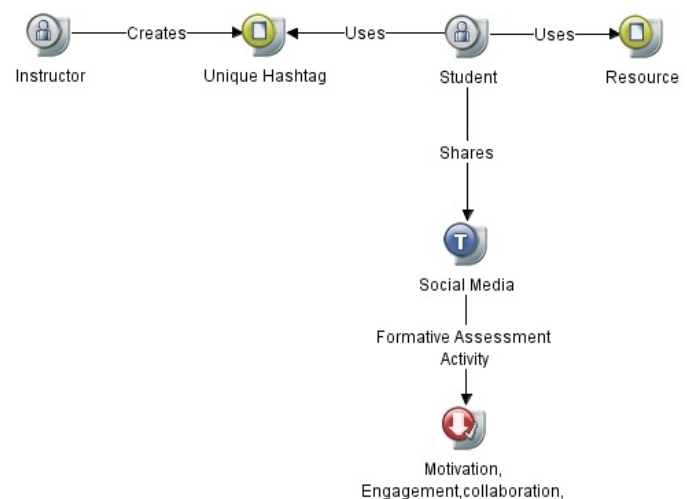


Figure 4 – Using social media to support learning.

Scenario 3: Request students to reflect on how they learn, what are their learning goals and main desires or limitations about the current MOOC course. This can help them to think critically about themselves and encourage them to act to overcome their obstacles or difficulties, which would also be related to the self-regulated learning.

The students have the opportunity to choose how to share their feeling or perceptions about this particular issue. In addition, they can express reflections considering their own learning style. A range of digital media formats (or types) can also be used to represent the reflections, using a discussion forum, figure, text, or shared video, among other ways.

Scenario 4: Students could receive - for example, by their e-mails - interesting and useful learning materials (video, text, games, etc.) and some organized and specific instructions to be performed outside the MOOC platform. Both, materials and instructions (and their related activities), are given according to their learning styles, defined from a survey completed during the enrollment period.

When a user feel ready, he/she needs to perform a quiz designed to test his/her ability about the previous context or activities. According to the result, he/she goes into what we call "active learning room". In this virtual room - the MOOC course - he/she would perform active learning activities based, for instance, on the project-based learning, problem-based learning, among others.

These "rooms" could contain people with similar interests and profiles. Considering another idea, these "rooms" could being opened whenever a number of students is reached. In this way, would not be necessary to wait by future dates in order to begin a course.

To conclude this section, according to Alario-Hoyos et al. [35], teachers and the instructional design team should be aware of the affordances provided by the existing MOOCs platforms at the time of designing courses in this kind of environment, since those may determine for instance the format of learning contents or the types of assessment activities that can be supported.

However, this current work did not consider this perspective because we believe that all the scenarios could be apply in the many available MOOCs platforms. So, considering this question, the present stage of these ideas is its instantiation under an available MOOC platform in order to create some implementation examples about the feasibility of creating personalized learning experiences using them. MOOCs platform is any environment that allows an individual or organization to create a MOOC, providing them with the necessary tools to do so. It can also be called Massive Open Online Education Platform (MOOEP). According to Fassbinder, Delamaro and Barbosa [39], the main MOOCs platforms are Google Course Builder (<https://code.google.com/p/course-builder/>), EDX Platform (code.edx.org), OpenMOOC (openmooc.org) and OpenHPI (https://openhpi.de). Other future perspectives are outlined next as well as the final discussions.

IV. DISCUSSIONS AND FUTURE WORKS

Despite the great enthusiasm instigated by MOOCs, they have also led to many skepticism. There are still several problems to be addressed to ensure that MOOCs be effectively incorporated as part of academic education on a large scale. The high dropout rates, for example, have triggered discussions about students' difficulties in the level of autonomy required, the ability to deal with the adopted technological environment, and the lack of physical presence of teachers and classmates.

Considering the need for changes in the educational and instructional structure of MOOCs, this research work is related with the context of an investigation about personalized strategies in MOOC project. Some ideas for the application of

FC concepts and principles in the project, development and delivery of such massive environment are presented.

In the next step of our research, we will focus on the investigation of new ways to map the main ideas and success stories of using Flipped Classroom in face-to-face environments into open online environment's projects, specifically in the context of massive education.

Future empirical investigation is envisaged using the Educational Design Research [38] with the intention of producing new theories, artifacts, and practices that represent and potentially affect learning and teaching. We envisage that the adaptation and incorporation of concepts of Flipped Classroom, already applied in classroom education, can also act as an effective intervention in supporting personalized learning in MOOCs, helping the student to take the active subject of role in the process acquisition of skills and knowledge construction.

In order to explore the impact of an intervention based on the use of Flipped Classroom strategies on large-scale virtual learning environments, a major experiment will be conducted. For this, two MOOCs will be created (MOOC control and experimental MOOC) in order to determine the impact that Flipped Classroom ideas have on the student's perception, their engagement with the content and the proposed activities, and the acquired knowledge. The control MOOC will be based on xMOOC type, i.e. using traditional learning teaching techniques such as videos, quizzes, discussion groups, among others. The experimental MOOC will be developed using the approach proposed in this paper.

Specific techniques will also be used to analyze i) quality of the MOOC instructional design proposed from the approach established in this work, ii) learning effectiveness, and iii) learner satisfaction.

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SmartLAK: A Big Data Architecture for Supporting Learning Analytics Services

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Abstract—In this paper, we present a big data software architecture that uses an ontology, based on the Experience API specification, to semantically represent the data streams generated by the learners when they undertake the learning activities of a course, e.g., in a course. These data are stored in a RDF database to provide a high performance access so learning analytics services can process the large amount of data generated in a virtual learning environment. These services provide valuable information to teachers and instructors such as predict the learner's performance, discover the real learning paths, extract the learner's behavior patterns and so on. The proposed architecture has been validated in the Educational Technology undergraduate course of the Degree in Pedagogy at the Faculty of Education of the University of Santiago de Compostela.

Keywords—Big data architecture, Learning analytics, Experience API

I. INTRODUCTION

In the last two decades a huge effort has been made for developing Virtual Learning Environments (VLEs). Aimed to promote students' anytime, anywhere learning, VLEs include tools for participants synchronous and asynchronous interaction, management of learning content, evaluation of the performance of students, and so on [1]. Nowadays, VLEs have evolved to even support different learning strategies, such as collaborative learning, informal learning with social networking support, adaptive learning through trading patterns, etc. However, in spite of the effort, most of VLEs do not provide the tools to analyze what is happening in a course. VLEs are like black boxes and thus teachers are unaware of what learners are doing, making difficult to improve or correct any deficiencies that might take place during the teaching and learning process.

To address this situation, the concept of learning analytics (LA) arose in the early 2010, understood as the measurement, collection and analysis of data to better understand the teaching and optimize the virtual environment in which it occurs [2]. However, a proper software architecture must be established to effectively store and retrieve the large amount of data generated by learners during a course, which is a clear need in current VLEs. Moreover, this architecture should include intelligent data analysis services and so provide valuable information to teachers and learners. For instance, the automatic discovery of the real learning process followed by the learners [3], [4],

the prediction of learner's performance [5], [6], the automatic annotation of the contents generated by learners in interactive activities or in practical exercises [7], are just some examples of techniques that can facilitate the decision support during the course. An overview of the current state of the art in techniques for intelligent analysis of educational data is available in [8].

Although some conceptual frameworks [9], [10] and/or software architectures [11], [12] have appeared in last years, at present there is no proposal that (i) collects in real time the large volume of information generated during a course; (ii) represents and stores this information following a standard specification to facilitate its interoperability with learning analytics services; (iii) enables these services to effectively access to the information generated in the learner's activities; and (iv) offers a set of intelligent learning analytics services that provide new and valuable information to teachers in order to take better decisions for improving the quality of the learning and teaching processes. The description of such software architecture is the focus of the paper.

In this paper, a big data architecture, called SmartLAK architecture, for supporting learning analytics services is presented. This architecture is composed of:

- A Learning Activity Sensor (LAS), which is a platform-specific component for capturing the sensitive data generated by the learners.
- An ontology, based on the Experience API (xAPI) specification, to structure the data generated by the LAS.
- A semantic data repository, where the data are stored in an RDF graph based on the xAPI ontology.
- A set of intelligent learning analytics services that consume the data stored in the semantic repository through an xAPI implementation.

This architecture has supported the analysis of the data generated by 60 learners enrolled in the Educational Technology undergraduate course of the Degree in Pedagogy at the Faculty of Education of the University of Santiago de Compostela.

II. LEARNING ANALYTICS-AWARE ARCHITECTURE

Figure 1 depicts the main components of the SmartLAK architecture, which supports the extraction and analysis of

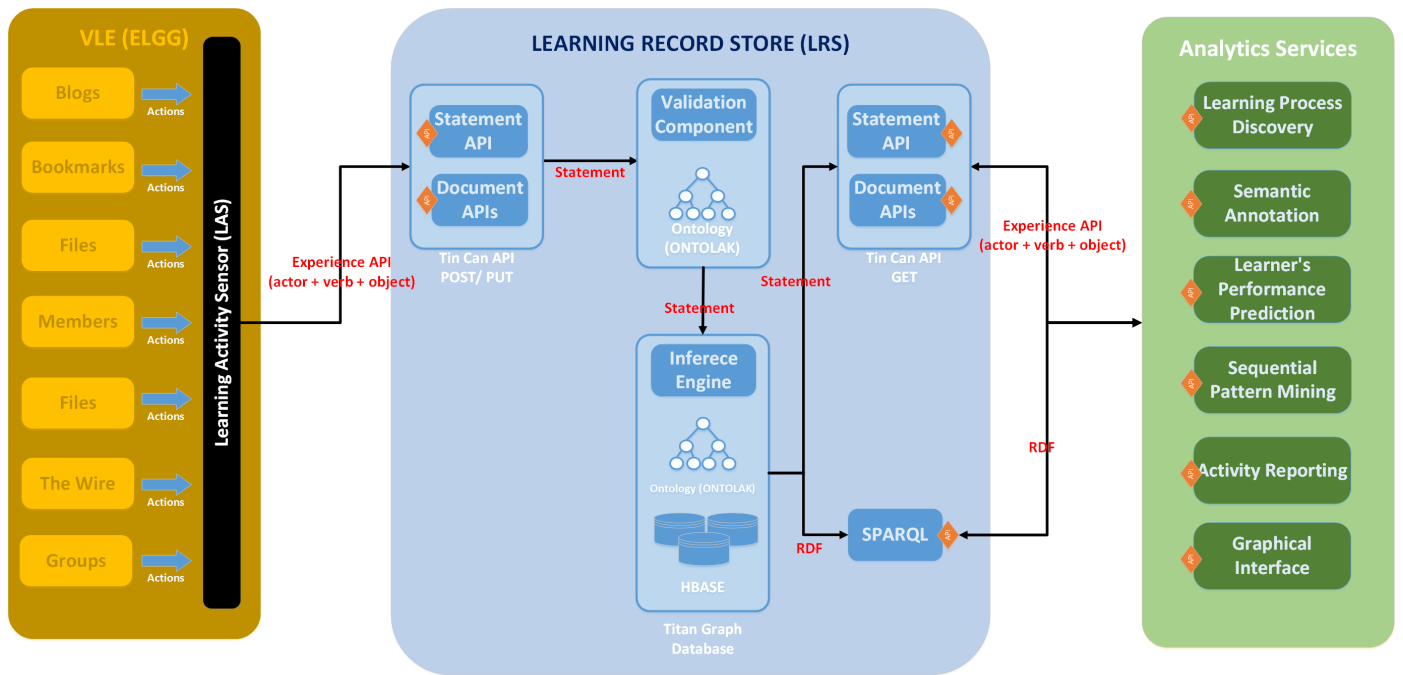


Fig. 1. SMARTLAK architecture

the data generated by the learners in its interaction with the VLE. The development of the SmartLAK architecture has been guided by three key factors: a standard service layer to capture and consume the data flow generated in the VLE (*xAPI services*); an ontology that semantically represents these data to favors the interoperability among the architecture components (*xAPI ontology*); and a high-performance database that enables consume large amount of data (*big data*).

A. Learning Activities Sensor

The purpose of the LAS is to capture the events generated by learners and/or teachers in their interaction with the VLE. In this context, events are atomic pieces of information describing something that VLE users have performed, such as creating a post in a forum, reading an input blog, answering a quiz question, deleting a comment, etc.

Most of VLEs implement event management systems, designed through a publish/subscribe pattern, allowing events to be tracked and represented as *statements* that describe the events and the context in which they occur. In the SmartLAK architecture, events are represented following the Experience API specification, formally known as TinCan API, that defines (i) a data model with the main features of an event, and (ii) an interface of services that will be invoked to store the statement in a Learning Store Record (LRS). Note that tracking events in a continuous way can be considered as an activity stream that requires a high performance infrastructure to effectively store these events when the number of learners (and therefore events) is very high (e.g., in MOOCs).

Taking this into account, the LAS component has been designed as an *event bus* that centralizes every event notification at a single point, where it can be routed as a statement to the LRS where the activity stream is stored.

B. Experience API Ontology

The main classes and relations of OntoLAK [13] are depicted in Fig. 2. The *Statement* class captures sentences in the form: "I spoke with Mike" or "John wrote an essay about surfing". Statements have three *required* properties. On the one hand, the *actor* property represents the subject of the statement. It captures the persons that triggered the event, e.g., the "I" and "John" of the former examples. The second property, namely *verb*, stores the predicate of the statement, e.g., "spoke with" or "wrote". Finally, the range of the *object* property can be an *activity*, an *agent*, a *group*, or another *statement*.

As it is depicted in Fig. 2, a statement can also detail the outcome of the event or the conditions under which it was performed by means of the *result* and *context* properties, respectively. A statement may include the attachments that are part of the learning record. Finally, the *authority* property is used to identify the agent or group who is asserting that statement is true. The remaining four properties of a statement, namely *uuid*, *timestamp*, *stored*, and *version*, are data properties that describe the UUID identifier assigned to the statement, the time when the event occurred, the time when it was stored in the LRS, and the xAPI version, respectively.

C. Learning Record Store

The objective of the LRS is twofold. On the one hand, it efficiently stores learning information (*xAPI statements*) about the events that were generated by learners and teachers in its interaction with the VLE. On the other hand, it facilitates a high performance access to this learning information and enables its processing through big data techniques (e.g., MapReduce). For achieving these objectives, the LRS components are the following:

- *Semantic validation component* is responsible for

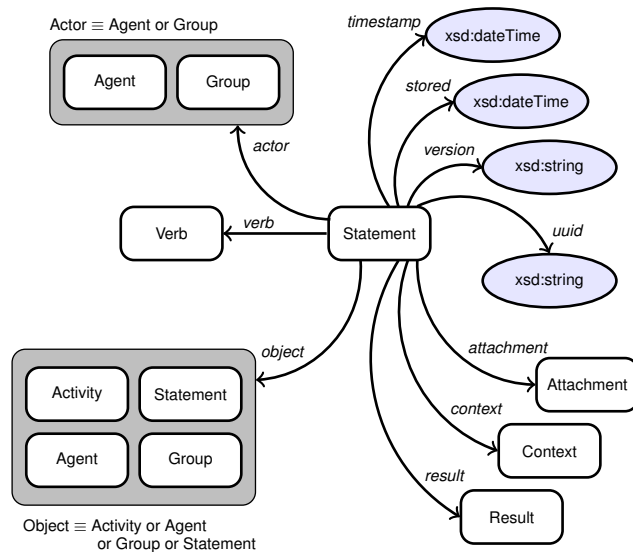


Fig. 2. Experience API ontology

checking whether a statement is compliant with the xAPI specification or not. This component uses Pellet [14], a description logic reasoner, to validate whether a statement that comes from the xAPI service layer verifies both the axioms and rules of OntoLAK, meaning that the constraints of the xAPI specification are fulfilled. In that case, the statement will be stored in the LRS database, guaranteeing that data are compliant with the xAPI specification.

- *Titan* [15] is a high-performance database that facilitates the integration of ontology-based components for conformance checking and semantic querying. In this architecture, Titan stores the information in a graph where data and their relations are explicitly represented, according to xAPI ontology. In addition, Titan provides the ability to expose the graph database as RDF triples through a Sail interface [16], which means that this graph can be exposed and semantically queried by means of a SPARQL endpoint. From the big data perspective, Titan is able to distribute the graph database through various machines in clusters, handling complex crossings graphs in real time and allowing the analysis of large volumes of data through Apache Hadoop.

The LRS interacts with the SmartLAK components through RESTful services that implement the xAPI specification interfaces: to store new statements in the graph database, POST/PUT HTTP methods are invoked from the learner activities sensor, while to access to the database graph, GET HTTP methods are invoked from the learning analytics services.

D. Intelligent Analytics Services

Intelligent Analytics Services (IAS) are independent components that process the LRS data to provide valuable information that enables teachers to better understand what is happening in the course or to facilitate the teaching and learning processes (e.g., assessment). An IAS is composed of

an intelligent algorithm, that provides the functionality of the service itself; a RESTful endpoint, that allow the service to be consumed by other IASs; a set of widgets, that allow visualize the results of the service execution; and a learning analytics sensor, that tracks the user activity when the IAS is integrated as part of a learning analytics dashboard. The current version of the SmartLAK architecture includes a set of IASs that are specially designed to support the learners' assessment. These services are the following:

- *Learning process discovery service* obtains automatically the real learning path followed by the learners during a course. In order to guarantee feasible and correct evaluations of the learning paths, this service retrieves complete solutions while focusing its search towards precise learning paths, i.e., models explaining only what the students did. Last, but not least, it retrieves simple representations of the discovered learning models. This service has been implemented with the ProDiGen algorithm [3].
- *Sequential pattern mining service* detects activity patterns that learners have following during a course. These patterns are understood as sequences of learning activities that occur with high frequency in comparison with other sequences. Thus SPM has been applied to detect activity patterns in self-regulated learning, where the interest is on
- *Semantic annotation service* classifies and annotates the textual content (e.g., blog inputs, posts in forums, comments, etc.) generated by the learners during a course, making easier the teachers access to contents through their topics or annotations. This service has been implemented with the ADEGA algorithm [7].
- *Learner's performance prediction service* obtains the degree of fulfillment of the educational objectives of a course, using as inputs the marks of the assignments of each learning activity that has been performed by the learners. This service has been implemented with the algorithm described in [5].
- *Activity reporting service* provides automatically generated natural language reports built from every student activity data. This service is based on linguistic description techniques adapted from the fuzzy sets field and natural language generation tools. This service has been implemented with the SLAR algorithm [17].
- *Graphical interface service* enables teachers to understand the learner's behavior through the visualization of the data available in the LRS and the results obtained from the IASs execution. Note that typically this component is not independent of the other IASs, since it needs their executions in order to be able to provide valuable information to teachers. Fig. 3 shows a screenshot of the graphical interface of the SmartLAK architecture.

E. Scenario

The current version of the SmartLAK architecture has been used to support the learners' assessment process of the

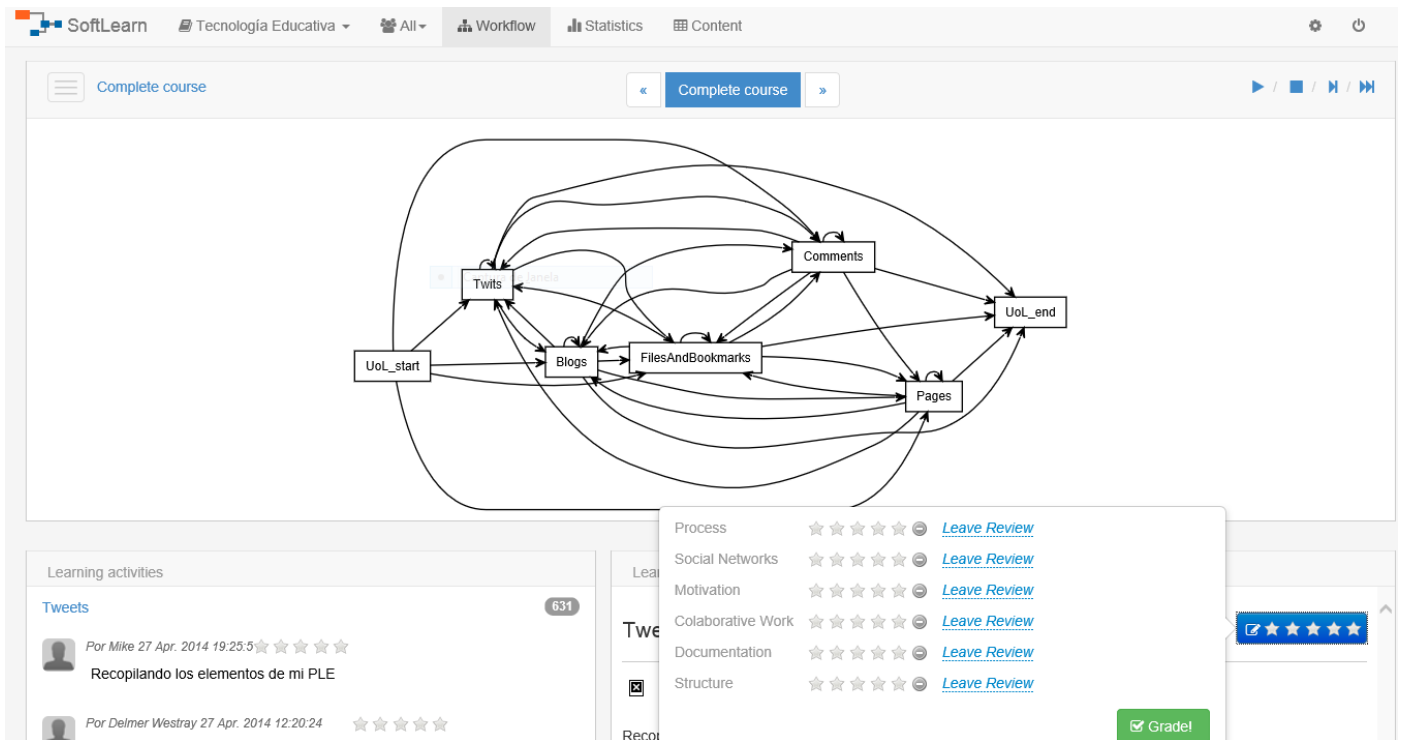


Fig. 3. Graphical interface of the SmartLAK architecture

Educational Technology undergraduate course of the Degree in Pedagogy at the Faculty of Education of the University of Santiago de Compostela. This course has 60 learners enrolled during the first semester 2014 and it was developed in a blended learning mode with virtual activities, where students undertake learning activities through a social e-portfolio with blogs, micro-blogging tools, favorites, pages, etc.

In this scenario, the SmartLAK architecture captured and stored more than 250.000 statements, and its learning analytics services helped teachers to assess the learner's performance based on its learning paths, the classification and annotation of textual content, and the participation statistics supported by a learning analytics dashboard (graphical interface).

III. CONCLUSIONS

We have presented a big data architecture, called SmartLAK, that uses an ontology based on the xAPI specification to represent the activity stream generated by the learners during a course, favoring the interoperability among the components of the architecture. This ontology is also used to check the conformance of the data stream with the xAPI specification, which guarantees that the data in the LRS will be compliant with the xAPI. Once this conformance is verified, data are stored in a high performance database that allow implementing services based on big data techniques.

As future work our intention is to improve the architecture with an Enterprise Service Bus able to integrate different data stream sources and a big data-oriented message queue to increase the activity stream performance. Finally, we plan to experiment with this architecture in several courses with a large amount of learners that would generate millions of data.

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The use of Learning Objects for teaching Computer Programming

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Abstract - Information technology has been contributing to various areas of knowledge; in particular, the field of education stands out. In what concerns the teaching of computer programming, literature contains important efforts that aim to assist in the learning process. Teaching algorithms and programming concepts for first year students has always been a great challenge for universities, new Computer Science students usually have difficulties in understanding and abstracting the problem logics. An alternative that has contributed to the teaching-learning process is the use of Learning Objects (LO), which contribute towards mediating and enhancing the teaching-learning process. One of the great difficulties of learning during the initial semesters of Engineering and Computer Science courses is related to the contents of computer programming, which increases the students' failure level and also the dropout rate of such courses. In order to decrease those rates, we have developed a project to create various learning objects to help teach concepts that are considered difficult to understand by students of Science courses, and the results were very positive. This paper presents the qualitative and quantitative results of the experiment we conducted with the development and application of learning objects to help teaching students of Computer Science. The project was conducted in 2013 and 2014 and outcome data showed that the use of learning objects contributes significantly to the teaching-learning process.

Keywords – computer programming; computer science education; educational process; software algorithms; learning objects.

I. INTRODUCTION

Computer programming is a fundamental course taught to Engineering and Computer Science students. Teaching algorithms and programming concepts to first year students has always been a great challenge for universities. Data structures, programming resources, binary trees, sorting, are some examples of very important subjects for students, and several of them do not learn it appropriately. The misunderstanding of programming concepts lead a significant percentage of students to abdicate from their courses.

New Computer Science students usually have difficulties understanding and abstracting the problem logics and transforming it into a step-by-step sequence in order to develop the algorithm later [1].

The primary target of initial programming courses is algorithm design. As these are considered core courses for the Computer Science undergraduate, it is extremely important that students can clearly understand all the concepts covered. However, these courses have experienced the highest failure rates in Computer Science courses.

This fact is due to two factors: a) the paradigm created inside and outside classrooms makes students come to first classes with the fixed opinion that this course will be a great obstacle, extremely difficult to be overcome; and b) some teaching methods used by teachers to present the concepts, because understanding how the computer executes its tasks requires much abstraction ability from the students [2].

Several reasons for student failures in learning algorithms and programming concepts have been described [3], [4]:

- Undisciplined study habits focused on memorizing;
- Unstructured previous knowledge, especially on the domains of mathematics and logics;
- Non-motivating teaching approaches;
- Taught contents are irrelevant to students' day-to-day lives;
- Difficulties in understanding problem wording;
- High levels of abstraction.

The difficulty in learning and teaching algorithms and programming concepts is making coordinators and teachers of Computer Sciences undergraduate courses concerned. These subjects deal with key contents for the formation of the Computer Science professional and present a high degree of difficulty in learning for students.

Many efforts have been made to explore alternative methods of teaching programming concepts to students of the initial years. Teachers have tried the adoption of new tools and pedagogical approaches to help learners engage in a more pleasant learning process.

In the last years, the use of Learning Objects has been experienced as a very important component of instructional tools. A Learning Object can be used in a considerate manner, addressing a part of content that will be worked with students. The instructor can use it as an additional way for teaching.

In this paper we present our experience in using Learning Objects in teaching several basic concepts of computer programming to students of Computer Science first years and the qualitative and quantitative results obtained during the experiments we have conducted with our students during two academic years.

II. BACKGROUND AND RELATED WORKS

Information technology and communication have contributed to various areas of knowledge; in particular, the field of education stands out. With regard to teaching basic concepts of computing, purpose of this study, the literature contains some efforts that aim to assist in the teaching and learning processes: Scratch is an environment that provides the construction of programs and was created with the aim of facilitating learning to beginners in programming. It was developed at MIT (Massachusetts Institute of Technology) using the programming language Squeak; Greenfoot, developed by the University of Kent, in England, and the University of Deakin, in Australia, aims to teach object-oriented programming from the construction of scenarios using the prepared environment for game development.

Greenfoot assumes that the student has previous knowledge of basic programming concepts [5]; the University of Wisconsin-Madison has developed Gamestar Mechanic, an

online platform to build games. The focus is on fostering problem-solving skills and creating motivation for learning science, technology, engineering and mathematics; and finally, ALICE is a 3D programming environment developed specifically for students who have their first experience with object-oriented programming. The software allows the student to learn fundamental programming concepts creating animations and games. In ALICE, 3D objects such as people, animals, vehicles, etc. form a virtual world where students create programs to animate such objects.

Experiments with the use of these software point to the fact that, despite the success of such experiments, much remains to be done in this direction [6].

An alternative that has contributed to the teaching-learning process is the use of Learning Objects (LO). These features tend to facilitate and provide technological support to educational processes.

According to [7], LO are digital or non-digital entities that can be used and reused during a learning process supported by technology.

Applications of Learning Objects can be: animations, videos, simulations, HTML pages, images, among others. Learning Objects can be used discreetly, addressing a piece of content that will be presented to students. The teacher, instead of offering the entire course material through handouts, books, articles or lecture notes, uses the LO which, in turn, will contribute towards mediating and enhancing the teaching-learning process. An LO is a support tool for learning used by the teacher to facilitate deeper understanding of the concept taught [8], [9].

III. LEARNING OBJECTS REPOSITORY

Several repositories for learning objects are available worldwide. Most of them have been developed by the initiative of universities and governmental incentives. A repository of learning objects is an organized collection of digital documents, to which the entire community may or may not have free and open access, and can be seen as a digital library. Students can access these resources made available by the teachers, in order to assist in the course teaching-learning process.

Some examples of Learning Objects repositories are: DOOR, DSPACE, Fedora, EPrints, Edutools, Ariadne, among others. Also the major universities in the world have devoted special attention to the repositories for LO; among them stand out BBC Learning, BozemanScience, Harvard Open Learning Initiative, Khan Academy, Learn NC, Merlot, Math Open Reference, MIT Open Courseware, Nobel Prize Education, Smithsonian Education, among others.

Most repositories store Learning Objects resources to various areas of knowledge, such as mathematics, biology, physics, chemistry, health etc. But there is a very small number of LO developed to teach the fundamental concepts of computer programming, further enhancing the learning

difficulties of students in the early years of Engineering and Computer Science courses.

IV. LEARNING OBJECTS FOR COMPUTER PROGRAMMING TEACHING

The authors of this work have been dedicating to the development of learning objects to help teach computer programming concepts to students in early grades of Computer Science course.

In this sense, learning objects have been developed to teach Pointers, Data Structures, Binary Trees and Data Classification. Such objects are available for use by the entire academic community, and can be accessed through the link: <http://www.fema.edu.br/oa/>

The technology employed for the development of learning objects involves the use of interactive animations created with HTML5 canvas resources, Flash 8 and Javascript. These technologies allow students to have a more intense relationship with the concepts taught in class, facilitating the understanding of the issues addressed by teachers.

V. LEARNING OBJECTS IN TEACHING POINTERS

The first learning object developed aimed to help the teaching process of Pointers to the first-year students of the Computer Science course. With the use of interactive features, the Learning Object works on the basics of algorithms developing, instructions, data and results, and allocation of data in memory. After the student learns the conceptual aspects, the LO applies a series of questionnaires to verify that student's learning level. If the student's understanding was not satisfactory, he or she can return to the previous steps and review the concepts again.

VI. LEARNING OBJECTS IN TEACHING BINARY TREES

The second learning object developed aimed to help the teaching of Binary Trees concepts to the first-year students of Computer Science. Also with the use of several interactive features, the LO covers the concepts of Binary Trees, and the basic procedures of handling the elements of a tree, such as adding and deleting nodes, pathways in pre-order, order and post-order, and the concepts of balanced trees based on AVL trees (Adelson-Velsky and Landis' tree). The processes and algorithms of all operations are explained according to the concepts studied.

As with the other Learning Object, in this case students can also return to the previous steps and review the concepts again, if necessary.

VII. THE PRESENT STUDY

After the development of each of the Learning Objects, the authors of this paper conducted an evaluation process to check the functionality of the tools and to check how useful they were in assisting in the teaching-learning process of students.

The evaluation process was conducted during the academic years of 2013 and 2014, and involved the participation of 106 students from the first year of Computer Science of Fundação Educacional do Município de Assis, FEMA, in Brazil.

For the presentation of the results obtained in the evaluation process, we will describe two case studies, the first of which was held for the implementation of a Learning Object for teaching Pointers and the second was conducted for the application of an LO for teaching Binary Trees.

VIII. CASE STUDY I

In order to know better the effectiveness of the Learning Object for teaching Pointers concepts, we conducted this first case study with 44 students in the first year of Computer Science at FEMA. This study was divided into four steps: identifying the students' knowledge about Pointer concepts, the use of the LO, the assessment of concepts learned after the use of the LO, and the LO environment assessment.

1st Step: Identification of Students' Knowledge about Pointers Concepts

In the first step, we applied the pre-test in order to identify the degree of confidence and knowledge of students about the content of pointer manipulation. The pre-test consisted of objective and essay questions where students should answer the theoretical and practical issues on the use of pointers.

The performance of the students after completing the pre-test is shown in Table I.

Table I – Students' Knowledge about Pointers – before the use of the LO

Right answers	% of students
0.0	13
0.5	32
1.0	23
1.5	14
2.0	14
2.5	2
3.0	2

It can be observed from Table I that 68% of students showed little or no knowledge of the content required in the pre-test, that is, they obtained scores of up to 1.0. Next began the activities regarding the 2nd part of the case study.

2nd Step: The Use of the Learning Object

In the 2nd step the application of the LO was conducted with the target audience. This step was carried out in the computer lab and had the duration of two classes. For its implementation, theoretical and practical activities contained in the LO were planned. It should be noted that the focus of the LO is essentially to present theoretical and practical aspects of using Pointers.

3rd Step: the Assessment of Concepts Learned

The post-test applied in the 3rd stage of the case study aimed to measure the knowledge acquired after completion of activities in the 2nd stage, that is, whether the developed LO fulfills its support role and aids in the learning of contents. The post-test had 4 questions (3 essay and 1 objective) on contents presented in Step 2.

Table II summarizes the performance of students after implementation of the post-test:

Table II – Assessment of Concepts Learned – after the use of the LO

Right answers	% of students
0.0	0
0.5	0
1.0	2
1.5	4
2.0	23
2.5	14
3.0	32
3.5	18
4.0	7

The post-test results show that 94% of students achieved higher accuracy on more than half of the questions to which they were subjected. The post-test was important because it helped us in understanding which concepts and skills were well taught during the 2nd stage and which still require extra time to be worked on.

4th Step: Assessment of the Learning Object environment

Finally, in Step 4, students answered a questionnaire of satisfaction about the contents taught. They could assess how the Learning Object was helpful in their learning, if it really was a feature that offered the support they expected, and how the experience in using the LO was. From the perspective of students, the survey results were encouraging, since 62% replied that the LO facilitates the understanding of the key concepts covered in the case study, and 84% of students see the LO as an important supplement to traditional teaching lessons format used by Computer Science course teachers.

IX. CASE STUDY 2

With the objective of verifying the contribution of the Learning Object on teaching Binary Trees, we conducted this second case study with 62 students of the first year of Computer Science.

These students were in the end of the first year, so they had already been studying algorithms and programming three quarters before, but this was their first contact with the concept of binary trees.

The same strategy adopted on case study 1 was also adopted for this case. The study was divided into four steps: identifying the students' knowledge about Binary Trees concepts, the use of the Learning Object, the assessment of concepts learned after the use of the LO, and the LO environment assessment.

1st Step: Identification of Students' Knowledge about Binary Tree Concepts

In the first step, we applied the pre-test in order to identify the degree of confidence and knowledge of students about the content of Binary Trees. The pre-test consisted of objective and essay questions where students should answer the theoretical and practical issues on the use of binary trees.

The performance of the students, after completing the pre-test, is presented in Table III.

Table III – Students' Knowledge about Binary Trees – before the use of the LO

Right answers	% of students
0.0	64
1.0	20
2.0	11
3.0	5
4.0	0
5.0	0
6.0	0

It can be observed from Table III that 84% of students showed little or no knowledge of the content required in the pre-test, that is, they obtained scores of up to 1.0. Next began the activities regarding the 2nd part of the case study.

2nd Step: The Use of the Learning Object

In the 2nd step the application of the Learning Object was conducted with 62 students. This step was carried out in the computer lab and had the duration of four classes. For its implementation, theoretical and practical activities contained in the LO were planned. It should be noted that the focus of the LO is essentially to present theoretical and practical aspects of using binary trees.

In the end of each stage of the LO, students needed to solve some problems, using the concepts learned. While they worked on the solution of the problems, the students' excitement and how easily they had understood the concepts was remarkable. Most students could successfully solve the proposed problems, and some of them could create new functionalities.

3rd Step: the Assessment of Concepts Learned

The post-test applied in the 3rd stage of the case study aimed to measure the knowledge acquired after completion of activities in the 2nd stage, that is, whether the developed Learning Object fulfills its support role and aids in the learning of contents. The post-test had 6 essay questions on contents presented in Step 2.

Table IV summarizes the performance of students after implementation of the post-test:

Table IV – Assessment of Concepts Learned – after the use of the LO

Right answers	% of students
0.0	0
1.0	0
2.0	0
3.0	6
4.0	34
5.0	42
6.0	18

The post-test results show that 100% of students achieved higher accuracy on more than half of the questions to which they were subjected. The post-test was important because it helped us in understanding which concepts and skills were well taught during the 2nd stage and which still require extra time to be worked on. However, the results were very satisfactory.

4th Step: Assessment of the Learning Object environment

For this fourth step, we conduct an assessment of the entire Learning Objects environment, and the results are presented in the next section.

X. EVALUATION AND RESULTS OF THE LEARNING OBJECTS ENVIRONMENT

At the end of the process of Learning Objects use, students answered a questionnaire of satisfaction about LO. They evaluated whether the LO has the ability to facilitate the understanding of concepts, whether the LO actually helped to better understand the concepts, if the LO has some element that hinders the understanding of the concepts, and if the use of LO can complement the learning of concepts.

Four questions were asked, and the answers given by the students in this LO assessment process are presented below.

Q1. Does the Learning Objects help understanding the concepts?

Answers	% of students
Entirely disagree	0
Disagree	0
No opinion	11
Agree	39
Entirely agree	50

This review has shown that 89% of students believe that the LO is a useful tool that helps in the process of understanding of the concepts presented.

Q2. Has the Learning Objects actually help in better understanding the concepts?

Answers	% of students
Entirely disagree	0
Disagree	5
No opinion	10
Agree	35
Entirely agree	50

This evaluation indicated that 85% of students answered that the LO assisted in the learning process of the concepts studied.

Q3. Does the Learning Objects have any element that hinders the understanding of the concepts?

Answers	% of students
Entirely agree	2
Agree	5
No opinion	19
Disagree	37
Entirely disagree	37

The answers to question number 3 express that only 7% of students found some element that could hinder the understanding of the concepts. Next they answered what these elements were, and that helped to improve the LO. The items most often mentioned by students indicating the elements present in the LO that were hindering the understanding of the concepts were:

- the displayed text is not clear enough for the comprehension of the concepts discussed;
- the graphical layout used for the presentation of content;
- more examples with everyday situations could have been used.

Q4. Can the Learning Objects complement the learning of concepts?

Answers	% of students
Entirely disagree	0
Disagree	0
No opinion	3
Agree	8
Entirely agree	89

The answers to question number 4 indicate that 97% of students believe that the use of Learning Objects can supplement the learning of concepts studied. This result can be proved with the post-test we applied at two case studies, where we can see that most students achieved higher accuracy on more than half of the questions to which they were subjected (Table II and Table IV).

We got very encouraging results, as they showed an important value related to motivation and beliefs of students with the use of Learning Objects. Even considering that this was a subjective assessment, this scenario converged to the importance of the use of learning objects for teaching computer programming concepts.

XI. CONCLUSIONS

This work aimed to present the experiences in using learning objects for computer programming teaching in Computer Science introductory courses. Computer tools were used as pedagogical basis, with the objective of providing practical activities fomenting the study assessment process.

We conducted two case studies. The first one was taken with 44 undergraduate students in the first year of Computer Science, in which we worked with a learning object for teaching Pointers concepts. The second case study was taken with 62 students, in which we worked with a learning object for teaching Binary Trees concepts.

In both case studies we could compare students' knowledge level about the taught concepts before and after the use of Learning Objects. It was evident in the answers gathered on first and third steps of both case studies.

For the first case study, we concluded that 68% of students had very little or no knowledge about Pointers concepts and the third step showed us that 94% of students had more than 50% of success in learning the contents taught. Results set out the growth of students' knowledge about Pointers concepts. Furthermore, it is important to highlight the students' behavior when using the learning object, they felt motivated and had fun solving the proposed problems, and these are essential factors for facilitating the learning. This is also an important factor to contribute for reducing the failure rates in Computer Science and Engineering courses.

In the second case study we concluded that most students (84%) had very little or no knowledge about Binary Trees. It is important to highlight that these students were in the end of the first year, so they had already been studying algorithms and programming three quarters before, but this was their first contact with the concepts of Binary Trees. In the end of this case, we could verify that 100% of students had more than 50% of success in the assessment, and 60% of students had more than 80% of success in the assessment. In this case it was also very clear that the learning object helped students learning the concepts for computer programming.

Finally, the results of the Learning Objects environment were very positive. For the assessment we conducted with the students, we concluded that 89% of students agree that the LO helps understanding the concepts (Q1). With Q2, we saw that the LO helps understanding better the concepts for 85% of students, indicating that the LO is a very good support tool for teaching. On Q3, we concluded that 74% of students indicated that the LO does not have any element which interferes in the understanding of the concepts. And, on Q4, we concluded that 97% of students indicated that the LO is a tool for complementing the concepts learning.

The results gathered on this project are very important and positive. It can serve as a basis for the academic community to start the development of more learning objects for teaching computer programming, making the learning process for first years students less difficult.

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Look ma, no templates! Problem-based learning of computational physics for novice programmers

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Abstract—We present a problem-based approach to teach computational physics to junior-level students with a variety of programming skill levels, many of whom have only 10 weeks of prior programming experience. The students solve tasks, relating to their current class topics, which are mathematically challenging but computationally tractable. The tasks are chosen to develop and reinforce student understanding of traditional physics content. We provide students with minimal code examples (47 lines of python code in a one-year lab sequence) and no textbook, and require students to search the internet for help to achieve the tasks assigned. This is effective through the use of a pair-programming pedagogy, when students are given tasks at a suitable level. This pedagogical approach should be transferable to any mathematical discipline for which computation is appropriate. Because student effort is focused towards accomplishing tasks within their discipline, they gain the practical skills needed to use computation effectively. Because we give students no templates or example code, they are forced to develop the skill of learning a programming language, and debugging code. This gives students confidence, and prepares them to learn other programming languages in their future career: a most important skill!

I. INTRODUCTION

We have set out to develop a computational physics course at Oregon State University that improves student learning of physics content while simultaneously providing students with valuable computational skills. This course neither uses canned simulations to help students understand physics content (as in [1], [2]), nor is it structured around numerical methods, with physics content chosen incidentally to illustrate those methods (as in [3], [4]). Instead, we have developed a computational laboratory that functions analogously to conventional laboratories: students learn computational methods as they apply them to the physical systems that they are learning in their “conventional” courses—although the junior-year physics curriculum at Oregon State is far from conventional [5].

The approach of integrating computation into the curriculum has seen an increasing trend. There is currently considerable work being done to integrate student-performed computation into instruction the teaching of physics content at the lower-division and high-school levels [6], [7], [8]. There has also been an encouraging trend in textbooks for upper-division and graduate-level physics that incorporate computational concepts into the presentation of physics content [9], [10].

In this paper, we will introduce the pedagogical approach we have developed in this course. We will begin by discussing the pedagogical philosophy of the course, and give one example of a classroom activity, including typical student output. We will end with a discussion of our preliminary assessment results.

II. PEDAGOGICAL PHILOSOPHY

Our pedagogical philosophy is grounded in the belief that all physicists (and likely all university graduates) need to be able to program a computer effectively. This is borne out by recent surveys of physics graduates by the American Institute of Physics, which show that over 85% of new physics PhDs use programming skills regularly in their work, as do 75% of the bachelors recipients for whom data was available. Thus computation is not the realm of Computational Physics students, but should instead be a skill learned by all physics majors. The desire to teach *all* of our physics majors was a significant consideration in the design of this course. In particular, we aim to ensure that even students entering our Physics major with no programming experience are able to exit the major confident in their ability to program a computer to solve common problems numerically.

In this section, we will outline the approach we developed to address the difficulty of teaching students who are already under a heavy course load to program effectively.

A. Course structure and prerequisites

This new computational laboratory course is designed to be taken by students who are taking our junior-year Paradigms in Physics courses [5]. This is an intensive sequence of courses that meet seven hours per week, and makes heavy use active engagement pedagogy. The pedagogy and content ordering of the Paradigms are novel, but the content taught during this junior-year sequence is a subset of the content taught in a standard upper-division physics curriculum. Therefore, we anticipate that this course can be adapted to work at other colleges and universities.

The course has as a prerequisite an existing lower-division Computational Physics course that is required of our physics majors. This course is taught using Visual Python [11], and covers typical topics in Newtonian mechanics. Students leave this course with an ability to write simple python programs, and with some understanding of methods for solving for

the motion of a particle acted upon by forces that they can compute. In practice, only about half of our students have taken this prerequisite, while the remaining students either had prior programming experience or a similar lower-division computational physics course at a local community college.

A primary design principle for the course was to have students do all programming in class. This was motivated by our experiences teaching Computational Physics in the lower division. We have found that the students who struggle most with programming are the least able to learn effectively through completing homework assignments outside of class. Given that these are the students who most need a computational course, it seems counter-productive to have the majority of time spent on the class happen outside of class, when those who need the course the most are least productive. So we developed this course as a one-credit laboratory that meets three hours per week, either one or two days a week, with no expectations of student work outside of class.

B. Pair programming

In order for this course to work for all upper-division physics students—even those who are hesitant to use computers—we use the *pair programming* approach, in which students work together to write programs [12], in a laboratory setting in which students work on their assignments with an instructor present to help with debugging [13]. Previous research has reported that this pedagogy eliminated gender differences in reported confidence in programming [14].

One student in a pair is the *driver* and the other is the *navigator*. The driver uses the keyboard and mouse to enter in the program, while the navigator looks for bugs, gives advice, and tries to plan ahead. Every half hour or so, the instructor tells the students to swap roles [15]. We assign students to pairs, and we usually change up the pairings each week, even when students are in the middle of a project, which results in one student in each pair working with an unfamiliar code. Although some previous work has changed pairings in a similar manner [16], we are not familiar with previous work that changes pairings in the middle of a project. This changing of partners serves several goals. One is to help students to learn to write code that is comprehensible and editable by others, by giving them the experience of struggling to read and modify other students' code. A second is to encourage the each member of a pair to ensure that they understand how their program works, since either student may need to finish the program the following week without the assistance of their original partner. Finally, the practice of regularly changing partners limits the damage due to the situation where a particular pair fails to work together well, and helps to prevent the situation in which one student habitually defers to his or her partner.

Our experience with pair programming has been overwhelmingly positive. We have observed that students who are working in pairs are far more resistant to the frustration of tracking down bugs in their code than students working individually. This gives students the valuable experience of going through the lengthy process of tracking down bugs. At the same time, pair programming allows an instructor to effectively manage a larger class size, since students working in pairs are less dependent on the instructor to make progress.

The course proceeds as a sequence of projects, in which the students are asked to solve some task, which usually involve computing and visualizing a result. Typical projects take between one and three weeks, and end with a “show and tell” time, in which several students in the class present their code to the class, and show their results. We have found this show-and-tell to be both popular and instructive. Students gain experience in speaking in front of a group, which is always valuable. Show-and-tell also enables the entire class to benefit from a trick that one pair figures out, and gives students feedback on their programs.

C. Python + Numpy + Matplotlib

We have chosen to use python, with the numpy and matplotlib libraries. Python is a very easy language both to teach and to learn, and skills learned in python transfer well into other languages [17], [18]. Our experience using python in our lower-division computational physics course as well as the experiences of others [19], [20], [6] indicate that it is an excellent language for introducing programming to young physicists who have never before programmed. Python is also sufficiently powerful that students need not move on to a different language for their research needs. Python is widely used in the scientific community [21], [22]. The numpy and matplotlib packages allow python to be used for quick interactive matrix analysis and visualization [23], [24]. This combination of a general-purpose language that is easy to learn, and which is popular with research physicists makes python an excellent choice for a course such as this one, which aims to provide even novice programmers with the skills needed to use programming effectively.

D. Google it!

We provide our students very little in the way of teaching materials for python itself. There are abundant resources online for learning to program in python, and we encourage students to search for and use these resources. We believe that in this day and age, the skills needed to find online resources for programming are if anything more vital than the content that can be made available in a book on programming. Searching for help in programming is a skill that is *learned*, and as with most skills, learning requires practice.

We give students essentially no example code (47 lines of code for the one-year sequence). Our experience has been that when given example code, students approach tasks by copying the example code and modifying it. While copying and modifying sample code *is* expert-like behavior, there are several reasons why instructor-provided sample code can be problematic. When example code is provided by the instructor, students are not required to engage in several high-level activities. They can usually assume that the code is suitable for their use, relatively bug-free, and written in a programming language suitable for their coursework. Each of these determinations is challenging for novice programmers. By *not* giving students example code (apart from aforementioned 47 lines of code), but encouraging them to use online resources, we enable students to learn to program in a way that much more closely reflects the context in which they will actually use programming. The 47 lines of code we *do* give students is mostly examples for creating animations, since we ourselves

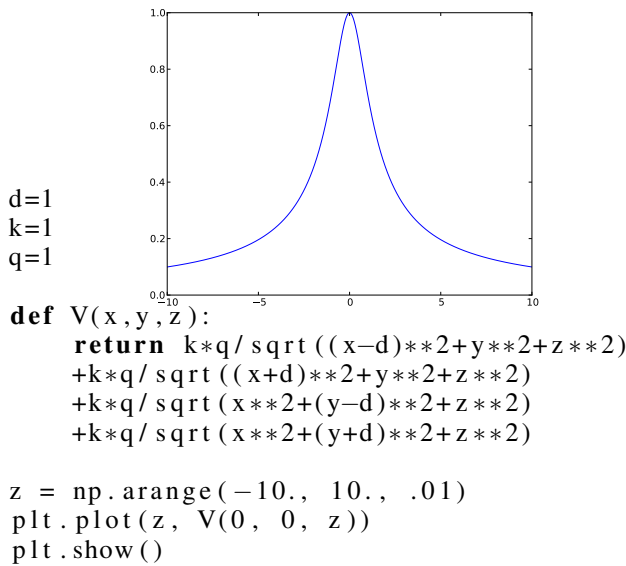


Fig. 1. Student code from day 1 and its output. The students have computed and plotted the electrostatic potential due to four point charges. The import statements and a redundant (but harmless) line of code are not shown.

have found that task challenging to figure out from resources on the web.

III. EXAMPLE PROJECT

On the first day of class, we ask students to write a function computing the electrostatic potential due to four point charges in a square, and to plot this function. The students have recently sketched a contour plot of the potential of this charge configuration in their electrostatics course. We encourage students to be creative in their visualization of the potential. Figure 1 shows one example of a student program and its output, generated in about two hours on the first day of class. Other pairs generated color plots or three-dimensional plots.

IV. PRELIMINARY ASSESSMENT

We collected considerable data regarding what actually happened in class. The instructor and teaching assistant wrote a half-page journal entry after each class period, noting what we did, and often recording either things that we wish we had done differently, or events during class that we found surprising. At the end of each class period, we collected survey results from each student answering the questions, “What did you do today?”, “What did you learn today?”, and “What was one thing that didn’t work well today?”, along with the name of their partner. These surveys were used to record class attendance, which resulted in a high response rate, although often brief and sloppy answers. We also saved a copy of the students’ code after each class period. Together, this data gives us a good picture of the amount of time spent on various activities, and what the students were struggling with.

After each quarter, an external evaluator conducted a focus-group interview with a majority of the students in the class over the past two years. We chose this format in order to identify consensus opinions, and distinguish these from

unique perspectives of individual students, as well as to assure students of anonymity.

Finally, we have performed several exam-style assessments, in which we asked students individually to perform some programming task in a given time period. We did not permit students to use any of their own source code, but did allow them to use any online resources. We used screen-recording software to record their progress, saved a copy of their source code, and noted whether they finished early. These assessments enabled us to identify specific learning goals that were not being achieved by the entire class.

In the following sections, we will summarize our conclusions from these assessments.

A. Format of the course

Students consistently expressed very positive attitudes about the course content and format. Even though they took the class while also enrolled in very work-intensive junior level paradigms classes, all students reported that they wished they had more time to work on the class.

Students expressed that they valued the pacing of the class. Most of them didn’t finish every project and a few didn’t finish one. Students’ didn’t see this as a problem, since their learning, both in terms of the physics and the communication skills, were always intensive and productive during class. Prior to the class, some faculty had been concerned that faster students would be bored by the slower pacing. No student reported anything that hinted the class had gone too slowly for them.

B. Pair programming

The overwhelming majority of students in the focus group interviews appreciated the group nature of the class format and the requirement that students must learn to communicate effectively with others while working. They saw this as both a worthwhile goal and for the most part an enjoyable process. Any frustrations associated with “wasting” time learning to communicate with new people were seen as necessary and in valuable in themselves. Even the one student who didn’t “like” the pair programming still said it was a good idea. After one particularly challenging class, one student reported that “troubleshooting with [my partner] was great.”

C. Physics content

Evaluating student learning of physics content material through the computational lab presents a significant challenge. A few students used python and matplotlib in their other coursework—particularly the analysis of experimental data.

In the focus group interviews, the group strongly agreed that they understood the paradigms class material more easily and in depth because of their experience in this class. Many said that they performed better on paradigms exams thanks to the class and those who did not still reported that they were better able to “visualize” the topics learnt in class.

D. Computational skills

In the focus group interviews, students widely recognized that numerical thinking was important for a physicist and that computational skills were very valuable. Students felt that the course satisfied both these learning goals well.

Your task: Write a program to numerically perform the integral

$$I = \int_0^1 e^{-x^2} dx$$

Fig. 2. Integral pretest task. Of the 8 incoming students who were assigned this task in Fall 2014, 5 were able to successfully write a program to compute the integral.

We are in the process of developing assessment methods suitable for this class. In particular, we have found it challenging to create tasks which are achievable by some, but not all, of our students. In addition, a pre-post comparison of results is problematic because a significant minority of our students enter the course with little programming experience. We will report here on pre-post results from the Fall of 2014. In addition to the source code generated, we collect screen recordings of these assessments in order to help us to understand student errors.

For the pretest, we gave students 30 minutes to complete a programming task. The students were randomly divided into two groups, and students in each group were assigned a different question. Prior to this assessment, we allowed students to familiarize themselves with our laboratory computers by writing a “hello world” program in python in pairs. Students worked on the assessment individually, and were allowed and encouraged to search the internet for help. We chose simple numerical tasks that did not require significant knowledge of python libraries to complete. For brevity, we will report on one problem in the pretest and a matching problem in the posttest. The task we omit showed qualitatively similar results, but several students failed to understand the mathematical nature of the problem in both pre- and post-tests.

In this following summary, we omit one student from both the pre- and post-test, who had previously taken the winter and spring terms of the course, and was thus not representative of a student beginning the sequence. In addition, we omit from the summary one student who is not a physics major, but is a professional programmer.

The first task (shown in Fig. 2) asked students to solve for the solution to a simple definite integral. An expert programmer would perform this integral in two or three lines of code plus an import. This task was given to 8 incoming students, of whom 5 were able to successfully complete the task in a half hour. Of the 3 remaining students, one produced a working program that integrated the wrong integrand. These results illustrate that we had a number of strong incoming students, with a few weaker students.

At the end of the term, we gave a two-hour final assessment. This assessment took the place of the final exam, but students were informed that their grade on the final exam would be based purely on participation. Again, the students were split into two groups, each of which were given a different task. These tasks were chosen to be analogous to those given in the pretest, but more challenging. We report here on a quadrature task analogous to the task described in Fig. 2.

Your task: Write a function $f(z)$ defined by:

$$f(z) = \int_0^z e^{-x^2} dx$$

and plot this function.

Fig. 3. Integral posttest task. Of the 7 students who attempted this task, all were able to write a working quadrature function, albeit in one case with a missing factor of Δx , and in other cases with incorrect behavior when $z < 0$. Of these 7 students, 4 were able to plot their function correctly.

As in the pretest, we asked students to compute a definite integral, but with several complicating factors. Firstly, the upper bound of the integral is a variable, and the students were required to write a function in terms of this bound. Secondly, we asked students to plot this function versus the variable upper limit (see Fig. 3). Students spend much of the fall term performing numeric integration in three dimensions, so this task directly tests material covered in the course. This problem was unusual in that the limits of the integral depend on the independent variable of the plot. In most cases seen in class students were able to pass an array to a function written for scalars to create the plot, relying on the elementwise arithmetic operators and functions implemented in numpy to transparently handle the arrays, as is seen in Fig. 1. In this task however, such an approach will fail, and explicit looping over the coordinate is required. An unanticipated challenge for this task was to write a function that works for values of $z < 0$, which corresponds to “integrating backwards.” While we did not prompt students to plot the function over any particular range, two did plot their results for negative values of z . We chose to interpret as correct solutions that gave correct answers for positive input.

All 7 students assigned this task were able to create a function integrated correctly, although several gave wrong answers for negative inputs. Of these 7 students, 4 were able to plot their results successfully. This demonstrates a considerable learning gain, as all of our students were able to tackle this more challenging integral with a variable bound.

V. CONCLUSION

We have developed a combination of three factors that enables an effective computational physics laboratory course, which fits into students’ heavy course schedules and provides students with valuable programming skills while simultaneously reinforcing physics concepts taught in their traditional courses. This combination consists of pair programming in a computer lab setting, requiring students to search for programming resources on the web, and the choice of python as a programming language. We anticipate that this combination can be effectively applied as a computational laboratory course suitable for any discipline that employs mathematics at a level that students find challenging.

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Interest-driven and innovation-oriented practice for programming course

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Abstract—In order to maximize the motivation of students in the programming practice, this paper offers an analysis on the core factors of practice case motivating students put in effort in programming practice, namely, "interest", "usability", and "hierarchy". Furthermore, we present typical practice cases which are carefully designed according to the motivating factors and give a description on the implementation and experience of our programming practice course at Harbin Institute of Technology. The designed programming practice can not only train the students' practical programming skills but also enhance their self-regulated learning skills, creativity and self-efficacy.

Keywords—programming practice; interest-driven; usability; programming course

I. INTRODUCTION

For the introductory programming course, a large amount of practice is typically required for students to develop good programming skills such as design, coding, debugging skills and so on. But it's commonly hard to sustain unless students are strong self-control or sufficiently motivated. To overcome the natural and inherent learning difficulties created by programming characteristics, an important issue should be put emphasis on: **how do we improve the level of motivation of students to devote themselves to programming practice?**

It is reported by numerous studies that the motivation has a remarkable effect on learning [1, 2]. However, how to prompt students to programming practice poses challenges. Research from many different perspectives has been devoted to the topic, but there is still no consensus on what is the most effective way to raise students' interest and effort in programming practice.

Assignments, labs and projects are typical exercise patterns to train students' practical programming skills. There is no doubt that a series of well-designed labs or projects would be benefit of attracting more attention of students and help them maintain effort longer, which can explicitly and strongly enhance student's practical skills. Different approaches of teaching programming to overcome these problems emerged: pair programming[3,4], game programming[5-8], apprenticeship method[9], test-first approach[10] etc.

In this paper we exact and try to answer the following questions which we believe have significant influence on the quality of practice.

- What kind of labs and projects can maximize the motivation of novice students?
- What format of labs or projects should be exploited?
- How should we evaluate the quality of students' submissions?

The main contributions of the paper include: the core features that "good" practice cases should own are proposed, namely, "interest", "usability", and "hierarchy". We also provide some recommendations on how to design effective programming practice activities and two typical practice cases. Finally, we report the experiences from its application at Harbin Institute of Technology, especially the experience in assigning student new role in project evaluation.

II. MOTIVATION FACTORS IN PRACTICE TASK SELECTION

In order to motivate students to put in effort in programming practice, practice cases should be of some critical properties, including "interest", "usability", and "hierarchy". In this section we will provide detailed explanation on these features.

A. Interest

Interest is an essential factor affecting students learning. Compared with those vapid and dull problems, an interesting and novel project will automatically prompt students to actively put in effort, determination, and focus to work on their goal.

B. Usability

We consider usability as one of the most important characteristics when designing a specific project for students to implement, that means, the programs students submit are not only ones just as assignments but also useful tools they can utilize in real life, that is, it is of value for application or academic research. This point is usually ignored in traditional pedagogical programming course. But the usability enables students to feel real sense of achievement, which improves their self-efficacy and keeps them continuously attracted in the programming practice.

C. Hierarchy

If a project or a lab is considered hierarchical, it means the requirement to solve the problem in the project or lab can be divided into several levels. Foundational knowledge and programming skills are needed for the

basic requirement; while to meet the higher requirement, students have to rouse the facilities they have owned to act. A hierarchical problem makes the problem-solving easier and step by step as climbing a mountain with steps.

In addition, a hierarchical problem should also be open, which guarantees students more freedom and creativity so that they can improve their program according to their own ideas, making it more functional, friendly, or of other good properties.

III. FORMAT OF PROGRAMMING PRACTICE

A. Strategy for programming practice

The aim of programming practice is to develop students' ability in coding, problem solving, self-regulated learning skills and computational thinking. In the design and organization of practice activities, the following strategies should be followed.

1) The programming practice should proceed in an orderly way and step by step. The critical skills are repeatedly exercised until they are fully grasped by students.

2) The programming practice should concentrate on training students' problem-solving ability. The labs and the projects should be attractive for the students, full of interest or practicality.

3) The constraints on the practice should be relaxed as much as possible, which will inspire the creativity of students. For example, students are allowed to choose any format, implement method, tools or functions to perform, design their own process and implement by themselves so that they can independently and actively practice to achieve the self-regulated learning ability.

4) Students should be given enough freedom during the project, which includes several aspects. First, the teacher can provide the selective tasks for practice, and it's free for students to choose one from them or just initiate a new subject only if it is permitted by teachers. Second, students are encouraged to freely choose the implementation path to reach the mile stones with the direction and the inspiration of the teacher. Once the basic requirement is met, student achievement will encourage them to challenge other objectives. Third, students also have the right to freely choose cooperators to achieve a challenging project. Finally, the criterion is changed from the teacher decision to the demonstration and presentation mutually evaluated among the students.

B. Organizations of labs and projects

We divide labs (one 150-minute lab per week) into junior labs and senior labs. For junior labs, we put emphasis on the training of students' fundamental programming skills, such as debugging, common algorithms and problem-solving strategies. For senior labs, higher requirements are brought in so that students need to flexibly apply their knowledge to solve some complex problems. Additionally, they will face some new methods in software development such as incremental testing, which enhances their programming skills as well as computational thinking [11]. For projects, students

need to perform a project in two weeks and they are evaluated by a specific assessment method.

C. Student Requirements

Students are required to be familiar with some types of integrated development environment (IDE) as well as the common algorithms when solving problems by computers. Furthermore, it is necessary for students to utilize constructional and object-oriented programming methods to solve some practical problems, which cultivates their program analysis, design, coding and debugging abilities and helps them to get into a habit of good programming style.

IV. TYPICAL PRACTICE CASES

We present several typical practice cases carefully designed according to the motivating factors: Game of life and the upgraded Gluttonous Snake.

A. Case 1: Lab- Game of Life

Game of life is a cellular automaton proposed by John Horton Conway in 1970. Cells are initialized in an array space and continue to evolve according to a series of specific rules until they maintain steady or all die. Due to its fantasy and rigorous evolution, the game is popular in all over the world and has been exploited as the practical task in programming courses in some universities[12]. Here we provide our revised version of Game of life as a lab task.

● Lab objectives:

After performing this lab, the students should be able to master the syntax of array declaration, array assignments and array initialization, write programs to model repetitive data using arrays, and manipulate the array data structure.

● Background:

Cells live in a world composing of an infinite two-dimensional grid, each of which is in one of two possible states, alive or dead. Every cell interacts with its eight neighbors from 8 directions, horizontally, vertically, or diagonally adjacent. At each time step, the following transitions occur:

1) Any alive cell with too few or too many alive neighbors will die;

2) Any dead cell with a suitable number of neighbors will resurrect;

The system is initialized by the given first generation of cells. Then by applying the aforementioned rules simultaneously to every cell, further generations are created continuously at each discrete moment.

● Task

Subtask 1:

Build up your own cell world and then initialize the positions and numbers of ancestor cells randomly or by user input.

Subtask 2:

Let cell population evolves according to the evolution rules and depict the transition process

Subtask 3:

Judge whether the cell population stops evolution, here if one of the following conditions are satisfied we consider the cell population are steady:

- 1) No changes happen in the cell world;
- 2) Cycle changes happen in the cell world(suppose the length of a cycle is no more than 4)
- 3) Some cells maintain invariant, meanwhile others are in periodic variation.

Subtask 4:

If the cells live in a three-dimensional grid world, can you design an upgraded game of life?

Analysis:

This lab is designed according to the aforementioned design principles. First, the lab topic inherits the natural interest from game of life due to its miracle; Then, the task in the lab is also well divided into several difficulty level to gradually train students to complete more and more complex task. Furthermore, there are sufficient space left for the students preparing to challenge themselves.

B. Case 2:Project- Gluttonous Snake

● Lab objectives:

After performing this project, students can learn the knowledge on object-oriented programming and master the methods of object-oriented programming, and strength their abilities of system analysis, design, coding and debugging.

● Background:

Realize an upgraded gluttonous snake game which could help users to learn English and recite words.

● Task:

Subtask 1:

User's account management: the system can keep a record of user's information, point and rank; meanwhile has the capability to handle the CRUD(create/read/update/delete) management of some personal information.

Subtask 2:

Implement the following game rules:

- 1)foods shown in the window may appear randomly everywhere and the snake updates its location and length timely;
- 2) the player can control the motion of the gluttonous snake by the keyboard, or if the player leaves it alone, the snake will move along;
- 3) when the head of snake reaches a food, the snake "eats" it, at this time, the food disappears, the length of snake grows up, and the player's point increases;
- 4) if the snake's head reaches the boundary of the window or enters into any part of its body, the game is over.
- 5) when the point is above the given value, the player passes the level;

Subtask 3:

Implement the game management function: the player can set various levels of difficulty based on the food-appearing frequency and the velocity of gluttonous snake;

Subtask 4:

Implement the word-reciting function:

- 1) At the beginning of the game, a word is shown to the player;
- 2) Letters randomly appear in the window as the foods of the gluttonous snake, so the player must manipulate the snake to eat the letters in sequence to form the word shown to him/her.
- 3) Once the snake successfully eats off the word, the player's point will increase.

Subtask 5:

Implement the extra word-reciting function:

- 1) The word list is randomly extracted from a word file in disk.
- 2) Only if user's snake eat off all the words in the word list, the player passes the current level.
- 3) With the game ranking increasing, the level difficulty of words increases.

Analysis:

The highlights of the project exist in two aspects: it is originated from the classic computer game "snake", most of students are very familiar with the game but never try implementing it, which easily raises students' interest; Further, the tasks are also divided into several levels of different difficult degrees. For those students with weaker programming skills, subtask1, subtask2 and subtask3 are suitable for them to strengthen their fundamental coding and debugging skills; for students preferring to challenging themselves, they will face with more complex and difficult tasks in subtask4 or higher. Finally, the idea behind the updated Snake with English learning is to combine the preliminary game develop with English words recitation, which is especially suitable for non-English undergraduates. The project enables students to make use of their own small software to learn English words as well as relax themselves.

V. PEDAGOGICAL RESULTS IN HARBIN INSTITUTE OF TECHNOLOGY

In this section we will give a description on the implementation and experience of our programming practice course in Harbin Institute of Technology.

A. Practical teaching syllbus

Considering the characteristic of our local institution and undergraduates, we present an updated teaching curriculum and lab curriculum for C Programming Language course in relation to CS2013 recommendations[13,14], highlighting the development of the students' abilities on programming, problem-solving, self-regulated learning, and computational thinking. The practical course syllabus and corresponding knowledge coverage based on CS2013 is listed in table 1.

B. Student works

Here we provide several typical students' submissions from different tasks, which are shown in figure 1, 2, and 3.

TABLE I. KNOWLEDGE COVERAGE

Lab/Project	task	Knowledge unit and topics covered in CS2013	Features
Lab	Number-guessing game	SDF/ Fundamental Programming Concepts/ Basic syntax and semantics of a higher-level language; Variables and primitive data types; Expressions and assignments; Conditional and iterative control structures;	Interest; Hierarchy
Lab	Game of life	SDF/ Fundamental Programming Concepts/Arrays; Pointers; Functions and parameter passing; The concept of recursion.	Interest; Hierarchy
Lab	Strong password generator	SDF/ Fundamental Programming Concepts/Strings and string processing; SDF/ Algorithms and Design/ The role of algorithms in the problem-solving process;	Interest; Usability; Hierarchy
Lab	Class attendance test tool	SDF/ Fundamental Programming Concepts/ Functions and parameter passing; The concept of recursion. SDF / Development Methods/Defensive programming.	Usability; Hierarchy
Lab	Upgraded game of life or class attendance test tool	SDF / Development Methods/Debugging strategies. Object-oriented programming PL /Object-Oriented Programming / Object-oriented design; Definition of classes: fields, methods, and constructors.	Interest; Usability; Hierarchy
Lab	Personal financial management software	SDF / Fundamental Data Structures/ Records, structs; Strategies for choosing the appropriate data structure; file I/O. SDF / Development Methods/ Unit testing.	Usability; Hierarchy
Project	Intelligent schedule	SDF / Fundamental Data Structures/ Records, structs; Strategies for choosing the appropriate data structure; file I/O. SDF/ Development Methods/ Unit testing; Debugging strategies;	Usability; Hierarchy
Project	Encryption machine	SDF/ Algorithms and Design/ The role of algorithms in the problem-solving process; Problem-solving strategies; Fundamental design concepts and principles; SDF/ Development Methods/ Program correctness; Debugging strategies; Documentation and program style	Interest; Hierarchy
Project	Gluttonous snake game	PL /Object-Oriented Programming / Object-oriented design; Definition of classes: fields, methods, and constructors. SDF/ Development Methods/ Unit testing; Debugging strategies; Modern programming environments.	Interest; Usability; Hierarchy
Project	File Compression	SDF/ Algorithms and Design/ The role of algorithms in the problem-solving process; Problem-solving strategies; Fundamental design concepts and principles; SDF/ Development Methods/ Program correctness; Debugging strategies; Documentation and program style SDF/ Development Methods/ Program correctness; Debugging strategies; Documentation and program style	Usability; Hierarchy

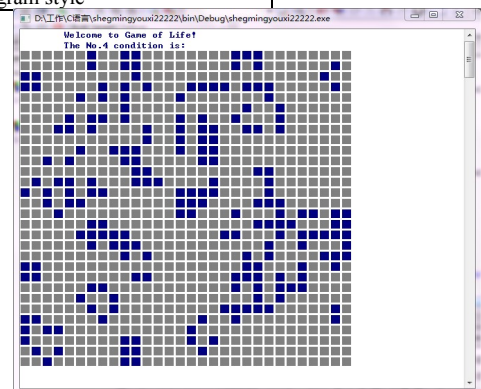
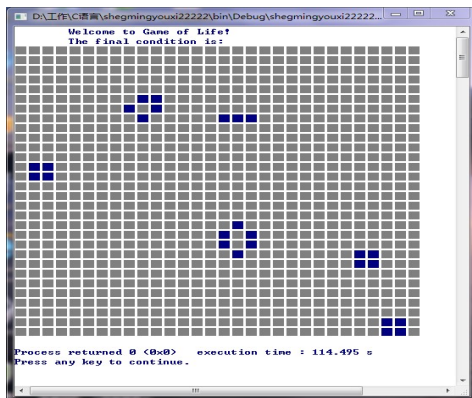


Fig. 1. Game of Life implemented in C.

The submission for Game of life is capable of the following extra functions: 1) users can change the evolution rules by input; 2) the system can automatically judge whether the evolution has stopped and once it is confirmed, the calculation will be terminated.

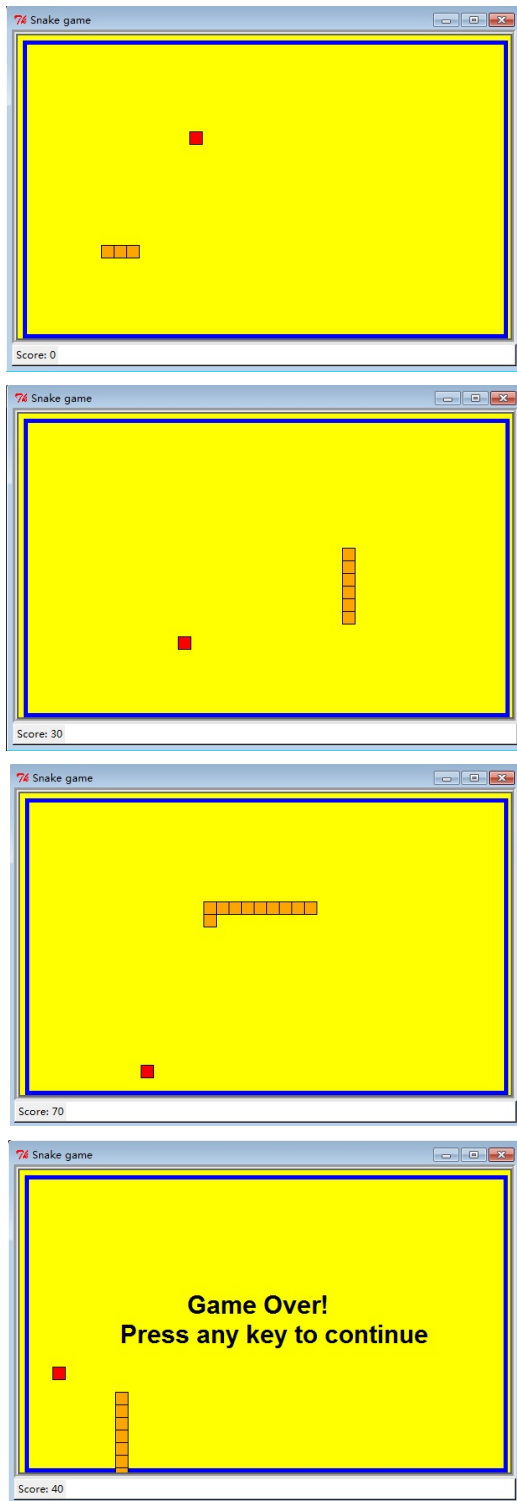


Fig. 2. Snake implemented in Python.

Figure 2 shows the work of a student who had faced with difficulty in programming. Through his great effort he performed 2 subtasks in 3 all in the given 2 weeks.

C. Student's new role in project evaluation

To motivate students to actively take part in the programming practice, we exploit a novel project assessment method by creating a new role for each student, a judge. When a team is making a presentation and defending for their own project, all other students take responsibility for assessing the project and giving scores from different aspects (shown as table 2). The weighted average scores are considered as the final score of a team. Besides, to avoid the possible injustice such as overestimating or underestimating because of emotional reasons, we eliminate those singular scores before calculating the final scores. Figure 3 depicts a score distribution to a submitted work "Encryption machine". 44 students and a teacher and a teacher assistant took part in the scoring activity. The final score calculated according to the following equation.

$$s = \left(\frac{w_1}{N} \sum_{i=1}^N s_i + w_2 s_T + w_3 s_{TA} \right) \quad (1)$$

Where w_1, w_2, w_3 are weight of student judge, teacher and teacher assistant respectively, N is the number of those effective scores s_i from student judges (without singularities), s_T denotes the score provided by the teacher, s_{TA} by the teacher assistant. In our application, we set $w_1 = 0.6, w_2 = 0.25$ and $w_3 = 0.15$.

TABLE II. SCORING ITEMS FOR PROJECT

item	technical difficulty	innovation	function	presentation	collaboration
score	10	10	10	10	10

TABLE III. SCORE DISTRIBUTION FOR WORK "ENCRYPTION MACHINE"

item	score
average score and variance from student judges	34.86(5.05)
score from teacher	32
score from teacher assistant	34
final score	34

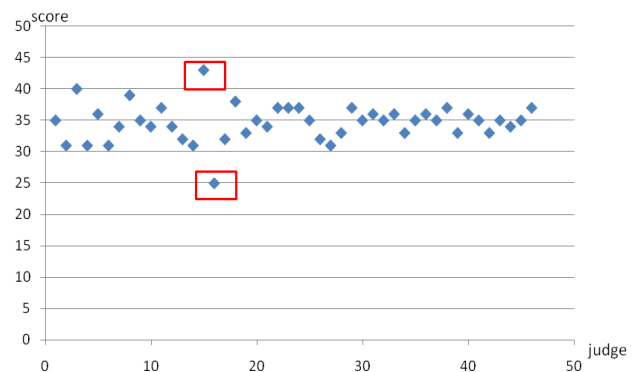


Fig. 3. Score distribution for a submitted project. Points in rectangle are singular.

D. Student response

The failure rate of the students in this course is listed in table 4. Compared with the failure rate of 2014, it can be found that the failure rate decreases significantly.

TABLE IV. STURENT FAILURE RATES IN PROGRAMMING LANGUAGE COURSE

term	student number	failure rate
2014-Spring	131	16.03%
2015-Spring	123	9.75%

Students prefer the improved labs and projects to the traditional ones. Many of them indicated that on course evaluations:

“I feel it’s no longer difficult for me to implement a lab, although sometimes I can’t finish all tasks, I still solved most of them.”

“I like those interesting subjects, they are awesome!”

“I really like the project style, especially we can do what we like to do. We chose a challenging problem and made a lot of improvement by ourselves and also learned something new during the project performance. It is really important for me.”

VI. CONCLUSION

Based on the analysis of the features of good practice pattern and content, we provide some recommendations and descriptions on our experience during the building of students’ programming capability. Considering the characteristic of our local institution and undergraduates, we reorganized and redesigned the labs and projects for programming course, which highlights the development of the students’ abilities on programming, problem-solving, and computational thinking. The designed programming practice can not only train the students’ coding skills but also enhance their learning skills, creativity and self-efficacy as well as boosting their confidence in challenges in the field of computer science and software development in future.

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Flipping a Programming Course: the Good, the Bad, and the Ugly

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Abstract — In the traditional form of teaching and classroom organization, lectures are given in class, and tests and examinations are given in class. The major drawback of this approach has been the difficulty of getting the students engaged in a traditional lecture. A computer science course in programming seems to be a natural class to implement a flipped classroom approach: individualized pacing for theory with cohort based skill acquisition. A flipped classroom is a form of blended instruction where students learn course content outside of the classroom and either homework or other forms of active learning activities occurs in the classroom. Herein is a summary of our observations based on several semesters of implementing a flipped classroom and report on observations made. There are numerous advantages to flipping a class such as allowing for more interaction during the face-to-face class meetings; it also allows for deeper learning to take place as students get their hands-on practice. We explore these practices and more, and compare and contrast what worked and what didn't work from our experiences. We also identify procedures critical to success and what procedures we view as less important.

Keywords—*flipped classroom; programming course*

I. INTRODUCTION

The first programming course discussed herein is a four-credit class which has traditionally been a three-hour lecture and a one-hour laboratory course. The course starts the student from the basic concepts behind programming such as the use of constants and variables all the way to the use of arrays, one-dimensional and multi-dimensional. It is a first course of a two-semester introductory sequence that covers the fundamentals of algorithmic problem solving. The typical audience for the course is first- and second-year students mostly in computer science and engineering. The course emphasizes general programming methodology and concepts common to object-oriented and procedural programming languages: algorithms, top-down structured program design, modularity, efficiency, testing and debugging, and user-friendliness. Java is used and the object-oriented paradigm is covered, including classes, objects, access control, abstraction, and encapsulation. Other topics include organization and hardware, input and output, subprogram units (methods), fundamental data types, reference types, control structures including conditions and iteration, and arrays.

II. THE FLIPPED METHODOLOGY

In the traditional form of teaching and classroom organization, lectures are given in class, and tests and examinations are taken in class [1]. Students are given homework which are completed outside of class. In a flipped classroom, some or all of this traditional methodology is reversed. A flipped classroom is a form of blended instruction where students learn course content outside of the classroom and either homework or other forms of active learning [2] [3] activities occurs in the classroom. The course content may be delivered by assigning readings from textbooks, watching and listening to videos prepared by either the instructor or a third party, or any combination of the two. In the classroom, students apply the knowledge they have read or watched by doing hands-on, practical work. The instructor is in class to guide students while they implement what they have learned outside of class. The continuous assessments (quizzes) of the students [4] [5] given outside of class are useful to spot trends which can be addressed in class as a “mini-lecture” or outside of class in a directed quiz-lecture (“quecture”). The quecture is a sequence of questions which guide the student in the review of a video or paper.

III. MOTIVATIONS FOR FLIPPING

Several motivations have driven us to flip our classes:

- Flipping liberates class time which can be used to address specific concerns and establish a “learning cohort”
- Students’ desire to be “doing” rather than “listening”
- The proliferation of technical tools such as recording videos, course management systems, and video hosting sites.

One of the main forces that has driven us to flip our computer science course is to procure more contact hours with the students doing actual programming. We all know that the more practice students have, the better they get at forming algorithmic solutions and implementing those solutions. Freeing up the class from lectures gives us this freedom to use our time dedicated to active learning. The time in class may

be one of the few times the students are able to interact and create a group to discuss concepts. The best students establish these cohorts early in the course, but it is hard for some students to create this network independently. Also, small corrections to bad programming practices, when caught early, can help develop good habits.

At the same time, students prefer to be “doing” rather than passively listening to a lecture given by the instructor. It is a lot easier to motivate the student when they are working on writing code than lecturing and perhaps quizzing them orally on the concepts in between lecture topics.

Another driving force towards this pedagogical approach is the proliferation of tools to help us create videos and manage course content such as Blackboard. As of recent, it has become easier to create your own videos whether it is simply narrating over prepared slides or recording a screen capture. Course management systems (Learning Management Systems) are also hosted at most universities allowing us to easily upload videos, create on-line quizzes and tests, and disseminate other electronic course materials to students.

All of these factors have been the impetus for making this flipped methodology both desirable and a possibility.

IV. THE FLIPPING APPROACH

Certain activities are delegated and required to be accomplished before class, some activities reserved for class time, and others for after the class. Candidates for pre-class activities are those in which one would be simply “broadcasting” to the class.

A. Before Class

Lecture videos are created by the instructor the content of which mimics the textbook content. Each chapter is broken into either 2 or 3 segments. Students are asked to either read the textbook or listen to provided videos. Original content can be supplemented with numerous online sources which provide rich interactive lectures with self-assessments. Care must be taken not to overwhelm the students with numerous sources.

To make sure students read or watch the material, quizzes are given before and outside of each class. The main purpose of these assessments is to make sure that students actually read or watch the course materials prior to class. From our experience, a simple randomization of fill-in-the blank questions is sufficient to curtail rampant cheating if the quizzes are given outside of class.

We have found a very high correlation of pre-class assignment completion and class attendance and use these assessments to take attendance.

B. During Class

During class time, laboratory work that correspond to the material assigned are given to the students. For example, if the lesson assigned for the class is on writing conditional statements using if-else, a laboratory that has the students write the code to find the roots of a quadratic equation (stating whether or not there is one root, two unique roots, or no roots)

might be assigned. Most of these labs are assigned to student pairs where a couple of students are grouped and the two student cohorts are expected to work together. These labs are assessed as well after they are submitted.

Tests and examinations are also given in class to ensure that students are assessed on the knowledge they have gained. These generally count for a larger percentage of their final grade.

C. After Class

After the lesson(s), a more challenging assignment is given on the topic and students are expected to work on these on their own.

A summary of the flipping approach and task distribution:

Before Class	<ul style="list-style-type: none"> • Read textbooks and/or watch video lectures • Take a short quiz after reading/watching
During Class	<ul style="list-style-type: none"> • Laboratory activity reinforcing material read/watched • Take examinations
After Class	<ul style="list-style-type: none"> • Complete assignment to reinforce topics learned

V. FLIPPING EXPERIENCES

We have implemented the flipped approach for several semester now and, over time, have honed some of the procedures around this technique. Here we present our observations and we group them based on the student’s and the instructor’s perspective. We also classify our observations based on benefits (good), harsh reality (bad), and the unpleasant (ugly). The results shown below are gathered through observations and direct feedback from students via conversations and questionnaires.

A. The Good

From the students’ perspective, the flipped approach gives them a chance to actively learn in class as opposed to passively listening to a professor lecture. This is a great incentive for those who truly want to learn. It is a chance to practice what they’ve read/watched. For those students who watch the video lectures, they have the option of pausing and replaying material that are more difficult. On the contrary, if an advance student picks up the material easily, they can fast forward or skip certain content material. Using pair programming as a cohort system, students have a chance to learn from each other as they collaborate on the same design, algorithm, and code.

As was mentioned earlier, this approach buys the instructor that precious time in class. It frees the instructor from lecturing passively, talking to the class rather than interacting and checking out students’ progress. This is possible because learning the syntax and definition of terms (shallow learning) has been delegated to before-class activity. Class time is now

spent creating a deep and active learning environment for the students.

B. The Bad

All this means that the student has to be proactive with their class, knowing what the material to be covered is ahead of class. As students watch videos or read the book, any difficulties are not addressed immediately but they typically wait until class meets to resolve them rather than reaching out for help earlier.

As quizzes are given outside of class, there is no supervision so there is no guarantee that the student is not getting external help in answering assessment questions. Another hurdle is that in order for the active learning to occur in a programming classroom, the room need to be equipped with enough computers for students.

A pathway for the more advanced students to bypass work or assessments designed to keep less motivated students in pace with the course must be provided, otherwise these students may underperform.

C. The Ugly

Since students do their reading/watching before class, this implies that students spend more time dedicated to the course than usual since there is also homework to complete after class. Another big difficulty is that students need to be self-motivated to complete all the pre-class work in order to succeed. This has proven to be the biggest challenge in our flipped classroom, as it is in a traditional classroom.

For the instructor, there is lot more preparation required. In addition to creating laboratories, assignments, quizzes, tests, there are lecture videos. Creating videos, as an activity, may not necessarily be a quick task; similarly, looking for appropriate, third party video material is also time-consuming. There is more grading involved since all the contact time generates student work; assessing these have proven to be time-consuming as well.

A summary of the good, the bad, the ugly:

	<i>Student's Perspective</i>	<i>Instructor's Perspective</i>
Good	<ul style="list-style-type: none"> Students write programs, instead of listen to lectures Student may pause video lectures or repeat sections Advance students may "fast forward" Peer and collaborative 	<ul style="list-style-type: none"> More personal contact between instructor and students Shallow learning occurs outside of classroom (syntax, terminology, etc.), Deep and active learning in class

	learning possible	
Bad	<ul style="list-style-type: none"> Students need to actively get ready for class Lecture questions have to wait 	<ul style="list-style-type: none"> Quizzes outside class, no supervision Need a classroom in a laboratory setting
Ugly	<ul style="list-style-type: none"> More work (videos + assignments) Need to be self-motivated to learn material 	<ul style="list-style-type: none"> Prepare lecture material (videos) Prepare classroom activity (lab work) More grading

VI. CONCLUSION

While a few educators still resist the change from the traditional pedagogical approach, many of us are embracing this new trend. Not every course or classroom is suitable for flipping. Our experience tells us that a course in programming is one course that is ideal for implementing a flipped approach. This is especially true when students have personal computers staring right at them throughout an entire class period; resisting the temptation to wander on the Internet rather than listening to a lecture is quite challenging. Turning this around by making the students actually use the computers and having a "lab day" every day dovetails with students' yearning for being hands-on. Learning definition and syntax are delegated to activities before class, while active and deeper learning takes place in the classroom for a rewarding experience, both for the students and the instructor.

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Enhancing Object-Oriented Programming Education using Static and Dynamic Visualization

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Abstract— While Object-Oriented programming in Java has been widely adopted as an introductory programming course in Computer Science, it is considered difficult to teach and learn. Studies have identified that the difficulty is from the underlying Object-Oriented concepts and principles. To help student programmers better understand the structure of a program and the concepts of Object-Oriented design, visualizations in various formats have been applied to programming environments.

This paper presents a web-based interactive educational programming environment, Javlinacode, and its unique design principles. Javlinacode is designed for teaching object-oriented programming in Java. It aims to enhance student programmers' programming skill and to help them understand object-oriented design concepts. It provides integrated static and dynamic visualizations: the static state of a Java program in an UML class diagram and the dynamic run-time state of the program execution. With the synchronized multi-view real time visualization along with source code, Javlinacode is highly expected to reduce student programmers' cognitive workload in Java programming and to enhance comprehension of the object-oriented programming and design concepts.

Index Terms—object-oriented programming, programming education, static visualization, dynamic visualization

I. INTRODUCTION

Brian Kernighan stated, "No matter what, the way to learn to program is to write code, and rewrite it, and see it used, and rewrite again. Reading other people's code is invaluable as well" [1].

In the process of learning Object-Oriented Programming (OOP) in Java, difficulties including programming language syntax, programming environment, and problem solving skills, have been commonly mentioned. Although Java is one of the most popular programming languages taught at universities and colleges, studies have discovered that it is difficult for students to learn due to the underlying OO concepts and principles such as encapsulation, abstraction, inheritance, and polymorphism. With inheritance, polymorphism, and dynamic binding features, objects in OOP typically interact with each other asynchronously and method calls are difficult to track. Comprehension of the functionality, structure, and behavior of a program is a crucial component of the programming learning

process. OO programs are known for being complex to visualize and their control flow difficult to follow making the learning process challenging.

A student's development environment is another factor that influences learning OOP because it requires students to manage issues such as platform dependencies and conceptual understanding of classes, objects, and Object-Oriented Design (OOD). It also appears that software visualization tools are seldom employed in the OOP development environment. This is because current tools visualize a single aspect (i.e. structure or behavior) of the software. As a result, visualizations from these tools are not enough to support the understanding of OOP.

In order to address the limitations of current visualization techniques, an approach is proposed to integrate abstraction along with structure and behavioral aspects. Many programming environments that provide graphical visualization have been developed to help students enhance OOP learning. While those are used in conjunction with source code, code writing is still a programmer's responsibility. Studies have pointed out students encountering difficulties in installing an IDE and JDK, and modifying system environment variables on their own machines. Somehow make clearer that this is not an issue with Javlinacode since it is web-based.

The aim of this research is to enhance OOP education by improving the effectiveness of OOP development environments with static and dynamic visualization. The motivation for this work is the lack of an interactive OOP environment integrated with both static and dynamic visualization. A static class diagram is generated from the static information which is derived from source code. Dynamic tracing visualization is generated from the dynamic information of the program execution. When polymorphism is taught using class diagrams, sequence diagrams, and source code, students need to simulate running the program in their minds to understand how it works. As the combined visualization of both static and dynamic aspects suggests [2], visualizing the dynamic run-time state in corresponding to the source code and static diagrams will reduce the burden of a complex simulation in students' minds.

JavelinaCode provides integrated static and dynamic visualization of Java programs at line level and a full overview of a project under development. This interactive hybrid visualization approach is expected to help students to better understand current code and to choose the right design alternatives. The research hypothesis explored in this paper is whether an interactive static and dynamic visualization that incorporates structural and behavioral views supports OOP comprehension in an OOP development environment.

II. COMPARING VISUALIZATION SYSTEMS

This section compares some programming environmental tools based upon how the OO features are highlighted in the visualization. Unlike JavelinaCode, these tools must be downloaded and installed as a stand-alone program, or plugged into Eclipse (AguiaJ) or NetBeans (CoffeeDregs).

A. BlueJ

BlueJ is an integrated software development environment targeted on novice programmers [3]. It allows programmers to interact with objects by inspecting their values, calling methods, and passing them as parameters. The strengths of using BlueJ include the ability to help students link source code and visualizations and the ability to support learning in the cognitive domain. Evaluation studies revealed that BlueJ is good for students in the first year object-oriented programming course due to its simplicity and pedagogy [3, 4] and it helped students to understand the object-oriented paradigm [5].

Hagan et al. report that students who participated in the experimental study had difficulties with installing and running the BlueJ system [6]. BlueJ does not place emphasis on communication between objects or illustrate the association or aggregation of classes [17]. Linking Java source code and its UML class diagram visualization is done in separate windows which makes it hard to find the correspondence among them.

B. CoffeeDregs

CoffeeDregs is an educational visualization tool of executing Java programs aiming to teach OOP and to build a conceptual semantic model through the visualization of the connections between static source code and dynamic execution in objects [7]. CoffeeDregs claims that visualizing the state of program execution helps programmers better understand certain behaviors of the code. From the qualitative experiments to assess its educational effectiveness, CoffeeDregs was found to be beneficial for students learning OOP [8]. However, the study also shows that the correspondence between source code and run-time execution visualization is not directly recognizable, in particular to trace instance variables and method arguments when fixing a problem.

C. Jeliot 3

Jeliot 3 is a program visualization tool designed to help novice students learn both procedural and OOP with the basic production of algorithm animation for the data flow of variables and the supporting visualization of control flow and expression evaluation [9]. Jeliot 3 helps students and teachers in sharing graphical and verbal vocabularies with animation

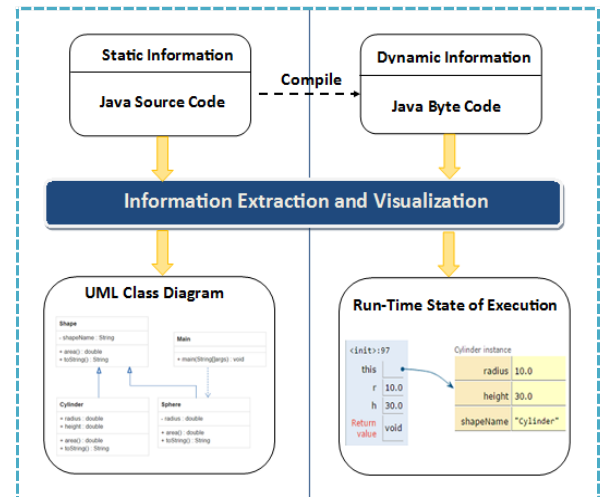


Fig. 1 JavelinaCode system overview

visualization that makes it easier to discuss programming concepts [8]. A qualitative investigation found that the animation of Jeliot 3 is easy to use and useful for students to debug programs [9]. However, other experimental studies report that the use of Jeliot 3 does not show any significant difference on students' attitudes toward OOP [10], and Jeliot 3 animation is difficult for novice student programmers to understand. It is suggested to add verbal explanations to the visual animation which might optimize students' understanding with the combination of graphics and audio or textual captions [11]. As the length of code and its complexity increase, visualization becomes difficult to understand and objects are sometimes overlapped which makes it more challenging to follow the program execution.

D. AguiAJ

AguiAJ is a pedagogical tool for interactive experimentation and visualization of OOP in Java [12]. AguiAJ greatly illustrates OOP concepts (encapsulation, interface, polymorphism, and inheritance) by showing and hiding private instance variables, indicating inherited members and overridden operations, and the usage of image domains [13]. Evaluation of AguiAJ reveals positive impacts on training in terms of suitability and visualization of the images used. It was concluded that AguiAJ is usable for interactive lecturing [13].

While AguiAJ supports an instant change between source code and object illustration, it is hard to map them together because the editor window and the visualization window are not visible simultaneously. The user must switch between windows.

III. JAVLINACODE

JavelinaCode is a web-based interactive and educational programming environment for enhancing program comprehension in OOP. It aims to enhance student programmers' programming skills and logical thinking, and to help them understand OOD concepts. This section describes

JavelinaCode by featuring its system overview, user interface, design principles, and implementation.

A. System Overview

Fig. 1 gives the system overview of JavelinaCode. A student accesses JavelinaCode through a front end web browser. Java source code created by student is sent to a back end server. From the source code, static structural information such as instance/class variables and their types, methods and parameters, and the relationships among classes is extracted and visualized in a UML class diagram. From the Java bytecode translated by the Java compiler on the server, dynamic functional information such as the values of the instance/class variables is extracted and the dynamic run-time state of the program is visualized.

B. User Interface

The user interface of JavelinaCode is presented in Fig. 2. The user interface consists of four main components: a static UML diagram area (a), an editor area (b), a dynamic run-time state visualization area (c), and an input/output console area (d). The editor area displays the active Java code a student user is currently working on, and, by selecting a tab, the user will be able to create multiple Java or text files and to add them into a project. When a new class is added, the default code representing the basic structure of a class is generated for the user to start immediately making changes to the existing code. For each line of code, its corresponding structural information will be highlighted in the class diagram and the functional information of data is synchronized in the run-time state visualization. Two sets of UML diagrams are also generated in (a): one for the active Java program in the editor and the other for the whole project. When an enlarge icon in area (a) is clicked, a detailed UML diagram for the project will be displayed as illustrated in (e).

C. Implementation

JavelinaCode is being developed on the AWS (Amazon Web Services) cloud computing platform on the back end virtual server running the Ubuntu 14.04 LTS operating system, Apache 2 HTTP server, and MySQL database server with php5 and Java 8 installed. Also, PhpMyAdmin is used to handle the administration of the MySQL and to interact with its databases for managing users and project files.

JavelinaCode is being implemented with a front end written in HTML5, CSS3, and jQuery and a back end written in PHP. Ace, an embedded open-source code editor, is fully integrated into the environment [14]. For the run-time state visualization of program execution, the Java Visualizer by David Pritchard and Will Gwozdz [15] based on the Online Python Tutor [16] by Philip Guo is fully integrated into the interface. The Java Visualizer reads Java source code as input, traces the Java bytecode data (objects, methods, and variables) translated by the compiler using Java debugger, and outputs the trace in JSON format for the front end visualization. Information of the abstract design of the Java source code is extracted to draw the UML class diagram.

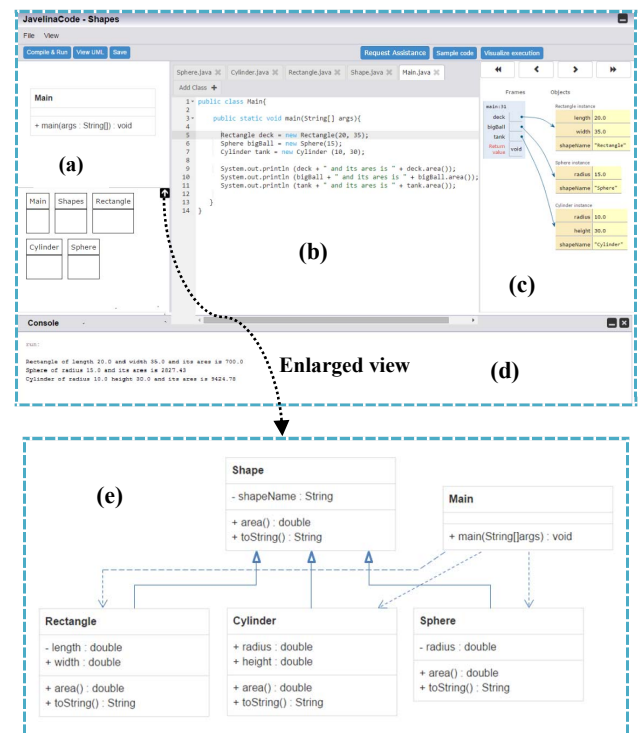


Fig. 2 Screenshot of JavelinaCode and UML class diagram

D. Design Principles

For the best practice of OOP and OOD, JavelinaCode is designed with the following principles: 1) *Easy to Access*, 2) *Easy to Use*, 3) *Easy to Understand*, 3) *Source Code and User Centered*, 4) *Static Visualization of Structural Information of a Program*, 5) *Dynamic Visualization of Functional Information of Data*, 6) *Static and Dynamic Visualization together*, 7) *Synchronized Multi-View along with Source Code*, and 8) *Structural and Functional Feedback in real Time*.

JavelinaCode is platform-independent. Students use a web browser to develop and run a Java program without any required software or plug-in installation. They are able to program anywhere and anytime using their laptops, desktops, tablets, and mobile phones. The project files created by a student are saved on the cloud storage. The student does not need any kind of memory systems to keep and manage the data. The student is free of concern with continuous version changes and evolutions to the Java language, IDEs, plug-ins, and operating systems. This provides a great deal of accessibility and usability to the program development environment. JavelinaCode will be further developed as mobile applications that run on both iOS and Android.

JavelinaCode is both source code and user centered. When a student writes a line of code, the corresponding structural information of the program is dynamically linked with the two sets of UML class diagrams and the functional information of data is synchronized in the run-time state visualization. Real time feedback of the current line of the code will be immediately given to the student. The links will be highlighted when the user hits the 'Enter' key after completing the line,

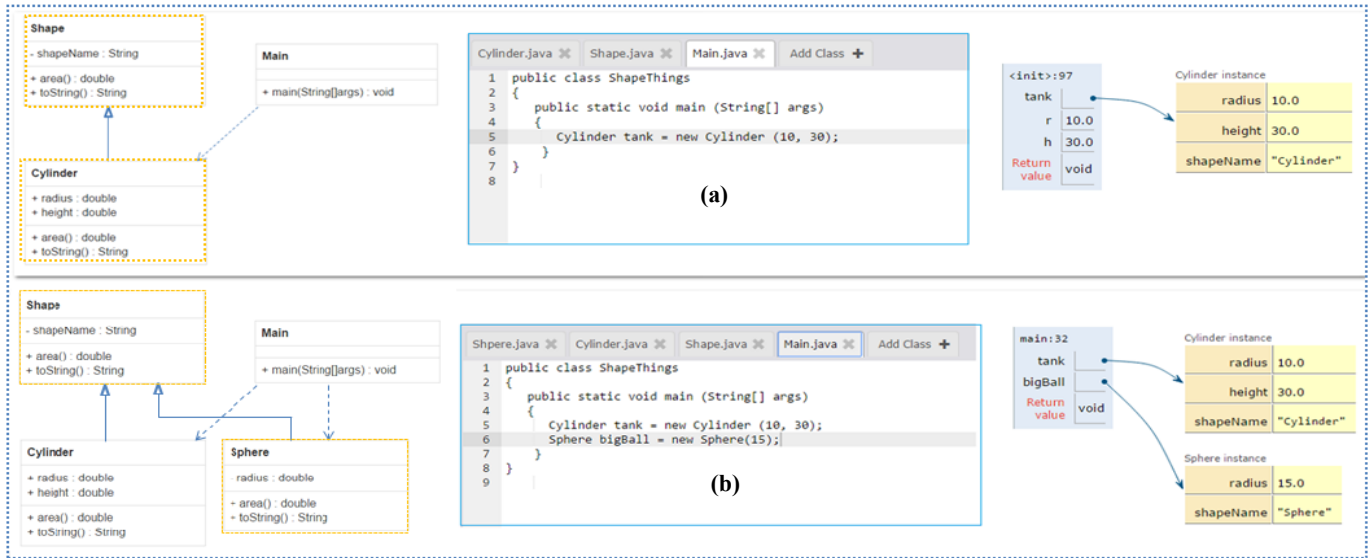


Fig. 3 Modeling example linking source code with static and dynamic visualization

such as variable declaration and/or initialization, method declaration, or expression. This will greatly help the student establish the mental model of program execution [17]. Fig. 3 illustrates the modeling example of linking and highlighting a line of code with its static and dynamic changes in visualization.

IV. MODELING EXAMPLE

The modeling example of JavelinaCode is presented in Fig. 3. In the example, the UML notation and the run-time state are instantly changed when a line of code changes. Upon the complete implementation, JavelinaCode will fully support all functionalities described here.

The running example involves three classes having inheritance and polymorphism relationships: Shape as a parent (super) class and Cylinder and Sphere as children (sub) classes. As illustrated in (a) of Fig. 3, after the Shape and Cylinder classes are defined with inheritance and an object of Cylinder is created in the testing Main class, its corresponding UML class diagram on the left indicates the inheritance relationship between Shape and Cylinder and association between Main and Cylinder.

The values of the Cylinder object are assigned to the instance variables, which are also visualized as the run-time state on the right. As shown in (b) of Fig. 3, when a new Sphere class is added and an object is created in center editor, the UML diagram also instantly changes showing the new inheritance relationship between Shape and Sphere and the association between Main and Sphere. The values of the instance variables of the Sphere object are also illustrated in the dynamic visualization.

V. CONCLUSION AND EVALUATION PLAN

This paper has demonstrated JavelinaCode, a web-based interactive educational programming environment, which proposes an approach to support programming in Java

providing both static and dynamic visualizations in a real time multi-view model. The main contributions of JavelinaCode are: a) Students use a web browser to run a Java program without any required software and plugin installation or configuration on a local computer. They are able to program anywhere and anytime using their laptops, desktops, tablets, or mobile phones. b) Students do not need any kind of memory systems to keep and manage project files. They are free of concern with continuous version changes and evolutions of the Java language, IDEs, plug-ins, and operating systems. c) JavelinaCode will help students establish the mental model of program execution along with the source code of a program. d) With the synchronized multi-view real time visualization along with source code, JavelinaCode is highly expected to reduce students' cognitive workload in Java programming and to enhance comprehension of the OO concepts such as inheritance, polymorphism, and OO design.

To evaluate its educational effectiveness, both qualitative and quantitative experiments will be conducted. The experimental studies will be designed to correlate student users' usage and performance in OOP and OOD by comparing the results of the data from a group of users using JavelinaCode and a group of users using a standard IDE. Accordingly, the following two null hypotheses are formulated:

- H1: Having JavelinaCode available does not impact the time of problem solving.
- H2: Having JavelinaCode available does not impact the correctness of the program comprehension.

While the experimental group uses JavelinaCode featuring the synchronized static and dynamic visualization, the other controlled group uses a standard IDE such as Eclipse or NetBeans in order to answer the questions. We may claim that the availability of JavelinaCode will reduce the amount of time taken to solve and answer the comprehension questions and increase the correctness of the solutions.

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Wireless Cybersecurity Education via a Software Defined Radio Laboratory

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Abstract—Cybersecurity is one of the fastest growing concerns in the world today. Recent global events show the need for more strict measures to protect the public from cyber attacks, which has triggered an increased demand for cybersecurity professionals. Many academic institutions began offering courses covering current cybersecurity concepts to satisfy this need. Although these courses educate students with proper skills, they lack the connection to current advancements in academic research. A more encompassing curriculum is needed in this rapidly growing field. For the most up-to-date education, we developed a course that takes a student-centric hands-on approach supported with Software Defined Radios to study current cybersecurity research projects in wireless networks. Our course consists of short lectures followed by lab sessions, where students implement security algorithms described by standards or by recent peer-reviewed research articles. Our results indicate that students appreciate the mixture of textbook and research topics being covered in the course and they feel more prepared for any future task in the cybersecurity field. While deviating from the textbook applies additional strain to educators, our paper shows that including current research practices in curriculum development efforts is a good investment towards a better educational outcome.

Keywords—*engineering education; curriculum development; data security*

I. INTRODUCTION

The amount of data that is being transmitted over the Internet is growing rapidly every day. The modern lifestyle is shifting users towards having multiple devices connected to each other and the Internet, which comes with the natural tendency to complete daily tasks online and share more information on social media sites. According to Youtube, one of the most popular video streaming services, “300 hours of video are uploaded every minute” into their servers [1]. As more of our daily lives shift from being face-to-face transactions to online encounters, the vulnerabilities of the Internet are being

realized. Global news shows that the information put into the Internet is not as secure as it should be.

With the increased need for Cybersecurity, the demand for professionals in this field is increasing. Many academic institutions started offering courses, certificates, and now even majors in Cybersecurity [2]. We have also started seeing initiatives from government agencies and private companies to raise awareness and attract more interest in Cybersecurity [3]–[5]. PBS NOVA Labs is offering an educational digital game, which introduces Cybersecurity basics, that can be played from any computer with an Internet connection [6].

In addition to offering students more hands-on modules, educators continued to look for additional tools that will support these labs and projects. There has been a growing interest in integrating Software Defined Radios (SDR) with hands-on course modules because of their flexibility. Initially, signal processing courses started taking advantage of them [7] for running labs covering topics such as modulation, encoding, and filtering. As their popularity increased, platforms such as GNURadio Companion [8], and OSSIE [9] emerged to offer visual development tools. These tools allowed students to create a signal, process it, and send it via the SDR. However, they lack key details pertaining to the hardware implementation aspects of SDRs. On the other hand, Computer Engineering and Software Engineering courses focus more on the hardware implementation portion and do not emphasize the signal processing capabilities of SDRs [10]. In this paper, we merge the gap between the SDR hardware implementation, signal processing and radio capabilities, and discuss a multi-disciplinary course that leverages SDRs to introduce wireless cybersecurity to students.

In order to provide up-to-date materials to our students, we developed a student-centric, SDR based wireless security course, where we support traditional textbooks with current research practices. Some of the

topics covered in our course are packet detection [11], eavesdropping and man-in-the-middle attacks [12], and encryption techniques including Physical-layer security [13]. During the labs, students are encouraged to implement various attack mitigation techniques on SDRs, which requires them to use hardware design techniques, along with signal processing concepts, and to comment on their findings. Grading is done by checking the validity and strength of their solution.

In [14]–[16], the authors discuss the benefits of offering a student-centric learning experience, which is especially preferred when the course is related to technology. In the recent years, this approach has been augmented by several others to include competition between students [17]–[19]. Our course tries to combine the benefits of both student-centric and game-based learning styles. We developed our labs to give our students as much experience as possible with the current SDR and security topics. We also created a wireless *hacking* competition as their final project.

In this paper, we discuss the use of SDRs in teaching wireless cybersecurity and the effectiveness of bringing research into the classroom in terms of student acceptance and success. We organize this paper as follows: In the next section, our course logistics and methodology is discussed. Section III then goes into details of the specific course modules we developed. In Section IV, we present a case study and investigate the specifics of one of the lab modules. Section V provides a summary of the course outcomes. Our end of term student evaluation results are summarized in Section VI. Then, we conclude this paper in Section VII.

II. COURSE DESIGN AND METHODOLOGY

A. Student Demographics

Since our SDR security course was being offered for the first time, a small pilot section was created, where 9 graduate students were enrolled. The decision to limit enrollment to this number was based on available computer resources and classroom space. All students were enrolled in a Masters of Science program within the Electrical and Computer Engineering Department at Drexel University. Out of the 9 students, there was only one female student. One of the students was pursuing his education while also working full-time at a company. No country of origin or race information was collected for the purposes of this paper.

B. Course Logistics and Flow

Our SDR based security course is developed and offered weekly at the graduate-level. We were assigned a 3 hour meeting period. Our classroom was a Digital Signal Processing (DSP) laboratory with built-in equipment racks and available computers for student use. Each work area was designed to accommodate 2 students. There were 4 work areas in total. Desktop computers were pre-installed with the Ubuntu operating system before the beginning of the course. Students were then guided to install any additional programs and/or packages as the course progressed. We ran the course by splitting the students into 3 groups of 2 and a group of 3. Although students had the freedom to choose who to be partners with, we encouraged them to form groups to include at least one person knowledgeable in Linux programming.

Drexel University offers a term based system, where each term consists of 10 weeks of in-class sessions followed by a week of final examinations. Table I shows a breakdown of the 10-week term by labs. A similar table was also given to the students as a part of the course syllabus. The table also reminds students of important dates, such as the course drop deadline. Each lab was originally designed to last for two weeks. Small adjustments were made as the term progressed.

TABLE I: Breakdown of the term by lectures and labs

Week	Lectures	Labs	Homework
1	Lecture 1	Lab 1	-
2	Lecture 2	Lab 1	-
-	Course drop deadline	-	-
3	Lecture 3	Lab 2	HW 1
4	Lecture 4	Lab 2	-
5	Lecture 5	Lab 3	HW 2
6	Lecture 6	Lab 4	HW 3
-	Course withdraw deadline	-	-
7	Lecture 7	Lab 4	-
8	Lecture 8	Lab 5	HW 4
9	Lecture 9	Lab 5 / Project	-
10	Lecture 10	Final Project	HW 5
11	Final Project due	Final Competition	-

The course was run as a series of short (usually 30-40 minutes), theory-based lectures followed by the student-centric lab assignment. The lab assignments were designed to leverage the concepts covered in the lecture portion but also to invite the students to indulge into research papers to complete their lab and the homework assignment at the end of the lab directions. The lab assignments were expected to be completed in-class.

Additional homework assignments were given at the end of each lab. Each homework was due before the beginning of the next lab. Students were provided with USRP N210 SDR platforms to work on their lab and homework assignments. They were also given remote desktop access to lab computers for when they would want to have access to the experiment setup with SDRs. Students were not allowed to remove the SDR nodes from the classroom. Throughout the term, two unannounced quizzes were given. These quizzes were mainly focusing on the theory covered in the lecture component of the course. Although a textbook was listed in the syllabus, most of the course material was custom prepared and distributed via the Blackboard Learn course management system. Blackboard Learn was also used to post grades, collect assignments, and make announcements.

The course was assigned 3 teaching assistants (TAs), who were knowledgeable in wireless communications, security, and SDRs. All assistants were present in the classroom during the labs.

C. Student Work Evaluation

Student work was graded regularly. Each week, specific lab checkpoints were communicated to students. In order to ensure students were not falling behind, these checkpoints were strictly enforced. When students reached a checkpoint, they called one of the TAs over to their table and demonstrated the functionality of their setup. They were also asked to clearly explain what they did and how they did it. A successful demonstration yielded full points for that checkpoint. In case something was wrong, the TA tried to help them by leading them towards the correct output without actually giving them the answer. If a checkpoint was not met at the end of the meeting time, partial credit was given. A general grading breakdown is presented in Table II.

TABLE II: Final grade breakdown

Labs & Homework	60%
Quizzes	10%
Final Project	30%

The final project, which will be described later, was a competition based setup, where students were *fighting* against the instructor and the TAs. The grading was performed based on how successful their security implementations were. Further discussion of the final project is discussed below.



Fig. 1: USRP N210 SDR [20]

III. CYBERSECURITY LAB MODULES

Our course was designed to introduce students to security vulnerabilities present in wireless networks. It took a Software-Defined Radio (SDR) implementation approach to demonstrate selected wireless network security challenges. With the use of open-source tools and commercial off-the-shelf SDRs, students gained hands-on experience to analyze wireless security problems and prototype their solutions.

This course met 3 hours a week for 11 weeks and covered five separate laboratory assignments spanning various topics in wireless security. The labs were organized as follows:

A. Lab 1: Introduction to GNU Radio and USRP

This lab introduced students to the concept of software radios and gave specific examples of an SDR design flow. Students were introduced to the course's main hardware platform, the Universal Software Radio Peripheral (USRP) seen in Fig. 1, and its accompanying software design tool, GNU Radio. The lab also included a run-through for setting up the development environment on an Ubuntu 12.04 installation and executing the included example designs. Most importantly, the lab showed a tutorial on implementing a single carrier wireless communication link between two USRP nodes. Students were then asked to extend this tutorial to come up with their own implementations.

B. Lab 2: Digital Communications Hardware Design

This second lab familiarized students with the tools and concepts required for hardware design in the context of digital communication. The USRP platform is extremely customizable and allows for user-defined operations on the hardware side. This lab merges several

different topics from Computer Engineering, Telecommunications, and Software Engineering to create an interdisciplinary bridge, which continues throughout the rest of the labs. Students were instructed to implement the modulation and coding components for a wireless link on the FPGA available on the USRP, rather than processing them on the host side. Some of the concepts introduced in this lab were adopted from current research described in [21] and [22]. The design environment was conducted in Xilinx System Generator, an industry-standard hardware design suite for FPGAs. Through this lab, students gained essential hardware design skills required for prototyping fast (in the order of nanoseconds) turn-around wireless systems with real-time attack and defense capabilities.

C. Lab 3: Basics of Eavesdropping and Encryption

This lab covered signal detection, classification, and encryption techniques. Students were introduced to the basics of passive wireless attacks, including raw signal capture and off-line processing to identify the frame structures of common over-the-air (OTA) wireless protocols including WiFi and 4G WiMAX. Provided with an always-on transmitted signal from the instructors (realized using the USRP), students were asked to sniff the OTA packets and identify their key signatures, such as the source IP address, port number, packet length, etc. The lab mainly illustrated the role of an eavesdropper on an unencrypted wireless network. However, state-of-the-art encryption techniques were also introduced along with the history of cryptography. This discussion was also complemented with current research practices in Physical-layer security schemes [13]. Students were asked to take additional measures to secure the wireless link using any of the discussed encryption techniques.

D. Lab 4: Real-Time Signal Detection

We continue to follow the multi-disciplinary approach in this lab by introducing students to real-time, hardware-based techniques for signal detection. It covered important signal processing techniques such as cross-correlators, energy detectors, frame filtering, and identification of signal components with low entropy. Students were asked to design, validate, and demonstrate a series of signal detectors. For extra credit, students should allow certain customization capabilities for their detectors, including the ability to search for signals from different standards such as WiFi and WiMAX signals. The lab required FPGA hardware logic design and embedded programming techniques to capture and analyze

packets in real time. This lab prepared students towards developing eavesdropping-resilient signal transmissions.

E. Lab 5: Introduction to Jamming

This lab covered the basics of signal jamming, a series of active attacks to render the wireless network unusable. Students were introduced to the different types of jammers and asked to improve upon their design from Lab 4 to realize a reactive jammer [23]. Reactive jamming is a sophisticated form of jamming attack, wherein the attacker listens on the wireless channel and triggers jamming waveforms on positive signal detection. Due to legal considerations concerning the operating of real-time over-the-air jammers, this lab was conducted primarily in simulation. The jamming performance was analyzed and evaluated under variable signal-to-interference (SIR) ratio and different modulation parameters. This lab also provided theoretical background on jamming mitigation techniques, such as frequency hopping and spread spectrum communication [24].

F. Final Competition: Multi-team Melee

By the end of the five labs, students had gained understanding of SDR programming basics and important wireless security principles. The final project consisted of an aggregation and extension of the labs covered. Students were asked to implement an over-the-air eavesdropper using the GNU Radio / USRP framework. The instructors provided a working WiFi 802.11g link using either commercial hardware or SDRs with a fixed bit rate. The students' goals were to listen in on this wireless communication and extract any useful information they could find. In the first phase of the project, transmitted messages were encrypted with a given restricted set of keys, which were provided to students. In the second phase of the project, the keys used in message encryption were drawn from an unrestricted set of keys, and students had to conduct brute-force attacks to guess the correct keys while eavesdropping on the wireless medium. The student team that could extract the most useful information from the provided wireless link would win the competition.

IV. LABORATORY CASE STUDY: REAL-TIME SIGNAL DETECTION (LAB 4)

In this section, we provide as an example the detailed description of one of the labs covered in our SDR security course. The materials presented here are representative of the scope and outcome expectations of every

other laboratory assignment. We focus our description on Lab 4: Real-time signal detection.

A. Lab Introduction

This lab introduces the concept of real-time signal detection in wireless communications. Signal detection is an important procedure to achieve synchronization between the transmitter and receiver, as well as to gain awareness of an active transmission in the channel. We will focus on two primary methods to detect the presence of a signal: cross-correlation and energy detection.

Wireless communications rely on successfully transmitting signals and correctly detecting them on the receiver end. A thorough understanding of packet detection principles is necessary to study cybersecurity principles. Many of the cyber attacks originate from an eavesdropper, who is trying to snoop on the packets in a wireless network. In this lab, we expect students to gain knowledge on packet detection principles and urge them to think of possible ways to develop algorithms to protect their data against an eavesdropper.

Cross-correlation: A cross-correlator performs template-based matching between the incoming wireless signal and a standardized template to identify the template presence in the signal. The template is usually designed with a very high auto-correlation property, yielding a high coefficient when correlating with itself. This enables us to pinpoint precisely the start of an active transmission frame in fine-grain synchronization.

The cross-correlator can be implemented as a matched filter, which is simply an FIR filter with tap coefficients set to the time-inverse of the template values. Recall that an N -th order FIR filter is implemented with an N -tap convolution:

$$y[n] = \sum_{i=0}^{N-1} h_i x[n-i]$$

In hardware, an FIR filter can be implemented as either a parallel or serial filter. Figures 2 and 3 show the block diagrams of example hardware implementations for both filter types. The serial version of the filter runs at $3x$ sample rate in order to produce outputs at the same rate as the input samples.

Energy Detection: an energy detector computes the short-term energy of incoming signal and tries to detect a rise or fall in the energy levels. Energy detectors are effective in detecting an active transmission without the

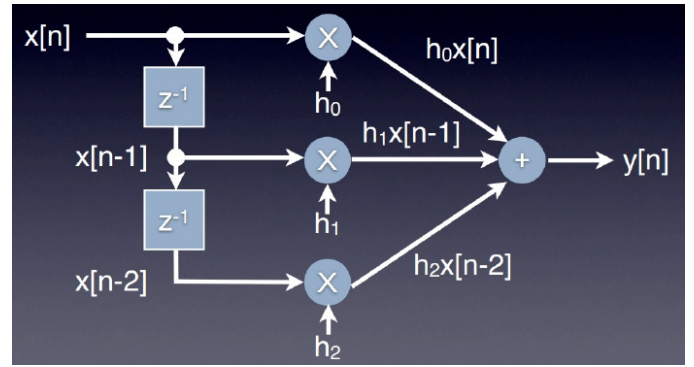


Fig. 2: Parallel 3-Tap FIR Filter Example

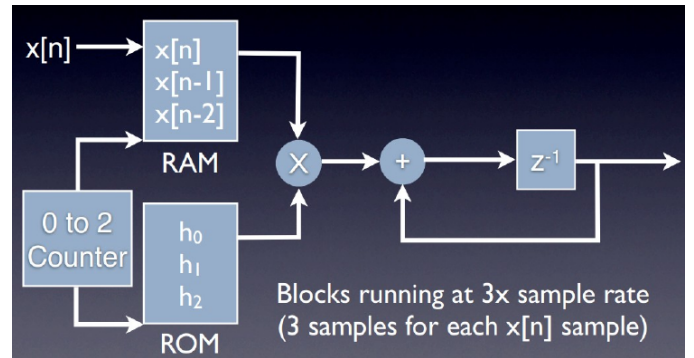


Fig. 3: Serial 3-Tap FIR Filter Example

need to understand the underlying modulation methods and data content.

In hardware, the energy detector can be implemented as an energy sum calculator, which continuously compares the energy level of incoming samples against the recent past to detect an energy rise or fall. Figure 4 shows an example structure of an energy detector. In essence, this hardware block keeps a running sum of N recent energy readings, where N is the desired length of the detector (specified here as 32 samples). At the n th instant, an energy reading $x[n]$ is computed from the incoming pair of I and Q values. The energy sum $y[n]$ is then updated according to the relationship:

$$y[n] = y[n-1] + x[n] - x[n-N]$$

The output of the energy sum calculator is compared to its own previous values after scaling by a user-defined threshold for either energy high or low detection. The thresholds are selected based on the desired probability of detection and false alarm rate.

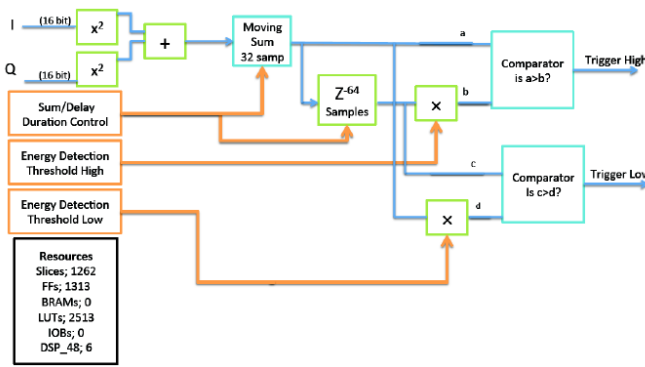


Fig. 4: Example Implementation of an Energy Detector

B. Lab Deliverables

The deliverables for this lab include two hardware implementation components: a single-rate, fully parallel FIR filter with $N = 8$ tap coefficients, and a single-rate, fully serial FIR filter with $N = 13$ coefficients. The serial design may include only one multiplier and one adder, so students are expected to use RAM memory for managing samples. Students may use either a blocked RAM or an addressable shift register (ASR) to implement the sample RAM buffer.

In addition, students need to deliver a hardware implementation of a *cross-correlator* with the 13-value Barker sequence $[1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1]$ as the template. Detailed simulation results in the System Generator are expected in the deliverables.

Students are also encouraged to identify and discuss any possible scheme that would prevent an eavesdropper to be able to employ the basic packet detection principles described above to gain access to the network. Some of the possible ideas include designing a different cross-correlator and/or leveraging the interference in the network.

V. COURSE DISCUSSION

Based on students' assignment completion and their grades against the rubrics, an overall final grade was calculated for all enrolled students. The grade distribution was shown in Table II. Once the numeric grades were calculated a standard letter mapping was used to identify a student's final letter grade. At the end of the term, 5 students received grades in the A range, 3 students received grades in the B range, and one student in the C range. This distribution yielded an average of 90.8% with a standard deviation of 10.0%. This high average could

be attributed to the extremely high educator (instructor and TAs)-to-student ratio.

VI. END-OF-TERM STUDENT EVALUATION RESULTS

After having developed and conducted the Software Defined Radio security course, a brief feedback survey was given focused on the course's reception. In this survey, students were asked to anonymously elaborate on their experience throughout the term. They were allowed to write as little or as much as they needed. Student participation for this survey was voluntary and students were allowed to see their final grades before the submission of the survey. The received testimonials were all positive. The word map seen in Fig. 5 was created to get a general idea of the student feedback, where the most frequently used words appear the biggest. As the frequency of a specific word gets smaller, its font size follows the same trend.

While most classes rely completely on teaching the theory, our class offered students guidelines to help develop and realize current research techniques in a student-centric approach. One of the students mentioned the following in his/her feedback: *"I feel like the class is the glue which combines different pieces of knowledge together. The class is both a challenge and a great opportunity for anyone who wishes to learn more security issues in SDR."* Another student adds to the submitted evaluations by focusing on the course's hands-on approach. He/she says, *"The course involved a lot of hands on learning using [...] hardware interfacing with student-created software in a lab setting. I enjoyed this course very much due to the fact that students were able to prototype designs on the computer and then realize them in live transmissions, comparing actual results, and demonstrating the security concepts."*

Simulations are much more effective in being flexible enough to teach over a range of concepts but true learning comes from seeing the end goal. We realized this need to concentrate the concepts being taught by guiding students to physical implementations. Not only simulations and implementations were important part of the student-centric learning goal; however, we also introduced the latest achievements in the research field during our labs. Our course was described as *"an excellent balance between background theory and hardware implementation"*, where we covered *"[m]odern topics related to wireless security and communication systems [...], which highlighted examples of current technologies using the techniques discussed."*



One of the students concluded his/her review by saying he/she “*would highly recommend this course and similar courses for anyone interested in pursuing a degree in wireless communications, cryptography, or signals intelligence related fields.*”

In this paper, we presented our graduate-level Software Defined Radio based Cybersecurity course. Our course balanced theory and implementation by offering students short descriptions of their upcoming labs and then following a student-centric learning approach during the labs. The five lab modules we designed not only introduced students to wireless security concepts but also leveraged the latest findings in related research fields. Students used SDRs throughout the term to implement their algorithms via hardware implementations, embedded programming, and wireless signal processing techniques. By going outside the boundaries of textbooks, and integrating current research into the classroom, we were able to offer a more up-to-date learning experience to our students. Although, our job as course developers was made more challenging by not being bound to a textbook and by following and integrating the latest research achievements into our course, testimonials we received show that the end product was appreciated by students.

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Student-centered Learning in Cybersecurity in Summer Semester

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Abstract—Work in Progress: University-level cybersecurity education is encouraged by both the US government and academic organizations. A new practical course in cybersecurity in the summer semester is introduced, in which junior students made teams to learn in a student-centered and competitive style. Students were provided with course materials in five topics. An online judge system was developed with problems of levels from the beginner to the advanced to encourage competitive learning. A contest was held, in which teams designed their own problems and tried to solve the others'. A scoring method was used to avoid the students' problems being too easy or too difficult. Considerable engagement of the students was observed during the course. Almost all problems in the online judge system had been solved at the end of the semester, and the problems designed by the students involved a considerable breadth and depth of cybersecurity related knowledge and technologies. Feedbacks from the students greatly appreciated the online judge system and the contest. They also gave suggestion on the contest and suggested more presentation and discussion in the course.

Keywords—cybersecurity; student-centered learning; online judge system

I. INTRODUCTION

Cybersecurity attracts more and more attentions in politics, economics, military, culture, and our everyday lives. IT related employees are expected to have basic cybersecurity mindset and skills, and cybersecurity professionals are in a great demand. The US government has recognized the importance of cybersecurity and has made efforts to promote cybersecurity programs and education, including the National Initiative for Cybersecurity Education (NICE) led by The National Institute of Standards and Technology (NIST) and the Centers of Academic Excellence (CAE) program led by the National Security Agency (NSA) and the Department of Homeland Security (DHS) [1, 2]. ACM's Education Board organized a workshop to give guidance to university-level cybersecurity education. In the workshop report, there is advice for all undergraduates and computing majors. The workshop participants considered that the practical activities are vital for students and that experiences in both offensive and defensive activity are desirable [3, 4].

However, learning cybersecurity requires knowledge in various foundation courses as well as some advanced ones. It is

very difficult for freshmen or sophomores to have a deep understanding without practical applications, although they can learn some security knowledge points and have some ideas about failure modes in a specific context [5].

With the above considerations, we constructed a new practical course in cybersecurity for junior students majored in computer science and technology in the summer semester in Tsinghua University. Through this course, students are expected to form a fundamental and comprehensive idea of cybersecurity with basic awareness and skills in cybersecurity through lots of problem-solving experience. It is even more important to arouse students' professional interests for further study and research in cybersecurity.

Most teaching and learning experiences in cybersecurity were in regular semesters [5-9]. It is more critical to provide a good learning environment to the students for us to achieve the teaching objectives in a 5-week summer semester. In [6], it is demonstrated that young people like competitions and challenges, and challenge-based exercises are well-suited for training in cybersecurity. So we decided to bring competitive elements into this course with a student-centered learning approach.

We grouped the cybersecurity related technologies into 5 categories. We prepared teaching materials, lecture notes and expansion reading materials for beginners, together with matched problems and solution hints for each category. A competitive online judge system was developed and deployed with plenty of problems in different levels of difficulties. The course was divided into 2 stages. Students made teams to solve assigned problems in the first stage, and designed their own problems for other teams to solve as a contest in the second stage. A scoring method was proposed to prevent too easy or too hard problems in the contest. The detailed description of this course is in the next section. In the third section, we presents our observations of student engagement and the course outcomes, especially the statistics of the contest among the teams. Feedbacks from the students and the future work is introduced in the last section.

II. COURSE DESCRIPTION

A. Background

“Computer Professional Practice” has been a practical course for junior students in computer science in the summer semesters in Tsinghua University since 2004, aiming to increase the students’ grasp of professional knowledge, practice ability, innovative mind, research skills, and team spirit. Students can choose one subject from several alternatives, each of which requests design and development of a big comprehensive system in 5 weeks [10].

Cybersecurity is a supplementary subject added in 2014. There were 19 students selecting this new subject, who had learned basic courses about computer architectures, compiler theories, operating systems, principles of network, and databases, as well as programming languages including C/C++, Java, assembly language and Python. However, only a few of them had learned a cybersecurity related course about contemporary cryptology.

In this course, students were required to go to a designated lab both in the morning and in the afternoon from Monday to Friday for 5 weeks. There were 5 lectures, each about 3 hours, given in the first two weeks in the lab. Students had about 125 class hours of lab time in total to learn by themselves under the teacher’s guidance. Additional 30 class hours were reserved for students to write reports and give presentations.

B. Course topics and materials

Cybersecurity involves a considerable number of technologies, which we roughly grouped into 5 categories as course topics: recon and forensic analysis, crypto, web penetration, reverse engineering, and exploit.

We compiled teaching materials for the first two topics and chose [11-13] for the other topics respectively. Lecture notes were also prepared, in which we introduced an overview of cybersecurity in the real world and discussed about some legal problems. Two more books about codes and cryptology were recommended for expansion reading. All these materials are really for beginners so that they can easily understand the topics.

To help students to better understand the materials, we provided appropriate beginner problems for each topic. For each problem, we gave hints or a step-by-step solution.

C. The online judge system

The course materials were very basic, and we wanted to encourage the students to learn advanced knowledge and technologies by their own choice. So we developed an online judge system to enable competitive learning in students.

The system was similar to the jeopardy-style in Capture the Flag (CTF) contests in cybersecurity. The correct answer to a problem is hidden somewhere. A registered user can submit the answer to an unsolved problem to earn the problem’s difficulty point which is then added to his/her problem solving score if the answer is successfully revealed. We not only deployed the beginner problems of each topic in the system, but many real CTF problems as well. The CTF problems need a variety of

basic or advanced knowledge and technologies beyond the course materials. More difficult problems have higher problem points. The answers, or the flags, of the CTF problems were changed to avoid solving simply by a Google search. We used virtual machines for web penetration and interactive problems. When a virtual machine makes no response, the system administrator will restart it. Fig.1 is the screenshot of a problem whose difficulty point is 50, and the translation in English is shown in Fig. 2.

There are several measures to promote student initiatives. Every user can look up the problem solving score rankings at any time. The number of users who have solved the problem will be shown to the upright of the problem description and the fastest three will be listed below the description (as in Fig. 1), which is also helpful for the students to find and learn from the solvers.

D. Assignments and the contest

During the course, students were asked to make teams of 2 or 3 persons and all assignments were for teams. In the summer semester in 2014, we got 7 teams in total.

The course was divided into 2 stages. The first stage was 2-week long, and we designed a series of 5 problems in the context of a student love story as the team assignment of this stage. The problems covered all the course topics. For example, in the first problem, students should collect information from a Twitter-like social network site, a blog site, and a free mail service site to find clues leading to the answer. A team could probably solve these problems, if they learned the course materials seriously and completed the beginner problems. A problem solving report was required to submit by every team



Fig. 1. The screenshot of a problem.

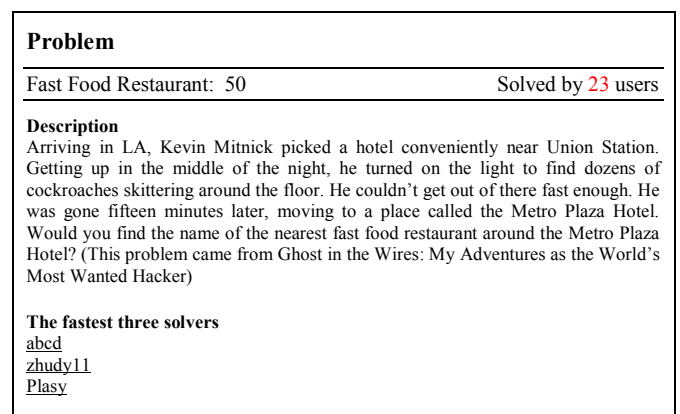


Fig. 2. Translation in English

for assessment.

The second stage was a contest stage. Each team were required to design 3 problems of their own and then help the TA to deploy them in the online judge system for other teams to solve. After the contest, each team should submit a report and make a final presentation illustrating how their problems were designed and deployed, and how their problems could be solved.

E. Contest scoring method

When deploying a student problem for the contest, the TA evaluated the problem's difficulty to assign a corresponding difficulty point. The TA might give minor suggestion to make the problem more solvable, such as embedding more hints and adding affirmative words in an intermediate result.

In order to make the contest challenging at an appropriate level, no teams should design unsolvable problems, neither beginner problems. We proposed a scoring method to avoid the inappropriate problems: A team's final score is calculated as the sum of their scores for all contest problems. Both the designer team and the other teams will be scored for every problem. For a problem with a difficulty point P , suppose there are x teams that have solved it and y teams that have not solved it. The designer team will be scored $2*S$ for this problem, and each successful team will be scored S , while the unsuccessful teams will be scored zero, where S can be calculated as (1).

$$S = P * (x + 2) / [(x + 2)^2 + y^2] \quad (1)$$

The value of the denominator in (1) is high when $x + 2$ and y make big difference, since the sum of x and y is a constant (equaling to the total number of teams minus 1). So the designer team will be scored low if the problem is too easy to get a small P and a large denominator. On the contrary, if the problem is too difficult, the designer team will not be highly scored because of a large denominator. The best situation for the designer is that approximately half teams have solved the problem.

The contest was finally composed of 21 problems from the students. The TA estimated the difficulties and assigned the problem difficulty points in 4 levels: 100, 200, 250, and 300 when deploying. TABLE I gives the number of problems of each difficulty level and the average number of teams that successfully solved for a problem in this level. It seemed that our scoring method was effective and the assignment of difficulty levels was rational.

F. Miscellaneous

We invited a member of the blue-lotus team from Tsinghua University, who had participated in the Defcon CTF contest, to give a talk about CTF contests during the course. We encouraged the students to watch a real online CTF contest held in the semester and to take part in GeekPwn, a security geek contest for smart devices. These activities presented the students a more real world of cybersecurity.

TABLE I. CONTEST PROBLEMS AND SOLVING RESULT

Points	100	200	250	300
Count	1	11	6	3
Avg. Solving	6	5.55	5.5	2

The assessment was summative according to the attendance rate, the team reports in both stages, the contest ranking result and the final presentation.

Students were asked to give some comments on this course as a feedback to help us to improve the pedagogy in the future.

III. OBSERVATION AND COURSE OUTCOMES

It was observed that the students were greatly engaged in learning. Besides 6 hours a day as the course time in the lab, they spent hours after class. Submissions in the deep of night or before dawn were often seen in the logs of the online judge system.

We were glad that all teams had solved the assigned problems in the first stage, which demonstrated that the students had understood the basic ideas and had the basic skills to deal with cybersecurity problems in the course topics.

The students found the advanced problems interesting and challenging. They usually had no ideas how to start with a problem in the beginning because of few experiences in cybersecurity. They discussed a lot in the team and among teams. They searched the Internet to find the original CTF problem and the corresponding write-ups to follow the solving steps. At the end of the course, nearly all problems in the online judge systems were solved, which was a big surprise to us.

We referred to several useful crypto tools in the course materials, which were free for download from the Internet. However, some students developed their own tools. This was really a good practice to help master the knowledge and skills.

Another surprise came from the contest problems designed by the students. These problems employed a considerable breadth and depth of technologies. In the process of problem designing, the students learned where and why there were vulnerabilities. Some students gave possible ways of inspection and prevention in the report.

All the facts implied that the students were able to explore and research in cybersecurity in depth.

IV. STUDENTS FEEDBACKS AND FUTURE WORK

We collected comments from 14 students. Most students said the course topics were really new to them and they learned more and deeper than expected before the class. They gave high credit for the online judge system with so many interesting problems and for the student contest. They had a full, challenging, and happy learning experience in this course. By learning cybersecurity, they began to look at the computers and the network in a new point of view, which led to a better understanding of what had been learned before. Meanwhile their programming skills had been improved.

Some students suggested we arrange team presentations to demonstrate how they solved the CTF problems in the online judge system, and organize group discussion on the most difficult ones. Some students wanted to know more about real websites, products, and services with cybersecurity defects, and to know more about means of protection and defense. These suggestions were useful.

Several students pointed out there were some contest problems that had too few clues to find the breach. We also noticed this phenomenon. Although the TA was experienced in cybersecurity and worked carefully, it was impossible to ensure the quality of all student designed problems for a limited time. The solution might be more TAs and earlier involvement in the design phase with the teams.

There have been more than 100 problems in the online judge system including the students designed problems for the contest. We will add additional problems. The method in [6] will be useful to find and remove the problems not so effective for learning. More features can be implemented to enhance the online judge system. For example, the answers of a few problems can be enumerated. This will be practically impossible if the system limits the submission frequency. The automated management of virtual machines is also desirable, in case there are too many virtual machines to run with the limited computing resources.

One more important thing to do in the future is to assess students' security awareness before and after learning. It is concerned as well whether they like to devote to research on cybersecurity or take on cybersecurity related jobs.

ACKNOWLEDGMENT

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Using a Case Study to Teach Students about Finding and Fixing Logic Flaws in Software

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Abstract—An application logic flaw is a type of software vulnerability related to privilege manipulation or transaction control manipulation. They are often difficult to identify using automated scanners. A case study on the eCommerce merchant software Bigcommerce, integrated with PayPal Express as a third party payment collector, was created to teach students about this topic. Case studies provide students with a real-world context, and help them understand complex topics better than traditional teaching methods. However, the computer science field, especially computer security, does not have many case studies available. The case study on logic flaws in software was taught in Spring 2015, and the teaching experience is discussed.

Keywords—software security; computing education; case study; application logic flaws; manual code review method

I. INTRODUCTION

With codebases reaching millions of lines, software vulnerabilities exist even in thoroughly tested code. Security expert McGraw separates these into two categories: bugs, and flaws [1-2]. Bugs are defined as implementation problems in software, such as off-by-one errors or buffer overflows [1-2]. They only exist at the code level and can typically be fixed on one line or in a localized area. Flaws, on the other hand, exist at both the code level and the design and software architecture levels. They are typically related to the architectural design, or application logic. Examples include bad error handling (fail-open), lack of encryption, and poor access control [2-5]. The vulnerability may be due to the design itself, or with how the code was implemented. To fix flaws, the logic or software architecture may need to be redesigned, and it could affect multiple areas of code. An estimated 50% of software security vulnerabilities are flaws [1-2].

Source code analysis tools are effective at identifying bugs, because bugs typically follow defined patterns. However, application logic is inconsistent and thus a poor candidate for automated testing tools. While several prototype scanners have been developed to identify application logic flaws, they are still in the research phase, so logic flaws must be found through manual testing [2, 6-7]. Therefore, it is important for computer science students to learn how to reduce logic flaws during software development, and how to test for them manually.

The topic of application logic flaws seems to be omitted or poorly addressed in both software engineering courses and textbooks. A case study was developed to teach students about

this topic. Case-based teaching methods can help students better apply learned skills to real world industrial settings. This helps bridge the gap between theoretical concepts and industry-related skills that exists in current software engineering education [8]. There is a need to develop case studies due to the lack of case studies available for software engineering curriculum. [9].

Existing resources on logic flaws provide very specific categories of vulnerabilities to test for, but do not cover how to handle logic that is custom to an application. For example, one web application may perform authentication on the client side, while another does this on the server side. An introduction to logic flaws was developed to address this shortcoming by explaining where logic flaws come from, and how to reduce flaws during development using industry standard best practices. It also describes the manual code review method used to discover an exploitable logic flaw in the case being studied.

A case study was developed to illustrate how a logic flaw could cause security vulnerabilities. The case is based on the research article *How to Shop for Free Online: Security Analysis of Cashier-as-a-Service Based Web Stores* [10]. It is about the eCommerce merchant software Bigcommerce, previously known as Interspire, using PayPal Express as a third-party payment collector. A logic flaw allowed attackers to complete an expensive order using the payment intended for a cheaper order. A PowerPoint animation was created to trace the API calls and back-end code representing the steps of the exploit from this case, and explain the manual testing method used to discover the exploit. A set of discussion questions has students apply this method to similar code in order to find potential vulnerabilities and then fix them.

This case study is meant to be easily integrated into existing upper-level undergraduate or graduate level computer science courses. It can be taught in-class or given as an online assignment, and should have 2 lecture hours and 1 hour for student discussion, or an equivalent of one week of instruction. At the undergraduate level, it fits under the Software Engineering or Information Assurance and Security Knowledge Areas in [11], and the topics of Secure Software Architecture and Design or Secure Coding and Testing for Software Security Engineering courses, or the topic of Testing Methods for Software Quality Assurance courses in [12]. At the graduate level, it could fit under the core body of

knowledge areas 6.2.1 Development Methods and 6.3.5 Testing For Assurance in [13]. Software engineering or security testing courses that use [2] as a textbook can use this case study after the Architectural Risk Analysis chapter.

The rest of the paper is organized as follows: Section II provides a literature review of using case studies in computer science education. Section III describes the materials developed for the case study on application logic flaws. Section IV describes the results and teaching experience. Section V concludes the paper and discusses future work.

II. CASE STUDY TEACHING METHOD

Research has shown that case studies are an effective teaching method. They actively engage students, increase students' motivation to learn since the topic is more enjoyable, and help students develop skills such as problem solving and working as part of a team [8, 14-17]. Using case studies in university education provides several benefits: case studies provide a real-world context to the topic being taught, help students synthesize the course content, and require students to apply critical thinking and analysis [18]. In [19] it was noted that "Even theoretical disciplines are beginning to adopt more experience-oriented instruction as opposed to passive, lecture-oriented instruction."

Engineering fields, including Mechanical Engineering, Civil Engineering, and Chemical Engineering, have used case studies as a teaching method with successful results [26-29]. It was found that students generally had better discussions and felt they improved their critical thinking skills when compared to similar courses taught with traditional methods [27, 29]. The use of case studies in university level Computer Science education is more recent. For example, the ACM/IEEE Computer Science Curricula 2013 [11] mentioned case studies for teaching ethics in computing, the effects of computing on a variety of populations, causes of computer failures, parallel programming, and distributed systems. However, only one case study was mentioned in the 2008 interim revision [30], which was on object recognition and tracking for graphic and visual computing. Case studies in the computer science field are lacking in both breadth and depth [9]. Commercial Harvard-style case studies are available; however, most of them are focused on business or management, and necessary technical details are still lacking in cases designed for Information Systems or Information Technology [9]. Within the computer science field, security is a relatively new topic. Therefore, we need more software security focused case studies.

There is also a gap in the computer science field between academic theory and industry skills and best practices [19-21]. Students may understand examples used in the classroom, but have little knowledge of practical aspects and challenges faced by industry [19, 22]. Reference [23] found that students needed additional instruction before they could successfully apply skills learned in university courses to industry settings. A multi-year study [19] showed that a graduate-level requirements engineering course taught with industry-based case studies resulted in higher quality student discussions, increased in-class participation, improved exam grades, and had higher self-reported levels of positive learning experience,

compared to when the course was taught with more traditional approaches in previous years. When compared to other courses in the same department, students also reported higher levels of problem solving skills, ability to work independently, and interest in the course [19]. At the undergraduate and graduate level several case studies on information security topics have been taught with successful results [12, 14-15, 24-25]. Students reported they were confident about applying what they learned to future jobs [24].

III. THE CASE FOR TEACHING LOGIC FLAWS

This section describes the learning objectives for the case study, the case that was used, and the materials developed to teach students about application logic flaws [31].

A. Learning Objectives

Logic flaws are regularly listed as primary causes of commonly exploited software vulnerabilities [2, 32-34]. Seven vulnerabilities out OWASPs' 2013 Top 10 list [33] and 16 vulnerabilities out of CWQ/SANS Top 25 list [34] are logic flaws. Since they are difficult to identify with automated testing tools, student should learn a manual testing method to identify application logic flaws.

The goal of this case study is to help computer science students understand the concept of application logic flaws, and why manual testing methods must be used instead of automated testing tools. As part of the accompanying discussion questions, students should be able to identify logic flaws in provided code using the following manual testing method:

- Manipulate the data
- Manipulate the workflow
- Manipulate both the data and the workflow.
- After each manipulation, trace through the entire checkout process and track how each argument affects the internal state of the transaction, and the end result.

To guide the development of this case study, a set of learning objectives was created. These are listed in Table 1.

TABLE I. LIST OF LEARNING OBJECTIVES FOR THE CASE STUDY

ID	Learning Objectives
1	Explain what an application logic flaw is.
2	Explain why it is difficult for an automated tool to find logic flaws.
3	Identify potential areas for logic flaws in HTTP interactions.
4	Critique back-end code for a set of HTTP interactions, which has logic flaws.
5	Fix logic flaws in a set of HTTP interactions to secure it.

B. Bigcommerce and PayPal Express Case

Reference [10] covered two popular eCommerce merchant softwares: NopCommerce and Bigcommerce, in combination with four 3rd-party cashier services: PayPal Standard, PayPal

Express, Google Checkout, and Amazon Payments. Using the manual code review method covered in III.A, serious logic flaws were discovered that allowed an attacker to complete orders for free or at reduced prices. The flaws were in Amazon Payments itself, or with how NopCommerce and Bigcommerce integrated with the remaining three cashier services to collect payment.

The case chosen was Bigcommerce and PayPal Express. An exploitable logic flaw involved the use of two sessions, and replacing a digitally signed argument from one session with the same argument from a second session. An attacker could pay for a cheap order, but prevent the final step of the checkout process from completing. In a second session, expensive items are placed in the order, but the attacker skips the payment step. Despite failed payment, Bigcommerce still generated a digitally signed argument containing information about this expensive order. This argument is then copied to the first session, and the final step of the checkout process resumed. The end result is that an expensive order is completed after paying for a small order.

C. Case Study Materials

This section lists the materials developed for the case study.

1) *Introduction*: The introduction to Logic Flaws includes material from Section I in more detail. It directly addresses Learning Objectives 1 and 2 from Table 1, defining what application logic flaws are, where logic flaws come from, and limitations of using automated testing tools to identify logic flaws. Specific recommendations for manual testing are listed [3, 7], including the manual testing method used by [10]. Recommended industry best practices [2, 35-36] are provided, organized by category of logic flaw. The case study is described in detail. It is also recommended to have students read [10].

2) *Case Study Animation*: To teach about the Bigcommerce and PayPal Express case, a PowerPoint animation was created. Before starting the animation the manual code review method from [10] is summarized, and notations used in the case study are explained. A sequence diagram is provided an overall view of the HTTP interactions between the user, merchant using Bigcommerce, and PayPal Express during a typical checkout transaction.

The two sessions used to exploit the flaw in this case are presented during the animation. Each step in the checkout process has two stages during the animation:

a) *Sequence Diagram*: The HTTP interactions for this step are animated in a sequence diagram. Parameters are color-coded based on the last party who could modify them. Fig. 1 shows an example slide.

b) *Back-End Code*: The back-end code is traced line-by-line, and a table maintaining the current variable state is updated. This table is also color coded to show which variables are used by which party. This code is based on [37] and modified for clarity. Fig. 2 shows an example slide. After the animation is complete, several slides explain steps taken

by Bigcommerce and PayPal Express to ensure the transaction was done securely and correctly, such as verifying that payment was attempted and did not fail. The exploitable logic flaw is then described in detail, including which steps let to the exploit.

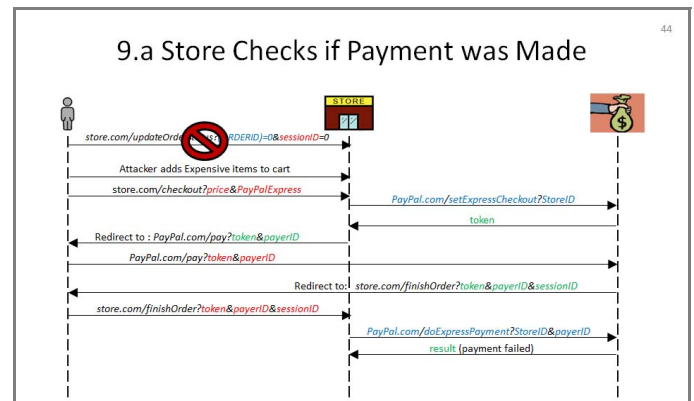


Fig. 1. Sequence Diagram with HTTP interactions.

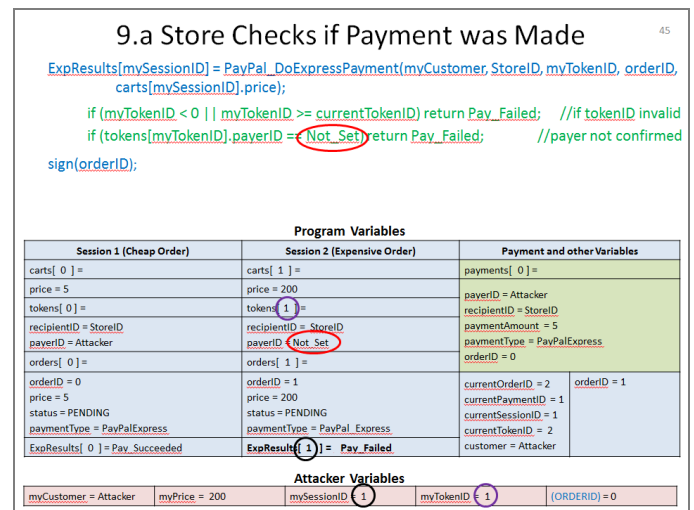


Fig. 2. Back-end code accompanying sequence diagram in Figure 1.

3) *Discussion Questions*: Eight discussion questions were developed based on the learning objectives and Blooms Taxonomy [38] to have students apply knowledge learned from the case study to similar code. Two additional cases from [10] were used for this. These questions were designed to be difficult, and should be given to students in groups of 2-3. Not all of the questions need to be given along with the case study; a subset can be chosen. Table 2 shows the mapping between the discussion questions, Blooms Taxonomy cognitive levels, and the Learning Objectives from Table 1.

Questions 1 and 2 ask students about application logic flaws and about the case study. Questions 3-5 are part of a set and should be given together. They use back-end code from the Bigcommerce and Google Checkout case [10], and are related to the primary learning objectives of identifying and fixing logic flaws. Question 6 asks students to brainstorm for testing methods to identify logic flaws. Questions 7 and 8 use

the back-end code from the Bigcommerce and PayPal Standard case, but only one question should be chosen. Question 7 asks students to trace through the code and complete a table maintaining the current variable state. Question 8 provides the same code with the table already completed, however the steps in the transaction are given out of order, and the correct order of API calls must be found. A grading rubric is available for instructors.

TABLE II. MAPPING OF DISCUSSION QUESTIONS TO LEARNING OBJECTIVES (LO) AND BLOOMS TAXONOMY

LO ID	Question ID	Learning Objectives	Blooms Taxonomy Cognitive Level
1, 2	1	What is a logic flaw, and why are they difficult to identify?	Level 1 - Knowledge Level 2 - Comprehension
	2	Why is it NOT a security vulnerability that the token, payerID, sessionID, and PayPalExpress URL parameters from the Bigcommerce and PayPal Express case are unsigned?	Level 4 - Analysis
3	3	Read through the following URLs representing HTTP interactions between three parties. Suggest potential security flaws for each of the arguments.	Level 4 - Analysis
4	4	Read through the following code and critique it.	Level 6 - Evaluation
5	5	Fix the following code to better secure it.	Level 5 - Synthesis
	6	Propose methods to test for logic flaws (does not have to be automated)	Level 5 - Synthesis
	7	Given the following code and variable table, trace through the variables at each stage.	Level 3 - Application
	8	The following URLs/code sequence is out of order. What is the correct sequence?	Level 3 - Application

4) *Prototype Automated Testing Tool*: To provide students with first-hand experience of the benefits and limitations of using automated testing tools to identify application logic flaws, a Virtual Machine was created. VMware was used to set up the Virtual Machine running Windows 7, and a tool called Corral [39] and its' prerequisites were installed. Corral was developed by the Microsoft Research Team, and can be used to scan for application logic flaws in C, .NET, or Java code when given a proper driver program to make the API calls.

IV. TEACHING EXPERIENCE

This case study was taught in the Spring 2015 semester in COMP 727 Secure Software Engineering [31]. This was an online course, and 21 students were registered. Students were given three weeks to complete the case study and discussion questions, which included Spring Break.

To help evaluate the effectiveness of the case study, students were given a voluntary pre-survey prior to starting the assignment, which asked them to rate their level of knowledge or skills for the learning objectives on a 5-point Likert scale. A post-survey with the same questions was given upon completion of the case study. It also asked students several questions evaluating the case study on a 5-point Likert scale, and open ended questions on what they learned or problems that were encountered. These surveys were approved by the Institutional Review Board (IRB) at North Carolina A&T State University.

The discussion questions were assigned in groups of three, for a total of seven groups. As this case study was taught in an online course, each group was provided with a Blackboard forum in which to record their groups' discussion. These forum posts were then reviewed to evaluate if students had active and lively discussions. Each group submitted a final report with their answers to the discussion questions, and these were graded using a rubric.

A. Survey Results

Participants in the survey were graduate-level computer science students. More detailed demographics were not collected. Three pre-surveys were submitted blank or partially blank out of 21 submitted surveys. Three post-surveys were also submitted blank out of 17 submitted surveys. Since an unequal number of usable surveys were completed, and several students declined to provide the information being used to pair responses, a paired statistical analysis could not be performed. Instead, a Mann-Whitney U test was more appropriate, with the before and after data treated as independent samples. It is a nonparametric test of the null hypothesis that two populations are equal.

The null hypothesis H_0 is that the two populations are equal, and the research hypothesis H_1 is that the two populations are not equal. With $N_1 = 18$, $N_2 = 14$, and $\alpha = 0.05$, the calculated critical value for this test is 74 [40]. Thus, H_0 is rejected if $U \leq 74$. The results of the Mann-Whitney U test are shown in Table 3. All of the p -values indicate these results are statistically significant, and H_0 is rejected for each Learning Objective. This indicates that students felt their knowledge improved for each of the Learning Objectives in Table 1. However, this was calculated using a relatively small sample size; therefore the results of this test may not be representative of the population of university-level computer science students. It is also not an evaluation of students' knowledge or skill level, and merely how they perceived their knowledge or skill level.

TABLE III. MANN-WHITNEY U TEST RESULTS OF STUDENTS' RANKING OF THEIR KNOWLEDGE/SKILLS ON LOGIC FLAWS ON A 5-POINT LIKERT SCALE

Learning Objective	1	2	3	4	5
U	49.5	72.5	41	57	67
Asymptotic 2-tailed p-value	.002	.032	.001	.004	.013

Additional questions on the post-survey included rating students' interest in the topic of logic flaws, and to review the case study. Overall, the results in Table 4 show students enjoyed the case study and felt it was useful. Most importantly, 78% of students felt the learning objectives were met and 63% of the students felt they improved their problem solving and critical thinking skills.

TABLE IV. RESULTS OF HOW MUCH THE STUDENTS AGREE OR DISAGREE WITH THE STATEMENTS ON THE POST-SURVEY

Question	Response
The case study was useful to help you understand the material	29% Strongly Agree 50% Agree
You were motivated to learn about application logic flaws	29% Strongly Agree 36% Agree
You enjoyed the case study	29% Strongly Agree 36% Agree
The learning objectives were met	7% Strongly Agree 71% Agree
The case study helped you to develop problem solving and critical thinking skills, and ability to think independently	21% Strongly Agree 43% Agree

From the open ended questions, the most important things students said they learned were:

- Never trust input from the client side of a web application
- How seemingly simple vulnerabilities can lead to serious logic flaws
- The process of tracing an applications' workflow

A few comments reiterated that students enjoyed the analytical thinking involved in this case study.

In addition to learning a manual testing method for identifying logic flaws, students also learned several key concepts about software security. First, that input validation is extremely important since input can be malicious and processes can be manipulated. Second, that a vulnerability in one part of an application may not cause immediate security issues, but can still detrimentally affect the end result of a process. Finally, students improved their skills of tracing through the steps of a process. Having learned these concepts, students are more knowledgeable about how software can be attacked, and may be more mindful about designing security into software and performing software security testing in the future.

During the case study, problems were encountered with:

- Running Corral on the Virtual Machine
- Understanding [10]

- Tracing the state of the variables when using the manual code review method

These were caused by a lack of information, and will be addressed in future work. The instructions for running Corral can be clarified, and a more detailed explanation of the scan results can be provided. The case study instructions can mention that [10] should only be read after the introduction discussed in III.C.1, and the introduction can be expanded to include a glossary of new terms covered in [10]. A blank trace similar to the table n Fig 2 can be provided with the discussion questions.

Notable comments were: "The case study was really good. It helped me a lot in enriching knowledge of application logic flaws," and "This is an interesting topic and something I think we need to do with all programs and applications that are released to the public and considered safe." This confirms that students enjoyed the case study and found it useful.

B. Discussion Questions

Out of the eight questions in Table 2, five were chosen: questions 2-5, and 8. Students were also asked to run Corral on provided code, and describe their experience with the tool. Later in the semester, question 1 from Table 2 was given on a mid-term exam.

Students' grades for the case study were based on their individual participation and quality of forum posts, the quality of the group discussion as a whole, and the final group report with answers to the discussion questions.

1) *Quality of Discussion*: Overall, the students' discussions in the online Blackboarded forums was high-quality and indicated that most of the groups had very active discussions. The posts show that students were in fact able to perform the high level of analysis, synthesis, and evaluation that was asked of them. The following is an excerpt from the student online discussion of one group:

"I think you are right. We may have been overthinking this stage of the order processing. If the cashier sends over the price information for verification then that would be sufficient as long as the merchant can always verify the origin of the message as coming from a cashier and not from an attacker." This shows that students were able to trace through the transaction process, and identify what input validation was necessary to verify that the price of the order matched payment amount received by the cashier.

2) *Graded Discussion Questions*: The rubric mentioned in Section 2.C.3 was used to grade each of the discussion questions in the group reports, and the question on the mid-term exam. Grades ranged from 75 to 100 percent, with an average of 90.7 percent.

Question 3 from Table 2 was the question most students struggled to answer correctly. Instead of providing their own responses based on the provided HTTP arguments, students referenced [10]. However, the question was asking for general responses and not about the back-end code behind those HTTP requests. Based on the comments in the post-survey, question 4 from Table 2 was the question students found most

difficult. Some groups relied on [10] instead of performing their own analysis and those responses were lacking the existing security measures in addition to listing the vulnerabilities they discovered. A correct method for fixing the discovered logic flaws was attempted by most groups in question 5 from Table 2; however it was not always implemented properly. Question 1 from Table 2 was given on a mid-term exam, and students were able to correctly define logic flaws and provide examples. They also understood why logic flaws are difficult to identify, for both manual and automated testing methods.

V. CONCLUSION

Based on the overall results, this case study was successful at teaching about application logic flaws to graduate-level computer science students. It adds to the number of case studies available for computer science education, specifically supporting secure software engineering or software security testing courses. It should help bridge the gap that exists between academia and industry best practices for software engineering.

The evaluations of this case study are limited, as it has only been taught once. The results were promising, but they are from a relatively small sample size. A quiz or simple exercise could be given along with the pre- and post-surveys to quantitatively evaluate and changes to students' knowledge or skill level of the Learning Objectives. The quiz could ask students several questions related to defining logic flaws and how they are identified through annual testing. An exercise involving a short segment of code could ask students to identify potentially vulnerable arguments, explain why they are vulnerable, and identify a logic flaw.

Another limitation is that students also may have difficulty applying this manual testing method to software that does not follow a client-server model, or to software unrelated to eCommerce, as the code structures and process workflows may be different.

Future work can be done to improve the case study as a whole, and more case studies on logic flaws can be developed to supplement the existing case. The animation can be re-done in a platform-independent format, to help prevent display formatting issues. The grading rubric for the discussion questions can be updated to include new possible answers, as the discussion questions are fairly open-ended. Incorrect answers can be added as well. In the animation, students recommended that a slide be added to each step of the transaction that summarizes the step before showing the sequence diagram and back-end code, to help explain what is actually happening.

Future work also includes teaching this case study again at North Carolina A&T State University, or in other universities. Several professors from other universities have already expressed their interest in using this case study as part of their curriculum.

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Healthcare Security : A course engaging females in cybersecurity education

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Abstract—The paper describes experience in teaching a sophomore-level healthcare security course. The course introduced security in context. The context was healthcare. The structure of the course is outlined. The pedagogy and research questions are described. Surveys conducted provide insights that security in context of healthcare is effective in engaging students in security topics.

I. INTRODUCTION

Women are seriously underrepresented in cybersecurity workforce [1]. We address this challenge by a healthcare based course to engage females in cybersecurity. Healthcare is a discipline that has attracted more females [2] than computing because of social and cultural reasons [3]. Healthcare informatics is a rapidly growing field and it is critical to address security in healthcare informatics [4]. We create a course that introduces and engages females in cybersecurity concepts, leveraging upon a large pool of female students interested in pursuing healthcare related professions. The anxiety to learn programming and the stigma attached to cybersecurity professionals as being male dominated ([5], [3]), are bypassed by creating a healthcare based curriculum to teach cybersecurity concepts. Healthcare based topics provide a context for engagement for students, interested to become healthcare professionals. We created a special topics sophomore level undergraduate course, Healthcare security (HS) to investigate the following questions.

- 1) What are the pedagogical practices that engage undergraduate females in cybersecurity education?
- 2) How does participation in the healthcare security course impact students' perception of themselves as future cybersecurity professionals?

Studies addressing student engagement in cybersecurity topics in healthcare were conducted in the HS course. More than 50% of the students in the course were female. The topics covered in the healthcare security course were: healthcare forensics, security analysis and audits in information technology (IT) systems, interoperability of medical devices, usability security of medical devices and malware breaches in healthcare devices. Given the wide variety of topics covered in the course, we were interested to know the engagement level of the students in topics in cybersecurity. The knowledge gained by the students in the course was evaluated using pre-post surveys on the learning outcomes of the course. The instructional delivery of the topics in the course was critical in student engagement. Periodic surveys were conducted on

students during the semester. The surveys were informative in evaluating the level of the student engagement on topics in cybersecurity. The high enrollment of female students in the HS course was possibly due to the following recruitment practices:

- 1) The advertisement flyer for the course stated no prior programming experience is required to register.
- 2) The healthcare provided the context for teaching topics in cybersecurity to undergraduate females ([6], [7]). The advertisement flyer for the course emphasized on security vulnerabilities in healthcare-related software and healthcare devices.

II. COURSE DETAILS

The course, *Healthcare Security* was a three credit sophomore level course and offered as a special topics course in the fall of 2014. The course was offered as an elective for bachelors degree in health informatics technology majors and associates degree in IT. The prerequisite for the course was foundational courses in IT or permission of the instructor. The topics in the course were digital forensics in healthcare, security analysis of IT devices, interoperability of medical devices, usable security of medical devices and malware in medical applications. In the course, there were no programming assignments and assumed the students had no prior programming experience. Some of topics in operating system were covered to support concepts in forensics.

The course was taught in a traditional lecture-class activity format. The instructional delivery emphasized on active learning with problem based approaches. There were two tests, a midterm and a final. The midterm was based on digital forensics concepts and healthcare forensics. The finals was based on the topics that were covered after the first midterm, namely security analysis of IT devices, interoperability of medical devices, usable security of medical devices and malware in medical applications.

III. STRUCTURE OF THE ASSIGNMENTS

The structure of assignments were problem based in the HS course. There were no programming assignments. The arguments put forward by Guzdial [8] to "understand computing before programming" and computational thinking [9], were motivational for not including programming. The emphasis of the assignments was problem solving [10] to address a diverse group of students, with different background and motivation to

pursue IT courses. The following are samples of assignments on the topics that were covered in the HS course.

- **Healthcare forensics:** The assignment focussed on the file retrieval from Linux.
You are hired by a hospital to recover data in the form of files. The files were stored in a server that had linux operating system. Write the steps that you will be performing in order to recover the files from the system. The steps should be based on the material "LinuxFileSystem" and the power point slides that has been uploaded. Write two pages (double space) for your description for retrieve the files.
- **Interoperability:** The emphasis of this assignment is understanding the concepts involved in the interoperability of devices.
A device runs on a software based on computer language Y on operating system Z Another device , runs on a software based on computer language,V on operating system W. State how will you construct a system so that the two devices can communicate with each other. Explain the key concepts and illustrate with an example.
- **Usability Security:** The assignment tested the understanding of modeling using graphs for user interfaces.
 - 1) *Choose an interface that you and your colleagues are excited about.*
 - 2) *State your assumptions when you model precisely.*
 - 3) *Model the interface with at least 6 different button using graph*
 - 4) *Draw the graph of your model*
 - 5) *State why you think the user model is a star or a complete graph.*
- **Malware in Healthcare Devices:** The assignment tested the security risks in healthcare devices.
Describe any security risks that may exist with implantable devices? List 3 ways to secure implantable devices.

IV. METHODOLOGY

Data was collected from the surveys for a qualitative study. The reasoning was that the small class size would not produce data on which statistical analysis can be performed. The responses from the survey provided the student perception on the topics as the course progressed. There were two sets of surveys administered.

- 1) *Pre-Post* Course surveys were conducted to evaluate the knowledge gained by the students after taking the course.
- 2) *Periodic* surveys were administered in the second week (first periodic survey), seventh week (second periodic survey) and in the fourteenth week (third periodic survey) of the semester. The surveys focussed on the impact of topics on healthcare security on student perception of computer and information security.

All the surveys were paper-based, anonymous and voluntary. There were total fourteen students who had enrolled in the

course. Out of 14 students enrolled at the beginning of the semester, 12 students completed the course at the end of the semester.

A. Evaluation of Learning Outcomes of the Course

The learning outcomes of the course were:

- 1) Become familiar with the healthcare laws, HIPAA and HITECH
- 2) Provide a working understanding of threats to data and IT systems
- 3) Describe the formulation incident response in an IT system
- 4) Explain the security analysis steps and audits for an IT systems
- 5) Provide a working understanding of fundamental concepts in interoperability of devices
- 6) Provide a working understanding of usability security of medical devices.
- 7) Describe different kinds of malware
- 8) Analyze malware breaches in medical systems and propose solution

Voluntary and anonymous surveys were conducted to evaluate the knowledge gained during the course in the semester. The Pre-Course and Post-Course survey were administered on the first day of the class and the last day of classes, respectively. Table I shows the responses to the queries directly mapped to the learning outcomes. For example, the question mapped to the first learning objective is *I am able to Become familiar with the healthcare laws, HIPAA and HITECH*. The likert scale options to the questions were strongly agree, agree, indifferent, disagree and strongly disagree.

Twelve students responded to the survey questions mapped to the learning outcomes. There were twelve responses to the question mapped to the first learning outcome. Several students in the class were familiar with HIPAA and HITECH from other that had health informatics as part of the curriculum. All of the female students in the Post Course survey either strongly agreed or agreed to have learnt the concepts. All the students agreed or strongly agreed to have a working understanding of threats to data and systems. The third question in the Post-Course survey reported four responses that were "Indifferent". The possible reason could be there was only one short assignment that addressed the topic. There were eleven responses to third learning objective and one female did not respond in the Pre-Course survey. The first three learning outcomes focussed on the basic concepts in health forensics. For the fourth learning outcome which focussed on the security analysis and audits, one female responded in different and only, one male strongly agreed in the understanding the outcome. One male student did not respond in the Post-Course survey for the fourth learning outcome. The security analysis could have been made more hands-on than lectures only for a better understanding of the concepts. The concepts on interoperability stated in the fifth learning objective was well received by all students. The data from Post-Course survey shows the learning was effective for concepts of usability security, when compared with Pre-Course survey. All of the responses were "Agree" or "Strongly Agree" to understanding different malware and the processes how they affect the systems. Students responded favourably learning to

Surveys	Pre-Course										Post-Course									
Likert Scale	A		B		C		D		E		A		B		C		D		E	
Outcome	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
1.	0	1	1	1	2	2	2	1	0	2	2	2	3	5	0	0	0	0	0	0
2.	0	2	0	2	2	1	1	2	0	2	1	1	4	6	0	0	0	0	0	0
3.	1	0	1	1	0	2	2	1	2	1	3	0	2	3	0	4	0	0	0	0
4.	0	0	1	2	0	0	4	2	0	3	1	0	3	6	0	1	0	0	0	0
5.	0	0	1	2	1	0	3	2	0	3	3	2	2	5	0	0	0	0	0	0
6.	1	1	0	1	2	0	2	2	0	3	2	2	3	5	0	0	0	0	0	0
7.	0	1	3	4	0	1	1	0	0	2	2	3	3	4	0	0	0	0	0	0
8.	1	0	0	1	0	2	3	1	1	3	2	0	2	7	0	1	0	0	0	0

TABLE I. STUDENT RESPONSES FROM PRE-POST COURSE SURVEYS ; LIKERT SCALE OPTIONS, A= STRONGLY AGREE, B =AGREE, C=INDIFFERENT, D=DISAGREE, E=STRONGLY DISAGREE; M =MALE, F = FEMALE

analyze malware breaches in medical systems and propose solution. Hands-on activities using software tools could have been led to better understanding of malware breaches. Female students surveyed to have learnt the concepts well in almost all the learning objectives. There were "Indifferent" responses by females in the third and eighth learning objectives.

B. Student Perception in Security Topics

The evaluation of student perception in security topics was using periodic surveys. The first periodic survey was administered in the second week of classes. The topic, healthcare forensics was taught during the first two weeks. All of the 14 (7 females and 7 males) students did the first survey shown in Table II. For the first question in Table II, one male student selected all the options and one female student selected (a) and (b). In the first periodic survey, the questions (1)-(2), the responses from female students indicated to learn about topics of security in healthcare. Question (3) indicates the females and males are inclined to be in healthcare IT field. Questions (4)-(5) clearly shows the interests of males slightly higher when compared to females in taking security related courses and careers in IT security.

The second periodic survey (shown in Table III) was administered in the seventh week of the semester, after the midterm. The midterm consisted of topics healthcare forensics , concepts of digital forensics and healthcare laws. The midterm included foundational concepts of operating system, incident response in an IT systems and threats to data and IT systems. One male student dropped the class after the first midterm. The responses of question (1) suggest that female students responded that their performance was good or extremely good. The female students felt comfortable in learning the material. All the students found the topics in the midterm intriguing. The number of students who wanted to take more computer and IT security courses was almost the same when compared to the first periodic survey. One female student did not want to take the any computer or IT courses in security which was not the case in the first survey. All the female students were interested in careers in IT security. Two male student were unsure of careers in IT when compared with first periodic survey.

The third periodic survey was administered in the fourteenth week of the semester and the responses are shown in Table IV. Twelve students completed the third periodic survey. The majority of the responses for the first question

Questions	M	F
1. Why are you taking this course? ¹		
(a) The topics are interesting and worth exploring.	2	1
(b) Wanted to learn about security in healthcare.	3	4
(c) Had to fill the credits as an elective for my degree.	4	3
2. If there was another course that was exclusively on "healthcare security", would you have registered for that course?		
(a) Yes	3	2
(b) No	1	3
(c) Unsure	3	2
3. Do you envision yourself in working in healthcare IT field ?		
(a) Yes	4	5
(b) No	1	1
(c) Unsure	2	1
4. Do you plan to take more computer/IT security courses in future?		
(a) Yes	6	4
(b) No	0	0
(c) Unsure	1	3
5. Would you seek careers that require skills sets in computer/IT security?		
(a) Yes	7	5
(b) No	0	0
(c) Unsure	0	2

TABLE II. QUESTIONNAIRE IN THE FIRST PERIODIC SURVEY; M = MALE AND F = FEMALE

whether the students had gained adequate knowledge in healthcare security were "No". The foundational concepts of the topics were introduced. The students were exposed to different security problems that may occur in healthcare systems. The students were expected to take higher level security courses. All students enjoyed the topics in the course. Two of the female students responded the negative opinion about programming led to positive opinion after taking the course. This is important because the course was taught without any programming assignments and in a "problem solving" approach. Five female students were interested in taking more computer/IT security courses in future, an increase from the first and second surveys. Ten out of twelve students expressed interest that they would seek careers in computer/IT security. One female student responded "unsure" to the fifth question in the third periodic survey when compared to the second periodic survey.

Based on the periodic surveys, the student perception of

Questions	M	F
1. How is your performance in the class so far?		
(a) Extremely Good.	1	2
(b) Good.	3	5
(c) Poor.	0	0
(d) Unsure	2	0
2. Does this course so far fulfill the reasons that made you take this course?		
(a) Yes	6	7
(b) No	0	0
3. Are you intrigued with the topics so far?		
(a) Yes	6	7
(b) No	0	0
4. Do you plan to take more computer/IT security courses in future?		
(a) Yes	5	4
(b) No	0	1
(c) Unsure	1	2
5. Would you seek careers that require skills sets in computer/IT security?		
(a) Yes	4	7
(b) No	0	0
(c) Unsure	2	0

TABLE III. QUESTIONNAIRE IN THE SECOND PERIODIC SURVEY; M = MALE AND F = FEMALE

the learning of topics security was positive. All the students, male and female enjoyed taking the course. Majority of female students were interested in take security courses in future and envision IT security as an career option. The retention of the course among female students in the course was hundred percentage.

V. CONCLUSION AND FUTURE WORK

In this paper, we described a special topics course, healthcare security. The topics in this course addressed concepts in security. The first set of surveys, Pre-Post course surveys provided insights knowledge gained in the course. Female students gained knowledge in the topics of security, based on the comparison of the responses in the Pre-Post course surveys. The second set of surveys, periodic surveys, focussed on the impact of the security topics on student engagement and student perception. The surveys showed that females are interested in healthcare and are intrigued in security of healthcare systems. The context based introduction of security in healthcare is a way to expose female undergraduates to topics related to computer and security. The "problem based" approach employed in the course seems to be positively received by female students. The retention among the females was hundred percent. In future, hands-in assignments based on software tools such as interactive disassembler (IDA) could be introduced to understand the concepts. The engagement of the students in the topics of security in the HS course provides insights to use mobile health and bioinformatics as contexts to teach cybersecurity concepts. The courses with different contexts would interweave cybersecurity concepts and hence, appeal to a diverse student population.

Questions	M	F
1. Do you feel that you have gained knowledge in healthcare security from this course?		
(a) Yes	5	7
(b) No.	0	0
(c) Unsure	0	0
2. Did you enjoy learning the topics in this course? as this course "healthcare security", would you you have for that course?		
(a) Yes	5	7
(b) No	0	0
3. If you had any negative opinion about learning security topics in IT such as "it requires too much programming", or "it is not interesting to me" then after taking this course, did any of those negative opinions change to positive opinion?		
(a) Yes	0	1
(b) No	0	1
(c) Neutral	5	5
4. Do you plan to take more computer/IT security courses in future?		
(a) Yes	3	5
(b) No	1	0
(c) Unsure	1	2
5. Would you seek careers that require skills sets in computer/IT security?		
(a) Yes	4	6
(b) No	0	0
(c) Unsure	1	1

TABLE IV. QUESTIONNAIRE IN THE THIRD PERIODIC SURVEY; M = MALE AND F = FEMALE

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CE2016: Updated Computer Engineering Curriculum Guidelines

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Abstract— Joint ACM/IEEE Computer Society undergraduate computer engineering curriculum guidelines are slated for release in 2016. These update the 2004 guidelines commonly known as CE2004. The presenters are part of the task group leading the revisions and will give an overview of the latest draft. Participants will engage in discussions on potential improvements to the guidelines to ensure that they are useful to programs as they work to ensure their curricula reflect the state-of-the-art in computer engineering education and practice and are relevant for the coming decade.

Keywords—Computer engineering; curriculum guidelines; CE2004; CE2016; ACM; IEEE Computer Society

I. BACKGROUND

This is the seventh conference presentation [1–6] supporting a process began by the ACM and the IEEE Computer Society in 2011 to update the CE2004 document, formally known as “Curriculum Guidelines for Undergraduate Degree Programs in Computer Engineering” [6]. Using nearly 300 survey responses plus input at conferences and working meetings, the authors are leading a significant update of the

document with a goal of a 2016 release. The document will be known as “CE2016”.

In various subject areas the authors are also consulting the related document “Computer Science Curricula 2013” (CS2013) and the draft produced by the parallel effort to update the software engineering guidelines (SE2004).

II. SPECIAL SESSION FORMAT

This special session will engage computer engineering educators in evaluating the current draft as it approaches completion.

The authors will give an overview of the structure of the CE2016 document followed by key areas receiving initial or substantially enhanced coverage. They will also discuss how computer engineering educators can contribute to the process. Small group discussions will focus on how the document can best provide value to both new and existing computer engineering undergraduate programs.

Specifically, the presenters will summarize topics added, expanded, and removed from the guidelines in response to feedback from academia and industry. They will show how the new document also aims for greater clarity by succinctly documenting the scope and purpose of each major “knowledge area” for computer engineering undergraduates. Drilling down, they will show how “knowledge units” give clarity to programs by specifying “learning outcomes” that define what successful students will be able to do. The document also incorporates details of the required mathematical background and includes many important, “discretionary” areas and outcomes that not all programs will wish to cover.

The agenda will be as follows.

0:00–0:15	Overview of the CE2016 guidelines document
0:15–0:25	Summary of key areas receiving initial or significantly updated coverage: embedded systems, digital systems design, multicore, security, mobile and power aware, software engineering, and verification and validation of computing systems
0:25–0:35	Plans for completion and ways individuals can contribute to the process
0:35–1:05	Small group discussions among the audience participants: How should the document change to provide a valued resource to both new and existing undergraduate computer engineering programs?
1:05–1:15	Report feedback to all attendees
1:15–1:30	Questions and comments from audience participants

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What the Heck is That?! Adaptation of Evidence-Based Instructional Practices

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Abstract— Numerous avenues exist for faculty to learn about new pedagogical techniques, but these techniques rarely make it into practice, even by experienced and motivated engineering educators. They often suffer from the perception of “that won’t work because my classroom is different.” The focus of this session is to help faculty explore this perception and to identify new techniques for potentially overcoming this limitation. Using the Diffusion of Innovation framework, faculty will be guided through several activities to explore ways of adapt known evidence-based instructional practices to a variety of classroom setups and course styles. They will then have the opportunity to confront the limitations they hold about implementing them in their own courses.

Keywords—*Diffusion, Pedagogical Adaptation, Evidence-based Instructional Practices*

I. GOALS OF THE SESSION

The purpose of this session is to capitalize on the benefit of peer interaction to support the diffusion of Evidence-Based Instructional Practices (EBIPs). Faculty will explore differences in their context and content, establish high empathy, and create an environment for more effective communication around EBIP adoption. Faculty will also build on each other’s ideas and conceptions of EBIPs in order to identify alternative implementations for their context.

II. DESCRIPTION OF SESSION CONTENT

As each faculty member decides to use an Evidence-Based Instructional Practice (EBIP) in their classroom, Diffusion of Innovation [1] tells us they will go through the five stages of the innovation-decision process: knowledge, persuasion, decision, implementation, and confirmation (p. 163). Physics [2] and Engineering [3] faculty member’s progression through the innovation-decision process has been investigated and it was found that many faculty members have moved beyond the knowledge stage of this process. Henderson [2] also found that a number of faculty tried using innovative practices in their classroom, but then stopped.

A key element within dissemination is the concept of “re-invention, defined as the degree to which an innovation is changed or modified by a user in the process of adoption and implementation” [1] (p.174); this concept is also

referred to as adaptation [4]. One of the benefits to re-invention is that it “encourage[s] customization of the innovation to fit it more appropriately to local situations or changing conditions” (p. 177). This allows adopters to adapt the innovation into their personal context [4]. When adopters are able to re-invent or adapt the innovation, they are also less likely to discontinue the use of the innovation [1]. However, when exploring the re-invention of innovation, adopters should be conscious of the fidelity of implementation [5] when discussing the innovation. Fidelity of implementation broadly means how well the implemented innovation follows the original [6]. Where faculty should be allowed to adapt EBIPs into the context of their specific classroom, they should maintain a level of awareness of the overall innovation and the critical elements that make the practice effective. This special session will apply the principle of diffusion of innovation and fidelity of implementation to support attendees’ adaptation and implementation of evidence-based instructional practices.

III. SESSION AGENDA

The session is planned to run on the following timeline:

(00 - 05 min) *What the heck is that?* In order to situate the attendees in the context of the special session, the presenters will play a video clip from a Saturday Night Live skit where Bill Murray and Steve Martin point to an unseen object and question “What the [heck] is that?” in a variety of tones. (<http://youtu.be/RV7Qz640OeM>). At one point, they think they have figured it out, only to realize that they still don’t know “what the [heck] is that.” At the back of the room, facilitators will place a poster with a list of evidence-based instructional practices.

The SNL skit can be seen as analogous to learning about a specific EBIP or seeing a colleague implement it, thinking “oh I know what it is”, then walking away confused when thinking about how to implement the innovation in their own course.

(05 - 10 min) *Overview of evidence-based instructional practices.* Drs. Cutler and Pembridge will provide a brief review of common EBIPs and their characteristics.

(10 - 20 min) *Spot the difference*. A common barrier to diffusion involves the adaptation of an implementation into a different context, leaving many faculty to proclaim “But my course is different”. Dr. Verleger will highlight the variety in the room by having participants identify a variety of contextual and subject matter differences across attendees.

(20 - 25) *Overview of Diffusion of Innovation and Adaptation with respect to Fidelity of Implementation*. Dr. Cutler will then explain the theoretical grounds for the following activities by providing an overview of diffusion of innovation, placing emphasis on adaptation, followed by implications of the adaptation while maintaining the fidelity of the evidence-based instructional practice.

(25 - 45 min) *Group Story Telling*. Using the method of group storytelling, participants, in groups of 3, will be given a mock context (size, setting, course content) and a randomly assigned EBIP. Together they will develop an implementation of that EBIP. To support this, the group will be supplied a small poster that will outline the necessary details that need to be explained. Following the activity, the groups will report out their implementation.

(45 - 80 min) *6-1-5 Method*. Adapting the 6-3-5 method from design methodology for brainstorming, participants will be seated 6 per table. Each participant will receive a different EBIP on a handout. They will be required to describe their context and how they would implement the EBIP. After 5 minutes the handout will be rotated to the next person, allowing them to build on the idea and share how they would implement the EBIP. This will continue until the handout you began with is returned to you. While the 5 minutes is a short time to provide details, it will require the participants to focus on the key components of the implementation, thus ignoring first instinct barriers.

(80-90 min) *Summary and Recap*

IV. DESCRIPTION OF ANTICIPATED AUDIENCE

This session should primarily be of interest to faculty at all levels interested in better understanding evidence-based instructional practices and mechanisms for integrating those practices into their courses. The session will also be of interest to faculty members struggling with identifying ways they can adapt any evidence-based instructional practices that they are already aware of because “their course is different”. There is also some potential benefit for graduate students who are interested in academic positions that include teaching, though this is not anticipated to be the target audience.

V. EXPECTED OUTCOMES AND FUTURE WORK

Participants will gain a better understanding of a variety of evidence-based instructional practices and reflect on their

experiences trying to incorporate them into their own courses. They will share their perceptions and ideas of how others may be able to integrate these practices. In turn, they will receive guidance from other attendees on integrating evidence-based instructional practices into their courses.

The research team will continue to investigate the barriers and constructive experiences that help faculty become more effective teacher-facilitators. Work currently being conducted by the team continues to address the faculty development research-to-practice gap.

VI. DISSEMINATION OF OUTCOMES

Following the session, all worksheets will be summarized and emailed to participants so that they may further explore alternative implementations of evidence-based instructional practices. These worksheets will include the course subject matter and context so that faculty may continue to use them for a variety of courses.

Prior to the session, the presenters will receive IRB to collect data. The primary data will include a survey that participants will complete upon entering the session, and the completed session artifacts. The findings of this session will then be disseminated at FIE the following year.

VII. JUSTIFICATION FOR SPECIAL SESSION

Rogers reminds us that “Mass media channels are relatively more important at the knowledge stage and interpersonal channels are relatively more important at the persuasion stage in the innovation–decision process” [1] (p.195). However, with many faculty who attend FIE have advanced past the knowledge stage [2, 3], and more personal channels should be explored to aid faculty in moving into the decision and implementation stages. This session will be highly active; engaging participants with each other to develop implementations in a variety of contexts, especially their own.

VIII. AUTHOR INFORMATION

James Pembridge graduated from Virginia Tech with a PhD in Engineering Education. His recent work has focused on the diffusion of evidence-based instructional practices through peer-review (NSF-TUES, DUE #1244852) and the application of a cyclical change model to explore stages of pedagogical change with respect driving and restricting factors (NSF-WIDER, DUE #1347790) [7-10].

Stephanie Cutler graduated from Virginia Tech in May 2013 with her PhD in Engineering Education. Her dissertation research focused on faculty adoption of research-based instructional strategies [5, 11, 12]. She currently works for the Rothwell Center for Teaching and Learning Excellence at Embry-Riddle Aeronautical University’s Worldwide campus where she aids faculty in bringing innovative instructional strategies into the classroom, specifically inquiry-based learning [14].

Matthew Verleger graduated from Purdue University with a PhD in Engineering Education. In his current role as a faculty member in the Engineering Fundamentals program at Embry-Riddle Aeronautical University, he is involved in department-wide work on the adoption of evidence-based instructional practices and conducts his own research on using peer review of artifacts in the classroom [15]. He also conducts research on hybrid and online learning models [16].

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A tale of two mobile learning journeys with smartphones and tablets: the interplay of technology and implementation change

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Abstract— This paper describes two mobile learning journeys in the zoo using either smartphones or tablets, and a mobile learning application SamEx, all designed and implemented as part of a research study in a Singapore primary school. Out-of-school semi-formal learning activities such as zoo trips present standard curricular topics where students go out of their schools in order to explore topics of interest in a semi-controlled designed environment. Typically, students observe and connect their observations with prior knowledge or further extend their knowledge on the go or later with their teacher in the classroom. The initial study in 2013 included the whole Primary 3 (P3) level of students, 305 of them, while the subsequent study in 2015 included 321 students. Between the years technology shift was inevitable – the participating school switched from smartphone devices to tablet computers, where each child has a tablet with the option to connect to both a WiFi network and to a mobile broadband network. Furthermore, the changes in the design of the mobile learning SamEx application were carried out in collaboration with the teachers, through a design-based research process. SamEx allows for the collection, organization and storage of media collected by students typically as responses to questions and prompts set up by their teachers. The initial design was oriented towards individual students, to support their individual in-class and homework learning tasks and assignments. The main features added to the application incorporated additional teachers' needs in carrying out curricular topics including inquiry learning and collaborative learning. The paper explores the evolution of both technology and the implementation of the application in the period, and problematizes the notion of inevitable technology change, constant software maintenance and enhancement and the effect of these changes on learning activities and outcomes.

Keywords—mobile learning; e-learning; tablet computers in education; software design

I. INTRODUCTION

Mobile learning technologies stimulate student engagement while enabling authentic learning scenarios used as part of diverse educational programs around the globe [1]. With the goal of providing a more sustained learning experience for their students, teachers in a Singapore primary school collaborated with a research team in 2012 in a Seamless Learning project in which the goal was the incorporation of mobile learning technologies into the science curriculum. An application named SamEx was developed and has been used as a part of the curriculum since then. The application is constantly improved through a process of iterative design with both teacher and student usage experiences in mind.

SamEx is an educational application for Android platform designed to allow students to post, store and share educational content with their colleagues and teachers either as responses to contextual prompts set up by their teachers or as student-initiated contributions. As a result of the two-year usage, the data on student involvement in form of media contributions, text answers, likes and comments is available for research analysis.

This paper focuses on the comparison of two mobile learning journeys using the data provided by SamEx application. The comparison is characterized by unavoidable technology improvement and insights provided by constant collaboration with the teachers. Analysis is conducted on the data collected from the Primary (Grade) 3 level students in the year 2013 and 2015. In 2013 the students had been using the smartphone SamEx application, while in 2015 the students were equipped with tablet computers running a redesigned and improved SamEx application. Analysis is based on the comparison of two student trips to the Singapore zoo, and characterized by a number of questions specifically designed

by teachers for the students to answer on the spot by providing textual, picture, video or audio responses via the application.

Section II provides an overview of the state of the art mobile learning and pedagogical approaches to it. Section III follows with a detailed description of SamEx design. Sections IV and V describe the methodology used and present the results of the data analysis, while Section VI discusses interaction specifics.

II. STATE-OF-THE-ART

The rapid development of mobile technologies has in recent years encouraged the emergence of a number of novel software applications, and also opened the possibility of transferring many existing applications from desktop PCs to mobile phones and tablets. Moreover, the ease of use, device portability, different connectivity options, built-in camera and various sensors made mobile platforms an ideal environment for many software applications. Used in the mobile educational applications, many of these features have potential of greatly improving user (learner) experience and motivation [2], which could in the end, lead to better learning results. Similarly to Web learning platforms in the late '90s, mobile learning applications are "the hot educational topic" throughout the last ten years [2].

Although handheld devices, smartphones and tablet computers exist for a number of years now, the real revolution in the field happened in 2007 and 2008, when Apple iPhone and the first Google Android based phones were unveiled. These two, along with Microsoft Windows Phone, are the prevalent mobile and tablet computer platforms today. As soon as the technology stopped being a limiting factor, and tablet or smartphone devices started coming with enough processing power and memory for demanding applications, many studies started actively researching appropriate pedagogical approaches to mobile learning [3].

Until recent years lectures were mainly designed so that teachers deliver knowledge to the students, who are mostly passive participants in the whole process [4]. Developments in e-learning, and especially m-learning, which is characterized by using mobile phones and unlike e-learning is available on any location, resulted in a more active involvement of students in the educational process.

There is a number of review papers on mobile learning written in the recent years, like [3], [5], [6], [7] and [8]. Sharples [3] gives an overview of the mobile learning field, accompanied with critical review of existing studies and general guidelines for development of future mobile learning applications, without information about specific technologies. Wu et al. [5] give a very comprehensive analysis of the field and existing mobile systems. Their study includes papers published until 2011, so a number of new trends and technologies are not included. Jacob and Issac [6] made an analysis of learning practices and the accompanying exploitation of mobile devices. They state the advantages and

disadvantages of a particular mobile device type in mobile education, as well as the usage of these devices amongst their students, with also no technology-specific information given. Parsons & Ryu [7] describe generic software architectures for mobile educational applications and conclude that the best (the "richest") platform for mobile learning seems to be the client-server architecture. Martin et al. [8] analyze the existing frameworks and middleware applications for mobile learning applications and focus only on these two aspects of mobile application programming, without a deep focus on available technologies.

III. SAMEX

A. System Design

SamEx was designed to support self-directed and collaborative learning activities and provides a participatory platform for students to contribute, share, and give feedback. Students can use it to take a picture to collect data or post information they found to be useful for their learning. These postings are shared with other students who can review, give comments and evaluate by giving "Likes" to the contribution.

SamEx was developed for the Android [9], Windows 8.1 [10] and Windows Phone 7 and 8 [11] mobile operating systems in the Seamless Learning Curricular Innovation project in a Singapore primary school. SamEx system architecture consists of the following components (Fig. 1): server-side components, web application for system administrators and mobile clients (Android, Windows 8.1, Windows Phone applications for smartphone and tablet devices). The system is based on a centralized data model where clients are not responsible for data processing, and thus focus on the interactions with users. SamEx server-side components are: relational database, web application and web services for communication with mobile clients. All three components allow for seamless data storage and administration for both users and administrators. The key issue in SamEx system design is maintaining a consistent state of the data between the server and client applications.

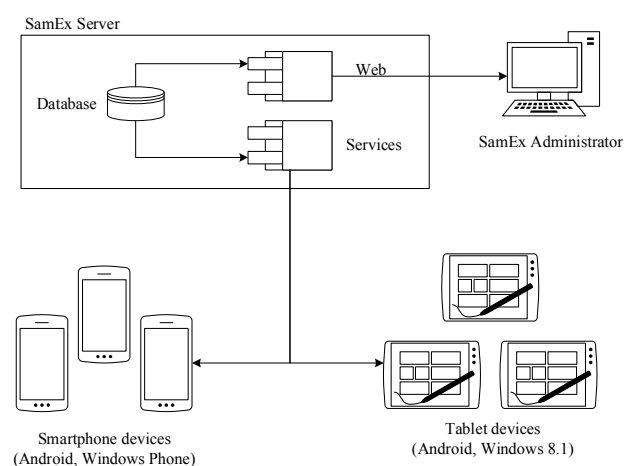


Fig. 1. SamEx system architecture

The generic SamEx mobile client application is built of several layers: a server communication service, a data access layer, and modules for user interaction (GUI). Data is periodically fetched from the server side and stored locally via a background service. A data access layer is implemented over the storage data structures, allowing developers to make easy structural changes without affecting the application logic for the communication with users.

SamEx can be installed on Android or Windows Phone smartphone or tablet devices. Students are given a mobile device with SamEx application preinstalled and preconfigured to immediately act as an active system component. SamEx web application provides an administrative user interface. Teachers and administrators are able to search, filter and sort data, and administer student groups or set up location-based prompts (so called “triggered questions”).

Activities in SamEx were designed for primary school students who used SamEx in their school activities. In addition to collecting, storing and accessing multimedia artifacts, SamEx can store contextual users’ information for potential educational use. Depending on the current time and users’ location, the system allows question prompts to be displayed on students’ smartphones potentially facilitating or scaffolding learning tasks. Students can therefore be guided in outdoor mobile learning trails or just prompted periodically in connection with their homework observations or other work they are recommended or required to pursue outside of school. Students can also subscribe to their peers’ contributions.

To reward students’ activity, SamEx leverages on its own badge system, an extrinsic motivational tool. By collecting media, answering location-aware questions, providing comments to other students’ questions and “liking” other students’ work, students take part in a game to accumulate points leading to the earning of badges in five categories with four levels in each category. The badges were designed as recognition to motivate student to participate and share in the inquiry process. The content of uploads is not automatically checked for quality, so it is possible for students to upload content just in order to get high badge scores. This is solved by closely examining contributions of students with suspiciously high counts of content.

B. Technology Shift From Smartphones to Tablet Computers

Between the years of SamEx usage a technology shift was inevitable. The participating school decided to switch from smartphone devices to tablet computers, which pushed the evolution of SamEx system. The changes in the design of the mobile learning applications were carried out in collaboration with the teachers and researchers, as part of the design-based research methodology.

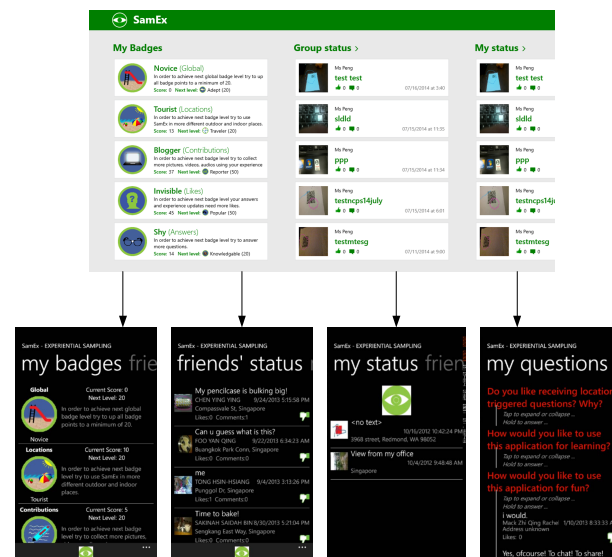


Fig. 2. Badges, my status, group status and questions in tablet (above) and smartphone (below) applications

The foundation of the new application design was the restructured home page for tablets (Fig. 2). In order to improve the application user experience, the new landing page exposes all important features on only one screen: recent statuses, questions and most importantly badge status for the current user. This design reduced the amount of time a user has to spend in the application by laying out the crucial information in a dashboard-like structure. With the new organization of the features, users rarely need to venture deeper into the application because the summary of the most important details is shown right after its launch.

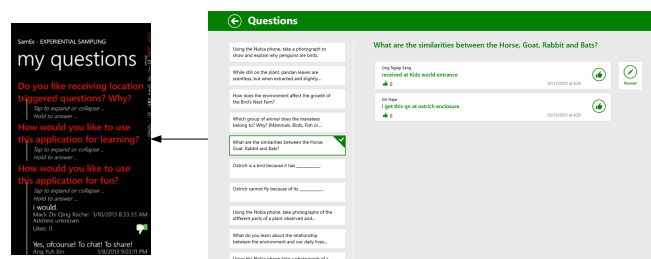


Fig. 3. Questions page in tablet (right) and smartphone applications (left)

Another improvement coming with the SamEx application on tablet devices is the enhanced interaction with media elements. Due to the larger screen, the preview of multimedia artifacts posted by the other students is now much more suitable from the visual perspective. Furthermore, the module for posting a new status now allows previewing, posting or discarding media on the same screen with a clean and user-friendly design (Fig. 4).

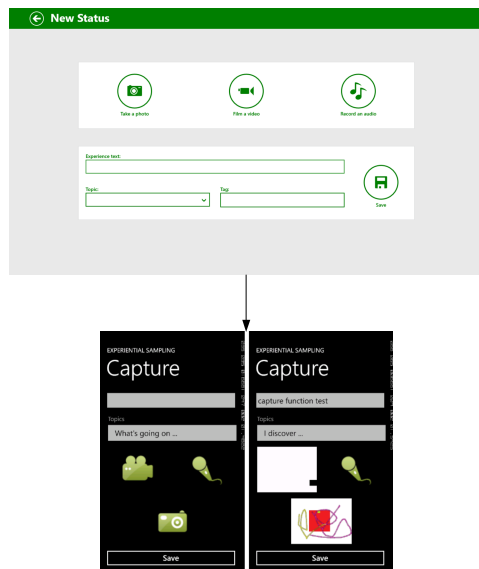


Fig. 4. New status page in tablet (above) and smartphone (below) applications

The SamEx module which gained the most from higher screen resolution on tablet devices is the Group Drawing module (Fig. 5). Students are presented with a canvas where they can draw, re-arrange the multimedia artifacts, add captions and collaborate in creating interactive dashboards. Interactive canvas functionality is much harder to utilize on smaller smartphone screens, which is why this module was not included in smartphone versions of SamEx mobile application.

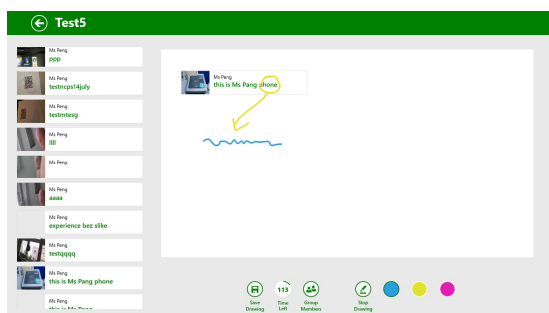


Fig. 5. Group drawing module in SamEx for tablet devices

On the other hand, tablet devices are larger and more robust which makes them difficult to use during highly mobile activities, whereas smartphone devices can easily be carried around in one hand or in students' pockets.

IV. METHODOLOGY

The students taken into analysis are primary three class students, divided into eight level classes: A, B, C, D, E, F, G, H, both in 2013 and 2015. During both 2013 and 2015 each group had a one day visit to the Singapore zoo. During that visit, students are encouraged to answer predefined questions involving specific zoo exhibits and spots. Some of those

questions are triggered via the application as a consequence of the user location change. Students can post their own text or media contributions, read their colleagues' observations and comment and like them. All the data provided by student contributions is collected and stored in the application database for further analysis. The result of SamEx application usage is a rich data set mostly composed of student contributions produced and stored in the period of two years.

Observations in this paper are based on the comparison of the data collected as a result of these two zoo trips. This was decided due to the conclusions of the preceding study where the application usage was the highest during the trips and thus richest in terms of content provided [12]. Even though both trips are characterized by almost the same locations visited and almost the same visit duration, the following differences were observed:

- Number of question prompts decreased from 23 in 2013 to 12 in 2015 in order to focus on student involvement in trip activities
- Questions in 2013 require a multiple choice, textual or experience based answer, while questions in 2015 are only experience-based
- Tablets used in 2015 had constant WiFi connectivity and GPS signal, which was not the case with smartphones used in 2013
- Eight group visits were spread throughout two weeks in 2013, while in 2015 the zoo visits were conducted in one week time
- Number of enrolled P3 students in 2013 was 305, while in 2015 a total of 321 primary three students were involved in the study

Taking these differences into account, the methodology of this study is aligned in order to respect and properly analyze these two approaches to the zoo visit. Student contributions taken into the analysis are exclusively the ones corresponding to the dates of the visit of the student's group in order to avoid at home or classroom usage and to only focus on the trip data. Student experiences are filtered in order to avoid repetitive duplicate experiences, due to errors in the system operation mainly due to the lack of WiFi connectivity.

Experience updates submitted by the students are grouped by text, user, and the quantity of audio records, videos, pictures and time. In case more than one experience with the same text and media files have been uploaded in a short time span, they are declared as repetitions, and only one is taken into consideration for the data analysis. Experience updates which contain no text and no media files are disregarded. Audio experiences are disregarded in analysis due to the considerable lack of this type of experiences. Furthermore, data analysis is based on contribution efficiency and frequencies, and not solely on the number of contributions in order to respect differences caused by the different number of question prompts, which will be described in more detail in further text.

V. DATA ANALYSIS AND INTERPRETATION

The first step in data analysis is the comparison of means of student contribution quantities from the two given years. The results of this step are presented in Table 1. Group 1 represents the cohort of 2013 students, while Group 2 represents 2015 cohort of students.

The variable named *Experiences* presents the total number of any type of student contribution (textual, media or mixed). *Experiences* can be uploaded either as answers to question prompts or as standalone. *Pictures* and *Videos* represent the number of contributions which include media files. *BaseUsageTime* is a variable which gives the information on total usage time of the application in seconds in the given time frame (during the trip). *QuestionAnswers* represents the number of uploaded answers to teachers question prompts. Question answers can be either textual answers, multiple choice answers or answers in form of experiences. Comments can be added to experiences, while likes can be added to either question answers or experiences. All the variable values are grouped by users.

Table 1 shows raw means are greater in group 1 compared to group 2. As previously mentioned, the number of questions was greater in the year 2013 (23 questions) than in 2015 (12 questions). This difference explains the decrease trend of variable values. However, an unexpected increase in number of question answers is present. Since the number of question answers is lower in 2013 than in 2015, but the total number of experiences is greater, it can be concluded that 2013 students uploaded their own contents more often than directly answering the predefined questions. A substantial difference between groups is present in *BaseUsageTime*. This is partially due to less content upload in general in 2015, and partially due to overall simplicity of tablet usage.

Next step in the analysis is the computation of efficiencies and frequencies based on the previously defined variables. Equations used to calculate these values are following:

$$\text{Experience Efficiency} = \text{Experiences} / \text{BaseUsageTime} \quad (1)$$

$$\text{Picture Efficiency} = \text{Pictures} / \text{BaseUsageTime} \quad (2)$$

$$\text{Video Efficiency} = \text{Videos} / \text{BaseUsageTime} \quad (3)$$

$$\text{Answer Efficiency} = \text{QuestionAnswers} / (\text{TotalQuestions} / 10) \quad (4)$$

$$\text{Comment Frequency} = \text{Comments} / (\text{TotalExperiences} / 1000) \quad (5)$$

$$\text{ExperienceLike Frequency} = \text{ExperienceLikes} / (\text{TotalExperiences} / 1000) \quad (6)$$

$$\text{AnswerLike Frequency} = \text{QuestionAnswerLikes} / (\text{TotalQuestionAnswers} / 1000) \quad (7)$$

TABLE I. MEANS OF CONTRIBUTIONS FOR GROUPS OF 2013 AND 2015

Measured variable / Group Id	N	Mean
Experiences	1	277
	2	192
Videos	1	277
	2	192
Pictures	1	277
	2	192
BaseUsageTime	1	294
	2	247
Comments	1	68
	2	51
QuestionAnswers	1	287
	2	182
ExperienceLikes	1	83
	2	92
QuestionAnswerLikes	1	32
	2	137

BaseUsageTime in (1), (2) and (3) is transformed into hours in order to make the results easier to interpret. The same principle is followed by introducing the factors 10 in (4) and 1000 in (5), (6) and (7).

Table 2. shows the means of these transformed variables. It can be seen that after these transformations the means are in fact greater in Group 2 in contrast to the initial results. Exceptions are variables *Video Efficiency* and *Picture Efficiency*. This can be explained by the fact that none of the questions in 2015 strictly required students to upload their collected pictures or videos. To query the significance of this difference among groups, an independent samples t-test has been conducted. Equal variances were not assumed for any of the variables except for *Comment Frequency*.

The results show that students demonstrated greater efficiency in the second group, by uploading more content in less time and providing a greater frequency of comments, likes and question answers.

TABLE II. T TEST RESULTS FOR CONTRIBUTION MEAN DIFFERENCES BETWEEN COHORTS OF 2013 AND 2015 STUDENTS

Group	Mean	MeanDiff	Sig (2-tailed)
Experience Efficiency	1 10.5459	-17.74	0.000***
	2 28.2831		
Video Efficiency	1 0.5011	0.28	0.041**
	2 0.2241		
Picture Efficiency	1 8.4991	4.43	0.000***
	2 4.0708		
Comment Frequency	1 2.0417	-0.90	0.305
	2 2.9425		
Answer Efficiency	1 2.5632	-3.78	0.000***
	2 6.3462		
ExperienceLike Frequency	1 5.5223	-2.68	0.165
	2 8.2056		
Answer Like Frequency	1 1.1266	-7.53	0.000***
	2 8.6527		

***p<0.001, **p<0.05

VI. INTERACTION SPECIFICS

An important feature of SamEx is question prompts, designed by the teachers in order to motivate and encourage students to participate in SamEx activities. The system allows for three types of question prompts to be created: open-ended (type 1), multiple-choice (type 2) and media (type 3) questions. Media questions encourage students to document their learning process with a photo, video or audio.

The reaction of students to various questions with different content, level of detail and type was analyzed. The questions set for the zoo trip in 2013 were of all three types of questions. The results are unexpected - there was a large number of incomplete or very brief textual answers, while the attached media was of high quality and to the point. Students seemed to gain a lot by making observations based on media questions and produced high quality media content, but failed to give the proper textual explanations along with the photographed artefacts. For example, the question "Using your phone, take a photograph to show and explain why penguins are birds" produced a lot of quality photos and videos, but the majority of students failed to answer the second part of the question. Giving the students too extensive tasks resulted in a lower contribution quality than expected.

Using the observations from 2013, the questions for the zoo trip in 2015 were designed differently. Teachers stopped actively encouraging students to provide media content and focused on shorter, simpler questions. Despite not being explicitly prompted to take pictures, the students continued to provide media contributions along with the textual answers, but with one big difference: the textual answers were now of much higher quality and more focused on the actual question when compared to the previous zoo activities. By giving the students more freedom and more open-ended questions, along with some hints about what to focus on, their answers became more creative while still in line with the learning objectives.

TABLE III. COMPARISON OF QUESTIONS FORMATS IN 2013 AND 2015

2013.	2015.
Using your phone, take a photograph to show and explain why penguins are birds.	How do you think the Stingray breathes in water? Hint: Is it similar to other fish?
Observe the fish and describe at least 5 characteristics that you can see.	Why is the bat a mammal? Hint: Which characteristic(s) of a mammal does the bat have?
Take a video of an insect to show that it is a living thing.	Which group of animals would you classify the hissing cockroach as? Give 2 reasons why.

VII. CONCLUSIONS

Results of the two groups of students laid out in this paper are challenging when it comes to comparison since the differences between them and the concept of their zoo visits are characterized by a number of differentiating factors. Through the analysis the authors came to a conclusion that the factors which carry the most differences are the number of questions, the type of questions and the use of tablets opposed to the use smartphones.

The number of questions is greater in the year 2013 in comparison to 2015, but students gave better answers in 2015, both in terms of quality and quantity. Teachers decided to decrease the number of questions in 2015 in order to allow students to focus more on the zoo artefacts and exhibits and verbal communication. This proved to be a successful approach, since students react well to a small number of well-defined questions, giving answers which are in most cases correct, concise and often accompanied by media even though not instructed. The better quality answers given by the students prompted their peers to view and respond to the contributions causing the comment and like frequency to rise.

The second factor is the type of questions used. In 2013 students provided adequate answers to multiple type questions and textual questions but the quality was lower in the case of experience-based questions. In contrast, in 2015 students gave high quality experience-based answers. The question type disparity, can be explained by the fact that the questions in 2013 contained more subquestions and strict rules, while questions in 2015 were more concise and provided optional possibilities of uploading media content which caused a favorable reaction from students.

Informal observations also offer an explanation of a more efficient user interface provided by tablets. As previously described, tablet devices offer the possibility of simpler and more accessible application usage. The smaller number of answers in 2013 can thus be explained with an issue of connectivity and location acquisition which was present in the smartphone version of the SamEx application and caused inconsistent prompts, so the students had to use experiences instead. What is more, graphic interface in the tablet application version offered easier and faster question answering and media attachment which explains the decrease of application usage time. The improved graphic interface on the larger tablet screen also promoted better social interaction between the students as they are able to easily view the answers and experiences contributed by their peers.

An obvious progress can be noticed in the gathered data, mainly in terms of efficiency and quality of the contributions provided by students. Technology shift, application improvement and graphical user interface redesign as well as the change in terms of class organization have proven beneficial for students. Cooperation between the technology and educational expertise through constant iterative redesign gives the expected affirmative results which are expected to further excel in the following years.

Acknowledgment

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The experiences of setting up, developing and implementing a mobile learning project in Croatia

The SCOLLAm project

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Abstract — This paper problematizes the challenges of setting up a new mobile learning project in a Croatia, a country where technology-enhanced tools in classrooms are not often used due to a number of reasons, two of which are the lack of infrastructure and no teacher professional development. There are three focal points of this paper: designing scalable and durable mobile learning solution, working with teachers in order to ensure an adequate teacher development and creating appropriate digital contents to match primary school level 2, 3 and 4 curriculum. Scalable and durable mobile learning solutions in the context of this project include two main platforms: (1) a mobile learning tablet application for primary school students and (2) a designer application mainly aimed at digital contents designers and producers, to also be easily used by the teachers. On the other side, it describes the processes of strengthening digital competences of the participating school teachers, including technology competence, leadership capacity and technology supported curricular innovation processes. Thirdly, the issues of design and implementation of digital lessons are explored with a special focus on digitalization of the existing non-digital lessons together with the teachers, wherever appropriate and feasible. As a result, conceptual prototypes of digital lessons are produced to be analyzed and discussed amongst teachers and researchers, after which the selected ones get integrated into digital lessons for tablet computer. In addition to describing the threefold process and the accompanying issues, the paper presents preliminary experiences and results in this novel research initiative, sets up mid-term goals and proposes and adequate methodology in achieving the project goals.

Keywords — *mobile learning; educational technology; tablet computers; informal learning; mobile applications*

I. INTRODUCTION

Introduction of innovations and new technology in a system that operates in more or less similar way for many decades is not an easy task. With other difficulties, such as lack of adequate infrastructure, scarce financial resources and insufficient professional development of teachers, there is a number of challenges to overcome in order to successfully implement a desired system improvement. Croatia is a country that still feels the consequences of war, economic transition and the recent global economic crisis. Many schools are poorly equipped, without sufficient number of computers and fast internet connection, which is one of the reasons why

Informatics is still only elective course in all primary, and in many secondary schools in Croatia [1].

In September 2014, in such circumstances, a project to explore the potential of using mobile technology for seamless and mobile learning in Croatia was launched. Named SCOLLAm (“Opening up education through Seamless and COLLABorative Mobile learning on tablet computers”), this three-year project is one of the first scientific research projects closely related to mobile learning that is implemented in Croatian schools. SCOLLAm is building up on the experience of team members and in similar projects from Sweden, USA, and especially the Seamless learning project conducted by the National Institute of Education in Singapore [2]. The main goals of the project are: proposal and design of a technologically innovative, scalable and durable mobile learning platform, cooperation with teachers in order to ensure an adequate teacher development and their competences in the ICT and mobile technologies fields, and creation of digital content tailored for usage in the first years of primary school.

SCOLLAm research team is multidisciplinary, comprised of scientists from both, ICT and fields of teaching methodology and pedagogy. Together with school teachers and international e-learning and m-learning experts as a team consultants, SCOLLAm created a small mobile learning community, which, in addition to their work on the project, encourage and participate in the discussions on the modernization of teaching, and carry out various studies on the use of technology in everyday teaching.

In the first stage of the project focus was on the analysis of teaching methods and tools the teachers are using in their everyday work with students, estimation of digital and ICT-related competences and education level of teachers, and analysis of the current state of computerization in a typical Croatian classroom. In the second stage a prototype digital lessons will be created and tested. For this purpose two software applications are being developed: a mobile learning platform named SCOLLAm [in]Form, and a designer and player of digital lessons – [in]Form Author. Other parts of the system include collaborative learning, augmented reality, analytics and adaptivity modules, which will be, when finished, integrated into the [in]Form platform.

The rest of this paper is organized as follows: in section II the experimental school and project participants, together with some details about Croatian schooling system, are described. The research methodology is described in section III. Current status of the project, findings, issues and design decisions that had to be made are discussed in Section IV. Section V describes the work of the team members in improving the digital competences of teachers. Finally, Section VI concludes the paper.

II. PARTICIPANTS: FROM AN EXPERIMENTAL SCHOOL TO A NATIONAL LEVEL PARTICIPATION

The project is implemented in cooperation with elementary school Trnjanska from Zagreb. It is a small school with around 25 mix-gender pupils per generation. The research focus is on the first four grades, with students aged 7 to 10 years. Elementary school education in Croatia is split into two four-year parts, with lower four grades, having one dedicated teacher for most of the subjects as per curriculum (Croatian language, mathematics, nature and science, music and visual arts and physical education) [1]. Members of the research team regularly attend lectures in all four classes, participate in field lessons, and organize meetings and consultations with teachers. Team members are monitoring and analyzing activities in the classroom, and suggest the possibilities of their “digitalization” or enrichment with additional digital content. Often teachers themselves propose their own ideas how to improve the existing lessons with simple mobile games or questionnaires.

In the autumn of 2015, a national-wide project named e-Schools starts in Croatia. The project that will last for next three years aims to computerize and equip about 150 Croatian schools with modern technologies, tools and teaching materials. E-Schools is a preparation for an even larger national informatization project that starts in 2019. The SCOLLAm team is actively involved into preparation of both of these projects, in fact SCOLLAm serves as a pilot to both. Results

and experience from SCOLLAm will be used in planning these and other Croatian educational system computerization projects in the future.

III. RESEARCH METHODOLOGY

The research methodology of the project is based on the Design-Based Research (DBR) [3][4][5] approach. It is an approach that combines theoretical and empirical research in education, giving better insight why and when a certain intervention in educational process gives a positive outcome. The whole DBR process is iterative, starting with predefined learning goals, through a series of iterative “design – develop – implement - test – analyze - redesign” cycles, resulting in a design principles and theories closely linked to the context in which they are applied [5].

Through a series of stages the researchers of the SCOLLAm project are iteratively collecting information and gaining a better understanding of the seamless mobile learning system implementation. Fig. 1 gives a deeper insight of stages in the project research and development process. On the basis of observed lessons the conceptual model and lesson description documents are created. These materials are input into the next stage, the identification of digitalization opportunities. Together with teachers, the researchers from both pedagogical and ICT field suggest and design prototypes of new “digitalized” lessons. Lessons are then iteratively evaluated and modified, and finally integrated into the SCOLLAm [in]Form platform (Fig. 2).

The platform itself is client-server based. According to Parsons & Hokyoung [6] this seems as the most flexible and popular solution for mobile educational applications.

IV. DESIGNING MULTIPLATFORM MOBILE LEARNING SOLUTIONS

SCOLLAm builds upon a number of educational projects

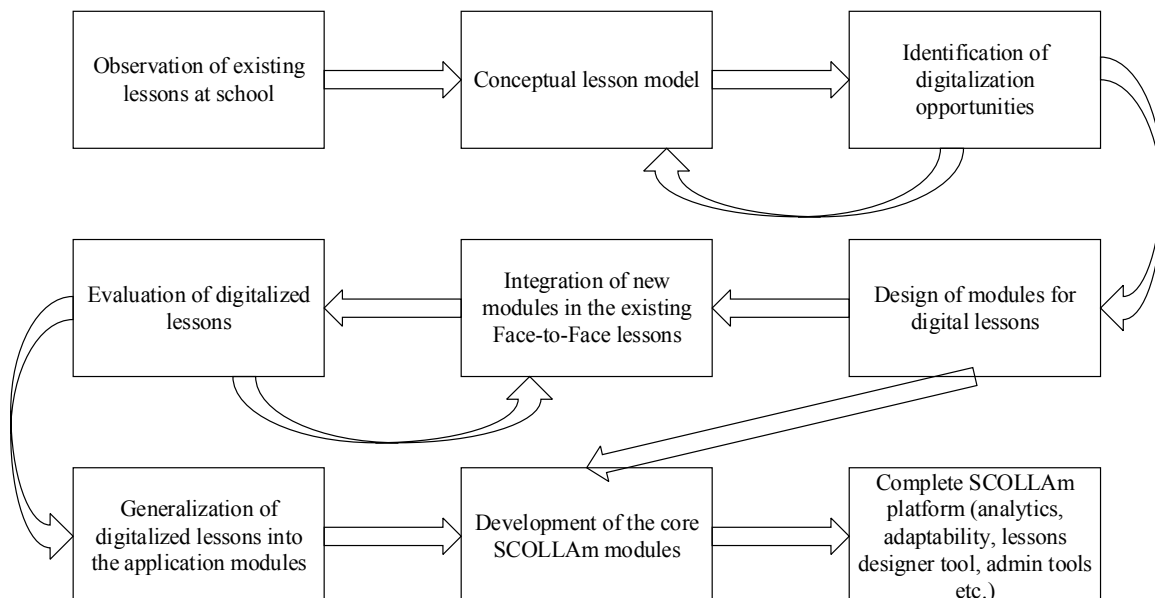


Fig. 1 The SCOLLAm research methodology flowchart

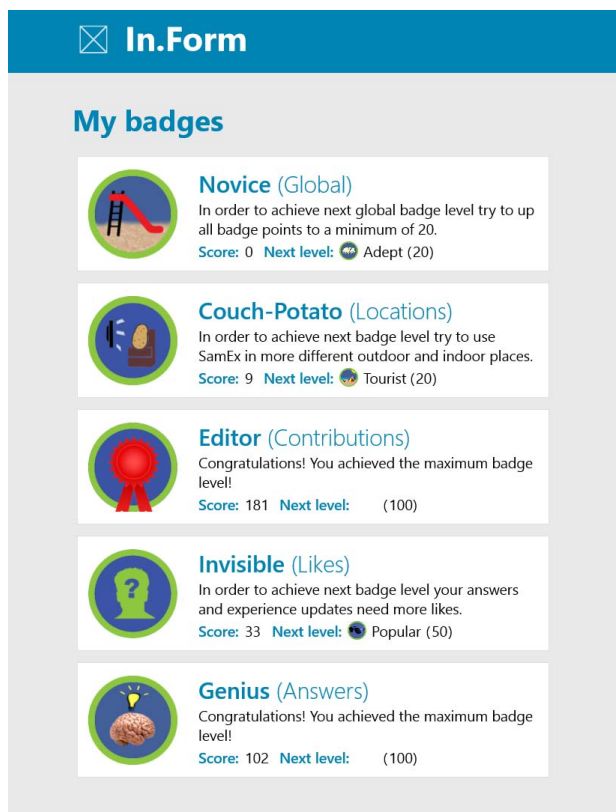


Fig. 2 [in]Form platform

carried out by team members in the past, that included work with primary and secondary school children [7], university students [8], as well as people with specific communication needs. For most of these projects custom mobile applications were developed, but the solutions were generally platform-specific. For instance, the mobile social learning platform SamEx [7] was developed only for Windows Phone, preventing it to reach a large number of Android and iOS users.

In the early stages of the SCOLLAm project, various single platform tools to extend SamEx's functionalities were developed for Windows Phone and Android operating systems. The code was also platform-specific, often duplicated and thus hard to maintain and further developed, especially when additional operating systems are concerned. With that in mind, in this project the goal was set to develop a single - integrated mobile learning platform. The platform is intended for two categories of users: primary school students and their teachers - who are also content designers. For the content generation part, a single web application named "[in]Form Author" (Fig. 3) is developed. It is used from the desktop computer, via internet browser, to design and generate lessons. Lessons are saved in JSON format (with additional media files), packaged, and subsequently deployed to the students' mobile devices where they are executed via mobile application module named "Player" (Fig. 4). Apart from Player, the existing SamEx code-base is used to include the support for collaborative learning, badges, experiences etc. in our mobile learning platform. Unfortunately, SamEx code, written in C# was available only for the Windows Phone platform, and the project objective is to support all three major mobile platforms.

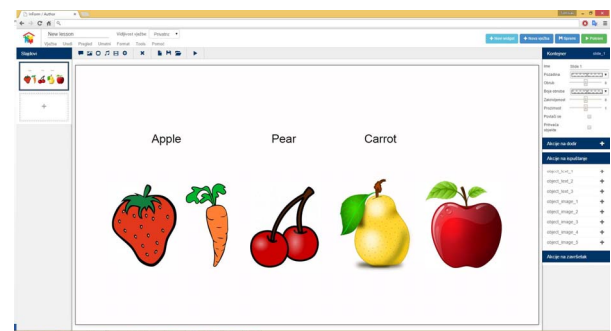


Fig. 3 [in]Form Author - digital lessons authoring tool

In terms of user experience and speed, the best approach would be to develop separate parallel applications for all targeted platforms [9] [10], but that yields duplicate code in different programming languages, intertwined with platform-specific API calls. Such approach requires significantly more resources for development and, equally important, long-term maintenance and development of our application and was assessed as not appropriate in our case. The alternative is to abstract the mobile platform differences, that is to use cross-platform mobile development approach, where a single code base would be maintained. Though it is apparent that 100% write-once-run-anywhere code base cannot be achieved in this project because certain advanced mobile device's capabilities (augmented reality, shared canvas drawing, etc.) are required, the goal is to maximize the common code base and provide the platform specific code only when it is necessary.

There are three main types of approaches to cross-platform development [11] [12]:

Pure web applications – application is written in HTML and related technologies (CSS, JavaScript, etc.) resides on the server, and is accessed via internet browsers on the respective devices. Applications are typically CSS-styled (e.g. jQuery Mobile) to mimic the look-and-feel of the native applications

Hybrid applications – also written in HTML but are embedded inside a thin native container (e.g. WebView in Android, UIWebView in iOS). They are also executed by a browser, though it may not be apparent, being that the browser is integrated in the native application.

Compiled or interpreted applications – applications written in a single programming language and then converted and compiled into native applications for each targeted platform. Unlike the previous two approaches, the resulting applications are true native applications. However, frameworks in this category vary in the level of support of generic UI, that is – sometimes it is necessary to define separate UIs for different platforms.

Pure web applications were not an option since they lack the hardware and data access on the mobile devices, and therefore only leading hybrid and generated (compiled and interpreted) frameworks were considered: Titanium¹, open-

¹ <http://www.appcelerator.com/product/>

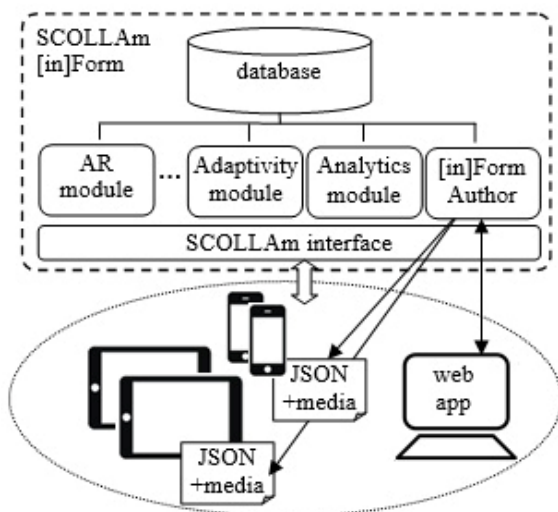


Fig. 4 The SCOLLAm architecture

source Cordova (ex PhoneGap)² and commercial Xamarin frameworks³.

Titanium, though being a high-quality mature development framework, was discarded because of the limited Windows 8 support, and only Cordova and Xamarin frameworks were evaluated in further detail.

Both Cordova and Xamarin seem as an acceptable solutions, with Cordova having the advantage of being free, while Xamarin has a better technical support and a state-of-the-art development environment (Xamarin leverages Microsoft's Visual Studio). Cordova also uses more widespread and open technologies (HTML5+JavaScript) when compared to Xamarin's C#. What tipped the scale in our particular case, is the ability to leverage the existing legacy C# codebase and the excellent Xamarin's IDE and more integrated environment. Also, Xamarin enables us to nicely structure the project and separate the generic views (through Xamarin Forms technology) from the OS-specific views (through Xamarin iOS and Android projects), as it enables to mix-and-match those approaches⁴.

The Player part of our learning mobile solution, which is a packaged web page and data, will be executed through native web view container, as hybrid approach is employed in that part. At the time being, the complete legacy code with additional features is ported to Xamarin framework and most functionalities are covered with single code-base generic forms which greatly facilitates maintenance and further development. Xamarin has proven to be a right choice for our particular project.

V. STRENGTHENING DIGITAL COMPETENCES OF TEACHERS

The teacher development and strengthening of IT competences among teachers is, besides mobile learning platform development, one of the most important parts of the

project. For that reason, the team members constantly cooperate with teachers, discussing lessons design, the development of the educational tools, but also discussing privacy, security and safety issues and concerns some teachers and parents have. Team members and teachers who are a part of the project participate in various events related to the development and planning of the future Croatian education system, attending different informal and formal educational meetings and conferences. In addition to discussions about the possibilities of using tablets and other technological tools in everyday teaching and as a part of ongoing efforts to improve their IT competences, the teachers attended The Carnet Users Conference⁵, a leading Croatian IT and education conference, which took place in Zagreb from 19th to 21th November 2014. A BoF (birds of a feather) session on the topic "What should we do with the tablets in the classroom?" was organized by team members as part of the same event.

Additionally, course on internet safety and cyber bullying by Kidscape⁶ was organized for team members and the principal of Trnjanska elementary school. Similar lectures and discussions for parents are also planned.

VI. CONCLUSION AND FUTURE WORK

In this WIP study the current state of one of the first mobile and seamless learning implementation projects in Croatia was presented. Based on the previous experience in similar domestic and international projects, the SCOLLAm project aims to go few steps further, offering the complete mobile learning platform, digital lesson authoring tool, collaborative and augmented reality modules, adaptation and analytics.

The project is entering the second phase where the mobile learning platform and a range of additional application modules will be developed, and tested in the pilot school.

In the end, the research aims to propose technologically innovative mobile learning solution, together with system architecture, a number of digitalized lessons, experimental modules, different insights and good practices that were identified during the project.

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² <https://cordova.apache.org/>

³ <http://xamarin.com>

⁴ <http://xamarin.com/forms>

⁵ <http://cuc.carnet.hr/>

⁶ <http://www.kidscape.org.uk/>

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CHiLO: Using an e-textbook to create an ad-hoc m-learning environment

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Abstract—Open education offers higher education opportunities for underprivileged communities and solves the problem of deficit in learning resources, such as human and material resources, throughout developing countries. Open education, however, has certain challenges in terms of dependency on the Internet. The use of mobile devices is expected to aid in meeting these challenges. Mobile learning (m-learning), which is learning through mobile devices using various modes of communications like a phone line and contiguous communications, can potentially provide learning services anytime and anywhere without using the Internet. Our Creative Higher Education with Learning Object (CHiLO) project aims to provide an adaptable learning environment corresponding to diversification and uncertainty in large-scale online courses such as MOOCs using device-agnostic m-learning centered on e-textbooks with media rich content. It also aims at a comprehensive open network learning system through the use of various existing technologies and various learning resources, including OER on open network communities, such as SNS. Our set of experimental outcomes demonstrates the efficacy of m-learning using CHiLO, particularly with an e-textbook, including media-rich content, nano lectures, and digital badges.

Keywords—*m-learning; MOOCs; e-textbook; micro-credential; Social networking service*

I. INTRODUCTION

The Education for All (EFA) movement by the UNESCO is a global commitment to provide quality basic education for all children, youth, and adults [1]. Open education (OE) movements such as Massive Open Online Courses (MOOCs) radically contribute in enhancing opportunities for higher education around the world as well as creating a new learning artifact or ecosystem while sharing personal knowledge [2]. OE movements offer higher education opportunities particularly for underprivileged communities and also alleviate the challenge of learning resources' deficit, such as

human and material resources, for developing countries [3]. However, since the majority of online education available today utilizes video streaming, which requires substantial and sustainable connections and relatively high bandwidth, it does not offer equal opportunities to different populations. About 60% of individuals do not have access to the Internet globally [4]. Further, 80% of people in the world do not have a personal computer [5]. Therefore, people in remote locations and developing countries have difficulty accessing online learning environments [6].

Mobile communication devices are so ubiquitously used in the world that "Globally, mobile-broadband penetration will reach 32% by the end of 2014—almost double the penetration rate just three years earlier (2011) and four times as high as five years earlier (2009)" [4]. Mobile communication devices that provide satellite communication and a personal area network (PAN) such as Bluetooth, a traditional telephone infrastructure, as well as Internet access, proliferate in the world. It implies that these mobile communication devices do not depend on only the Internet.

Therefore, the use of the mobile devices may potentially provide a solution to these challenges. Mobile learning, or "m-learning" based on the mobile devices, comprises learning services that can be used anytime and anywhere without the Internet connection. Moreover, the m-learning also should be device agnostic mobile learning or ad-hoc m-learning.

Our Creative Higher Education with Learning Object (CHiLO) project aims to develop a radically new learning system for introducing changes to higher education based on large-scale online courses such as MOOC that differs from a traditional classroom. It uses a CHiLO learning system that provides a flexible and diversified learning environment based on learners' abilities and living situations using m-learning technology. The CHiLO system possesses a capacity of

effectively high portability in electronic publication 3.0 (EPUB3) format as well as a comprehensive open network learning system through the use of various existing technologies and learning resources, including open educational resources (OER) on open-network communities, such as social networking services (SNS).

The CHiLO system comprises the following four components developed with a novel design: (a) CHiLO Lectures based on one-minute nano lectures; (b) CHiLO Badge providing authentication and certification; (c) CHiLO Book with a packaging of learning resources, such as CHiLO Lecture and CHiLO Badge using an e-textbook with an EPUB3 format; and (d) CHiLO Community, such as SNS, bulletin boards, and chat rooms.

In this study, we report m-learning's possibilities for CHiLO through our experiment on one of the massive open online courses in Japan, Japan Massive Open Online Courses (JMOOC). Our experiment demonstrates evidence of m-learning's effectiveness through the use of e-textbooks.

II. AD-HOC M-LEARNING

A. Online education and Digital divide

Online education is characterized by cost-effectiveness with transparency, scalability, flexibility, and accessibility consistency. Online education also improved student performance by enabling to influence many different students [7, 8, 9]. Nevertheless, in developing countries, open education has not become popular [7, 9, 10].

Online education has two barriers [11]. The barriers are categorized as external and internal. The internal barriers include lack of equipment, unreliability of equipment, lack of technical support, and other resource-related issues. The external barriers include both school-level factors such as organizational culture and teacher-level factors such as beliefs about teaching and technology and openness to change.

These two barriers have also been observed in developing countries [12]. In particular, the internal barriers including lack of equipment, unreliability of equipment has indicated as having a serious effect in the developing countries. In the external barriers, the people face digital divide issues including a lack of necessary skills-set, knowledge, and concepts that are needed for effective consumption-access, locate, operate, manage, and understand [13].

B. Mobile Learning

Mobile learning (m-learning) is defined as the combination product of mobile technology and e-Learning technology [14], or learning that occurs with the help of mobile devices [15]. M-learning is expected to bridge the digital divide that provides the opportunity to learn from anywhere at any time in developing countries using mobile devices that has the following features [16].

- **Affordability of Demand-Side:** The many pricing models offer affordability and choice, even for very low-income customers (cheap handsets, micro prepayments, top-up cards). [17]

- **Reduce of electricity problems:** Mobile devices do not necessarily require a stable power supply [16]
- **Several communication:** Mobile devices can be utilized through several communication technologies such as global system for mobile communications (GSM), wireless application protocol (WAP), and Bluetooth, without permanent physical connection to cable networks [16].
- **Ease of use:** Mobile devices are easy to use without the need for computer skills [17, 18].
- **Pervasive and ubiquitous:** Mobile devices are pervasive and ubiquitous and are increasingly changing the nature of knowledge in modern societies [17, 19].

C. M-learning based on ad-hoc network

Mobile ad-hoc network (MANET) is a network of mobile devices that are interconnected in an ad-hoc manner to share data. Data are shared in a multi-hop manner by being passed between devices, with each device having the potential of routing data to another device in a mesh network [20]. MANET is an effective approach to make up the digital divide in developing countries that do not possess reliable network connection such as the Internet [20].

M-learning using MANET improves learning in a poor network environment [21, 22, 23]. MANET uses grid technologies and creates a rapidly changing learning environment for mobile learners, who can dynamically join and leave these communities. [24].

III. COMPONENT TECHNOLOGY

CHiLO comprises different technologies such as e-textbooks, micro-credentials, and SNS, is a combined advantage of m-learning.

A. E-textbook

A learning method using e-textbooks provides a new way of learning adapted to the network-learning model.

The e-textbook, which is not only device-independent but also available offline or online, has adopted m-learning. Furthermore, e-books have the interoperability of EPUB and major e-book formats, namely Kindle's K8 format, iBook's .iBooks format, and others [25]. EPUB3 is a distribution and interchange format standard for e-books developed by the International Digital Publishing Forum (IDPF) [26].

With the advent of the EPUB3 format, e-books now include media-rich and interactive contents. The International Digital Publishing Forum [27] stated that "the EPUB specification is a distribution and interchange format standard for digital publications and documents. EPUB defines a means of representing, packaging and encoding structured and semantically enhanced Web content—including HTML5, CSS, SVG, images, and other resources—for distribution in a single-file format." Thus, the EPUB3 format has greater sourcing flexibility. In the education field, learning materials in EPUB3 format are easily repurposed by tutors, adapted to

improve learning outcomes, and also offer a way of avoiding vendor-lock-in [28].

IDPF has proposed the EDUPUB format to meet the requirements of next-generation learning content based on the e-book EPUB3 format [27]. EDUPUB implemented a system for cooperation with the Learning Management Systems (LMS), the Analytics System, the Student Information Systems (SIS), and the assessment system on EPUB3 using JavaScript and JavaScript Object Notation (JSON) (see Fig. 1).

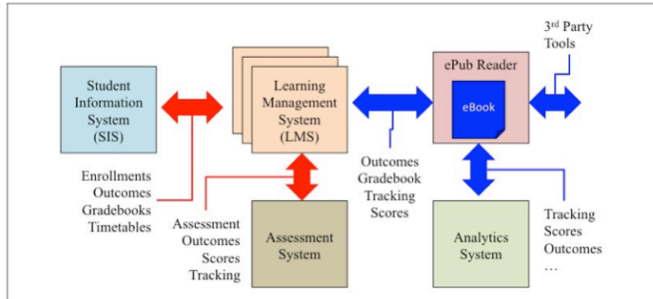


Fig. 1. Overarching EDUPUB Architectural Model [14].

New generation e-textbooks like EDUPUB and EPUB3 show equal to or greater educational effect than traditional LMS. Smith and Kukulska-Hulme [29] reported the following on the results of an 18-month project (2010-12) led by the Institute of Educational Technology (IET) at the Open University, UK.

- 1) E-books on portable devices are apt for the lifestyle needs of distance-education students.
- 2) Internet access allows for timely downloading and use, when it is available. "situational reading" occurs when one or more books with desired content are accessible to learners when needed, thus matching readers' requirements in relation to the situation they are in.
- 3) An e-book can contain all the resources needed by a student in one package.

B. Micro-credentials

The challenge in a traditional online course like course-centric learning is that learners of diverse backgrounds and levels receive the same service, such as studying uniform material with fixed lecture time [30, 31, 32]. A micro-credential system of competency-based education (CBE) connecting with learning paths in current efforts to demonstrate their mastery of those competencies [33] solves the challenge. CBE focuses on effective learning for adult learners, for instance, working and self-supporting students in a brief period. The CBE uses a digital framework, such as digital badges whose conventional system has been successful in motivating participants by showcasing challenges that have been overcome, displaying pathways, and improving social connections using SNS such as Stack Overflow and Foursquare [34].

Mobile devices are effective for micro-credentials because m-learning students use bite-sized contents within a fragment

of time without wasting a minute [18, 35]. Brandman University is offering a completely online competency-based bachelor's degree since 2014 [36].

C. Social networking services

Many studies strongly suggest that cooperative learning is more effective than individualistic learning with respect to contributing to motivation, raising achievement, and producing positive social outcomes [37]. Interactive learning using SNS such as Twitter, Facebook, LinkedIn, and others has drastically developed cooperative learning [38, 39, 40].

Furthermore, mobile devices improve communication among members of a social network within a country as well as internationally [41].

Online classrooms using social networking services through mobile devices solve the challenge of resource deficit, such as teachers and educational materials; this is very effective in the brick-and-mortar classrooms of developing countries or impoverished areas.

IV. ARCHITECTURE OF CHiLO

A. Overview

CHiLO, based on e-textbooks, aims to develop an affordable and scalable design for using m-learning with regard to large-scale online courses. It consists of the following four components (see Fig. 2):

- The CHiLO Book using e-textbooks in EPUB3 format;
- The CHiLO Lecture based on one-minute nano lectures embedded in CHiLO Books;
- The CHiLO Badge in CHiLO books that provides authentication and certification using Mozilla Open Badges (see <http://openbadges.org>); and
- The CHiLO Community such as SNS, bulletin boards, and chat rooms.



Fig. 2. Four components of CHiLOs

A. CHiLO's Architecture

1) CHiLO Book

The core component of CHiLO created through an e-textbook with an EPUB3 format contains media-rich contents, including graphics, animation, audio, and embedded video. The CHiLO book based on micro credential method consists of learning materials for a classroom hour. Those who complete a CHiLO book receive a CHiLO Badge as a certificate of completion.

Another idea of online education involves the use of e-textbooks by EDUPUB. However, most e-book readers do not

currently support the media-rich functions of the EDUPUB format, such as embedded videos, JavaScript compliance, and JSON. One reader that does support JSON is Radium, which is an open source EPUB reader developed by the IDPF. One of Radium's disadvantages is that it currently does not support mobile devices, such as smartphones and tablets. The CHiLO book offers a realistic solution by combining an e-book reader and a web browser. The EPUB3-based CHiLO book ensures access to a learning environment anytime and anywhere even without connecting to the Internet, thus avoiding the difficulties of most e-books. The CHiLO book as an e-book is also available in e-book stores such as the iTunes Store and Google Play Books. Another potential disadvantage of an e-book is that it requires a special application like an e-book reader and even downloads the e-book in the e-book reader. Learners without this access will need to use the web-based CHiLO book.

2) The CHiLO Lecture

The CHiLO Lecture comprises videos with scripts, quizzes, and other learning materials. Videos are one-minute nano lectures. This concept emerged from an experiment that revealed that most online learners' viewing time is approximately one minute [42].

A CHiLO lecture is equivalent to one section in a traditional textbook. A CHiLO book comprises approximately 10 CHiLO lectures. A standard CHiLO course, which is comparable to a traditional university course with one academic credit, consists of 10 CHiLO books.

3) The CHiLO Badge

It is difficult to perform indirect assessments, e.g., of learning time and academic workload, in large-scale online courses. Although CHiLO adopts a direct-assessment approach for learning outcomes, completion of a CHiLO course is measured in standard course hours, which correspond to academic credits.

Whenever a learner completes a CHiLO book, he or she receives a CHiLO badge, which is a simple mechanism for successful outcome assessment in CHiLO. When a tutor wishes to check a learner's progress, he or she asks the learner to present his or her CHiLO badges, thus removing the need to confirm using indirect assessment tools, such as grade books or tracking past results or test scores.

4) The CHiLO Community

The CHiLO Community provides both a social network function. Learners may share the downloaded CHiLO Book and have discussions on open SNS on the Web, such as Facebook and Twitter.

A CHiLO Community comprises many learners and a few tutors, known as "connoisseurs." These tutors act as substitutes for teachers. A learner who has studied and completed CHiLO books in a specific field can become a connoisseur. The connoisseur and learner are on equal footing, so a connoisseur often exchanges information with learners in their community.

In the CHiLO Community, a learner does not learn from a tutor but rather learns independently using CHiLO books as a

learning resource. In this way, learners are constantly required to find suitable CHiLO books within the community. The CHiLO Community provides methods for discovering, sharing, aggregating, and repurposing CHiLO books for learners.

V. RESULTS OF DEMONSTRATION EXPERIMENT

A. Experimental Methodology

In collaboration with the Open University of Japan (OUJ) and the Japan Foundation, we produced 10 CHiLO books named "Nihongo Starter A1 (NSA1)," which were composed of 10 successive lessons for those who would learn Japanese for the first time.

The NSA1 series was distributed in two different EPUB3-based and Web-based formats in accordance with the CHiLO architecture, and functions of assignment tests and issuing badges were implemented by linking Moodle modules of quizzes and badges. Both of the formats included hyperlinks to Facebook groups, which were created as the "CHiLO community" and were opened for the learners and teachers.

As a demonstration experiment, we distributed CHiLO books of the NSA1 series in about one year (from April 2014 to March 2015) at no charge through three different distribution channels shown in Table I. Among these distribution channels, the OUJ-MOOC site is one of the platforms supported by JMOOC, which is a MOOC provider in Japan (see <http://www.jmooc.jp/en/about/>).

Table II shows the start/end dates and terms in which each class (Class1–Class5) was held as a CHiLO community. In each community/class and term, our staff members of the support team for NSA1 facilitated discussions and question-and-answer sessions among the community.

TABLE I. DISTRIBUTION CHANNEL

Distribution channel	EPUB3-based	Web-based
<i>OUJ-MOOC site</i>	✓	✓
<i>iBooks Store</i>	✓	N/A
<i>Google Play books</i>	✓	N/A

TABLE II. LEARNING COMMUNITIES AS CHiLO COMMUNITIES

	Start	End	Term
<i>Class 1</i>	4/14/2014	5/1/2014	35 days
<i>Class 2</i>	6/2/2014	7/6/2014	35 days
<i>Class 3</i>	8/4/2014	10/15/2014	73 days
<i>Class 4</i>	11/3/2014	12/21/2014	49 days
<i>Class 5</i>	1/12/2015	3/22/2015	70 days

We evaluated the demonstration experiment by analyzing these data sources below:

- 1) Downloaded data of the CHiLO books provided by iBooks Store and Google Play books.
- 2) Site access logs on OUJ-MOOC server and aggregate data by Google Analytics.
- 3) Access logs to Moodle quiz module that linked the CHiLO Books with both EPUB3-based and Web-based formats.

- 4) Questionnaire results from learners (n = 105) who had earned all 10 badges of the CHiLO books in NSA1.

B. General Data

We found the results of the demonstration experiment held from April 2014 to March 2015 as shown below:

- The total number of download-volumes on three distribution channels together is 17,590 for the EPUB3-based CHiLO Books and 5260 for the Web-based CHiLO books.
- Comparing the number of lesson 1 downloads (6774 books) to that of lesson 10 downloads (1304 books), lesson 10 was only 19% of the lesson 1 total.
- 3156 learners took assessment examinations at least once.
- Despite the number of download-volumes being greatly reduced from lesson 1 to lesson 10, the percentage of those who earned a badge in each lesson held a range of 11% to 17%.
- 145 learners earned all badges of the 10 CHiLO books on NSA1.
- 3181 learners participated in the CHiLO communities (Class 1–Class 5) on Facebook.
- The total number of posts in the CHiLO communities (Class 1–Class 5) on Facebook is 1219, with 4046 comments to the posts and 5808 “likes”.

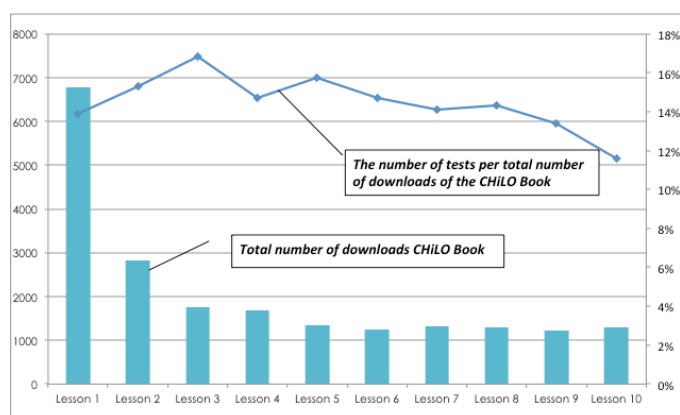


Fig. 3. Total number of CHiLO books downloads and percentage of those who earned a badge on each lesson

C. Data Analysis

Table III shows the number of downloaded NSA1 CHiLO books by country. Although there were legal restrictions in some countries and regions to download EPUB3-based CHiLO books in iBooks Store and Google Play books, in this demonstration experiment, we found that CHiLO books had been downloaded in different countries and regions: Google Play books in 45 countries, iBooks Store in 34 countries, and OUJ-MOOC in 109 countries.

Particularly, CHiLO books was downloaded frequently in developing countries such as Indonesia (2,022), Thailand (1,833), Philippines (1,201), Mexico (710), Malaysia (690), Colombia (678), Venezuela (532) and Brazil (499). This result shows that CHiLO book and its format appeal to people from developing countries.

TABLE III. THE NUMBER OF DOWNLOADS OF NSA1 CHiLO BOOKS BY COUNTRIES

	Total	Google	iBooks Store	OUJ-MOOC
United States	3,625	1,214	1,844	567
Indonesia	2,022	1,578	0	444
Japan	1,833	488	701	644
Thailand	1,384	1,308	0	76
Philippines	1,201	826	0	375
Mexico	710	88	164	458
Malaysia	690	541	0	149
Colombia	678	14	31	633
Venezuela	532	16	11	505
Brazil	499	183	69	247
Other	8,954	2,114	895	5,945
Total	22,128	8,370	3,715	10,043

In terms of the population on these results (see Fig. 4), we found some interesting features. That is, there is no significant difference in gender (male = 54%, female = 46%), and the ratio of age groups 18 to 44 years old accounts for 89% of the total population. It may be presumed that these features indicate that the CHiLO books and their formats are suitable for higher education because the main target population for higher education, in general, fits the age group of 18 to 44 years for both the genders.

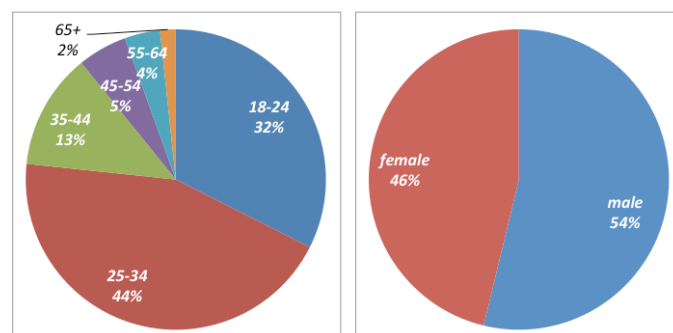


Fig. 4. Ratio of people who downloaded CHiLO books by age (left) and gender (right)

Questionnaire results from those who have earned badges on this demonstration experiment (n = 105) are the following.

- 91.4% (96) of the respondents learned with the CHiLO books at home.
- 79.0% (83) of the respondents primarily used PCs.
- 50.5% (53) of the respondents used the EPUB3-based CHiLO books in some way (see Table IV).

TABLE IV. QUESTIONNAIRE RESULTS: WHICH CHiLO BOOK DID YOU USE, EPUB3-BASED OR WEB-BASED CHiLO BOOK? (N = 105)

Mostly used the eBook version.	17	50.5%
Mainly eBook version, sometimes Web version.	13	

Used both eBook version and Web version at the same rate.	6	
Mainly Web version, sometimes eBook version.	17	
Mostly used Web version.	52	49.5%

Concerning the analysis of device-specific access to the Moodle quiz module, 56.1% (1,771) accessed from PCs, 18.1% (572) from tablet PCs, and 25.8% (831) from smartphones (see Fig. 5).

Furthermore, we divided the access logs into EPUB3-based and web-based CHiLO books; in the case of web-based ones, about 69% of the accesses were from PCs, while in the case of EPUB3-based ones, approximately 73% accessed from mobile devices such as smartphones and tablet PCs (see Fig. 6).

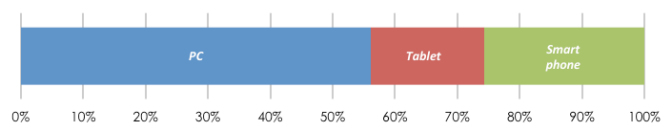


Fig. 5. Ratio of traffic of quizzes in each CHiLO Book by device

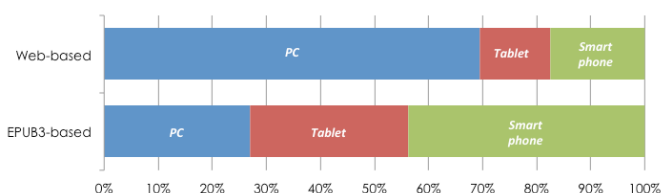


Fig. 6. Ratio of people who responded to the questionnaire by CHiLO book format and devices

While we did not appeal to learners to choose either the web-based or EPUB3-based CHiLO book on this demonstration experiment, some learners responded to our questionnaire noting that they used PCs primarily at home, but that they also downloaded and used EPUB3-based CHiLO books in case they did not have access to the Internet.

To consider the above results, it may be presumed that learners on this demonstration experiment tend to switch the devices effectively depending on their Internet connection; they would learn through web-based CHiLO Books on PCs when they could get access to the Internet at home or at school. On the other hand, they would download EPUB3-based CHiLO books and learn the contents on their own mobile devices such as smartphones or tablet PCs when they did not have Internet access.

VI. EVALUATION AND FUTURE DEVELOPMENT

A. Evaluation

From the results of the demonstration experiment, we consider that the CHiLO system has two advantages.

First, CHiLO can offer flexible formats wherein we can provide learning content to people in different countries. Although CHiLO books were unfamiliar to most of the people

who participated in the experiment, we obtained the result that we successfully delivered our books to a large number of people including those in developing countries.

Second, CHiLO can potentially provide a device-agnostic and ubiquitous learning environment in which learners select web-based or EPUB3-based CHiLO books according to their preferences.

The badge-earning rate in this experiment was not very high. According to the report by [43], a survey for people who registered for HarvardX/MITx courses showed that 57% of responding participants expressed an intention to earn a certificate. That indicates that not all of the participants in MOOCs have an intention to earn a certificate by completing a course. It also suggests that participants who pay to “ID-verify” certify at a substantially higher rate, 59% for verified students compared to 5% for non-verified students, on average, across 12 courses. This is an interesting result, but we need further investigation to take a cue for improving the completion rate because the direct cause is not clear.

B. Issues

An issue in the demonstration experiment is that the learners did not completely enjoy the merits of EPUB3-based CHiLO books. The learners reported that EPUB3-based CHiLO books were not successfully downloaded, videos could not be played, and assessment examinations could not be connected. The possible cause for the reported problems is that some EPUB3 reader apps cannot play videos, and learners must connect to Moodle for assessment examinations.

Another issue is that we offered only one successive series of CHiLO books in the demonstration experiment. There are still things about the learners’ behavior traits, such as motivation, ability, and skill that are unclear.

C. Future Development

To solve these issues, we are now starting to develop the CHiLO Reader and the CHiLO Analytics (see Fig. 7).

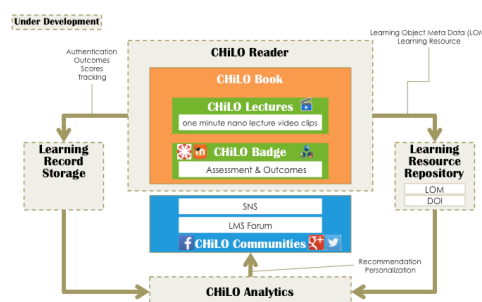


Fig. 7. Context-awareness and ad-hoc learning

The CHiLO Reader: To solve problems of EPUB3 reader apps, an e-book reader app optimized for using CHiLO books. Its purpose is to enhance the usability of CHiLO books. The CHiLO Reader is compliant to EPUB3 with embedded JavaScript and JSON data. This enables us to develop embedded-type CHiLO books (see Fig. 8) that contain assessment examinations and a digital badge-issuing feature. With embedded-type CHiLO books downloaded in each user’s devices, it is possible to enjoy learning activities

without an Internet connection, beginning with viewing a video lecture and resulting in winning a badge. The CHiLO Reader also has the feature of recording learning history (outcomes, scores, tracking, etc.) when it is offline, and sending it to a Learning Record Storage when it gets online.

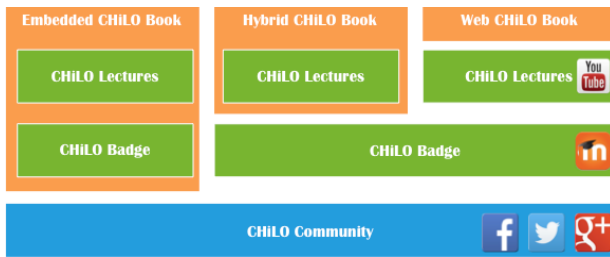


Fig. 8. CHiLO Book Architecture

CHiLO Analytics: To figure out the learners' behavior trait. Recommendations of learning content, learning methods, and the learning community that fit the learner's purposes and preferences are made possible by analyzing the learner's activity logs, which are stored in the learning record storage (LRS). This collects and stores learning events such as outcomes, scores, and tracking acquired from the CHiLO Reader, and the learning resource Repository, which stores Learning Object Metadata (LOM) for CHiLO books.

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VII. CONCLUSION

A learning system based on an e-book is now being introduced into the field of education and their improvement is being widely studied. At IDPF, the EDUPUB standard is being discussed and implemented (see <http://epubzone.org/news/edupub-phoenix-2015-report>). To solve the issues of web-based online courses, we developed the CHiLO, an m-learning system based on e-books and conducted a demonstration experiment. Our results and findings are meaningful for future research on a learning environment based on the m-learning system.

The learning environment can be packaged into one e-book. When such e-books are delivered as an OER, flexible and diverse learning environments are possible any time, any place, and on any device, both in online and offline situations.

Bell [44] stated "since the scope of the change exceeds personal and interpersonal learning activities to include larger scale organizational and societal change, additional theories are needed to explain change, to plan interventions and to develop policies" (pp. 100-101). A traditional online course using the existing educational approach such as standardized education can neither respond to the various needs of diverse learners nor create possibilities of online education. CHiLO available for ad-hoc learning, which has a flexible and diversified service for the m-learning creates an ideal online environment.

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From Reality to Augmented Reality: Rapid Strategies for Developing Marker-Based AR Content Using Image Capturing and Authoring Tools

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Abstract— This paper builds on the authors' previous work with Augmented Reality (AR) technology, where interactive three-dimensional (3D) content was developed and combined with traditional printed materials to enhance the visualization and understanding of technical information. In this study, we describe a method to rapidly create custom marker-based AR content using 3D data from real objects and an authoring tool developed in-house. We present a two step process, where 3D geometry is generated automatically by capturing and processing a series of photographs of a real object and subsequently converted to an AR element that can be linked to a unique marker and used with a marker-based AR system. This system provides an opportunity for instructors to quickly and effortlessly create their own AR content to support their innovative teaching practices.

Keywords— *augmented reality; image-based modeling; 3D content creation*

I. INTRODUCTION

Although many instructors still rely primarily on lectures and traditional teaching practices and laboratory sessions, the growing body of empirical research shows that didactic lectures do not necessarily succeed in eliciting comprehension of complex concepts [1] and that learning can be improved when instructors incorporate teaching strategies that are interactive, student-centered, and take advantage of the existing technology [2, 3]. As stated by Millar [4], good teaching demands ongoing creative effort. In this regard, Augmented Reality (AR) technology provides an attractive and engaging resource to complement and enhance traditional teaching materials, usually based on pen and paper exercises, while promoting the development of visualization, self-assessment, and self-directed learning skills [5, 6].

The term “augmented reality” refers to the live direct or indirect view of a physical environment whose elements are augmented by computer-generated content (text, images, videos, 3D models, animations, etc.) [7]. Augmented worlds are generated in real-time and typically experienced via computer screens, projectors, or head mounted displays (HMD). The technology has been listed by the Horizon Report

[8] as a key visualization tool that will be widespread in higher education in the near future. According to this report, the ability of AR to respond to user input confers significant potential for learning and assessment, as students build new knowledge based on visualizations and interactions with virtual models that bring underlying data to life [8].

AR systems have been used effectively as educational tools in various fields such as visualization and engineering graphics [9-11], architecture [12], and medicine [13, 14]. However, most educational applications focus on very specific subjects, the content is usually predefined by developers, and it is difficult for instructors to create or update existing content. This situation was described by Kerawalla et al. [15] who reported that teachers recognize the educational potential of AR, but demand more control and availability of the resources, so they can adapt them to the specific needs of their students.

In this regard, the development of AR content (a fundamental component of the system to ensure a truly engaging educational user experience) requires the creation of 3D computer models, which is a time consuming task and often involves a high level of proficiency in the use of 3D modeling packages such as Maya, SolidWorks, or SketchUp. While traditional geometry-based approaches such as polygonal and surface modeling enable the construction of highly realistic and sophisticated 3D shapes, they have a steep learning curve and require a significant amount of training and skill, which can make them unsuitable for non-expert users [16]. Such limitations can easily discourage educators from creating custom materials. Therefore, there is a need for efficient, cost effective, intuitive, and simple tools that allow instructors (who cannot be expected to be 3D experts) to author custom 3D models for augmented reality environments and applications.

In this paper, we present a rapid approach to AR content development that requires no 3D modeling skills and no expertise with CAD packages. Our approach comprises the use of a simple image-based modeling tool and a custom AR authoring application, which allows content designers to set up AR experiences in just a few minutes. All content is created

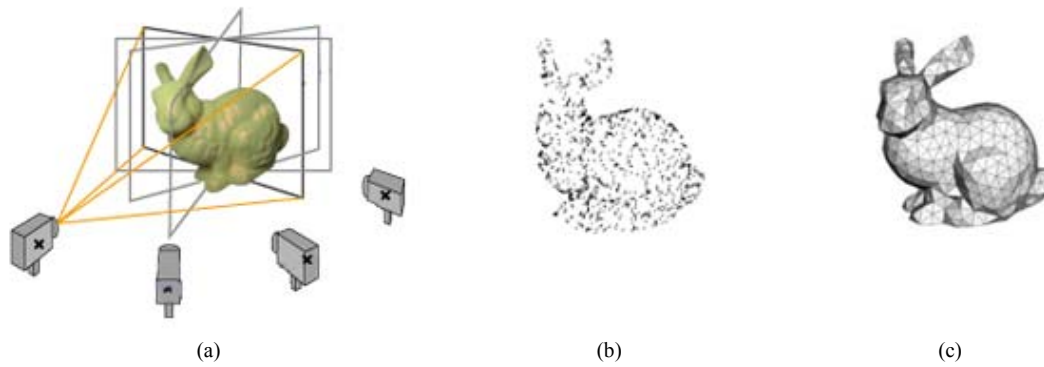


Fig. 1. Image-based modeling sequence: (a) image capturing, (b) point cloud, (c) 3D mesh

automatically from real objects through a series of photographs that are processed as 3D geometry by the image-based modeling tool. The conversion of the 3D model to an interactive AR element is performed by a separate authoring application developed in-house that links the 3D model to a two dimensional marker which can be physically manipulated by the user and works in conjunction with a software viewer that displays the content.

II. IMAGE-BASED MODELING

The process of developing a three dimensional computer representation of an object using graphics software is known as 3D modeling. Requirements and strategies for the generation of 3D models depend on a variety of factors such as the desired level of detail, completeness, reliability, accuracy, data volume, costs, and operational aspects, among others [17].

Different techniques exist (both manual and automatic) for creating 3D models, depending on the application and purpose. In general, manual methods allow more control over the geometry during the modeling process, but require more knowledge and expertise of the tool. Popular methods to rapidly generate 3D models from existing data, such as 3D scanning or photogrammetry, often involve geometry reconstruction techniques. These methods have been used successfully in many specialty areas, including ancient architecture and cultural heritage reconstruction [18-20], dentistry [21], and large-scale scenes such as urban structures [22].

Recent advancements in specialized hardware such as laser scanners and structured lighting systems have made 3D reconstruction possible for non-experts. However, these tools are often costly, not portable or scalable, and constrained in terms of material properties (scanners cannot scan certain materials) and environmental conditions [16]. In recent years, personal digital cameras (and their seamless integration with smart phones) are providing real alternatives to more expensive systems. Compared with conventional geometry-based modeling and hardware-heavy approaches, these cameras, when combined with the appropriate software, provide an intuitive and increasingly attractive proposition for affordable 3D reconstruction [17].

The term “photogrammetry” refers to a wide range of techniques and algorithms by which 3D properties of an object are derived from a set of 2D images. Using triangulation, any feature seen in at least two photographs taken from known locations can be localized in 3D space. Furthermore, it is mathematically possible to solve for unknown camera positions when a sufficient number of corresponding points are available [23].

Digital close-range photogrammetry has been an active area of research for years and is used in many different fields and industries, such as architecture, engineering, mining, quality control, geology, and archeology [24, 25]. Recent technical developments include automatic orientation and measurement procedures, generation of 3D vector data, and digital surface models [26].

Digital photogrammetry techniques require the user to provide a group of images of an object acquired from different viewpoints (typically, at small increments around the object). The way in which photographs are acquired is a critical aspect of the process, as it greatly determines the quality of the final reconstruction [27].

The second step is computationally intensive, as it involves the generation of point cloud data from the source images. In this step, specialized algorithms identify points of interest in the image set and calculate the 3D coordinates of the surface of the object using the collinearity equation that defines the relationship between object and image coordinates [28].

Finally, a 3D mesh model is generated from this point cloud. Depending on the quality, the resulting mesh may contain gaps, so additional cleanup is sometimes necessary. The complete sequence is illustrated in Fig. 1.

Digital photogrammetry techniques have matured considerably to a point where a number of stable software tools have become widely available both as commercial products and as free and open source tools. Examples include programs and services such as Photoscan, Acute3D, or Autodesk’s 123D Catch and Memento, which was the tool used to create the examples shown in this paper.

III. MARKER-BASED AUGMENTED REALITY

Augmented Reality is a visualization technology where virtual content is rendered in real time and seamlessly overlaid onto real live footage providing an enhanced or “augmented” view of reality [29].

In terms of hardware, augmented reality can be experienced through a regular desktop PC equipped with a Webcam (Desktop AR). The camera captures the real world view and specialized software generates the augmented content, which is positioned, oriented, and displayed on the computer screen as an augmented mirror. Early work of the authors with augmented reality books involves desktop AR experiences for teaching engineering design graphics [10], as shown in Fig. 2.

Handheld devices such as tablets and smart phones can work as see-through tools or “magic-lenses” to visualize AR content [30]. Previous work of the authors with augmented reality books includes AR experiences using this “magic lens” metaphor [9], as shown in Fig. 2.

Finally, special displays and eyeglasses, such as the popular Google Glass, can also be used to experience AR. These devices integrate a series of cameras that capture real world images and combine it with the virtual content, which is displayed directly on the transparent lenses. Other visualization technology includes virtual retinal displays [31] and special head-worn displays (HWDs) [32].

There are many tools to develop augmented reality content, some of which require technical and programming skills. A common technology is based on markers. In this technology, fiducial 2D images are used to recognize the three dimensional space seen by the camera and correctly position and orient the virtual content on the screen. Because of their simplicity, markers can be easily integrated in printed lecture notes and assignments, allowing instructors to enhance educational materials, and students to visualize the contents being described on paper in full 3D [9].

Two different elements can be used: black and white patterns and regular images. Black and white markers are the most recognizable, reliable, and widely used type of augmented reality. They are typically square shapes with unique black and white patterns inside. This unique pattern allows the AR software to select the correct AR content that is linked to the marker.

Alternatively, regular images provide a “markerless” interaction, which is a more ubiquitous and user friendly approach [33]. Any image can be used to trigger AR content but a high level of contrast and detail in the image, as well as more processing power, are required. Examples of both black and white markers and image-based markers are shown in Fig. 3. A comparison of both approaches is described in Table 1.

In this paper, we use a custom authoring tool called *Aumentaty Author* (available at <http://author.aumentaty.com>) to develop AR content from 3D models generated through image-based modeling techniques. The tool was designed with simplicity in mind and no prior programming experience is required to use it.



Fig. 2. Desktop AR (top) and "Magic lens" (bottom)



Fig. 3. Sample AR elements: black and white markers (top) and regular images (bottom)

TABLE I. MARKER (BLACK AND WHITE) VS. MARKERLESS (IMAGES) AUGMENTED REALITY

Marker	Advantages	Disadvantages
Black and white markers	Common and easy to find and create. Relatively low computer requirements. Efficient tracking.	Intrusive and Invasive. Marker similarity. All markers are combinations of black and white patterns, which can be confusing for the user. If part of the marker is covered the virtual model is lost.
Markerless (Images)	Any image with sufficient level of detail can be used as a marker. Ubiquitous. There are no intrusive markers which are not part of the environment. They allow occlusion and virtual buttons.	The image must have significant details and proper contrast. More complex image tracking. More hardware demanding.

IV. METHODOLOGY

We present a simple and intuitive approach to AR content creation that comprises two steps: creation of 3D models from real objects using an image-based modeling tool (*Autodesk Memento*, in our case), and conversion of the 3D model into an interactive AR element using an AR authoring tool (*Aumentaty Author*, in our study). The proposed methodology is illustrated in Fig. 4.

Although many AR tools, libraries, and services such as *ARToolkit* [34], *Hyperspaces* [35], *EonReality* [36], and *Augment* [37] are available (and could certainly have been used for our purposes), we selected *Aumentaty Author* for affordability reasons and to ensure proper integration of AR content with future custom applications and materials. Using our own software also gives us full control over different marker types and sizes, templates-based markers, adaptive thresholds to manage illumination variations in the scene, and a graphical interface for camera calibration and pattern creation.

A. Creation of 3D Models

The first step requires the acquisition of 3D information of the object that needs to be modeled. Because of the nature of image-based modeling software, objects with plain, transparent, glossy, or reflective surfaces will not work correctly. Similar problems occur when underexposed or overexposed photographs are used.

Multiple pictures will be taken by shooting at least a loop of sequential photographs about the subject (two loops at different heights are usually recommended). For better results, the same lighting conditions must be used for all photographs, and the object being photographed must not move. Additionally, to facilitate the 3D reconstruction, it is also recommended that the object being photographed occupies at least 70% or more of the pixels in the images and that the sequence of pictures has some overlap.

The set of photographs can now be processed by an image-based modeling tool. In this paper, we used *Autodesk Memento Beta*, a solution for converting captured reality input into high definition meshes that can be fixed and optimized.

Depending on the quality of the resulting 3D model, additional cleanup may be required to eliminate unnecessary noise or busy surroundings. Basic fixing/cleanup can be performed by smart selection and clean up tools available in *Autodesk Memento*.

Finally, the textured 3D model reconstructed by *Autodesk Memento* can be exported to several formats: OBJ, STL, PLY, and FBX. Because of the formats supported by our AR authoring tool and based on *Aumentaty* recommendations, models are exported to FBX so they can be processed successfully.

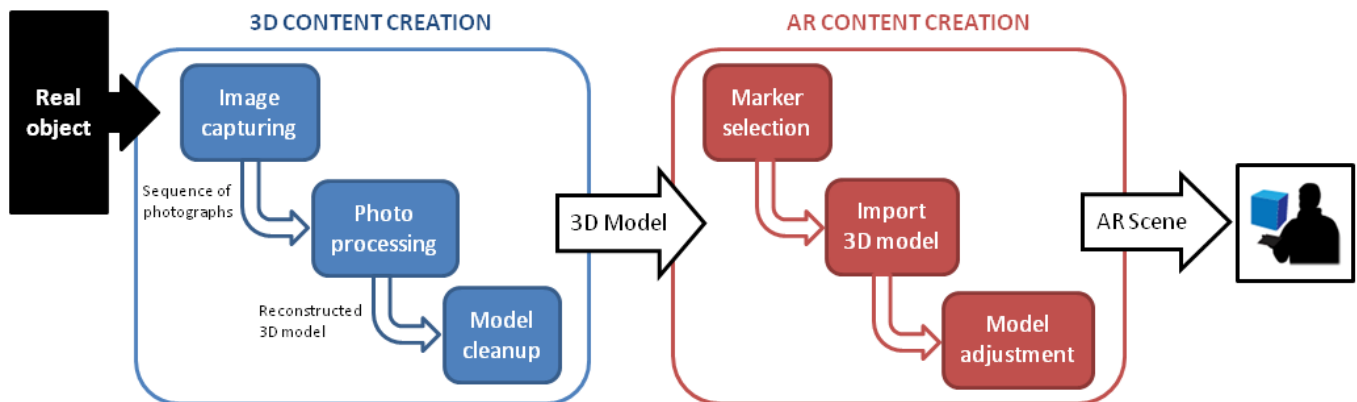


Fig. 4. Proposed methodology for creating Augmented Reality (AR) content

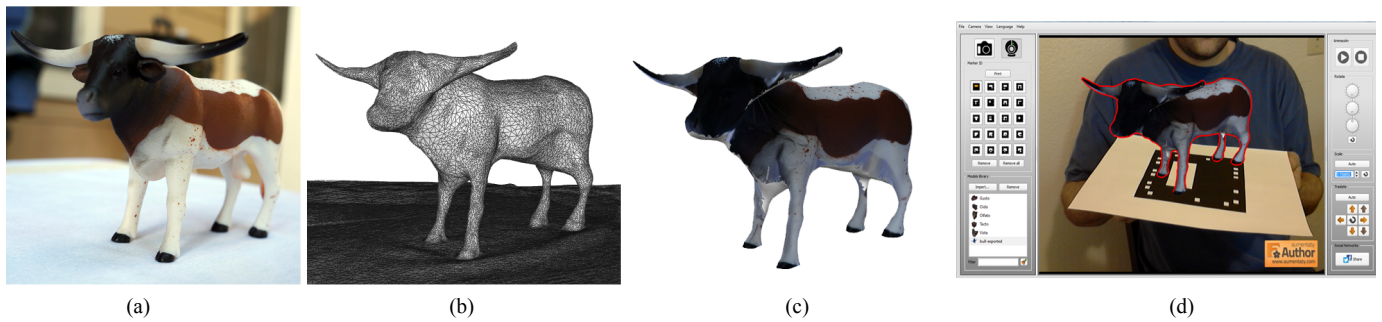


Fig. 5. AR creation process: (a) real object, (b) reconstructed mesh (low quality), (c) cleaned textured model, (d) augmented reality content

B. Creation of AR Content

Aumentaty Author uses computer vision algorithms to calculate the relative viewpoint of the camera with respect to a real world marker. The software integrates computer-generated three-dimensional objects with the real footage captured by the camera. When the marker enters the area that is visible for the camera, the position and orientation of virtual object is calculated based on the marker's orientation and shown on the screen.

In terms of scene definition, creating an interactive AR element with *Aumentaty Author* is a visual and intuitive process. First, a marker is selected from the marker ID menu and printed, so the scene can be visualized interactively as it is being created.

Next, the camera that will be used for AR needs to be activated (in case there are multiple cameras installed) and pointed to the printed marker. In the application screen, the marker will turn orange, indicating that the AR software is recognizing the marker. At this point, the user can browse for the model that was created in the previous step, select it, and drag and drop it from the models' library area of the interface to the icon that corresponds with the marker that was printed in the first step. The 3D model will be placed over the marker in the software interface to provide a visual cue of the link that was created. The tool can import 3D models in the following formats: FBX, DAE, and OBJ. If textures are used, they must be included as part of the 3D file, and not at separate files. If animations are included in the model, they will be played repeatedly when the scene is exported and visualized with *Aumentaty Viewer*.

The controllers located on the main panel can be used to move, scale, and rotate the 3D with respect to the marker. This allows for basic adjustments in the scene, which are useful in many situations such as when the model has a different vertical orientation from the marker's scene or the 3D model is too large with respect to the marker. This basic process will be repeated as many times as models and markers are used in the application. A maximum of 12 models can be included in a single scene.

Finally, the AR scene with all markers and models will be exported to *Aumentaty Viewer*, so it can be visualized on any device (desktop or mobile) equipped with a camera. *Aumentaty*

Viewer is a 3D content viewer that can open AR scenes created with *Aumentaty Author*. Content can also be exported to portable devices and shared via email and various social networks. An example of the process is illustrated in Fig. 5.

V. CONCLUSIONS AND FUTURE WORK

Augmented reality has the potential to become an effective tool to enhance traditional teaching materials and deliver instruction. In previous research, we studied the educational value of both mobile and desktop-based AR in the area of engineering design graphics. However, the creation of content for these applications remains a time consuming task that requires a significant level of technical expertise.

The methodology we discussed in this paper was designed to be simple and easy to implement, as no 3D modeling experience is required to develop content. Unless there are problems with the photographs, the image-based modeling part is mostly an automated process. The 3D reconstruction is live, which means that results can be refined by taking more pictures of the object in the region where it failed.

We noticed that not all meshes come out of the reconstruction process perfectly. Although many require additional cleanup work, specialized tools in Memento, such as "slice and fill" or "smart selection" are usually sufficient in most situations.

In terms of AR authoring, we propose a tool that is easy to use by teachers. *Aumentaty Author* provides a graphical environment that does not require any scripting or programming skills and content is created by experiencing the augmented reality content as it is being created. Users learn to work with the authoring tool almost immediately and the interaction with the markers becomes natural very rapidly.

Despite its simplicity, the proposed methodology still relies on users having access to the real object that needs to be modeled (so photographs can be taken), which may not be easy depending on the content. In addition, the computational resources involved in reconstructing the 3D mesh are significant, which makes time an important factor in the process. We are preparing a usability study with a group of teachers to validate both the proposed methodology and the tools used.

Long term plans include collaborations with K-12 educators in the creation and integration of custom AR materials in the classrooms. We plan to perform a study at different levels, examining both the use and limitations of the proposed methodology in terms of content development and usability, and also the impact of such contents in the students' understanding of the material. As a technical challenge, we are interested in building special hardware for mounting multiple cameras so we can speed up the image capturing step.

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An investigation of the use of mobile mathematics applications: An African perspective

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Abstract

A report published in 2014 by the World Economic Forum ranked the quality of South Africa's mathematics and science education in the last place out of 148 countries. Educational experts believe that learners can benefit from educational mathematical applications. Senior post-graduate students at the Central University of Technology in South Africa, therefore, embarked on a socio-constructivist project to develop appropriate educational mathematics applications for primary school learners in their community. This paper focuses on the first stage of this project where the aim was to investigate the use of mobile mathematics applications by primary school learners within the South African context. Quantitative and qualitative data was collected by using a survey targeting mathematics teachers and parents of children in grade 1 to 3 in the Free State province of South Africa. The results indicate that 64% of grade 1 to 3 learners have access to mobile devices and that both teachers and parents have a very positive perception towards the use of mathematics applications by their learners and children. In addition 30% of parents have downloaded mobile mathematics applications for learners to use at home. The most important reason why parents are not downloading mobile mathematics applications is because they do not know where to find them, or they do not have time to search for appropriate applications. High costs associated with Internet connectivity and the fact that not all learners have access to mobile devices were two key obstacles mentioned by teachers involved with the use of mobile mathematics applications in primary school education.

Keywords— *Mobile learning, mathematics applications (apps), mathematics education, primary school*

I. INTRODUCTION

"Do not worry about your difficulties in mathematics. I can assure you mine are still greater" [1]. World famous scientist Albert Einstein originally directed these words at young learners, in an attempt to encourage them to persevere despite their perceived difficulties. Unfortunately, these words offer little consolation to learners in South Africa (SA), whose performance in mathematics (math) is the worst of all middle-income countries in the world, and even worse than many low-income African countries according to international studies [2]. In addition, according to a report published by The World Economic Forum in 2014, SA also has the worst quality of math and science education of all 148 countries surveyed [3].

Consequently, the poor performance of learners in math greatly decreases the national pool of learners who are able to

gain admission into engineering degree and diploma programs after completing grade 12 [4]. Higher Educational Institutions (HEIs), therefore, stress the importance of investigating and implementing innovative methods that may help to improve math performance of school learners in their community. The Information Technology (IT) department at the Central University of Technology (CUT) in SA initiated a project at the start of 2015 where senior post-graduate students were involved in a socio-constructivist project to design and develop appropriate mobile math applications (apps) for grade 1 to 3 learners in their immediate community. The goal of the project was two-fold. The first goal was to create a platform where post-graduate students and math teachers in the community could collaborate in an effort to improve the current low math performance of SA learners in the Free State Province. The second goal was to immerse post-graduate IT students in a socio-constructivist environment where they could work in groups, applying their existing knowledge of mobile programming to a real-world problem. A diagnostic assessment of grade 1 to 3 learners in their community was firstly undertaken to determine the access to mobile devices and the extent of exposure to current educational math apps. Perceptions of parents and teachers towards the use of mobile math apps were also sought. Therefore, the first phase of the project involved an investigation into the current usage patterns of mobile math apps by grade 1 to 3 learners in the Free State province of SA. Each group of post-graduate students were expected to gather data from the parents of the learners and the teacher they collaborated with. The aim of this paper is to report on the findings of the first phase of this project.

To the authors' best knowledge, only a few papers have been published pertaining to the use of mobile math apps by school learners in SA. The aim of this paper is to fill this gap and to provide a report regarding the current state of mobile math apps usage by grade 1 to 3 learners. The contribution of this study is that it lays the foundation for future research by HEIs and other stakeholders in the development of appropriate mobile math apps. The paper is structured to firstly provide the context for the study. Secondly, the research methodology is discussed followed by the results and discussions. The paper concludes with the implications of the study.

II. CONCEPTUAL FRAMEWORK

This section provides the study's context within SA in the following way: 1) pedagogical theory 2) shortage of engineers; 3) low graduation rates of engineering students; 4) bad

performance of learners in math; 5) using Information and Communication Technology (ICT) solutions in math education; and 6) smartphone penetration. This section concludes with the research questions of the study.

Firstly, this section will focus on the pedagogical theory that underpins the project that post-graduate students from the IT department of CUT were involved with during the first semester of 2015. These theories include constructivism and socio-constructivism.

Constructivism is a learning theory that offers an explanation of the nature of knowledge and of how human beings learn. It maintains that individuals create or construct their own knowledge or new understandings through the interaction of what they already know and believe and the events, ideas, and activities with which they come in contact [5]. In addition, knowledge is acquired through involvement with content, instead of by repetition or imitation [6]. Constructivism and socio-constructivism share similarities. However, socio-constructivism requires groups of students to drive individual learning where the emphasis is on the collaborative nature of learning [7]. Collaborative learning activities encourage students to explore their course material in groups, thereby helping them to form connections between their newly acquired and existing skills and knowledge, allowing them to actively respond to the ever-changing needs of society [8]. The discussion will now turn to the current shortage of engineers in SA.

SA is suffering from a chronic shortage of engineers in various disciplines [9][10]. For example, according to CEO Sandra Burmeister of the executive search firm Landelahn Business Leaders Amrop SA, 74% of local construction companies are struggling to fill engineering positions [11]. In addition, the SA mining industry faces a skills shortage in many of the technical disciplines, a situation which is exacerbated by large numbers of SA mining professionals immigrating to Australia [10]. Moreover, a survey of nearly 800 SA engineers in 2012 found that the confidence level of respondents to whether the current skills shortage in their profession will be adequately addressed by government in the short to medium term was just 40%. Furthermore, the confidence level of respondents on whether the current education system is providing the necessary skills for the creation of potential engineers was only 41% [12].

Despite efforts of the SA government and the Engineering Council of SA (ECSA) to address these engineering shortages, initiatives are severely hampered by two factors, namely the low graduation rate of engineering students in higher education and the poor performance of grade 12 learners in math and science for their final school examinations [9]. Graduation rates in engineering disciplines from 1998 to 2010 were a mere 13.8%, as compared to the international average of 25% [9]. The second factor that has an impact on the shortage of engineers in SA is the poor performance of school learners in math and science, which is demonstrated by the results of the 2014 National Senior Certificate (NSC). It indicates that of the 225 458 candidates who wrote math, only 35.1% obtained a mark of 40% and above. In addition, of the 167 997 candidates

who wrote science, only 36.9% obtained a mark of 40% and above [13].

Regarding the performance of school learners in the NSC for math and science, the Department of Basic Education in SA (DBE) only releases the number of candidates that achieve a mark of 30% or higher. However, the DBE does release the distribution of results of the Annual National Assessment (internationally benchmarked national test), for Grade 9 math performance. According to the 2014 assessment, only 1.5 % of grade 9 learners obtained a mark of 50-59%, 0.8% a mark of 60-69% and 0.4% a mark of 70-79% [14]. This situation subsequently places tremendous pressure on math teachers at grades 10 through 12 who are expected to make up for large deficiencies in the run-up to the NSC. These figures indicate that the national pool of learners that would be able to obtain admission to an engineering degree or diploma qualification after grade 12 is very low [11] given that one of the key entry requirements to engineering related programs in SA requires a minimum math and science mark of 50%.

When the results of the Annual National Assessments (2013 to 2014) are further analyzed, it is evident that learner's poor math performance is already noticeable in lower grades with the average mark for grade 4 learners in 2014 being only 37% [14]. This low average mark at an early stage of the school career of a large number of learners indicate that corrective measures are warranted at the primary school level to improve math performance in SA.

The preceding observation is supported by several international studies that indicate that the problem with math has its roots in primary school, where many learners fail to gain basic math skills [15]. Additionally, McCarthy and Olifant [2] state that there is significant evidence demonstrating that the best way to improve math performance is to focus on primary school learners. They furthermore emphasize that the learning deficiencies which exist at the start of learner's primary school education hinder their ability to improve in later years. Therefore, as time progresses, these learners tend to fall further and further behind, until it is nearly impossible to attain the required math performance [2]. Emanating from the preceding discussion, it is reasonable to deduce that the low performance of grade 12 learners in math is caused by inadequate teaching and learning of foundational math principles in early primary school years. Consequently, in an effort to enlarge the pool of students that will be eligible for engineering related programs in the future, it is crucial for HEIs to investigate the use of innovative methods, specifically in early primary school years, to try and improve the current poor math performance. The authors agree with educational experts who believe that learners can benefit from educational math apps, and that the focus should be on supporting learners using ICT solutions [4].

As far as the use of ICT solutions in math education is concerned, several researchers are in agreement regarding the benefits that it offers. Baya'a and Daher [16] state that ICT integration into math education provides math teachers with integrative teaching methods that support learners' independent learning. Appropriate math apps seem to have great motivational appeal [17] and encourage active participation [18] in the discovery of math topics and concepts causing a

deeper understanding of math principles [16]. In addition, one of the most recent and comprehensive studies conducted, involving 800 teachers of learners aged 3 to 8, revealed that 71% of these teachers who use digital educational games reported improved math performance amongst their learners [19].

Mobile math apps can assist learners in various ways to master math skills. Prensky [20] argues that mobile educational apps include some of the most useful learning tools that have ever been available and are preferable to books and laptops as learning tools. More specifically, Subramanya and Farahani [21] have identified several key benefits of mobile apps for learning concepts in math including: self-paced learning; reinforcement of abstract concepts; supplemental learning aids; anytime/anywhere use; enhanced retention; being entertaining and engaging; encourage the use of multiple (rich) media; immersion in interaction; self-assessment; provisions for exploration and experimentation; providing positive feedback; cost-effective; customizable; and time-effective. Another very important potential learning benefit of mobile apps, as identified by Bos & Lee [22], is the repetitious use of content that will enable weaker learners to use an app repeatedly to learn or practice difficult concepts.

In addition to the various benefits that mobile math apps have for learning, several studies now confirm that their use has led to improved academic performance. For example, a study centered on a mobile math app, Motion Math, has revealed that fifth graders who regularly played the game for 20 minutes per day over a five-day period increased their math test scores by 15% on average [23]. Likewise, a Stanford College study revealed that an experimental group that regularly played the mobile math app, Wuzzit Trouble, showed a 20.5% increase in numeracy between the pre- and post-assessment, compared to the control group who did not play Wuzzit Trouble [24].

Despite the advantages of ICT solutions for math education, it is not always possible for young learners in SA to access math apps due to low computer and Internet penetration, especially in rural parts of SA. For example, only 10% of SA schools have access to one or more computers [25], while only 3.95% of SA households own a computer [26]. However, newly developed math apps and games are available on less expensive mobile devices that now offer access to many who previously or currently do not own personal computers. Consequently, a dramatic increase in the percentage of the population that can access math apps is now possible [25].

This leads to a brief discussion on smartphone penetration in SA. According to World Wide Worx, SA's leading independent technology research organization, smartphone sales in SA already outnumber ordinary phone sales, and they estimate that by 2017 more than half of the population using phones will be using smartphones [26]. More specifically, the 2014 study conducted by the SA Audience Research Foundation revealed that 36% of the SA population owns a smartphone, while 5% are tablet owners [27]. In contrast, the overall smartphone penetration in Africa is estimated to only be between 6% and 15% [28].

The research questions that arise from the preceding discussions and that were included in the first phase of the project of the development of math apps by post-graduate IT students at CUT include the following: 1) To what extent do grade 1 to 3 learners have access to smartphones or mobile devices? 2) To what extent do parents and teachers of grade 1 to 3 learners download educational math apps for their children? 3) What are the obstacles for the use of mobile educational math apps from a parent and teacher perspective? 4) What are the perceptions of teachers and parents towards the use of mobile educational math apps?

III. RESEARCH METHODOLOGY

A cross-sectional design was used where both quantitative and qualitative data was collected using survey questionnaires as the data collection instrument. Cross-sectional designs are used when a cross section of a population is sampled and studied at a single point in time using one questionnaire, one survey, or one observation. The reason for using a cross-sectional design was due to the fact that it is a relatively inexpensive method enabling the researchers to gather similar data from a large number of respondents [29]. A cluster sampling strategy was followed where a cluster or group of population elements constitutes the sampling unit [30]. The reason why this research strategy was followed is due to the fact that learners in schools are already grouped together in classes, and only one teacher can be contacted to distribute the surveys to all the learners in the class. The advantage of cluster sampling is that the generation of the sampling frame for clusters is economical, and the sampling frame is often readily available at cluster level. A disadvantage of cluster sampling is that the sample may not reflect the diversity of the community [31].

Senior post-graduate students of the IT department at CUT, located in the Free State province of SA, were divided into 12 groups with a maximum of four students per group. The groups were required to find a math teacher of grade 1 to 3 learners in their immediate community to collaborate with. The 12 student groups selected 12 teachers from 8 schools in their community for this collaboration. The teachers were thus selected by the post-graduate students themselves and became the target population along with the parents of these grade 1 to 3 learners. The sample of class groups that were selected by students closely represents the overall population of SA. According to the 2012 census of SA, 9.6% of the population is not previously disadvantaged (PD), while the percentages of PD members include 79.2% for black, 8.9% for colored and 2.49% for Indian or Asian descent. The sample included one class group from a non PD school and 11 class groups from PD schools, resulting in the sample containing 8.8% of non PD learners and 91.2% of PD learners from eight primary schools in the Free State province of SA. Of the eight primary schools that were selected only one school was a private school situated in the township, while all the other schools were public schools. Two questionnaires were distributed: one for parents of learners and one for the teachers of the learners. The first survey questionnaire was based on various studies that investigated the usage of mobile devices and apps by young learners [32], [33], [34] and featured mainly quantitative data. A total of 534 questionnaires were distributed and 452 were

received back resulting in a response rate of 85%. From the 452 questionnaires that were received, only 437 could be used for analysis due to the fact that 15 questionnaires had some information that was missing (therefore $n = 437$). A second survey questionnaire was distributed to the teachers of these primary school learners and featured mainly qualitative data. The quantitative data was analyzed with the help of Statistical Package for the Social Sciences (SPSS) and the qualitative data was analyzed by making use of content analysis.

IV. RESULTS

The first objective of the study was to determine to what extent grade 1 to 3 learners have access to mobile devices. A total of 437 parents responded to the question and the results are summarized in Tables I through III. As depicted in Table I, a total of 37% of learners have no access to a mobile device per week (27% are not allowed to access the parent's device and 10% of the households do not own a smart mobile device). This is comparable with 29% of pre-school to grade 2 learners, and 16% of grade 3-5 learners in America that do not use any family-owned mobile devices [33]. As can be seen from Table I, some learners have access to only one mobile device (36%), while others have access to two (25%) or more mobile devices (2%).

TABLE I. ACCESS OF LEARNERS TO MOBILE DEVICES (SMARTPHONES AND TABLETS)

Mobile Device Access	n	%
Learner not allowed access to mobile devices	120	27
No smart mobile device in home	42	10
Access to one mobile device	159	36
Access to two mobile devices	109	25
Access to three mobile devices or more	7	2
Total	437	100

If these percentages are combined, it results in a total of 64% of all learners that have access to at least one mobile device (smartphones and tablets). These results were not expected by the researchers due to the fact that it is much higher than the penetration rates of the general population (with only 36% of the SA population owning a smartphone, and 5% owning a tablet [27]). These results align with international results reported by Common Sense Media in 2013 that 72% of learners under the age of eight in America have used a smart mobile device, which included smartphones and a tablets [35].

Table II indicates the type of smartphones learners have access to, with Android smartphones (38%) leading the pack followed by Blackberry devices (27%), iPhones (21%) and Windows phones (13%). In addition, a total of 62% of learners (271 out of 437) have access to smartphones that can be compared to 65% of primary school learners between six and ten years of age in Germany that have access to a smartphone [36]. Furthermore, Grunwald Associates LLC reported in 2013 that 43% of pre-school to grade 12 learners in America use a smartphone [33].

TABLE II. TYPE OF SMARTPHONE LEARNERS HAVE ACCESS TO

Type of smartphone	n	%
Android	104	38
Blackberry	74	27
iPhone	58	21
Windows	35	13

Table III depicts the type of tablets learners have accessed; with Android tablets (55%) again leading the pack, followed by iPads (37%) and finally Windows tablets (8%). In addition, a total number of 145 learners out of 437 (33%) have access to an electronic tablet, which is six times the national tablet ownership of 5% [27]. Furthermore, it is almost equal to the 34% of pre-school to grade 12 learners in America that use tablets (according to a study that was conducted by Grunwald Associates LLC in 2013 [33]). However, research conducted by Pearson in 2013 estimated the usage of tablets by grade 4 to 12 learners in America to be 41% [34].

TABLE III. TYPE OF TABLET LEARNERS HAVE ACCESS TO

Type of Tablet	n	%
Android Tablet	80	55
iPad	53	37
Windows	12	8

In addition to the results presented in Tables I through III, further data analysis of the 437 questionnaires revealed that only 36 out of 437 (8%) learners owned their own mobile devices compared to 25% of German learners (between 6 and 10 years) [37] and 19% of American learners [34]. Fig. 1 displays the amount of time per week that learners have access to a mobile device.

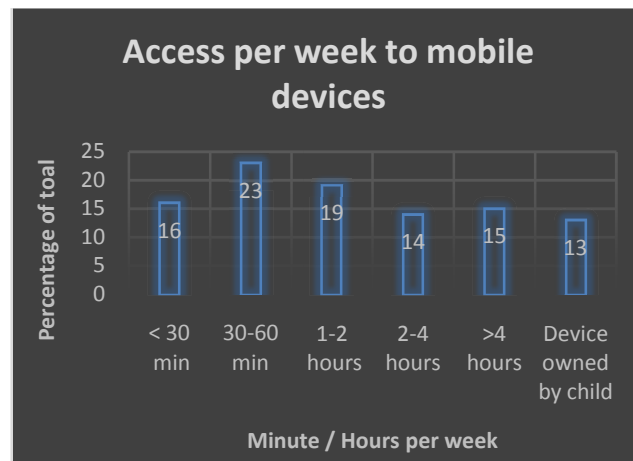


Fig. 1. Amount of time per week learners have access to a mobile device.

A total of 58% of the parents indicated that their children spend less than two hours per week (17 minutes per day) on their mobile devices. The remaining 42% of learners are allowed to use their mobile device for more than two hours per

week. This can be compared to access levels of 15 minutes per day for children 8 years and younger in America [35].

The second objective of the study was to determine to what extent parents of grade 1 to 3 learners download educational math apps for their children. Table IV indicates that 44% of all parents have downloaded educational apps for their children on a mobile device, while 30% of parents have downloaded math educational apps for their children. This can be compared to 58% of parents in America that downloaded educational apps for their children in 2013 [26], and 40% of parents of pre-school to grade 3 children in America that have done so in 2012 [37].

TABLE IV. APPS DOWNLOADED BY PARENTS

Downloaded Apps	Yes	No
Educational apps	44%	56%
Math educational Apps	30%	70%

Parents were also asked if their children used any of the apps that they have downloaded on a regular basis. Table V shows that parents indicated that 68% of children regularly use their downloaded educational apps and 55% of children used their downloaded math educational apps on a regular basis. This can be compared to a study that was commissioned by Joan Ganz Cooney Center at Sesame Workshop regarding young learners who used mobile devices for learning, which reported that most learners reused an educational app several times and only 1% reported abandoning apps after just one attempt [32].

TABLE V. REGULAR USE OF DOWNLOADED APPS

Regular Use	Yes	No
Educational apps	68%	32%
Math educational Apps	55%	45%

In order to determine whether teachers have downloaded any educational math apps they had to answer yes or no to the following question: "Have you downloaded any educational math apps or games for children on your mobile device in order to be able to inform parents on the availability of math apps/games that can assist their children with the learning of math skills?" The question results are summarized in Table VI.

TABLE VI. MATH EDUCATIONAL APPS DOWNLOADED BY TEACHERS

Math apps downloaded	n	%
Yes	5	45
No	6	55
Total	11	100

As can be seen from Table VI 45% of teachers have downloaded math apps. Teachers were also requested to list the

most important skills that should be incorporated in educational math apps/games for grade 1 to 3 learners. Content analysis was performed on the feedback that was received from teachers and the results are summarized in Table VII. These results reveal that teachers view addition, subtraction and multiplication skills to be the most important skills that need to be incorporated into math apps, followed by shapes, place value, counting skills and number bonds and concepts.

TABLE VII. MATH SKILLS TO BE INCORPORATED IN MATH APPS

Type of math skill recommended	%
Addition and subtraction	21
Multiplication tables	17
Shapes	13
Place value	13
Counting skills	8
Number bonds and concepts	8
Money problems	4
Patterns	4
Expanded Notation	4
Long division/ multiplication	4
Fractions	4

The third objective of the study was to determine what obstacles existed in using mobile educational math apps from a parent's and teacher's perspective. Feedback obtained from parents is firstly presented, followed by the feedback received from teachers. The reasons why parents have not downloaded math apps for their children is summarized in Table VIII, with 34% of parents reporting that they are not aware of appropriate math apps, while 16% reported that they do not have time to search for appropriate apps. This suggests that 50% of the polled parents would benefit from information that would assist them to select suitable math apps for their children. In comparison, 43% of American parents reported that they needed help finding educational apps [33]. A quarter of the parents that were approached indicated that data costs to download and use educational apps are very high, while 13% of parents stated that their mobile devices do not support educational apps. The least important reason mentioned by parents for not downloading math apps relates to the belief that children cannot learn any skills from apps (12%).

TABLE VIII. REASONS WHY PARENTS HAVE NOT DOWNLOADED MATH APPS

Reasons	n	%
Don't know about appropriate educational apps	110	34
Data costs too high to download or use apps	80	25
Don't have time to search for appropriate educational apps	52	16
Mobile device does not support apps	43	13
Do not believe child can learn skills from apps	40	12

Table IX presents the results of feedback received from teachers regarding why they are not downloading educational math apps. The most important reason relates to the fact that teachers have never considered the possibility that mobile math apps or games can assist their learners with learning math skills. Another reason is that they do not think parents will be interested in downloading math apps to assist their children with the learning of math skills.

TABLE IX. REASONS WHY TEACHERS HAVE NOT DOWNLOADED MATH APPS

Reasons	N	%
I have never considered the possibility that mobile math apps or games can assist my learners with learning math skills	3	23
I do not think parents will be interested in downloading math apps to assist their children with the learning of math skills	3	23
I do not know where to search for appropriate educational math apps or games	2	15
Data costs too high to download or use apps	2	15
Do not have time to search for appropriate educational math apps or games	2	15
Mobile device does not support the downloading of apps or games	1	8

Teachers were also asked the following open-ended question: "What in your opinion is currently the biggest obstacle for the use of mobile math apps in South Africa?" The content analyses of the results of this question revealed two key aspects. First, almost all teachers reported that the data costs associated with downloading these educational apps are high. Secondly, many reported that not all learners have access to mobile device technology. Teachers also mentioned that parents are not aware of suitable math apps which may be downloaded for their children's use.

The fourth objective of the study was to determine what the perceptions of teachers and parents are towards the use of mobile educational math apps. In order to investigate this objective, parents and teachers were presented with the following three questions:

- I believe that mobile educational math apps can increase the math skill level of my child/learners.
- I am in favor of the use of mobile educational math apps to teach children math skills at home.
- I am in favor of the use of mobile educational math apps to teach children math skills at school.

A summary of the responses (Likert-scale used) to the three questions is shown in tables X through XII.

Table X reveals that the total percentage of parents that believe that mobile educational math apps can increase the math skill level of their children is 76% (the sum of 42% that agreed and 32% that strongly agreed). In comparison, 75% of American parents with children in grade R-2, and 72% of American parents with children in grade 3-5 reported that

mobile apps help teach children math content and skills [33]. In addition, the APM Marketplace report revealed that parents think that mobile technology can be especially effective for subjects like math and science, with 62% of parents reporting that mobile technology has increased the math skill level of their children [38]. Table X further revealed that the total percentage of teachers that believe that mobile apps can increase the math skill level of their learners is 81% (45% plus 36%). This figure can be compared to 71% of American teachers of learners aged 3 to 8 that indicated that educational games improved the math skill level amongst their learners [19].

TABLE X. I BELIEVE THAT MOBILE EDUCATIONAL MATH APPS CAN INCREASE THE MATH SKILL LEVEL OF CHILD/LEARNERS

Option	Parents		Teachers	
	N	%	n	%
Strongly Disagree	13	3	1	9
Disagree	12	3	0	0
Neutral	94	21	1	9
Agree	187	42	5	45
Strongly agree	144	32	4	36
Total	450	100	11	100

Table XI indicates the total percentage of parents that are in favor of the use of mobile educational math apps at school (total of 74% by adding 40% and 34%). It also indicates that the total percentage of teachers that are in favor of the use of mobile educational math apps at school is 91% (55% plus 36%).

TABLE XI. PARENTS AND TEACHERS IN FAVOUR OF THE USE OF MOBILE EDUCATIONAL MATH APPS AT SCHOOL

Option	Parents		Teachers	
	n	%	N	%
Strongly Disagree	11	2	0	0
Disagree	19	4	0	0
Neutral	88	20	1	9
Agree	179	40	6	55
Strongly agree	152	34	4	36
Total	450	100	11	100

Table XII indicates the total percentage of parents that are in favor of the use of mobile educational math apps at home (total is 72% by adding 38% and 34%). It also indicates that the total percentage of teachers who are in favor of the use of mobile educational math apps at home is 72% (36% plus 36%). Comparing the results from Table XI and Table XII reveals a noteworthy aspect in that teachers are far more positive regarding the use of mobile educational math apps at school (55% + 36% = 91% in favor) compared to their use at home (36% + 36% = 72% in favor).

TABLE XII. PARENTS AND TEACHERS IN FAVOUR OF THE USE OF MOBILE EDUCATIONAL MATH APPS AT HOME

Option	Parents		Teachers	
	n	%	n	%
Strongly Disagree	11	2	1	9
Disagree	20	4	0	0
Neutral	92	20	2	18
Agree	171	38	4	36
Strongly agree	154	34	4	36
Total	450	100	11	100

V. DISCUSSION

The main contribution of this study is that it sheds light on the usage of educational technologies of grade 1 to 3 learners in the Free State province of SA, focusing on mobile math apps. There is a general tendency to include only secondary learners in initiatives aimed at the improvement of math skills, while several research studies indicate that the best way to improve math performance is to focus on primary school learners [2]. It is therefore, important for HEIs, in particular faculties offering engineering, science and technology programs, to conduct research on methods that can be used to improve the math skills of primary school learners. Consequently, post-graduate students in the IT department of CUT collaborated with primary school math teachers in their communities to design and develop appropriate math apps for grade 1 to 3 learners. The aim of the first stage of this project was for post-graduate student groups to investigate the use of mobile math apps among these learners in their immediate communities. This focused on the following four objectives: 1) determining the level of access of learners to smartphones and tablets; 2) establishing whether parents are downloading educational math apps for their children; 3) identifying obstacles to the use of mobile educational math apps by learners; and 4) determining what the perceptions of teachers and parents are towards the use of mobile educational math apps.

In terms of the first objective of the study, the results indicated that 64% of all learners in the target population have access to a smartphone or a tablet and that 8% of learners own a mobile device. Learners have the highest level of access to Android smartphones and tablets. These results tend to suggest that SA is not far behind first world countries where 72% of learners in America [35] and 65% of learners in Germany have access to a smart mobile device [36].

In relation to the second objective, the results indicated that 44% of all parents have downloaded educational apps for their children on a mobile device, while 30% of parents have downloaded math apps for their children's usage. More than half of these learners are using the math apps on a regular basis. This compares favorably with 58% of parents in America that have downloaded educational apps for their children in 2013 [35].

Pertaining to the third objective, the results showed that 50% of parents are experiencing trouble searching for educational apps, either not knowing where to search or not

having time to search for them. SA parents are not the only ones struggling with this problem, as 43% of American parents admitted that they needed help in finding educational apps [33]. This implies that the number of parents that download and use mobile math apps may drastically increase if parents were assisted in selecting the appropriate math apps for their children. Providing appropriate math apps developed specifically to improve the math skills of their children would also prove beneficial. The majority of teachers and a quarter of parents reported on the high costs associated with mobile data, which poses a real obstacle to its future usage. Another obstacle relating to the usage of mobile math apps is the fact that not all households have access to mobile device technology, but predictions indicate significant increases in smart device usage [26] which should remove (or reduce) this as a hurdle in the near future.

In terms of the fourth objective, the results showed that the majority of parents and teachers believe that mobile educational math apps can increase the math skill level of their children/learners. The results also indicated that the majority of parents and teachers were in favor of the use of mobile educational math apps at school and at home.

These results have various implications for the development of math educational apps for grade 1 to 3 learners in SA. The study has established that more than 60% of grade 1 to 3 learners do have access to a mobile device, but that more than half of the parents do not know where to find appropriate apps and need assistance with the downloading of apps. In addition, it has established that both parents and teachers are very positive towards the use of math apps at home and at school. Furthermore, teachers recommended that addition, subtraction and multiplications skills are the most important skills that post-graduate IT students should incorporate into their apps. These findings indicate that teachers and parents have a positive attitude toward the design and development of appropriate math apps for their grade 1 to 3 learners. These developed apps can be made available to parents and teachers through the current collaboration, thereby overcoming the problem of high downloading costs as well as the problem of parents and teachers not knowing where to find applicable apps. The collaboration between students and teachers could also potentially ensure that the apps that are developed target the specific needs of the specified learners.

The second phase of this project will include the testing of the developed math apps in order to determine if these apps do assist learners to master the necessary foundational math skills. In addition, this research could lay the foundation for additional research to understand the usage patterns and habits of learners pertaining to mobile math apps in order to promote learning efficacy, fun learning and learner engagement. Collaboration from various stakeholders, including parents, game developers, basic education teachers, government, the DBE and the private sector should be strongly recommended to achieve this goal.

A limitation of this study is the fact that the sample size was limited to school learners in one province of SA, thereby negating inferential statistics. Furthermore, the only variable

that was used to select clusters was whether the group represented the PD population of SA or not.

VI. CONCLUSIONS

The purpose of this study was to investigate the usage of mobile math apps by grade 1 to 3 learners in the Free State province of SA. Literature indicated that mobile math apps have a tremendous potential to improve the math performance of primary school learners. The collaboration between senior post-graduate IT students at CUT with primary math teachers from their communities could play an instrumental role in the development of appropriate math apps that could alleviate the great demand for innovative and educational math apps.

However, an enormous collaborative effort is strongly recommended between various stakeholders to overcome two key obstacles, namely high data costs associated with mobile devices and the lack of awareness of where to find appropriate math apps. This is especially important to ensure the successful integration of mobile technology to assist many learners in improving their math skills. Perseverance in adopting and spreading the use of mobile educational math apps must continue to be advocated, despite the perceived difficulties and obstacles which may be encountered.

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Digital Defenders

Computer Security Literacy via Game-Based Learning

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Abstract— Within the field of computer and information security, there has been a relatively recent surge of interest on a multitude of topics. However, this body of research typically focuses on the implementation or theory of security controls and mechanisms at the application, operating system, network, and physical layers. The user layer, long recognized as the weakest link in the security chain, has had little to no attention paid to it by comparison, especially from a sociotechnical perspective which is fairly new to engineering. With the introduction of new technologies putting modern society in an almost constant state of flux, familiarity with technology is no longer simply a luxury, but almost a necessity. To that end, we propose the development of an educational game to help instill vital engineering skills as well as practical and relevant computer security practices to users who might not necessarily have a technical background. This approach would take advantage of the relatively recent explosion in the popularity of video games and digital distribution platforms such as Steam to reach a wider potential audience base. In addition, we would assess the effectiveness of this approach utilizing the evaluation of training programs as proposed by Kirkpatrick.

Keywords—educational game; game-based learning; education; computer security literacy.

I. INTRODUCTION

Although recent years have seen a steady decline in violent crimes including murder, forcible rape and armed robbery within the United States, there has been a phenomenal increase in the commission of cybercrimes such as extortion, financial scams and sabotage. This corresponds to the growth in popularity of what are now arguably indispensable technologies to everyday life, prime examples being the internet, as well as home and even corporate computer networks. As with most new technologies however, one of the most crucial challenges to their broad application is with regards to issues of personal, national and even international data security. Several news stories from all over the globe within recent years shines a glaring light on this critical issue, including the theft of approximately a million dollars from several ATMs [1], the collection of credit card information that affected millions of consumers when a Target was compromised starting with a relatively simple phishing attack [2], and even the acquisition of the private email

correspondence of President Obama by a Russian hacking group [3].

Within the field of computer and information security, there has been a relatively recent surge of interest on a multitude of topics, ranging from secure programming practices, protocols and algorithm design to cryptography and ethics. However, this body of research typically focuses on the implementation or theory of security controls and mechanisms at the application, operating system, network, and physical layers. The user layer, long recognized as the weakest link in the security chain, has had little to no attention paid to it by comparison, especially from a sociotechnical perspective which is fairly new to engineering [4].

To quote the old adage, knowledge is power. With the introduction of new technologies putting modern society in an almost constant state of flux, familiarity with technology is no longer simply a luxury, but almost a necessity. While engineering students are able to keep abreast of these changes with relative ease, non-engineering students may oftentimes find themselves lost. Thus instilling in them the basic vital skills of an engineering education, such as general problem solving skills, and the ability to question a process or procedure, is an important step towards relieving their fears of using new technologies, and to allow them to adapt in an increasingly technological society.

This paper is structured as follows. We will first further clarify and elaborate on the problem of computer security literacy as well as our stated goals in section 2. We then delve into the motivation behind utilizing game-based learning over more traditional methods in section 3. A rough design is then offered in section 4, followed by a description of the proposed criteria for its assessment in section 5. Finally, we present our conclusions as well as future challenges that need to be tackled to produce a viable prototype.

II. PROBLEM STATEMENT

As we noted earlier, there has been a phenomenal rise in the number of cybercrimes committed in recent years. Besides the use of a computer in the commission of a crime however, many of these crimes shares another common thread - the hackers often take advantage of the user layer. The vast majority of these users more likely than not do not possess any engineering

or technical training, and are thus oftentimes more susceptible to attacks which exploit this, including phishing, computer virus hoaxes, and so on. The obvious goal then, is to raise awareness on such attacks and bestow knowledge on sound security practices. Computer security professionals most commonly accomplish this through awareness campaigns and the creation of websites that contain security tips and advice [4]. In addition, conventions and competitions such as DEFCON, and the National Collegiate Cyber Defense Competition are held annually. Recently, a limited-release massively multiplayer game was even created in which players have to actively hack and exploit the game code in order to win by design [5].

Unfortunately, such measures don't do enough to overcome the common perception that computer security is a topic of concern only for the technological elite. Our goal then, is to devise a solution which will reach a larger audience, specifically those who might not be as technically inclined to begin with.

III. GAME-BASED LEARNING

As has been known for some time, one of the key ingredients of successful learning is motivation - a motivated learner will tend to find a way to overcome any obstacles or difficulties over their less-motivated kin. Unfortunately, traditional pedagogical strategies tend to come across as 'dry' and 'technical' to current students, which leads to a natural erosion in their motivation to learn more about a subject. Several authors such as Presnky [6] explain this phenomenon by arguing that current students are what are termed as 'digital natives', people used to interacting on a daily basis with rich interactive digital media devices such as computers, mobile devices and video game consoles [6, 7].

Yet there is an industry which specializes in motivation - the computer and video games industry. Game designers have long been experts in the art of player engagement - the ability to keep people in their seats hour after hour, day after day, at rapt attention, actively trying to reach new goals, elated by each success and determined to overcome each failure, all the while begging for more. Since its inception in 1974 with Pong, there is now an estimated 170 million people who play games at least casually in the US as of a study done in 2009 [8], which constitutes more than half of the US population. In addition, the growing popularity of major digital distribution platforms such as Steam and GOG.com makes it easier than ever to reach them, compared to traditional retail distribution methods with cumbersome CD and DVD boxes. As of February 2015, Steam alone has 125 million active users, boasting as many as 9 million concurrent users as of March 2015 [9].

To quote another old adage then, one might as well fight fire with fire. Instead of competing against the video games industry, it makes a great deal of sense to attempt merging the content of learning with the motivation of games [7]. Educational games have the potential to enhance the learning process in several respects. One of the most discussed and pointed out of course involves player engagement. The ability to capture and hold a person's attention while keeping them engaged and immersed is a quality which can be easily

exploited to motivated a student to keep at a particular subject matter for hours at a time - which as almost any educator can safely tell you, is a trying task at the best of times [10, 11]. Another interesting trait is the ability to provide deep, immersive in-game worlds which students can freely explore at their leisure, promoting self-directed learning [12]. Additionally, games oftentimes have a short feedback cycle - an almost immediate and steady stream of rewards and punishments for each action taken by a student, which in turn gives them the perception of relatively rapid progress [13]. Last but not least, in comparison to traditional training methods, game-based learning allows students to make mistakes and learn from them in a risk-free environment [14]. The following table shows a comparison between traditional training methods which include lectures and online tutorials, hands-on training methods such as apprenticeship programs, and game-based learning.

TABLE I. COMPARISON OF TRADITIONAL TRAINING, HANDS-ON AND GAME-BASED LEARNING [14]

	Traditional Training	Hands-On Training	Game-Based Learning
Cost-effective	X		X
Low physical risk / liability	X		X
Standardized assessments allowing student-to-student comparisons	X		X
Highly engaging		X	X
Learning pace tailored to individual student		X	X
Immediate feedback in response to student mistakes		X	X
Student can easily transfer learning to real-world environment		X	X
Learner is actively engaged		X	X

The effectiveness of hands-on training approaches such as apprenticeship programs can't be disputed - it has a rich history which traces all the way from ancient times to the present day. However, well-designed game-based learning could potentially retain the advantages of both traditional training and hands-on training, being both relatively cost-effective and low-risk (safety training utilizing a virtual representation of machinery as compared to using live machinery). In addition, as we noted earlier, learners are free to re-enact a precise set of circumstances multiple times, exploring the consequences of different actions which could have disastrous consequences in real life. For example, learners could deliberately cause a virtual explosion to understand why gas line disasters happen, which would not be a viable nor desirable option during hands-

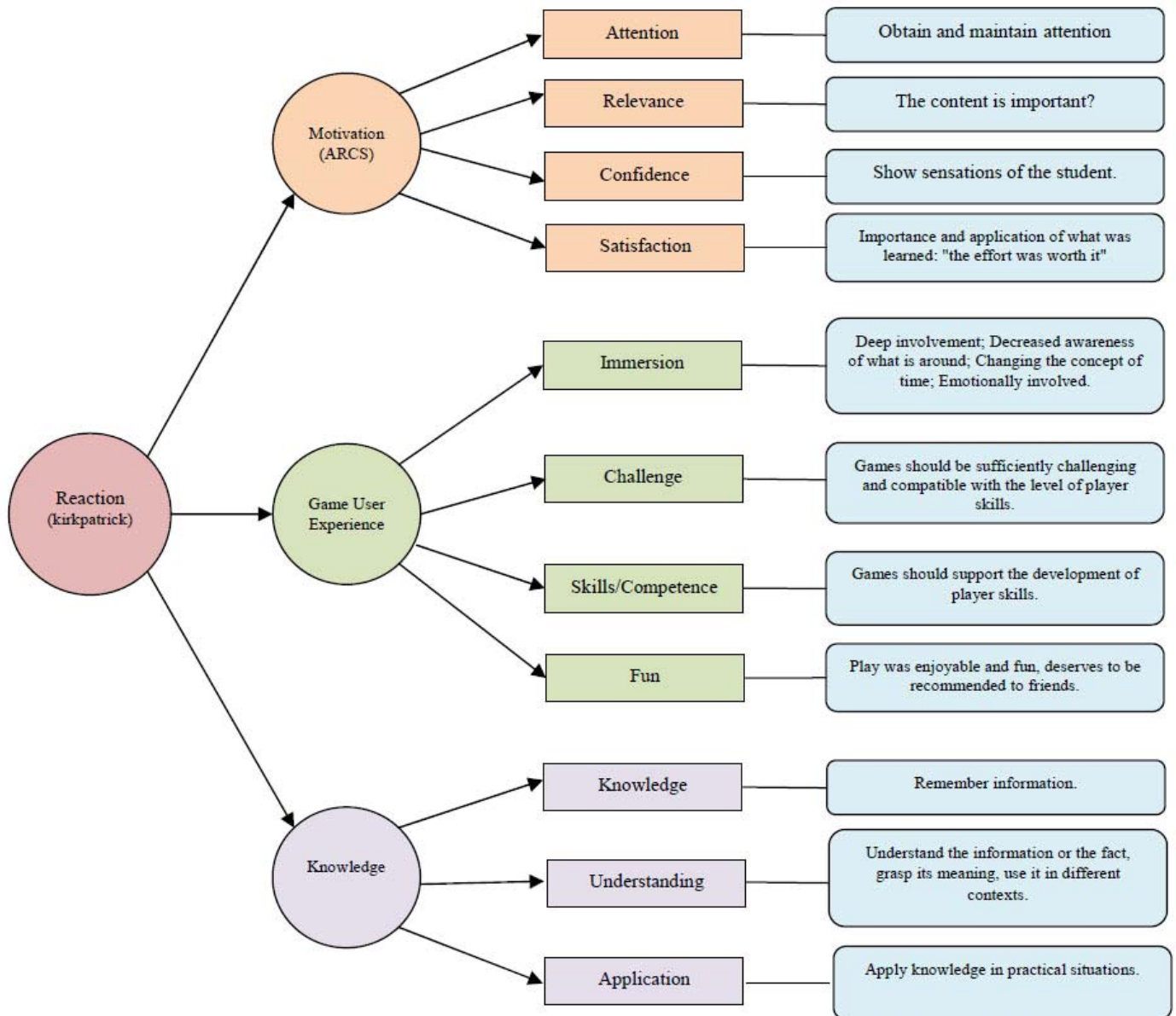


Fig 1. Proposed assessment criteria [15].

on training. Finally, with virtual reality head-mounted displays such as the Oculus Rift making virtual reality relatively affordable in the near future for consumers, game-based learning could potentially become even closer to the real thing, engaging learners even further.

IV. PROPOSED SOLUTION

As one might deduce, our solution then for tackling the perception that computer security is a topic of concern only for the technological elite is to package this information in the far less intimidating guise of an educational game, while at the same time taking advantage of the many benefits associated with game-based learning as we illustrated earlier. Our goals

with this approach, in addition to overcoming the perception barrier mentioned, would be to provide context to everyday computing tasks to better understand how security relates to these actions [4], and to reach a broader audience than most traditional means of education.

Placing players in the role of a penetration tester, the aim of our proposed game would be to infiltrate the corporate headquarters of a fictional major corporation and steal as much sensitive corporate and technical information as possible. Much like how actual social engineers and penetration testers operate, preparation will be key before a player ever sets foot in this fictional major corporation. They would have to case the establishment, going through the company website, perhaps researching key employees through spoof versions of popular

websites such as Facebook and LinkedIn, and so on. Utilizing the information obtained during this phase of the game, players would then attempt to gain physical entry to the office complex, which depending on how well they did, might be accomplished by impersonating a company employee, a janitor, or even a third party such as a pest exterminator. From there, players would attempt to obtain confidential information such as company secrets, or technical information such as the version number of an operating system or anti-virus software while moving through the office in a turn-based manner. They would have to avoid security personnel while doing so, unless they managed to obtain or manufacture fake credentials in the preparation phase. At the end of a week, players would then be scored based on how much information they managed to obtain.

As mentioned above, time is a factor in doing well in the game. Players are given only an in-game week to plan and infiltrate the office complex, with every action taking a set amount of time. In addition, players would only have a limited amount of funds to spend, which can be used to purchase uniforms, create fake credentials, and so on. This adds a sense of challenge to the game, which might otherwise seem boring to the player. In addition, while some security concepts might have to be understandably simplified to avoid overwhelming players with complications, an in-game encyclopedia with more in-depth and accurate explanations of these concepts would be included in the game for players, complete with links to online resources to allow them to research more into them should they choose.

We intend to utilize the Unity game engine for the development of this educational game, owing to the lack of fees for its usage, its ability to easily target games to multiple platforms and its relative ease of use compared to most other engines.

V. ASSESSMENT CRITERIA

One of the most essential evaluation models of training programs still in use today, is based on the work of Kirkpatrick, which is based on four hierarchical levels:

- **Reaction:** What participants thought and felt about the training. This includes how the training motivated and awoke interest in learning the content.
- **Learning:** The resulting increase in knowledge and/or skills, and changes in attitudes. This occurs during the training program.
- **Behavior:** Transfer of knowledge, skills, and/or attitudes from classroom to the job (change in job behavior due to training program).
- **Results:** The final results that occurred because of attendance and participation in a training program.

The evaluation metrics we chose was developed by Mesquita et al. [15] for educational games, and is based on Kirkpatrick's first level, as our interest lies specifically in determining the degree of motivation of students, as well as the value they attribute to the experience they had in the educational game. The proposed assessment criteria are

presented more clearly in Fig. 1. Based on this assessment model, a basic questionnaire will be set, which students would be invited to answer after playing.

VI. CONCLUSIONS AND FUTURE WORKS

In this paper, we explored and laid out a case for the creation of an educational game aimed at turning users into assets instead of liabilities in issues of cyber security, especially those lacking a technical background. We explained the advantages of our choice of using an educational game instead of more traditional means such as awareness campaigns and websites. In addition, we described a rough design for the educational game, as well as described the proposed criteria for its assessment.

Despite their inherent potential however, several challenges and issues will need to be overcome in the development and evaluation of an educational game. During the design stage, one of the major challenges will be to maintain a careful balance between its educational and entertainment value. If the player finds the game itself boring, they will inevitably quit the game, and nothing will be achieved. If too much effort is directed towards just its fun factor however, there will be little impact achieved as well. Thus this leads to the difficult task of achieving a measure of educational value to the already challenging task of developing game elements that are fun and engaging. Another consideration would be the cost involved in its development. While a large part of the traditional costs associated with the development of a video game can be defrayed with the use of relatively recent professional game engines such as Unity with affordable costs and no licensing fees, care will still need to be taken to limit the scope of the game to a manageable level for a small team. Finally, human-computer interaction experiments will need to be conducted to evaluate the effectiveness of our educational software, taking into account Kirkpatrick's four levels of learning.

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Integration of the Arts and Technology in GK-12 Science Courses

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Abstract

This paper, overview a study performed in two 10th grade chemistry classes at a girls High School in Philadelphia, PA. . Discussion with the teacher of the two classes, led to the realization that students are finding a hard time understanding the structure of an atom. Comprehension of the atom is a foundational skill in Chemistry, without the understanding of the atom, many topics in chemistry will be very difficult to understand. To tackle this problem, students in these two classes worked in groups of four, and each group was assigned a periodic element. They used iPads provided by the university to first design the structure of the atom in an app called AutoDesk 123Design. Students then provided their design to a NSF funded GK-12 graduate student fellow, and the 3D models were printed via a 3D printer at Drexel University. Once all atoms were completely printed, the students were able to paint and put together the different components using various household materials. A short PowerPoint presentation was also done by each group to discuss the various elements assigned, their structure and how electrons move in the orbitals of their specific atom. To assess their knowledge a pre and post-test was given to each student, and as a benchmark. Two additional classes that did not participate in this activity were also given a pre and post-test to be used as a control. Results of this study showed that the experimental group had a stronger understanding of the subject matter as opposed to the control group, thus, indicating that technology and arts may had a positive correlation to students' learning experience.

INTRODUCTION

The NSF GK-12 Fellowship program pairs graduate students with teachers of STEM in K-12 classrooms in the Philadelphia Greater area in an effort to expose K-12 students' to the grand challenges engineers are facing and simultaneously piquing their interest in the STEM fields. Using the 14 Grand Challenges established by the National Academy of Engineering, the graduate students and teachers develop hands-on modules and activities that enhance the students'

personalized learning and also upsurge the visibility and significance of engineering and science in society.

Education has been an essential part of society for thousands of years. Currently, however, technology has slowly entered the classroom and has changed many things especially the way information is now digested¹. Digital tools, such as computers, audio and visual tools, are slowly replacing standard traditional teaching methods. Studies have shown that an increase of technology in the classrooms has led to increase in test scores, problem solving skills and improve students' self-concept and motivation^{2,3}. The result of these studies has pushed an initiative in the United States to integrate technology in the classroom. Programs like E-rate program and various state formula programs controlled by the US Department of Education have been put into place to allocate money to different districts and manage the distribution of the funds⁴. However, there are many internal and external barriers typically faced by K-12 schools both in the United States and other countries when integrating technology into the curriculum for instructional purposes. Inadequate technological support, scarcity of time to insert technology in the curriculum, and leadership who aren't supportive of technology are just some of the many barriers that K-12 educators encounter⁵.

These barriers were evident in the two 10th grade chemistry classes at Philadelphia High School for Girls that the fellow was placed in during the academic year of 2013-2014. The computers they received were slow with many of them unable to properly function. They were being taught via

traditional teaching methods such as lectures, discussions, seat work and direct instructions. However, their interests were not piqued from the very first day, thus making basic theories difficult to teach and to comprehend. Upon discussion with the teacher of these classes, she expressed her dismay in the students' inability to remember what an atom is and the structure of the atom, specifically the Bohr model. An atom is the basic unit of a chemical element and thus is the fundamental concept in which many topics are built on in chemistry. As an alternative to her traditional method of teaching this lesson, the fellow decided to integrate an emerging form of technology to teach the structure and properties of an atom. Utilizing 3D printing is a fun and innovative way to integrate technology and the arts into the curriculum in hopes of making a difficult topic more manageable.

Research Question & Hypothesis

The Fellow sought out to investigate whether technology in the classroom have a positive effect on student's ability to retain information and also find the topic at hand more interesting. The fellow hypothesized that the students who use technology to learn atoms will have a better grasp on the structure, and shape of the atom as oppose to those who were taught the traditional way.

METHODS

Research & Tutorial

Students were placed in groups of four and were assigned an element from the periodic table. They worked for two days in the school's library to research their specific element, paying attention to how their element form bonds, how electrons move in their orbitals, and their isotopes. Using iPads borrowed from the Excite Center at Drexel University, students were given a tutorial by the fellow on how to use the application *AutoDesk 123Design*. Their tutorial consisted of learning the different settings and features of the application through various activities that included them building various shapes and items.

Design & Printing

Two days were allocated to the students to design their atom. They were responsible for designing the nucleus of the atom with the proper number of

electrons and neutrons. They were also told to design the electrons in a way that facilitate building the atom once all parts are printed. The fellow saved all the files, and printed them using a 3D printer at the Excite Center at Drexel University. Students then painted and used wires and pliers to assemble their atom together, as examples can be seen in Figure 1. Graded presentations were also done, where each group had to explain their atom and various characteristics of their element.

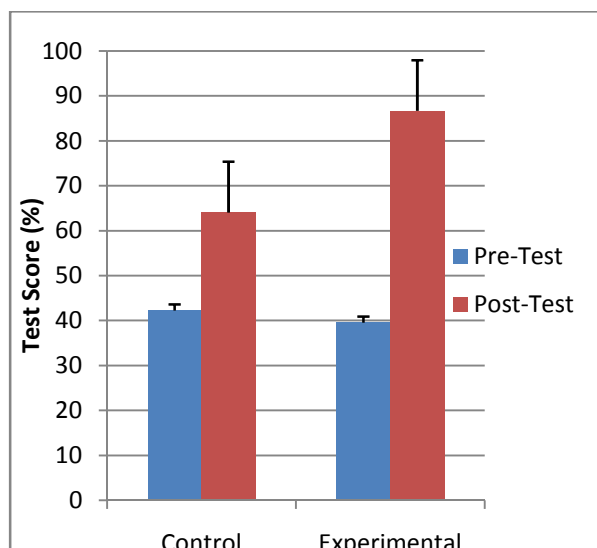
Evaluation

To evaluate the effectiveness of this activity, a pre and post- test was given to the two 10th grade chemistry classes that the fellow was assigned to. As a control, two 10th grade classes who did not participate in this activity were also given a pre and post- test. The Pre & Post test were exactly the same and consisted of 10 questions with the last question consisting of drawing an image of an atom. Figure 2 depicts the results of the pre and post test for the control and experimental group. Pre-test average for control and experimental groups are 42.3 +/- 3.2 and 39.6 +/- 3.7 respectively. The Post-test average for control and experimental groups are 64.1 +/-11.3 and 86.7 +/-12.5 respectively, where, n=63 for experimental and 54 for control. avg+/-SEM)

RESULTS



Figure 1: Above are two examples of two different groups final 3D model of an atom. To the left is Carbon and to the right is Boron



DISCUSSION:

Our findings show that the students who participated in the activity (experimental group), scored significantly higher on the post-test than those who did not (Figure 1, $p < 0.05$). A breakdown per question dives further into the pre-test and post-test to analyze how the students answered each question (Table 1). The last question on the pre and post test, question 11, asks students to draw and label a diagram of what they believe an atom looks like. (See Appendix for all the questions of the pre and post test). The experimental group that developed i). a model the atom, ii) 3D print of it and iii) put the different parts of the atom together were able to more accurately draw the structure of the atom as opposed to the control group who were taught the structure of the atom the traditional manner. Students in the experimental group showed a greater understanding of how ions are formed by losing and gaining electrons as oppose to those in the control group (questions 8 & 9). Both groups however, were not able to properly explain an atom in words (question 1).

These findings have shown positive correlation between integrating technology in the classroom and students' performance in the classroom. Although there are still many barriers that need to be conquered in the classroom, especially in urban areas, technology in the classroom has shown positive impact on the students performance and understanding. Studies have shown that technology in the classroom keeps students engaged, brings excitement into the curriculum, allows students to learn at their own pace and also prepares them for the future that they will later be working in⁶. Technology also allows teachers to teach sections in their curriculum that were once difficult to understand in a new way that will capture the

Figure 2: Results of the pre and post test for the control and experimental group.

	Pre-Test		Post Test	
	Contr ol	Experiment al	Contr ol	Experimenta l
Q1	22%	19%	52%	64%
Q2	31%	37%	44%	81%
Q 3	42%	39%	61%	83%
Q4	38%	36%	67%	94%
Q5	27%	24%	59%	87%
Q6	42%	44%	66%	85%
Q7	39%	39%	60%	88%
Q8	21%	19%	55%	81%
Q9	23%	21%	57%	84%
Q10	52%	49%	64%	91%
Q11	11%	13%	49%	92%

Table 1: Depicts the breakdown of the pre & post test by question.

The value in the table is the percentage of students in each group that answer the question correctly

attention of the students. Technology however, is not perfect, and we certainly shouldn't diminish the roles of traditional learning processes – such as handwriting, and lectures – but when used correctly, technology can help both teachers and students soar to success.

FUTURE WORK

This study was done on a small population of chemistry students in one high school. Future work will include and is not limited to: i) using 3D printing to teach atoms in all the chemistry class at this specific high school ii) speaking to other fellows at other high schools in the district in hopes that they will integrate 3D printing into their atoms curriculum and iii) finding other forms of technology to integrate into science and math courses throughout the district in hopes of making subject matter that was once deem difficult more manageable.

ACKNOWLEDGMENT

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APPENDIX

Pre& Post Test Questions

1. How would you describe an atom?
2. The nucleus of an atom is made up of what?
3. The electron has what kind of charge?
4. What subatomic particle has a neutral charge?

5. How many electrons are in the first energy level?
6. Which subatomic particle has a positive charge?
7. How many electrons can fit in the 2nd valence shell?
8. When an atom loses an electron, what is the overall charge of the atom?
9. When an atom gains an electron, what is the overall charge of the atom?
10. Which subatomic particle is the smallest?
11. Draw and label a diagram of what you think an atom looks like

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Introducing Gaming Tools for Computing Education in STEM Related Curricula

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Abstract — In this paper, we provide an overview of two Computer Science for High School teacher training workshops, offered at Fairfield University in 2012 and 2013. These professional development programs offered the skills necessary to integrate Google Apps education and interactive, metaphor-based computer games tools into middle and high school curricula, to help students learn computer science and engineering concepts. The first year workshop was primarily focused on the implementation of computer science and gaming concepts within STEM curriculum. The focus of the second year workshop was two-fold, first to continue the implementation of computer science and engineering concepts through STEM education, and second, to create connections and extensions for high school teachers who have already been introduced to STEM curricula and teaching models. Multiple urban and suburban school districts were included in a collaborative program with our university, designed to teach educators how to use computer science as a mean to make connections between different curriculum areas and teach higher order problem-solving skills. Various learning activities during the workshops are presented, and outcomes and teachers' feedback after attending these workshops are discussed.

Keywords—CS4HS; teacher training; Computer Science; STEM; gaming

I. INTRODUCTION

Research and data from several professional journals have indicated the absolute promise of STEM education to improve documented students' performance and knowledge in science, technology, engineering and mathematics, especially when early intervention occurs [1]-[2]. This will exceed the lack of performance that currently exists. The application of these integrated skill sets will make the difference in terms of future student achievement. Various explanations have been cited to prove this. One factor consistently mentioned has indicated a general lack of understanding relative to the structure of the disciplines involved in STEM education. Mathematics, as taught at the middle school level, involves different assumptions and conceptual understanding than science. This fact does not seem to be readily understood by curriculum planners and teachers. According to the Common Core State Standards, middle school mathematics, for instance, involves the concepts of ratios and proportionality, equilibrium and balance. Conversely, middle level science, as stated in the

currently released science standards and emphasized in the philosophy of the Next Generation Science Standards, focuses on experimental design, gathering data, pattern recognition used to predict future outcomes. "If...then" statements used in formalized hypothesis indicate that a set of assumptions are used to predict future results. Coincidentally they are also used in higher mathematics and by Microsoft Excel in the development of relational databases. These skills are key to language arts learning as we consider the Common Core State Standard's call for conceptual understanding of cause and effect and the emphasis on nonfiction reading skills for all students.

Another area of concern is the selection of STEM themes in the curriculum development process with little or no regard to the structure of the disciplines, or their habits of mind, or the true technology integration. For instance, an unit on cell biology may be identified for development into a STEM unit. Often curriculum planners will examine the unit and identify areas where mathematics, technology and engineering may be correlated into the expanded unit. This forced trans-curriculum relationship tends to result in segregated units of study where students have a difficult time making conceptual associations among the various disciplines. It also makes developing of effective assessments difficult, with each discipline creating various assessment models unique to the area of study. Therefore selecting a broad topic that easily and fluently encompasses each of the STEM domains with seamless technology integration is essential for the future success of the unit. True STEM education speaks to the total immersion of inquiry and integration as strategies throughout all disciplines. These strategies lead to greater student achievement for all. The "T" in STEM, that of technology, if employed correctly, is the glue to bring together the disciplines and to ensure the highest achievements for all students.

However, at the same time, computer science in K-12 education in the United States is also in crisis, according to the Association for Computing Machinery (ACM) and the Computer Science Teachers Association [3]-[8]. Middle school students use computers in their daily lives, but unfortunately they never quite understand what computer science is and how it relates to problem solving and computational thinking [9]. Their exposure to computers in school is most likely with spreadsheets, word processing, and presentation tools. Few

high schools offer a computer science course, and even fewer middle schools offer one, which is usually the time when students are beginning to formulate their ideas about careers. The lack of exposure to computer science at the K-12 level leads to few students choosing computer science as a career in college [10]-[11]. The U.S. Bureau of Labor Statistics predicts that the United States will only be able to fill about one-third of technology jobs in 2018 with U.S. citizens.

In this paper, we address these issues by offering professional development workshops to middle and high school teachers in school districts throughout the state of Connecticut. Through grant opportunities from Google, we have run two CS4HS workshops at Fairfield University in the summer of 2012 and 2013. The CS4HS program promotes computer science education worldwide by connecting educators to the skills and resources they need to teach computer science and computational thinking concepts in fun and relevant ways. The seamless infusion of technology presented to teachers at our CS4HS workshops, and ultimately provided to students, helps reduce the educational needs of our schools since it acts as the glue necessary to ensure a higher level of achievement for students. Our approach used the concept of gaming to assist secondary education by increasing student engagement. Increasing student engagement occurs when students become more interested in their schoolwork. This continues to be one of the most difficult tasks that teachers face. It is important that teachers ensure that students have a good balance of fun and learning while engaged in classroom activities [12]-[14]. Educational games aim to do just that. Gaming emphasizes entertainment, which can have its benefits among young audiences, but could be far more powerful if used as an educational tool. Learning how to develop, integrate, and teach educational games, and use them to effectively instruct middle and high school students STEM-related concepts with focus on computational thinking, was the focus of our workshops.

Our training also emphasized Google Apps, such as Google Drive and Google App Script, as both of these apps help support collaboration among their users. Educators and their students are able to create, share, and present materials more efficiently through these tools. They allow students and educators to work collaboratively while in the classroom but also outside the classroom to extend the learning opportunities through the use of technology. By focusing on Google Apps, the professional development activities were centered on creating and presenting collaboratively. Thus all disciplines can be aided by this process. The collaboration model is also used in many of today's popular video games. Lee Sheldon in his book "The Multiplayer Classroom" explains the benefits of having students build challenging game strategies [15]. This experience used as part of a class creates a new environment where students are challenged to be an engaged and active decision maker within the class. The gaming industry designs games as entertainment for their users, so classrooms should be able to work on that same principle creating entertainment for students while engaging them in higher order problem solving and cause and effect principles. All of these actions are based on the idea that the skills of the collective parts are greater than the skills of an individual. The objectives include generating

interest and enthusiasm for teaching and learning STEM and Computer Science related fields of study.

II. OUR APPROACH

There is preponderance of research and data published through many professional journals that states the advantages of using STEM based curricula for improving students' performance in mathematics, science and technology [16]-[19]. This data is causing a growing shift within schools to move towards a STEM based curricula. This change can be seen in Fairfield and New Haven County in Connecticut with the implementation of STEM curricula in the schools in towns such as Bethel, Bridgeport, Fairfield, Madison, Monroe, Naugatuck, and others. Though the specific content taught in the math and science curricula is different, there are connections between the two disciplines, as both the Common Core State Standards and the Next Generation Science Standards put a strong emphasis on higher order problem-solving skills and causal relationships. Causal relationships such as "If...Then" or "While...Do" are the data flow concepts presented in high school computer science classes. These relationships can also be seen in the Common Core State Standard's conception understanding of cause and effect within non-fiction reading skills. These causal relationships are introduced in all subject areas and should improve student understanding of balance vs. imbalance, pattern recognition, data gathering and the ability to predict future events and form hypothesis.

Computer science curricula and the course offering within Fairfield and New Haven County schools vary significantly, from a basic introduction to Computer Science to AP Computer Science courses. Some schools are now offering courses in video game design, some have developed multiple course offering, and others are just starting to investigate courses they would like to offer. It is through these opportunities that teachers can include the implementation of educational games and gaming tools to create further connections between all subject areas not by a forced use of technology but rather an immersion into technology by allowing multiple teachers to demonstrate the advantages of working among disciplines. This collaborative effort will show students that disciplines are not islands of independent knowledge but networks that must be connected in order for knowledge of all subject areas to grow.

A. Workshops Goals

The main goals for the two workshops were as follows:

- To recruit and provide training to middle and high school teachers from local area towns (including, but not limited to, Ansonia, Bethel, Bridgeport, Madison, Monroe, Naugatuck, Ridgefield, Shelton, and Trumbull Public and Parochial School Districts)
- To make teachers aware of computational thinking resources and educational tools as they specifically relate to Computer Science and technology curricula based upon the State of Connecticut framework

- To have educators gain knowledge of the structure of Computer Science and STEM disciplines and become familiar with methods of computational thinking unique to them
- To have educators gain knowledge of Google Apps to foster collaborative learning
- To educate teachers in making connections between disciplines through the use of metaphors-based games and technology, leading to higher achievement for students
- To design and implement a set of CS learning activities to be utilized in regular classroom models and/or in after school clubs for middle and high school students
- To increase teacher awareness and enthusiasm for Computer Science and STEM related activities, leading to increasing student self selection into CS and STEM classes and career fields

In the ten school districts of interest, middle school Computer Science curricula is currently near inexistent. The involvement and enrolment in Computer Science and technology courses at high-school level is not encouraging either. Unfortunately, middle and high school students do not realize that other fields with educational nature can be used in the Computer Science and STEM disciplines. The overall goal for our program is to provide ways for educators to teach middle and high school students how to solve problems creatively and uniquely, in relationship to other disciplines. A particularly useful technique for teaching these skills is using simulated activities to reinforce problem-solving concepts. When learning, it is important for students to learn about how to approach a given problem space. It is well known that students have different learning styles. For students to effectively retain the information, the lessons must include elements of all senses, visual, auditory, tactile and kinesthetic. There are many studies about multiple intelligence and learning styles and all of them show that students retain more of what they learn when the information is presented through multiple media and subliminate real world situations [20]-[23]. Students remember less of what they read than when they hear or see visuals related to what they are hearing; or if they watch someone do something while explaining it. Moreover, students retain much more of the information they learn in a simulation. These simulations' educational value is increased even more when the simulations reflect real world situations. Lastly, it is important that teachers allow students to have some feeling of accomplishment at the end of their work. This feeling of accomplishment compels students to continue to learn and work harder. Along these ideas, our workshops give teachers the opportunity to experience educational tools through a set of Computer Science resources and learn how to engage students in problem solving and computational thinking.

B. Target Audience, Recruiting Strategy, and Benefits

Each year, twenty middle and high school teachers were recruited for the workshop in several ways. Teachers were contacted by email from lists provided by the participating

school districts and at large. Recommended candidates also received follow up information from the program director and the teacher coordinator. Teachers and administrators were invited to attend an informational meeting regarding the summer workshop. Both workshops have reached their full capacity within a month of advertisement and were running with a waiting list of over twenty teachers.

The population of students in the participating districts who will be impacted by this program was very diverse. Approximately 40% of the students are male and 60% are female. The diversity of ethnic groups varies from a mix in the Diocese of Bridgeport (68% African American, 14% Caucasian, 3% Asian 1% Hispanic and 1% Other) to a slight demographic mix in the Naugatuck school system (8% African American, 77% Caucasian, 3% Asian, 11% Hispanic, and 1% Other) to little diversity in Monroe Public Schools (2% African American, 89% Caucasian, 3% Asian, 5% Hispanic and 1% Other). The author of this paper, as the program director, and the teacher coordinators in collaboration with the district curriculum coordinators were in close collaboration for the content of the workshop, in order to address the diversity of the participating districts. Moreover, Fairfield University, as a Jesuit institution, has a further obligation to the wider community it belongs to, to share with its neighbors its resources and special expertise for the betterment of the community as a whole.

Besides the obvious benefits of participating in the workshop, teachers entered into a network of professionals to continue fostering the relationships built at these workshops and extended to other school districts around the nation. A Google group for CS4HS participants is available so that sharing resources and expertise, and communication can continue amongst participants after the end of these workshops.

In addition, teachers attending these workshops can apply for continuing education units to be utilized for certification purposes through their school districts.

C. Workshops Format

1) First Year Workshop

The first CS4HS workshop was held Wednesday to Friday, on June 27-29, 2012, from 8:30 a.m. to 3 p.m. in the School of Engineering at Fairfield University in Fairfield, CT. Morning presentations were held in an auditorium while afternoon hands-on activities were held in a computer lab.

During the 3 days workshop, various learning activities alternated between presentations and hands on activities (Fig 1). Teachers were introduced to several popular game development platforms used for computing education including Scratch, Alice, and Game Maker. They were exposed to educational resources and Computer Science learning activities, such as CS Unplugged, and provided examples of collaboration among computing, STEM, and other fields [24].

Presentations included a speaker from Google on Google technologies, also topics such as Computing Basics: Algorithms and Abstractions, Educational Computer Games, CS Unplugged, Computing in Lesson Plans: Some Ideas, Merging Musical Arts and Technology, Pattern Recognition

and Clustering, Resources for Graphics and Animation, Careers in Computer Science, and Software Engineering Serious Computer Games.

Typical hands-on sessions evolved around the following tasks:

- Identify the concept to educate students about
- Develop the proper metaphors for the concept
- Identify the proper tools, such as modeling software and platform
- Determine how educators can develop and use the game to educate their students

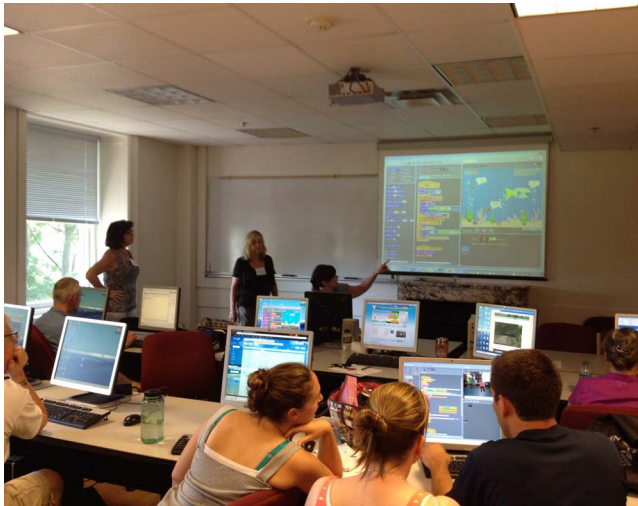


Fig. 1. Participants’ games demo on the last day of the workshop.

The issue of how these topics could be addressed, as most middle and high school students do not take Computer Science classes, was also discussed. Several strategies for incorporating these games into middle and high school curriculum were brainstormed during the workshop with teachers sharing their STEM curriculum and in particular, any computer science related modules, courses, or clubs. The workshop included a pre- and post-attitudinal survey to help gauge teacher attitudes towards educational gaming in the classroom, in addition to the standard Google CS4HS participant survey (Fig. 3). For the latter, a Likert scale was adopted for the quantitative questions, with 1 (strongly disagree) to 5 (strongly agree) as the choice of answers.



Fig. 2. Participants in the computer lab for hands on activities.

What grade/grades do you teach?	If you are a teacher, what subject(s) do you teach?	Overall, I found this workshop to be worthwhile.	I felt a sense of community among participants of this workshop.	What did you like about the program?	What didn't you like about the program?	Is there anything you wish you had learned during the workshop, but didn't?	Would you recommend this workshop to other colleagues?	If you are a teacher, how likely is it that you will incorporate knowledge you've learned into your curriculum?	What would enable you to incorporate what you've learned into your classroom?	Is there anything else that you would like us to know about your experience?
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Fig. 3. Google CS4HS participant survey.

The breakdown of the teachers participating in the first year workshop was as follows:

- 3 teachers were grade 9-12, 14 teachers grade 6-8, with a very high percentage of 8th grade teachers; we thought it is important that teachers of students about to start high school need to get the students excited about Computer Science in preparation for the high school more technology-oriented curriculum
- 2 male, 15 female
- 4 from private schools, 13 from public schools
- The range of teaching disciplines included: science, technology, math, computer science, and media, with the majority in science

2) Second Year Workshop

The second CS4HS workshop followed the same 3 days structure in June 2013, with various learning activities

alternating between speakers/presentations, panel discussions, and hands on activities (Fig 2). However, based on lessons learned from the prior workshop, some of the topics and presentations were altered to better assist the teachers with information and programs/games that can be brought back to the classroom and incorporated into lesson plans to enhance STEM based student learning. Thus, some more theoretical presentations have been replaced by customized resources, networking time, and programming assignments. In addition to exposing the teachers to game development platforms used for computing education, such as Scratch and Game Maker, they were introduced to Google Apps through examples, as a better way of collaborative learning in K-12 education. The hands on activities helped them determine how to develop and use games and Google Apps to educate students and make connections with other disciplines.

A Google speaker has been invited to provide insight for using Google Apps in education, including Google Drive and Google Apps Script. Google Apps Script - a Cloud Based

JavaScript platform allows users to quickly write simple applications. The teachers were walked through many tips and tricks around Google Drive and other third party applications that provide value to education, as well as provided with many related educational resources [25]-[28]. Other presentations were focused on resources for teaching computational thinking, video game design, and gamification of the classroom. A panel of high school teachers who have been successful in teaching either programming, gaming classes, or STEM-related topics in a way that engages their students, was also included, as a great opportunity to share best practices and lessons learned. The workshop also included a pre- and post- attitudinal survey to capture teacher attitudes towards educational tools in the classroom, in addition to the standard Google CS4HS participant survey (Fig. 4) and the results are presented in section III.

The breakdown of the teachers participating in the second year workshop was as follows:

- 13 teachers grade 9-12, 7 teachers grade 6-8
- 8 male, 12 female
- The range of teaching disciplines included: computer science, technology, science, math, and special education

All teachers, in both workshops, received a stipend for attending the workshop. Most of the budget was supported through the Google CS4HS grant. Additionally, there were advertising materials, as well as media packages for each participant, generously donated by the School of Engineering which also provided computer hardware/software, facility use, and network administration for the duration of the workshops.

Google Apps and Gaming Tools for CS Education 2013 Pre –Attitudinal Survey	Google Apps and Gaming Tools for CS Education 2013 Post –Attitudinal Survey
Your Name: _____ Grade: _____	Your Name: _____ Grade: _____
School: _____ School District: _____	School: _____ School District: _____
How often do you utilize technology in your classroom? (Frequency and with what subjects)	This workshop has contributed to my enjoyment of technology in the following ways:
I enjoy using technology because	After completing this workshop the use of technology in my classroom will: Circle one, Increase/ Decrease/ Stay the same
The thing I like most about integrating technology for students is.....	Why?
The thing I like least about using and developing technological resources in my classroom is.....	What technologies/concepts will you introduce to your classes/school in the Fall 2013?
I think the best approach to the teaching of technology within the curriculum is	How will these technologies/concepts be integrated in your classroom and into your instruction of students?
The biggest obstacle for me to utilize technology effectively is	What obstacles may prevent you from utilize the technology/concepts introduced at this workshop?
What Google tools have you used?	How has your understanding of computational thinking changed? (I used to think, but now I think.....)
Do the staff and students at your school have Google accounts? (will they?)	How do you plan on using gameification and/or video games in your classroom/school?
What presentation/collaboration tools do you currently use with students and staff?	How will you share what you have learned with your colleagues and students?
What do you know about using gameification to aide learning?	What type of follow up professional development would interest to you?
How have you used gameification to date?	What would you change about this professional development?
How are gaming/simulations and/or modeling utilized in your classroom to further student understanding of different topics?	
What do you know about computational thinking?	
How have you used computational thinking to date?	

Fig. 4. Example of pre- and post- attitudinal surveys.

III. SURVEY RESULTS AND EVALUATION

A. What Worked for Our Workshops

Based on the feedback received from the participants through the Google CS4HS survey at the end of the workshops, we were pleased by the variety of activities appealing to them, as follows:

- Hands-on activities that could easily be integrated in middle and high-school curricula
- Breakout sessions and discussing ideas in groups
- Presenting end of workshop results to the whole group
- Introducing several gaming platforms (including Scratch) and related gaming activities
- CS Unplugged ideas and resources
- Having Google speakers give presentations on various Google Apps for education
- Panel discussion on current Computer Science situation in high schools and sharing successful programs and implementation ideas for programming, gaming, and robotics classes
- Meal and refreshment time provided an excellent opportunity for them to network with each other and with the presenters

The participants liked the “immediate availability of materials” presented, that the topics were “timely and the information current”, “lots of different ideas for things to do in the classroom” were given, that “computer time to test out and utilize the information” was allocated during the workshop, and “sharing information and communicating ideas” with other teachers has been a priority.

Most of the post-attitudinal survey comments, when compared to the pre-attitudinal survey responses, have shown a great deal of change in how the participating teachers viewed Computer Science and its relationship to other fields. Comparing teachers’ understanding of computational thinking before and after the workshop indicates that the teachers left the workshop better prepared to infuse it in their classes. Some of their responses are summarized as follows:

- “I used to think it was too complex to teach it, now I know it can be broken down into smaller pieces.”
- “I used to think it was all Math but now I think it is more process and logic.”
- “Now I view it as more realistic problem solving.”
- “I used to think that algorithms were related only to Math.”
- “I do not think I knew what computational thinking meant, now I do.”
- “I have never heard about computational thinking before this so I now understand how important it is to push computational thinking in the classroom.”

- “I think about algorithms now...”
- “I had no idea that computational thinking involved sets of numbers and so many steps...”
- “I used to think it would be hard to integrate more technology but now gamification can attract more students”
- “I used to think it is important to teach the program language but now I feel it is also important to teach the thought process”
- “I used to think it was hard but now I know anyone can do it”

Examples of first year workshop games generated by the participants and presented during the last day of the workshop are provided in Fig. 5. Some teachers wished the workshop duration was extended a few more days to have more time to work on the programs and learn the software better, as they got excited about the topics.

B. After the Workshops

After the first year workshop, in the post-attitudinal survey, more than half of the participants highly expressed their interest in incorporating knowledge they learned into their curriculum in various ways such as:

- Using Scratch in their classes
- Incorporating games or game strategies into class exercises
- Using CS Unplugged when teaching computational thinking topics
- Promoting Computer Science as a discipline and professional career to their students

With curriculum refined, after the second year workshop, in the post-attitudinal survey, unanimously the participants expressed their interest in continuing learning about the topics they were introduced during the workshop and adding them into their curriculum in various ways by:

- Using Google Apps for education to facilitate collaboration and sharing
- Using gamification strategies in their classes to engage and motivate students
- Incorporating games or game exercises into lesson plans
- Using CS Unplugged and computational resources documents in the classroom with little additional preparation



Fig. 5. Examples of games created by teachers during the workshop for various STEM topics (i.e., in anatomy, math, and language art).

While the more fun and interactive activities were immediate success for teachers and probably fitting directly into their curricula, the more theoretical lectures and exercises did not sync well with the audience. In the surveys, most of the participants expressed their lack of time in classroom preparation which would make it harder to implement them due to both teachers' and students' inappropriate background skills.

Consequently, we made several changes in the content of the workshop between year one and two. As a result, the Google CS4HS survey for the second workshop was showing a great improvement, with all participants (100 percents) responding either 5 (strongly agree) or 4 (agree) to all quantitative questions in the survey as follows:

- "Overall, I found this workshop to be worthwhile"
- "If you are a teacher, how likely is it that you will incorporate knowledge you've learned into your curriculum?"
- "I felt a sense of community among participants of this workshop"

Moreover, all participants (100 percents) expressed their satisfaction with the workshop by answering "Yes" to the "Would you recommend this workshop to other colleagues?" question.

IV. CONCLUSION AND FUTURE WORK

In this paper, we present the framework and outcomes of two CS4HS Google-sponsored workshops that helped middle and high school teachers learn more about computational thinking, gaming, and Google Apps for education. The ability to solve problems with a given problem space but also recognizing relationship and similar problem types benefit students in all disciplines. For teaching these skills, using simulated activities to reinforce problem-solving concepts is a powerful technique.

For each workshop, a diverse group of middle and high school teachers in Computer Science and STEM disciplines from Connecticut school districts, was recruited and introduced to game development platforms, techniques for gamification of classroom, and Google Apps for a more collaborative way of learning in education. They were also exposed to educational resources and various computer science learning activities, with or without the use of computers, and provided examples of collaboration among computing, STEM, and other fields.

Based on surveys, the feedback received has been very enthusiastic and we are hopeful that ultimately it will reflect in raising student awareness of relevance of CS fields and future changes in enrolment. Many teachers mentioned that while they thought Computer Science is all about programming, after attending these workshops, they will dedicate more time to activities enforcing problem solving and computational thinking which are crucial in many fields.

Similar teacher training workshops have the potential to work as well at other universities due to an increased demand

to prepare a STEM-proficient workforce and future Computer Science experts. We plan to continue offering other workshops like these in the future and expand our efforts to new school districts as part of preparing K-12 education for a stronger foundation in CS and STEM. Currently, we are working with several teachers for similar proposals that would support professional development for in-service teachers in the state of Connecticut. We are also actively looking to adapt the program and join national efforts to create opportunities for the teachers to transform CS and STEM education into vibrant and inspiring learning environments.

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Scaffolding in educational video games: An approach to teaching collaborative support skills

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Abstract—Because collaboration plays a key role in today’s society, it is beneficial to prepare people at a young age for collaborative work. However, there is no academic or professional consensus on the most effective approach. To remedy this shortcoming, our research will expand on one promising method: the incorporation of collaborative scaffolding into collaborative educational video games. Although there will be several challenges, we have already made progress through the development of a multilevel taxonomy of collaboration to aid our evaluation approach. Our findings will bring academics and educators one step closer to developing methodology for the seamless integration of 21st century skills, such as collaboration and technological proficiency, into today’s classroom curricula. In addition, researchers can utilize our taxonomy to more easily identify aspects of collaboration relevant to their interests, and educators can use the taxonomy to help identify collaborative skills that students lack.

Keywords—computer aided instruction, electronic learning, curriculum development, career development, collaboration

I. INTRODUCTION

21st Century Skills [1], such as collaboration and technological proficiency, are necessary in today’s ever connected world, yet there remains a lack of insight into best practices when it comes to teaching collaborative skills. One option is to embed collaboration into activities, either explicitly through team formation or implicitly by assigning a goal impossible to achieve alone. A major advantage to this methodology is its seamless integration into existing curricula; there is no need to take time away from teaching traditional topics because everything is imparted concurrently. However, without explicit guidance, there is no guarantee that group members encounter and ingrain the necessary collaborative skills. Another approach is to create activities aimed purely at teaching and encouraging collaboration. In this case, potential frustration from a lack of academic understanding will not interfere with the collaborative process, but classtime must be set aside.

Although the value of collaboration has been known for some time [2], [3], technology’s rapid evolution requires us to reexamine methodologies to collaboration education. An approach not yet explored is the incorporation of collaborative scaffolding into educational video games. Aside from educational benefits [4]–[6], such games have already been shown to have positive effects, such as an increase in motivation to learn [8] and improvement in self-efficacy and self-esteem [7]. Through collaborative play in particular, children have shown

an increase in collaborative behaviors [9], [10], such as sharing [11], and a decrease in aggression [9]. The addition of specialized scaffolding allows educators to leverage the inherent benefits of collaborative educational games and facilitates the parallel teaching of collaboration and traditional topics.

To examine the impact of collaborative scaffolding, we built a collaborative multiplayer game and developed a pre-post study design. Through the process of creation, we encountered and predicted several challenges associated with developing study-specific technology, working with children, and running on-sight trials. To identify a focus for our evaluation, we performed an analysis of over 25 existing studies and surveys to identify the components of collaboration. We chose two facets from the resulting multilevel taxonomy for our study: performing part of a task for a group member (direct helping) and providing guidance to a group member (indirect helping). Moving forward, we plan to iterate on our materials, finalize our study design, and flesh out our data analysis so that we can examine the impact collaborative scaffolding has on these behaviors both during and after play. Aside from aiding our own work, the taxonomy can help researchers pinpoint aspects of collaboration relevant to their interests, and it can help educators identify collaborative skills that students lack.

II. DEFINITIONS

A. Collaboration

The concept of *collaboration* is not well defined in literature, and is often referenced in conjunction with *cooperation* and *teamwork*. Some researchers make an effort to distinguish between these terms [12]–[22], while others use them interchangeably [9], [23], [24]. The popularity of each term depends largely on the area of study; computer science favors *collaboration*, most prominently in the areas of Computer Supported Collaborative Learning (CSCL) [14], [15], [21], [23] and Computer Supported Collaborative Work (CSCW) [13], while *cooperation* dominates the field of psychology [3], [9], [11], [25]–[28] and *teamwork* is featured in the industry [2], [12], [29], [30] and military [19], [31] sectors.

Some researchers define collaboration by its behaviors and skills, which in turn are often defined themselves [12], [18], [32], while others define collaboration as an activity [20], [28], [33] or a context [25], [27], [34]. We developed our own definition, taking most of our wording from Roschelle and Teasley [20] and Ryan and Wheeler [27]:

Collaboration is the mutual engagement of participants, whose goals are interdependent and positively correlated, in a coordinated effort to complete a task.

For the purposes of our work on collaborative scaffolding in educational video games, *participants* will be the children who establish a *mutual engagement* among themselves, and *coordinated effort* will refer to their self-organized approach. Because the goal of each player on a team is for the whole team to win, player goals will be *positively correlated*.

B. Helping Behaviors

The concept of a helping behavior is closely tied to backup behavior. According to Porter et al. [29], *backup behavior* is help that occurs when “it is apparent that [a] team member is failing to reach those goals [defined by his or her role],” while *helping behavior* occurs when help is not strictly necessary. Our helping behavior definition is based on Porter et al.’s backup behavior definition, sans dependence on need:

A helping behavior can be described as the provision of resources and task-related effort to a group member intended to help that member contribute to task completion.

In contrast to Porter et al., Marks et al. base their definition of backup behavior on Dickinson and McIntyre’s [35] work and define it as occurring when “(1) providing a teammate verbal feedback or coaching, (2) helping a teammate behaviorally in carrying out actions, or (3) assuming and completing a task for a teammate” [36]. Although Marks et al. call these backup behaviors, they also qualify as helping behaviors under Porter et al.’s definitions. We use two of Marks et al.’s backup behaviors as a focal point for our research on collaborative scaffolding: performing part of a task for someone (assuming and completing a task for a teammate) and providing guidance (providing a teammate verbal feedback or coaching).

C. Scaffolding

Wood et al. coined the term *scaffolding*, meaning a “process that enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts.” [37] They went on to identify six scaffolding functions that we incorporated into our collaborative scaffolding design: recruitment, reduction in degrees of freedom, direct maintenance, marking critical features, frustration control, and demonstration. As a form of direct maintenance and frustration control, our collaborative scaffolding system mentions the benefits of collaboration to players when they are stumped. To mark critical features, the system directs student attention when collaboration becomes a necessity. Because the scaffolding system is limited by the game in which it resides, Wood et al.’s other functions are more relevant to the educational game itself, which has its own educational and game scaffolding. The game’s contents entice potential players (recruitment) and technology restrictions limit player input channels (reduction in degrees of freedom). In addition, mechanics are gradually introduced (direct maintenance), the difficulty level can be fine-tuned (frustration control), and in-game highlights and dialog guide the player (marking critical features).

III. RELATED WORK

A. Collaboration among children

Since our research focuses on middle school children, it is important to understand the relationship between kids and collaboration. Studies show that young girls perform better in a collaborative environment than in a competitive one, while boys perform equally well in both [38], [39]. In addition, a collaborative classroom goal structure, when compared to a competitive one, leads to higher achievement, greater acceptance among group members, and more positive attitudes towards tasks and teachers [40]. It is also better at promoting critical thinking competency, motivating further exploration into the educational subject, and encouraging positive expectations of future inter-student interactions [41]. Even at the undergraduate level, a collaborative structure leads to groups that show more subdivision of activity, attentiveness to fellow members, and friendliness during discussions [25]. Facilitating an effective collaborative environment requires child proficiency in collaborative skills, which we aim to teach and encourage through our collaborative scaffolding system.

Aside from environment, research has also been done on comparing collaborative and competitive tasks. Ryan and Wheeler [27] found that fifth and sixth grade students given collaborative, rather than competitive, lessons exhibited more collaborative tendencies during post-lesson game play. These tendencies came in four categories: seeking help for one another, positively responding to help sought, volunteering help for others, and establishing group strategies for sharing resources with individuals in need. In our exploration of collaborative scaffolding, we are also interested in the retention of helping skills, although we distinguish categories by the help itself instead of its initiation. Moreover, rather than compare the effects of a collaborative vs. a competitive task, we concentrate on collaborative vs. neutral scaffolding during in-game collaborative missions.

B. Scaffolding

Effective scaffolding systems often incorporate the concept of *fading*: “once the learner has a grasp of the target skill, the master reduces his participation (fades), providing only limited hints, refinements, and feedback to the learner, who practices by successively approximating smooth execution of the whole skill” [42]. To this end, our system tracks player input and in-game events to identify when collaboration is advantageous but overlooked. Ideally, as players progress they begin to identify collaboration opportunities on their own. In turn, our system limits its presence to avoid providing unnecessary information. In addition to fading, we incorporate all relevant scaffolding strategies from Quintana et al.’s [43] guidelines into our scaffolding design: (1c) Embed expert guidance to help learners use and apply science content, (2a) Make disciplinary strategies explicit in learners’ interactions with the tool, (5a) Embed expert guidance to clarify characteristics of scientific practices, and (5b) Embed expert guidance to indicate the rationales for scientific practices.

Traditional scaffolding systems tend to address educational topics like math and science. Research has also been done on collaborative scaffolding in general [44] and topics related to collaboration, such as exploratory talk [45], [46] and reaching

group consensus [47]. However, little of it addresses helping behaviors in particular, which is the focus of our work.

IV. STUDY DESIGN

A. Focus

To inform our exploration into the impact of collaborative scaffolding in educational video games, we developed a research question based on two dyads. The first dyad is setting. Our main interest is collaboration in a classroom context, but we also aim to explore the impact of collaborative scaffolding as it appears in real time during video game play. The second dyad is type of help. We chose to concentrate on direct and indirect helping to keep our scope broad but realistic. These focal points result in the following research topic:

Does collaborative scaffolding in an educational video game promote more instances of performing part of a task for a group member (direct helping) and providing guidance to a group member (indirect helping) than non-collaborative neutral scaffolding in the context of the game and a collaborative classroom activity?

B. Procedure

To explore collaborative scaffolding, we modified Singapore-MIT GAMBIT Game Lab's *Waker* (<http://gambit.mit.edu/loadgame/waker.php>), a 2009 action-puzzle Flash game that teaches displacement and velocity. We chose this game because of its light-weight nature, educational content, and potential for rapid modification. Since the game was originally single-player, we altered the code to allow simultaneous play, developed new corresponding levels, and implemented a collaborative scaffolding system.

Our mixed-factorial study design meant that we needed to create two versions of content for the scaffolding. For the treatment group, we will have collaborative scaffolding with statements such as "Remember each of your abilities, and use them to help each other." and "Sometimes things are easier to do together." We can think of these phrases as positive, in line with scaffolding's formal definition. Scaffolding can also be neutral or even negative. In the context of an educational video game, neutral collaborative scaffolding would include statements that neither help nor hinder players, including "It must have taken a long time to build this place." and "It sure is bright outside." We will use this type of scaffolding for our control group. Negative collaborative scaffolding hinders people with statements such as "You don't need anyone's help." and "Working with others is a waste of time." We chose not to use this type of scaffolding in our study.

During each trial, students will start by taking a short pretest that covers their collaborative experiences and attitudes towards collaboration, as well as their knowledge of the topics that the game will teach. They will then split into small groups and perform a simple collaborative classroom activity during which we will take note of any direct or indirect helping. To collect data during the activity, we will use audio recorders and several observers. After the activity, students will break into two groups: the control and the treatment. Students in each group will form pairs and play the appropriate

version of the game before filling out a short questionnaire on engagement and motivation. They will disperse into small groups to perform another group activity, after which students will fill out a post-test once again pertaining to collaboration and knowledge of the subject area.

V. CHALLENGES

Although our research on the effects of collaborative scaffolding in educational video games will contribute both to academics and educators, there were considerations and concerns that needed to be addressed as we developed our system and that still need to be addressed as we finalize our study design. For example, in determining an appropriate game, it was important to remember that just because an activity appears collaborative does not mean it lacks implicit incentives for competition. In the workplace, two employees with similar jobs may work on the same project but try to discredit each other because of an upcoming job opening in management. In the classroom, a teacher may try to encourage collaborative skills by randomly assigning groups for a project, but group members may compete to look better by requesting the least help or finishing their part first. Actively avoiding help and rushing to finish a task can easily lead to subpar results. The teacher may choose to have students always work in the same groups to avoid such a case, but they will not gain experience in dealing with different types of people.

Technological challenges existed beyond the collaborative nature of the game. When using school computers, reliable internet access and computer permissions for installing software are not guaranteed. We developed a stand-alone Flash game for our trials because it will not need to be installed, and we will be able to store all logging locally to avoid potential issues with the internet. We also had to carefully approach our design of the scaffolding content and levels. Because the game is collaborative, students of varying gaming experience and learning abilities will share challenges and scaffolding feedback. This imbalance will potentially prevent group members from maintaining a state of *flow*: "the state in which people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it" [48]. If the levels are too easy, players will get bored, but if the scaffolding is not helpful enough, players will get frustrated and may give up. To help ensure that our system will maintain an adequate balance, we will perform preliminary testing and iterate on its design.

The logistics of running our trials will also pose challenges. Because we will be working with children, they will need additional privacy protection. To this end, we will limit our data collection to computer logging, audio recording, and direct observation to avoid storing video records. In addition, we will not refer to students by name, and all data will be anonymized before analysis.

Running trials on-site at local middle schools and after-school programs will also have implicit challenges. Recruitment opportunities will be limited by the number of schools in the surrounding area due to the logistical limitations of performing trials far away. Scheduling will also be a major concern; we will need to work around holidays, standardized

testing days, and exams, as well as periods of inactivity, such as the summer break between academic years. Another timing concern will be within the trial itself, as class length and meeting times vary among schools and programs. Often they are too short to run an extensive session, but splitting a trail into multiple days leads to lost data due to student absences. For our work in particular, curriculum timing will also have an impact. If students have just covered the academic topic our game teaches, then they will have little need for the scaffolding, as the game will be too easy.

Although we have addressed many of the challenges thus far, there remain several unanswered questions we must tackle in the near future, including:

- How should we word instructions to participants?
- How does raw in-game data correspond to helping behaviors?
- What contingencies must we implement to account for real-world imperfections during trials, such as computer errors?

VI. EVALUATION

Collaboration is a broad and vague notion, yet our focus on the impact of collaborative scaffolding requires a method of evaluation. To deconstruct the concept and determine a focal point, we analyzed over 25 existing studies and surveys from a wide range of disciplines and with diverse target demographics. The resulting multilevel taxonomy is split into four components, each consisting of additional subcomponents.

The first component in our taxonomy is *group quality*: group aspects indirectly related to task completion. Even if group members are highly intelligent and capable of performing necessary functions, if members feel isolated, lack motivation, or simply do not get along, then group performance suffers. For example, when a conflict arises, ineffective conflict resolution can lead to a prolonged period of time wasted on overcoming the dispute rather than completing the task.

The next component is *coordination*: the methods that groups use to organize group members and their actions. Without coordination, a team cannot effectively distribute subtasks to maximize group performance, nor is it trivial to respond to environmental changes.

Coordination is usually achieved through effective *communication*. While this component does not encompass task-specific content, such as strategies, it does include considerations before message sending, apt response to message reception, and the appropriateness of message content. Without adequate communication skills, group members cannot articulate thoughts and opinions, which inhibits the ability to form a shared mental model and prevents the creation of an optimal strategy based on the informed opinions of group members.

The final component of collaboration is *support*: group members helping each other complete a task, satisfy a role, take on a responsibility, or understand a concept. The quality of support is based on many factors, including an individual's willingness, time, resources, and ability to help, as well as a person's understanding of the tasks assigned to group-mates. Without support, group members cannot build off of

each other's experiences and knowledge, meaning time is wasted learning without a teacher or mentor and re-developing solutions for obstacles overcome in the past.

For our evaluation, we chose to focus on two subcomponents of support: direct and indirect help. *Direct help* involves explicit aid through the supply of instructions, an explanation of what to do next, or the partial or total completion of a task assigned to another group member. *Indirect help* occurs through resource sharing or by providing guidance, education, structure, suggestions, advice, or constructive feedback. Instead of keeping these subcomponents vague, we selected an example of each to use in our study: performing part of a task for a group member (direct helping) and providing guidance to a group member (indirect helping). In our trials, we will count instances and note interesting examples of these actions during group activities and video game play.

VII. IMPLICATIONS

Because collaboration plays a key role in today's society, it is beneficial to prepare people at a young age for collaborative work. However, there is no academic or professional consensus on the most effective methodology. Through our research, we will explore one promising option: collaborative scaffolding in educational video games. No matter the results, we will gain invaluable insight into how we can approach collaboration education, which we will encompass in future design guidelines. Our work will help shape the collaboration education design space through its application to future software products and research. In addition, it will contribute to the validation of video games as an area of study and as an educational tool.

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Project Management Game 2D (PMG-2D):

A Serious Game to Assist Software Project Managers Training

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Abstract - In these times of great changes, managing software projects effectively is a big challenge and it is increasingly more difficult to find skilled professionals. This paper presents the Project Management Game 2D (PMG-2D), an educational serious game that aims to assist inexperienced software project managers to be trained, considering cost, time, risk and human resources management areas. The PMG-2D simulates a real software development environment where the player, acting as a project manager, goes through all basic phases of a software project lifecycle. There are many roles in the team that have to be managed, and the members have different personalities in order to challenge the player when dealing with people and their conflicts and performance, among other characteristics. The mechanism implemented to control the character's personalities is based on the theory of the Five Big Factors, described by the lexical method conceived in the Psychology area. The evaluation was conducted within the context of a software engineering continuing education course, and 25 participants have played the game and answered a questionnaire. When analyzing the results, it was possible to find evidence that the game, besides assisting the project management training, stimulates the player to learn more about it.

Keywords - Electronic Learning, Unsupervised Learning, Project Management, Management Training

I. INTRODUCTION

A project is an essential tool for any changes of product and service activities. It may involve only one or thousands of people, organized into teams and its duration can be from a few days to several years. As stated by the ISO 10006 technical standard, a project is "a unique process consisting of a set of coordinated and controlled activities with start and finish dates, undertaken to achieve an objective conforming to specific requirements, including constraints of time, cost and resources." [1]

When considering some growing scenarios of rising domestic market, as presented by [2], it is evident the need for qualifying project management professionals, considering that it is a real challenge to manage software projects effectively and it is hard to find available and qualified professionals with this expertise. Many reports point out the main cause for software project fails as the lack of project management activities and skills. It is also stated by [3] that large scale software projects are like puzzles that need to be solved, once the manager follows a well documented management processes, making all parts fit together and in the right place.

One question that this work aims to answer is if it is possible to manage projects, make decisions, take risks and

also make mistakes without compromising the real projects for the organizations, and at the end even learn with right and wrong decisions. The base for stressing these possibilities is the Project Management Game 2D (PMG-2D), a serious educational game, which intends to help inexperienced project managers to be trained, considering the management of costs, time, risk and human resources.

Educational games are excellent tools to improve the teaching-learning process because they stimulate and inspire the students, providing a more attractive and ludic way of learning. They are different from traditional approaches because they encourage participants to achieve goals due to lack of resistance and fear of failing [4]. However, it is not enough to use any kind of game within any activity. In order to effectively learn and better retain the practices, the students have to be more active and use instructional methods in which they participate in cognitive tasks of higher levels, as stated by [4]

Recently many educational games are being used to teach software engineering and project management, like SimSE [5], PM Master [6], SESAM [7], among others. When using a game, it is possible to simulate the behavior of some professional roles, as in PMG-2D in which the objective is to stress the actions and decisions that a project manager could take. The idea of using this game is to provide inexperienced project managers the opportunity to deal with many professional challenges, in a fun and motivating way, leading the participant to act and take his own decisions.

Within this context, this paper presents the project that planned, designed and implemented the Project Management Game 2D, aiming at teaching inexperienced project managers some of the most important concepts and approaches of project management, at the same time that it tries to be challenging, motivating and fun.

The rest of the paper is organized as follows. In section II, the background of the factors of personality used and concepts of serious games are presented. In section III the research method is explained and in section IV the project and the product features are presented. Section V discusses the evaluation results and, finally, in Section VI, the conclusions and future lines are given.

II. BACKGROUND AND RELATED WORKS

This section will provide the theoretical approach used to determine the NPCs (non-playable character) personality and

the way they work and interact within the game context. It also presents the concepts of serious games that form the basis of the game.

A. Five Big Factors

The Five Big Factors model was conceived in the 30s by the British Psychologist William McDougall [8], who had suggest analyzing the personality of people considering five factors, in order to define a profile for human personality.

However this model has just spread and gained attention from the 80s on, when researches had started to prove the existence of the five basic personalities traces. So, in the last decades many respectful psychologists had agreed with the Five Big Factors [9]. The personalities imposed to the characters of the PMG-2D game are those presented by William McDougall: neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness.

Considering that the goal is not just to ascertain the project employee's personality, but also to define its final state, some new attributes were introduced. Composing all the attributes and the factors, it was possible to conceive an "if-then" rules decision tree, thus classifying a state of personality. Following are presented the attributes that are also considered by every character of the game: stress, food, physical, health, relationship (with friends and family), motivation, adaptation, interest, experience, training, cooperation (with company employees).

When analyzing the Five Big Factors previous works it was possible to better understand the personality factors, which attributes are more relevant and to what other attributes these main five factors are mapped. Some questionnaires were created in order to better understand the factors and among them, the NEO-PI-R (Revised NEO Personality Inventory) conceived in 1992 by the researches Paul Costa and Robert McCrae is here emphasized. To answer the questionnaire, the authors have proposed a table dividing the factors into six facets, as presented in Table I.

These facets were largely used to conceive the algorithm that controls the state of each NPC that will play a role during the project, in the game.

B. Serious Games

A serious game is a software or hardware conceived following the principles of interactive game design, aiming at transferring concepts and knowledge to the user.

TABLE I. FACETS OF NEO-PI-R QUESTIONNAIRE

Neuroticism	Extra-version	Openness to experience	Agreeableness	Conscientiousness
Anxiety	Warmth	Fantasy	Trust	Competence
Angry Hostility	Gregariousness	Aesthetics	Straight-forwardness	Order
Depression	Assertiveness	Feelings	Altruism	Dutifulness
Self-Consciousness	Activity	Actions	Compliance	Achievement striving
Impulsiveness	Excitement seeking	Ideas	Modesty	Self-discipline
Vulnerability	Positive emotions	Values	Tender-mindedness	Deliberation

The origin of using games with the educational purpose precedes the current technological revolution and widespread use of computers. One of the first serious games was considered the Army Battlezone, a project developed by Atari in the early 80s that was created to train soldiers in a simulated battlefield [10]. Michael and Chen define a serious game as a game in which the education (in its many forms) is the main objective, other than the entertainment.

Some recent approaches consider more complex environments where the objective is to get the users to feel immersed in a presentation or situation as if they were inside a real environment. These environment are called Immersive Virtual Environments and demand a very complex set of hardware and software, as can be found in 3d head mounted displays and full-domes projection rooms, using 3d, surround sound, high realism, large field of view etc.

These technologies can provide the sensation of presence and immersion to the user, but the cost to have these facilities and the lack of tools and complexity to develop proper software make them a very expensive option. [11]

The concept of immersion is the intensity that the system presents information about the virtual world to the senses compared to the extent these senses if received from the real world [12]. The presence concept is the subjective sensation of feeling inside a real environment and the extent to which the user responds to the virtual environment as if it was the real environment [13]. The main difference between them is the fact of the user is included in the narrative in the presence.

Both immersion and presence, with special emphasis in the last, were considered during the development and evaluation of the game, but with very limited expectations due to the target environment: a regular personal computer and small screen, with no extra hardware or even special tool other than a two dimensional game framework. The evaluation questionnaire was partially built considering the presence evaluation tool, as proposed by [14]. Some of the dimensions considered during the evaluation of the game were control, concentration, feedback and balance between challenge and skill.

The evaluation of a simulation game is a complex matter, as stated by [15], and some of the dimensions proposed by the UGALCO frameworks, as challenge, competence, immersion and positive effects were also considered to conceive the evaluation questionnaire.

Some related works are SimSE [5], a software engineering simulation game where the student plays the role of a project manager experiencing all phases of the life cycle, dealing with the team and resources of the project. It is a digital game and can be played by just one person. Its main weaknesses are: the lack of a proper game; the lifeless art and the poor feedback both visual and auditory. It is more a simulation than a game, as it lacks some important game's features, like: aesthetics that are rich both visually and spatially and that immerse players in worlds that seem real [16].

Another work considered is the PM Master [6], which is a board game with questions about project management in some knowledge area, as scope, time, quality and others. The player that first answers the set of questions correctly wins the game.

It is necessary to have groups of 4 to 6 players for each round of the game. It is a very limited game based only on questions and answers about project management. It is not very engaging neither motivates students to play again. It also lacks more enticing features of games and has no meaningful mechanics of play. It does not provide a sandbox environment where the players can explore a project development cycle, elaborate plans and make interesting decisions.

The ProGames [17] is a serious game that teaches programming by playing games. This work adopted an evaluation approach of four dimensions considering usefulness, ease of use, ease of learning and satisfaction. From the 29 questions, some of them were considered in the evaluation questionnaire of this work, like "It is pleasant to use", "It is user friendly" and "I am satisfied with it" and some other similar.

Lost in Space [18] is a game that teaches XML where the player controls a ship by performing tasks assigned with instructions in XML. Some common characteristics with the PMG-2D game is that both tries to practice time pressure handling, establish clear and defined objectives and calculates the score of the player, in order to train and show the progress as the game advances.

In [19] the authors propose a game focused on teaching requirements collection and analysis at tertiary education level. Once requirements phase is known as the most challenging phase of the entire lifecycle, the focus of this game was to lead students to practice such activities in order to improve their knowledge and skill to deal with the difficulties of this phase.

III. RESEARCH APPROACH

The research method used follows the guidelines proposed by Jean-Marie Van Der Maren [20]. The author proposes three different approaches to conduct a research project: the Evaluation Research, the Intervention Research and the Development Research. The last approach was the selected due to the characteristic of the project that matches the subtype Object Development Approach, aiming to develop an object by analyzing the needs (requirements) and producing tools, techniques or strategies. In this case the deliverable is a serious game, altogether with the supporting documentation that is used to teach project management.

The Object Development Approach has four phases: Market Analysis, Object Analysis, Preparation and Development, as following described:

1) Market Analysis (Context Analysis)

This phase of the method aims to identify the research goals, needs, motivation and the main participants involved. When performing this phase, the correlated works were identified, mainly considering serious games for software engineering.

2) Object Analysis

Based on the Market Analysis, the Object Analysis phase defines the object in order to build a model, which is a consistent representation of the project's elements, still in a preliminary stage. This phase is divided into two parts: object's conceptualization and object's modeling.

During this phase it was identified a need to search for works about personality models and serious games. A plan was made based on such searches that included the main mechanics of the game, target audience and possible contributions.

3) Preparation

Once the research object has been conceived as a model and its representation is considered stable and coherent, the Preparation phase starts defining possible alternative strategies for the project, evaluating these strategies and after selecting and building the prototype, as the materialization of the object. In this phase the Game Design document was prepared based on the previous definitions and the game was implemented in C/C++ using the framework Chien2D 2. A set of preliminary tests was performed and improvements were made based on the feedback of the authors.

4) Development

The last phase of the research method can start when it is possible to have a prototype of the research object and its evaluation can be done. A cycle of tests, evaluation and change has to be conducted up to the point when the object is considered in compliance with the specifications and can be released to the market or for practical use. The work followed these steps of the method and after some cycles of tests, evaluation and changes, the game was considered ready to be evaluated. A structured questionnaire was conceived and the game was executed under a monitored and controlled environment with 35 professionals of information technology, who stressed the game and answered the questionnaire. The results of this phase are presented in the evaluation section of this paper.

IV. PMG-2D DEVELOPMENT PROJECT

During the Object Analysis and Development phases of the research method, the software development process used the incremental approach and the following modeling assets were developed: project charter and project plan, requirements specification, use case diagram, class diagram, activities diagram, sequence diagram and state diagram, use case specifications, test plan and test cases. The concepts that the game intended to teach were discussed during its development in order to evidence their importance to all members of the research team.

A partial and adapted version of the use case diagram of the PMG-2D project is presented in Figure 1, and shows part of the activities the player, within the role of a project manager, has to perform. This can be considered the iterative part of the game. The other functionalities are internal and respond according to the stage of the project during the game and the algorithms that treat all relationships of the project stage, team and employees' status and intervention of the player as the project manager.

An employee can perform the following activities: develop solution, test, deploy, send message, resign, be late, have difficulties, refuse overtime, leave earlier, argue with others, give feedback, attend meetings, ask for rest, get sick, among others.

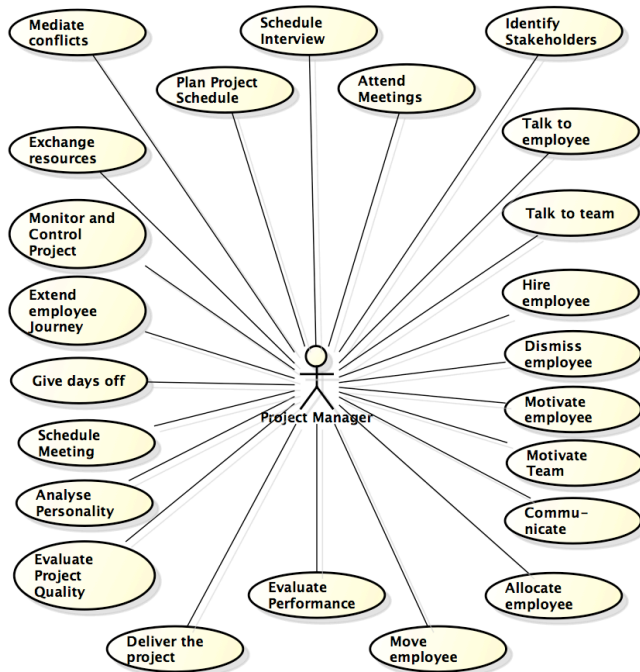


Fig. 1. Partial use case diagram with Project Manager actor.

The employee class has 38 main attributes, besides the Five Big Factor previously presented, and among the most important are: capability, experience, interest, adaptation, motivation, relationship, health, physical conditions, stress, responsibility, union, performance, training, work schedule, salary, position, feedback, problems and others.

Each of these attributes have scales that vary as time passes during the game play, according to if-then rules based on a decision tree, and also considering random situations, in order to bring more reality to the game. Most of the attributes also vary taking into account the relationship with other attributes, for instance, it is very likely that an employer will argue with others if his/her stress level is high and the relationship and salary attributes are low.

To illustrate the inner workings of the algorithm, let's consider one of the rules: performance of the employee. First, it is necessary to compute the Activity and Personal attributes and then get the Performance attribute, which will determine the amount of work the employee will be able to perform in a fraction of time, as following:

Performance = (Activity * 0.35) + (Personal * 0.35) + ((100 - Neuroticism) * 0.05) + (cordiality * 0.05) + (Responsibility * 0.20)

Activity = (Capability * 0.30) + (Experience * 0.3) + (Interest * 0.2) + (Adaptation * 0.2)

Personal = (Relationship * 0.2) + (Motivation * 0.25) + (Union * 0.2) + ((100 - Stress) * 0.25) + (Salary * 0.1)

Most of the attributes are related to other attributes and the final state of the character personality results from the composition of them all, considering 38 different aspects that have direct influence to his/her performance, relationship, health, stress, motivation among others.

A. PMG-2D Execution Life Cycle And Features

The game PMG-2D was structured in five groups representing the life cycle of the project management process according to PMBOK [21]: initiation, planning, execution, monitoring / control and finishing.

The game starts in the initiation phase where the project manager must identify the project stakeholders. The game presents the project charter so the player can understand the overview of the project. The next phase is the planning phase that will point to the player the need for a requirements analysis. To guide the player in this process the game presents the work breakdown structure (WBS) for the project. The main goal of the player is to create a roadmap for the project.

Next phases are execution and monitoring/control. The player will be trained in the abilities of cost management, time constraints, risk and human resources. To make the game more interesting, the manager has its own basic needs that must be fulfilled and if they are not, the project may not be complete in the best possible way due to the absence of the project manager during working time.

Some screenshots of the game execution are following presented, considering different phases and places where the project manager interacts with the game. Figure 2 shows where the Project Manager character starts the phase and is also where he or she rests, eats and does basic needs. In the office, as shown in Figure 3, the player can select the doors that will provide some actions, as hire or dismiss employees, monitor and control the evolution of the schedule and budget of the project, attend meetings with the team or clients, and analyze and make decisions concerning the employees and their allocation to activities.

The dashboard of current status of team members is presented in Figure 4 and shows all members of each role: developers, testers and supporting personal. The activity progress bar of each member is shown, as well as their status and location, and the overall information of the project as budget and client's evaluation.



Fig. 2. Project Manager at home



Fig. 3. Project Manager selecting the rooms of the office.

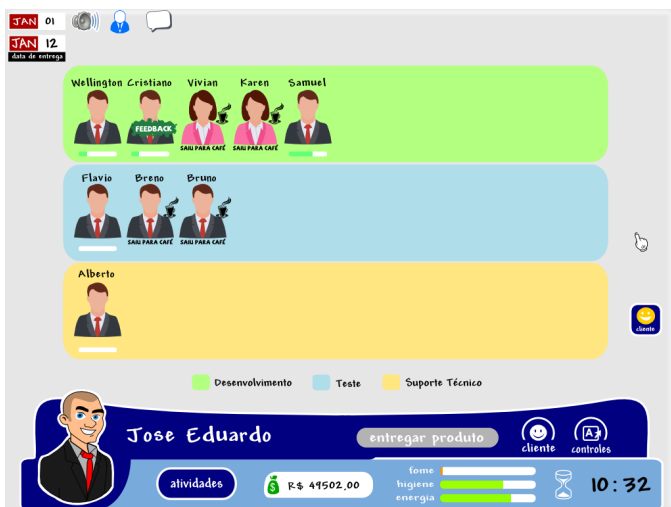


Fig. 4. Dashboard of team members.

Another important functionality of the game is presented in Figure 5, showing for each activity of the schedule: phase in the project's life cycle, complexity, current status, responsible employee and allocation conflicts. This dashboard has to be frequently accessed in order the player to know the current scenario and make decisions concerning the team allocation and even team composition.

As the project evolves in the game, it is necessary to monitor the activity of all team members in order to avoid having too many employees that are specialized in a role not anymore needed or with lack of members to other demanding activities. The game also presents a Gantt chart to show the progress of the different project activities.

Whenever the player makes a wrong decision, the game shows alerts of what went wrong and what could have been done to correct the action. It also presents the chapter and section in the PMBOK where the player could get more information about that specific topic.

Atividade	Fase	Complexidade	Andamento	Funcionário
Atividade 01	Desenvolvimento	Baixa	5%	Wellington
Atividade 02	Desenvolvimento	Media	12%	Vivian
Atividade 03	Desenvolvimento	Baixa	10%	Cristiano
Atividade 04 (dp. 2)	Desenvolvimento	Baixa	0%	
Atividade 05	Desenvolvimento	Media	12%	Karen
Atividade 06 (dp. 4)	Desenvolvimento	Media	0%	
Atividade 07 (dp. 5)	Desenvolvimento	Baixa	0%	
Atividade 08	Desenvolvimento	Media	0%	
Atividade 09	Desenvolvimento	Alta	12%	Samuel
Atividade 10	Desenvolvimento	Media	0%	
Atividade 11	Desenvolvimento	Alta	0%	
Atividade 12 (dp. 1)	Desenvolvimento	Alta	0%	
Atividade 13 (dp. 1)	Desenvolvimento	Baixa	0%	
Atividade 14	Desenvolvimento	Alta	0%	
Atividade 15 (dp. 11)	Desenvolvimento	Media	0%	
Atividade 16	Desenvolvimento	Alta	0%	
Atividade 17	Desenvolvimento	Baixa	0%	
Atividade 18	Desenvolvimento	Baixa	0%	
Atividade 19 (dp. 1)	Desenvolvimento	Media	0%	

Fig. 5. Schedule of the project

At the end of the execution, monitoring/control phase, when all scheduled activities have been finished in order to deliver the product, the last phase starts, showing its most important topics. A final score is presented as a result of the correct and incorrect decisions of the player during the game. The objective of the score is to compare the player's performance taking into account his or her previous run, or to compare the performance of a group of participants or even an entire class.

V. EVALUATION AND DISCUSSION

The evaluation consisted of a practical use of the game by a group of 35 professionals. The participants were software development professionals, all with a higher education degree and attending to a specialization course. The execution of the game took 60 to 90 minutes in order to perform all steps of game.

After playing the game for the first time, participants were asked to answer a structured questionnaire. The evaluation instrument was conceived with 51 questions addressing all the phases of the game and all matters of software project management the game intended to teach.

The first part of the questionnaire was dedicated to learn about participants' profile, asking him about previous professional background and current job and company. Among the organizations that they work for, a wide variety was identified from small local software development organizations up to global large ERP players.

A. Motivation

One of the first questions concerning the motivation to play the game was if the beginning of the game had something interesting that called their attention. It was observed that 84% of participants agreed with this statement: 40% totally agreed and 44% partially agreed. In the begging of the game all instructions are presented and there are some animations representing the initial phases of a project, and some concepts are presented (the project charter and work breakdown structure of the project), so it is possible to understand that graphical and interactive approaches are interesting and called

the participant's attention to the game. Also another motivation factor that was addressed was that 88% of the participants agreed that the design of the game is attractive, what was considered a great concern during the design and conception phases of the game development.

B. Relevance

The next section of the questionnaire considers the relevance of the game to the participant, and one question called the attention of the authors that asked them if the content of the game was relevant to their interests, and 96% agreed, also 68% of them totally agree, making this answer the largest amount of totally agree answer of all questions. So the participants were considered as very well interested in learning about project management and really involved with the execution and evaluation of the game.

According to one question stating that the participant had liked the game in the extent that he/she would like to even learn more about the matters addressed by the game, 92% of them agreed, so it is possible to infer that one of the goals of the game was achieved, when trying the teach and promote more interest in software project management.

Still in the relevance section, more than 92% agreed that the content of the game was relevant to their interests and that what they could learn with the game was useful. It was considered a very positive result because the first questions tries to identify if the content is relevant but the second question is more specific considering the learned content, this last being event greater the amount of participants that agrees with 96% against 92% of the previous question.

C. Confidence

The third section of the questionnaire evaluated the confidence of the participant when playing the game. Here it is possible to evidence that some participants had faced some difficulties managing the project proposed by the game. A significant percentage of them, 40% partially agree that the game was more difficult to understand than they would wish and 32% of them considered that the game had so much information making it difficult to identify and remember important goals of the game, as presented in Figure 6.

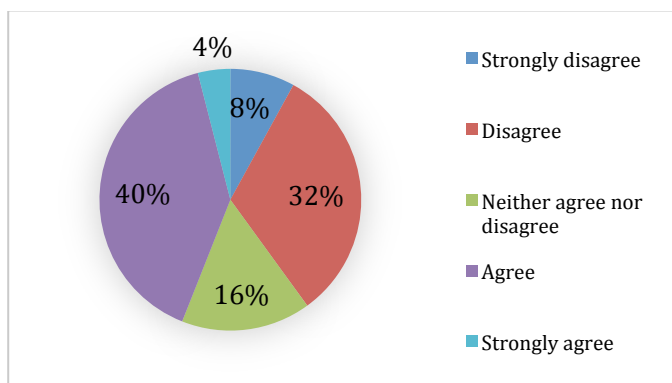


Fig. 6. Question: the game was more difficult to understand than I wish.

The three other questions addressing the confidence of the players presented positive results, showing that just 20% of the participants partially considered the activities difficult, 20% stated that could not understand a significant portion of the game material and, finally, just 4% of them found the content of the game so abstract that it was difficult to keep the attention to the game.

D. Satisfaction

The satisfaction when playing the game was measured with some questions and the first showed that just 56% had experienced the feeling of satisfaction when completing the exercises of the game, and 28% were indifferent to this matter, showing that the challenges could not generate a great satisfaction to the players. Another question, concerning if the feedback after the exercises or other comments of the game helped the player to feel rewarded for the effort was not conclusive due to the diversity of the results obtained, as seen in Figure 7.

The last result from this section was the statement that the player felt good when completing the game, with 48% agreeing, 28% being indifferent and 24% disagreeing. Some participants faced some problems to complete the game due to the time it took for them, so at the end some interactions were made faster than they would like, causing this result.

E. Immersion

Six questions addressed the immersion sensation when playing the game and most of them resulted in positive results, as 88% affirmed that had put effort to get good results, 16% affirmed that in some moments desired to quit the game, 74% felt stimulated to learn with the game and 76% had not noticed the time passing during the game.

Two other questions presented some more diffuse results, but it was expected because the challenges of the measured characteristics were greater. The questions were if the player lost consciousness of what was happening around him or her while playing, and if the player felt himself or herself more inside the game environment than in the real world. Both questions had approximately the same results of agree and disagree answers.

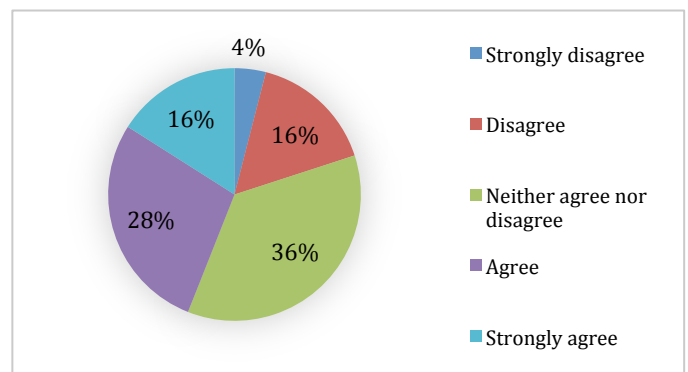


Fig. 7. Question: feedback after the exercises or other comments of the game helped the player to feel rewarded for the effort.

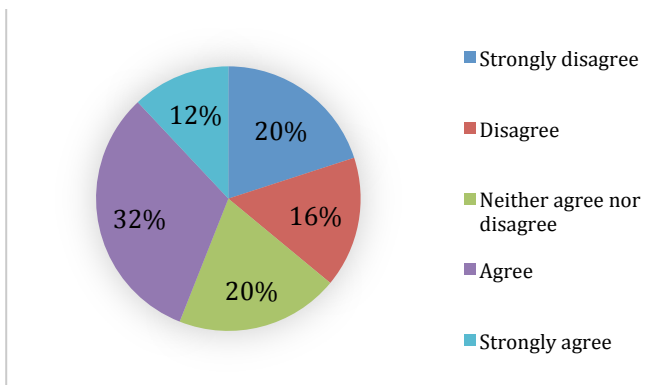


Fig. 8. Question: I like playing this game for a long period.

F. Challenge

The challenge of the game has showed adequate considering the first three items evaluated in this section of the questionnaire, all showing more than 76% of agreement considering that the participants had liked the game and did not felt anxious our tedious, also that the game kept them motivated to continue using it, and lastly that their skills had gradually improved as the challenges were overcome. Two other questions with less agreement stated that 68% of the participants consider that the game offers new challenges in and appropriate rhythm and 60% considers that the game is appropriately challenging, with tasks not too easy or difficult. In general, the challenge was considered adequate and also the gradual evolution of the phases.

G. Skills and competence

The skills and competence developed were evaluated as positive by 84% of the students that felt they were making progress, but the other aspects measured indicated some issues as just 64% of them felt succeeded, 48% felt competent and just 44% considered that had achieved rapidly the goals of the game. Some imposed tasks of the game, as the conception and monitoring of the schedule and budget of the project, are really challenging and the consequences of the decisions taken and the results to the project are not an easy task, especially for those with few or no experience in project management.

H. Fun

The section of the questionnaire that evaluated the fun when playing the game showed some diverse results. Some questions presented positive results as 80% of the participants affirmed they would like to play the game again, just 20% found the game with a bad dynamic, and just 12% were hoping the game to end soon. One specific question showed no convergence because when asked if when interrupted the participant was disappointed that the game had ended, almost one third of the participants agreed, one third disagreed and 40% were indifferent, leading the authors to consider that even the interpretation of the question could have generated this dubious result. Another question also have presented some diverse results, as presented in Figure 8.

The last question that tried the identify the fun of the game showed that 68% of the participants have not found problems in having fun with the game, but 20% were indifferent to this

matter and it raised an alert for the authors in order to identify the exact issues that causes this feeling, but some were informally identified as the large number of activities needed to compose the schedule of the project and the constant monitoring and control of the team and skills to accomplish the original plan.

I. Knowledge

The last section evaluated the knowledge of the player after the execution of the game, and all three items resulted in a very positive scenario, as 84% of the participants consider they can remember more information related to project management, 84% consider they can better understand the matters presented by the game and, finally, 84% stated that they can better apply the concepts related to the game. The last two questions had none of the participants disagreeing with the questions.

Considering that the participants were professionals holding an under-graduation diploma and had experience in software development projects, not necessarily as project managers, the results were considered to be very positive and indicate that this approach to teach software development project management concepts is effective and has a very wide field of application.

VI. CONCLUSIONS

Considering the challenges to hire experienced project managers, or even to train new ones, the Project Management Game 2D was planned and conceived to help inexperienced software project managers to learn common concepts and project management activities such as cost, time, risk and human resources management areas.

The game was conceived considering all phases of a project lifecycle and tries to stress all major milestones and some important artifacts involved within software development projects. The player, in the role of a project manager, is immersed in a project that has limited human and financial resources, as well as a challenging schedule, and is challenged to take decisions that will be analyzed and evaluated by the game, receiving feedback of mistakes and tips to learn how to deal with specific situations.

All decisions have consequences and will affect the rest of the project, making it a very dynamic and involving experience. At the end of the play a score is shown and, along with all messages presented during the execution of the game, they show the performance of the project manager. This will stimulate the student to improve his knowledge and play the game again.

The mechanism implemented to control the character's personalities is based on the theory of Five Big Factors [19] and also implements if-then rules based on a decision tree to determine the state of each project team inside the game. The skill to deal with the employees and the large possible combinations of factors are important issues that the player has to deal with during all phases of the simulated project.

The evaluation of the game was made applying a structured questionnaire to professionals that have played the game and answered the questions concerning the following sections:

identification and experience, followed by the specific evaluation of the game considering the motivation, relevance, confidence, satisfaction, immersion, challenge, skill and competence, fun and knowledge. In all sections it was possible to evidence that the game has met its goals, with special attention to motivation, relevance, satisfaction, fun and knowledge.

This work may be improved in two areas: in-game improvements and evaluation process.

Regarding in-game changes, one feature that is intended to be implemented in the future is a “save and continue” option, as the current version of the game just implements a pause option. It is also planned to implement other aspects of PMBOK that were not implement in the first version. Also an important activity that will soon be performed is the translation of the game from Brazilian Portuguese to English, in order to expand the target professionals and students who could use the game to learn concepts of project management in an autonomous way.

The evaluation process may consider other approaches, like meta-cognitive strategies [22]: recording, modelling and thinking aloud. The PMG-2D game may benefit from this student self-conscious analysis due to its subjective nature regarding the knowledge acquisition. Such approach may help to identify what parts of the game play are not helping the students to make better decisions. Another step to improve the evaluation process will be submitting it to a group of professionals to play the game for two or more times. As reported by [18] the participants that played the game Lost in the Space for several times, showed a considerable improvement in their performance, demonstrating the learning process success due to the recurrent execution of the game.

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Engaging Graduate Students Through Online Lecture Creation

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Abstract—We propose a new active learning activity called “slecture” (a contraction of the words “student” and “lecture”). In this activity, students create online lectures based on the in-class lectures of their course instructor, and post these online lectures on a publicly accessible website. As an experiment, slectures were integrated into the mandatory assignments of a large engineering graduate course with a diverse student population. In our implementation, the students were free to pick the topic (from a list provided by the instructor), medium, and language of instruction. The students’ slectures were peer-reviewed at the end of the semester, and full credit was given for timely completion of the assignment. In a semester-end survey, students indicated that they learned more from making a slecture than from the other active learning techniques employed throughout the course. Furthermore, nearly 60% of the students rated the learning value of making a slecture at least as high as that of attending the lectures. The high level of enthusiasm for the slecture creation, especially among students who rated the learning value of the classroom lectures lower than the rest of the class, suggests that this activity may be a good way to engage students and stimulate learning.

Keywords—*active learning, learning-by-teaching, online lectures, graduate students*

I. INTRODUCTION

Active learning has become a common pedagogical approach in undergraduate engineering classrooms in the past years, including flipped classrooms, clicker use, and project-based learning. Such types of “learning by doing” and others have been shown to engage students and promote learning [1]. One reason active learning is effective is because it reaches students who learn better via different channels than traditional lectures [2]. By employing a variety of teaching strategies, an instructor can more successfully reach students who have different learning styles.

On the graduate level, much of the discussion of active learning has focused on training graduate teaching assistants to integrate active learning methods in the undergraduate

courses they teach [3]-[5] or on integrating peer review work in graduate courses [6]-[8]. The somewhat limited literature on active learning in graduate engineering courses raises the question whether these students also can benefit from other types of active involvement in their classes. However, there is a need to convince sometimes reluctant graduate students of the benefits of these other activities [9]. Hofstede’s work on “(in)tolerance of ambiguity,” later expanded by Selinger, has shown that students from collectivist/ambiguity-intolerant cultures, from which many engineering graduate students come, may be uncomfortable with pedagogical contexts which are not as structured or instructor-centered [10].

Nevertheless, instructors at many levels of education anecdotally note that their own knowledge of their course material has increased by the need to explain it to their students. Thus, it is not surprising to discover the multidisciplinary richness of the “learning-by-teaching” literature [11]-[13]. In fact, one study found that preparing for, and then actually teaching some information may result in long-term learning for the person doing the teaching [14]. Many of these “learning-by-teaching” activities include the use of online platforms as a way to further engage these students who have grown up in a digital environment [15].

Building on the learning-by-teaching principle, co-author Boutin developed an innovative active learning activity she named “slecture,” a contraction of the words “student” and “lecture.” As described in Section II, slectures are online lectures created by students based on the teaching material of a professor. These online lectures are posted on a free and publicly accessible peer-learning website; they are not formally reviewed or graded by the instructor before being posted. The goal of this active learning activity is to increase student engagement and learning, while promoting the development of students’ communication skills.

This paper describes a simple mechanism for integrating slectures within a graduate course. It also describes a small pilot experiment in which we implemented this mechanism and surveyed the students to gather their impressions of the learning effectiveness of this new active learning activity.

Our preliminary results indicate that the students involved in the experiment found the educational value of creating slectures to be almost on par with that of attending the

classroom lectures. In fact, those students who were less satisfied with the classroom instruction than the rest of the class actually showed a preference for developing slectures over attending the lectures. In contrast, other forms of active learning with which we experimented were perceived as less valuable, from a learning perspective, than both the classroom instruction and the slecture creation. While our data is too limited to enable us to draw any firm conclusion, the results of this small pilot experiment are very encouraging.

II. BACKGROUND ON SLECTURES

Slectures were invented by Boutin in 2010 as part of an online learning project called Project Rhea [16]. The goal of Project Rhea is to encourage students to create learning material and share it with their peers online. This is done through a publicly accessible website on which the material is archived and organized.

Slectures were invented as a mechanism to encourage students to create online learning material on the Project Rhea website. The idea is to have students create online versions of their professors' courses. While the students get permission from the professors to use their teaching material, it is the students who bear the responsibility for the accuracy or correctness of the online courses they publish.

The first slectures were created in 2010 by Maliha Hossain, a master's student in the School of Electrical and Computer Engineering at Purdue [17]. These slectures were based on the image processing lectures (ECE637) of Prof. Charles Bouman. Hossain subsequently created slectures for a graduate course on the topic of random variables (ECE600) taught by Prof. Mary Comer [18].

These online courses thus created generated a significant amount of interest, not only from students who subsequently took these graduate courses for credits but also from web users from around the world who found their way to the Project Rhea website through search engines. Hossain praised the activity for helping her learn the material significantly better than had she merely taken the courses.

III. INTEGRATING SLECTURES INTO GRADUATE COURSES

It seems plausible that a large number of graduate students could benefit from making slectures for their classes, but few students can commit the time necessary to build slectures for an entire course, as Hossain did. However, one can build an entire online course by dividing the semester's material into short topics and asking each student to create a slecture for one specific topic; by combining the slectures for all topics together, the material for the entire semester then can be made accessible online. This is an activity that can easily be integrated inside an existing graduate course as a homework assignment.

The issue of quality may be a concern: one could imagine that not all students would put in the effort to create excellent material, which would affect the value of the resulting online course. One way to mitigate this is to assign more than one student per topic, thus covering each topic more than once, potentially in different ways. While this creates a healthy amount of competition among the students covering the same topic, the probability of obtaining at least one usable slecture per topic is increased. The quality concern can be further alleviated by encouraging students to publish under their real name, thus strengthening ownership and responsibility. While

this cannot be mandatory because of FERPA and other privacy issues, we found that the vast majority of students quite willingly did so.

IV. PILOT EXPERIMENT

Our study was conducted in 2014 in a graduate course on machine learning taught by Boutin. The enrollment for the course was fairly large for a graduate course, with 66 students from multiple disciplines, including computer science, mathematics, as well as electrical, computer, civil, nuclear, and industrial engineering. There were both masters and PhD students in the class with a mixture of domestic and international students. Because of the widely varied backgrounds of the students in the class, the lectures were conducted in a flexible style, with the instructor adapting her instruction to students' questions as they arose.

Making a slecture was a mandatory assignment for the course, counting for 8% of the course grade. The course was divided into 16 topics by the instructor, with each topic covering about one week of the course material. For the reasons of quality mentioned in Section III and due to the large number of students in the class, each topic was covered by more than one students. To increase the diversification between the slectures covering the same topic, we allowed students to choose the medium of instruction (text, video of student explaining at the blackboard, video of a hand on paper with audio, or a PowerPoint presentation with audio). Since there were many international students, we further increased the variability by allowing students to choose the language of instruction.

Each slecture was peer-reviewed by another student in the class towards the end of the semester. The peer review was posted online in the Comments/Questions section of the slecture, and counted for 2% of the course grade. The peer review allowed all students to receive feedback on their slecture, a task which would have been overly burdensome for the instructor alone to undertake. Full credit was given for timely completion of the slecture/peer review, regardless of correctness or clarity.

In addition to the slecture creation, the course also included three open-ended homework assignments. Specifically, after some pattern recognition techniques had been covered in class, the students were instructed to find a data set and use this data set to experiment with these techniques for comparison purposes. The nature and extent of the experiments was not specified, so the students were free to build their experiments as they saw fit. A description of the experiments, along with the results and conclusions, were to be presented in a formal report. Each of the students' reports was subsequently double-blinded peer-reviewed. This was done through the Project Rhea website, which includes an application (Mediawiki extension) for double-blind peer review. Thus, each report was anonymously reviewed by another student following specific guidelines. In particular, when preparing the peer reviews, the students were instructed to summarize the work described in the report, comment on the positive aspects of the work, and provide constructive feedback regarding the aspects of the work that could be improved. They were also asked to give a grade based on a pre-specified rubric. However, the students were reassured that the grade assigned by their reviewer would not necessarily be the grade assigned by the course instructor.

TABLE 1: STUDENT-PERCEIVED LEARNING EFFECTIVENESS FOR DIFFERENT CLASSROOM ACTIVITIES

	Classroom instruction	Hmwk	Peer-review of other student's hmwk reports	Read peer-review of own work	Make a slecture
Av. Score (out of 10)	8.24	7.71	6.98	6.48	8.17
SD	1.91	2.36	2.5	2.45	1.94

TABLE 2: STUDENT-PERCEIVED LEARNING EFFECTIVENESS OF SLECTURES VERSUS CLASSROOM INSTRUCTION

	Rated slecture higher than classroom instruction	Rated classroom instruction and slecture equally	Rated classroom instruction higher than slectures	total
# students	14	11	17	42

V. RESULTS

A total of 60 students successfully completed the slecture assignment. Of those, 40 chose to do it in the form of a “text” (i.e., Mediawiki mark-up language with equations typed using Latex code), and the remaining 20 chose to produce a video (either a video of the student explaining at the blackboard, the student’s hand on paper with audio, or a PowerPoint presentation with audio.) Ten students produced slectures in languages other than English; two students provided an English translation for their foreign-language slecture.

While the students were provided with lecture notes to use as the basis for their slecture, the material created by each student tended to be quite unique beyond the choice of medium or instruction language. For example, some students chose to cover the topic in detail, adding mathematical proofs, background material, or new examples. Other students provided a concise summary of the material, focusing on presenting the theory in a complete and logical fashion but without any extraneous material.

Students were surveyed at the conclusion of the semester to ascertain their preferences for the different active learning techniques employed in the course. Specifically, they were asked to rank on a scale from 1 to 10 (10 being the highest), how much they learned from a) classroom instruction, b) homework assignments, c) peer reviewing someone else’s assignment, d) reading the peer review of their own homework assignments, and d) making a slecture. Of the 66 students enrolled, 42 students responded.

Table 1 summarizes the average score and standard deviation (SD) for each activity. As one might have expected, the average score for “classroom instruction” is the highest. Although our results are limited, a tailed t-test indicates that the comparison is statistically significant for two of the

comparisons, namely “classroom instruction” versus “peer-review of hmwk” ($p=8.3 \times 10^{-4}$), and “classroom instruction” versus “read peer-review” ($p=6.9 \times 10^{-7}$). The two other comparisons, “classroom instruction” versus “hmwk” ($p=0.0615$) and “classroom instruction” versus “make a slecture” (with a very large p value at $p=0.4142$) are too close to be statistically significant at the 5% level). Indeed, the score for “make a slecture” is nearly as high as that of “classroom instruction.” More detail is given in Table 2, where we see that 17 students said they learned more from attending the lectures than making a slecture; 11 indicated equal preference for the two activities; and 14 said that they learned more from making a slecture. Thus, nearly 60% of the respondents (25 out of 42) indicated that creating a slecture was at least as valuable, from a learning perspective, as attending class.

The high perceived value of the classroom instruction is illustrated in Fig. 1, which shows the distribution of the scores for this activity. Indeed, most of the scores are tightly clustered near the top. However, there were some students (five out of 42—nearly 12%) who were less satisfied with the classroom instruction than the rest of the respondents: these are seen as the few scores scattered between one and seven.

This clustering of scores suggests using the value of seven as a threshold to divide the students into two groups: those who were generally satisfied with the educational value of the classroom instruction, and those who were not. Comparing the scoring pattern of the students satisfied with the classroom instruction with those who were not reveals an interesting pattern. In fact, as shown in Table III, the students who gave a high score for the classroom instruction did not tend to prefer any of the active learning activities over the classroom instruction. Among this group, the slectures were the learning activity that was the least disfavored, with a score only 0.3 points below the classroom instruction score, on average. In contrast, the students who were less satisfied with the classroom instruction preferred all three active learning activities over the classroom instruction, on average. Within this group, making a slecture was the most preferred activity, with a score of 1.6 points above the classroom instruction score, on average.

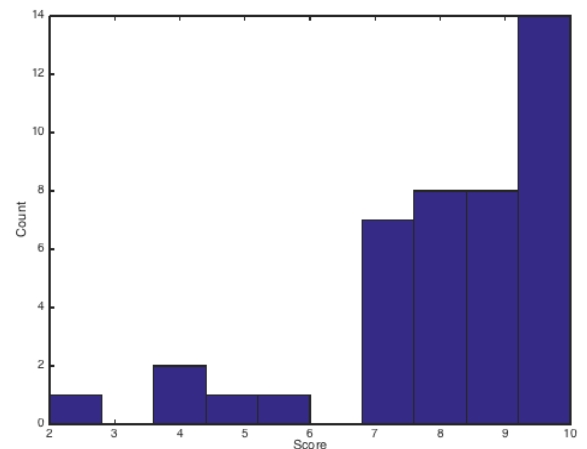


Fig. 1. Histogram of Classroom Instruction Scores

TABLE 1: PREFERENCE OF ACTIVE LEARNING ACTIVITIES OVER CLASSROOM INSTRUCTION

Classroom instruction score	Average of difference between slecture score and classroom instruction score	Average of difference between peer review score and classroom instruction score	Average of difference between hmwk score and classroom instruction score
<7 (5 students)	1.6	0.2	0.4
>7 (37 students)	-0.3	-1.46	-0.64

VI. DISCUSSION

The fact that, overall, attending the classroom lectures was the preferred learning activity supports research that indicates that students who have not been previously exposed to active learning may prefer the type of instruction to which they are accustomed [10]. Other research also points to potential cultural and nonverbal explanations for some students' discomfort with online peer review [10]. However, when we split the students based on their perception of the educational value of the classroom instruction, the pattern that emerges suggests that a fraction (about 10%) of the students may be significantly more interested in active learning activities, and less in the traditional lectures, than their peers. Among the active learning activities with which we experimented, these students showed a marked preference for

making slectures. On the other hand, even the students who enjoyed the classroom lectures ranked making slectures higher than the other active learning activities, ranking it nearly as high as the classroom instruction.

Thus, slectures appear to be generally a well received way of engaging students in a graduate course, including students with different learning styles. This could be because of the inherent nature of the work, which has a very student-centered focus that promotes creativity; other than being restricted to choose from a list of relevant topics, all the other decisions on slecture format and content were left to each individual student to make. It is possible that this freedom allowed the students to draw on their preferred learning styles.

Several students commented on the efficacy of the "learning-by-teaching" aspect of creating their slectures. "Teaching is definitely the best way to learn!" one wrote. "This is like studying for tests in groups and teaching each other," another commented. Several noted that they planned to go online to review their classmates' slectures to improve their knowledge of a particular topic.

What the students may not have realized while immersed in the creation of their slectures, is that in order to convey technical information, they also got practice in communicating effectively to Project Rhea's vast unseen audience. This is a professional skill that they will likely use in the future, whether working in industry and collaborating with colleagues in other countries, or in academia, teaching Massive Open Online Courses (MOOCs) or other online courses.

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Effectiveness of Practices with Sensors in Engaging in Meaningful Learning in Higher Education: Extending a Framework of Ubiquitous Learning

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Abstract — This paper aims to specify strategies for learning scenarios that incorporate ubiquitous features to support pedagogical practice. Thus, the development aims to verify if the resources of technology with context awareness promote significant changes in teaching practice, and can impact positively or not the effectiveness of learning and engagement of learners. In this regard, a reference ubiquitous environment called Youubi was used to support learning activities based on context. It consists of a framework of services that are easily integrated from applications in API format. In order to achieve the objectives of this research, the proposed method consists of three (03) phases. The first phase was a systematic review of the ubiquitous learning environments in order to identify which architectural features and their learning processes are used in learning scenarios based on the context. In the second phase an installation designed with the Youubi ubiquitous environment proposed a learning scenarios and new pedagogical practice for teachers in higher education. The third stage will be the design of high fidelity of ubiquitous learning scenarios prototype. After that, the actions will consist in validating the ubiquitous learning scenarios. In this paper we present the results of the systematic literature review. From these outcomes, we will generate pedagogical strategies for ubiquitous learning scenarios. These may also be used as recommendations to improve of current ubiquitous learning environments as well as the design of the Youubi environments.

Keywords-component: Educational Practices; Ubiquitous Learning; Framework; Effectiveness.

I. INTRODUCTION

The ubiquitous computing and location technologies have gradually been inserted in education as a differentiated practice to support indoor and outdoor learning. Environments that incorporate ubiquitous technology in pedagogical activities seek to enhance the learning spaces of learners through their daily activities in an integrated and continuously

way. This type of environment can be regarded as a factor that favors in a unique way the effectiveness of practices that increase the engagement of learners in learning through user interaction mediators resources with devices such as bar code labels, Global Positioning System (GPS), labels or RFID tags (Radio Frequency Identification) and wireless sensor networks. We can understand that the ubiquitous learning is characterized by the provision of learning services intuitively mediated by these built-in features in order to encourage learning in the right place at the right time. Thus, it is important to analyze new pedagogical approaches using these resources to support learning situations that may occur at any time and place and integrated into the context form. Ubiquitous technologies are accessible through devices such as tablets, smartphones and smart watches, which combined with the interactions of people and artifacts available in the environment, contribute to new experiences in the daily lives of people.

However, this new way to share and access information still far from be taken advantage when it comes to teaching practices in the classroom. Many of these devices are used personally and isolated from favoring context of social interactions that help the cooperative learning practices enriched by technology. In this sense, [1], [2], [3] and [4] discuss the possibility of new forms of learning using these devices, not only in the classroom, but also in many places that can help the teaching-learning process. Thus, mobile devices emerge as mediators that expand the possibilities, scenarios and forms of interaction, expanding the learning beyond the borders of the traditional classroom. Mobile and ubiquitous technologies enable learning within the context and ubiquitous mobility, due to the new models of existing interactions on mobile devices such as sensor technologies [5] [7].

Faced with this new scenario, educational environments need to develop a new model, Ubiquitous Learning (u-learning) or Ubiquitous Education [6], supporting educational processes that can be accessed at any time, anywhere integrated with the context both virtual and real apprentice, enabling significant changes in pedagogical practice in the classroom. Technologies that support this type of model situations cause learning through activities integrated with everyday life, and continuously [8].

Thus, this research focuses on exploring the activities of inadequate behavior in learning situations that incorporates the ubiquitous computing resources. We seek to analyze the effectiveness of this technology in the educational context in order to promote meaningful learning. The central question in this research is: The appropriateness of learning activities using ubiquitous situations creates more favorable conditions for effective learning?

The guiding hypothesis of this research is: The appropriateness of activities in ubiquitous learning situations promotes the student's ability to accomplish proposed activities. To validate it, a stage that is in progress, we seek to develop the pedagogical model of communication of u-learning environment Youubi. The designed ubiquitous learning environments allow assess whether, on the one hand, the resources of technologies with context awareness, promote significant changes in pedagogical practice. On the other hand, may or may not have a positive impact on the effectiveness of learners to promote a significant improvement in their learning.

This paper is organized as follows: Section II presents the u-learning environment Youubi. Section III discusses aspects related to learning environments based on the context. Section IV presents the original proposal of the methodology to be used in the search. Finally, section V presents the first results of the research.

II. YOUUBI U-LEARNING ENVIRONMENT

It is a ubiquitous learning environment, distributed under an open source license and developed based on reference architecture (Figure 1).

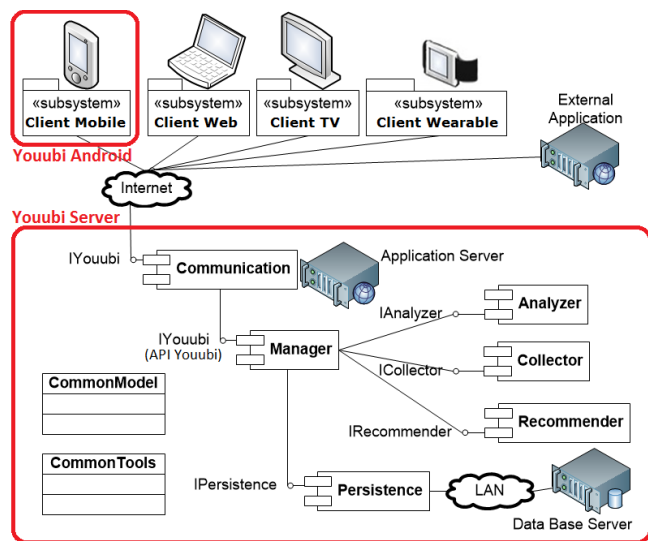


Figure 1. Architecture Youubi System [9].

In addition, to implement its communication layer in Web Service, the services offered by the server can be consumed

by the following platforms: mobile, Web, TV, smart watch and other systems via an API (Application Programming Interface) [10]. Main components:

- **Communication:** implements the Web service communication layer, with RESTEasy framework, which provides the services of Youubi API over HTTP requests (Hypertext Transfer Protocol).
- **Manager:** receives requests from clients and implements their respective business rules, updates the user behavior indicators based on interactions with the system.
- **Collector:** responsible for collecting data on other systems that provide access API such as Google, YouTube, Wikipedia, Facebook, Twitter, OpenRedu, Moodle, and others.
- **Analyzer:** responsible for the periodic review of the data stored in the database in order to identify new information that can enrich the user profile.
- **Recommender:** responsible for analyzing the data stored in the database to generate recommendations for all elementary Youubi entities, based on the context of the users.
- **Persistence:** responsible for the storage of data in the database, which ensures the insulation between the rules of persistence and business.
- **Common Tools:** consists of a number of utilitarian methods such as conversion algorithms. This component can also be used by both the client applications as the server-side component.
- **Common Model:** composed by JavaBean classes that represent the architectural entities. Among the main model classes are the elementary entities (Person, Post, Event, Challenge, Location and Group), which respectively represent the user and the content and activities handled by the environment.

Youubi was being adopted in this research because it is designed to support learning activities based on the context of learners. In order to test the architecture and perform experiments with students and teachers in a real environment, one mobile client was implemented and integrated to the u-learning environment Youubi. Accordingly, it is an open source application and the usability was already evaluated with real users [9].

III. ASPECTS RELATED TO LEARNING ENVIRONMENTS BASED ON CONTEXT

In essence, the technologies based on the concept of u-learning are context sensitive. An application is classified as 'context-sensitive' if it uses information about the context of relevant entities in its domain to provide information or services to its users [13]. Therefore, the information that makes up the learner's context can be, for example, his identity, physical status, behavior, location, social interactions, interests, device used and other environmental information obtained by sensors. Thus, the information can be used to deliver content and services closer to the context of each learner [13], as well as to adapt learning strategies for each student [12]. In addition, this set of requirements is a key factor in the process of monitoring the student. It is possible to be aware of its' context, their learning practices and how she/he is acting [11]. In this sense, to provide effective use of services through ubiquitous resources is essential to have a clear definition of tasks, collaborative activities, which shall

be made available, and finally, how will the student interaction with these elements according to its context.

So, to model educational activities that promote learning effectiveness with use of ubiquitous technologies, it is indispensable to have a clear definition of: the tasks, the type of activity to be provided, the information to be made available, how will be the interaction of the student with these elements according to the context and with the quality of the designed interaction design [14]. In this sense, [3] states that when designing a learning environment supported by mobile technology is needed further evaluation of usability in order to assist designers in the design of activities. When designing learning activities that incorporate u-Learning resources, they must be designed in constant negotiation over the design process, with a view to the dynamics of the services offered by mobile technologies.

IV. PROPOSED METHODOLOGY

The methodology consists of three (3) phases:

Phase I: In the first step was performed a systematic literature review (SLR) on ubiquitous learning, in order to outline the current knowledge about the different architectural approaches and learning processes involved in learning paradigm ubiquitous. In the second stage we will apply methods of ethnographic research with teachers of a *Computer Licenciade Degree* in the Federal Institute (IF) called '*IF Sertão Pernambucano*', to capture the teaching practice with the use of technology in the educational process. To procedure the ethnographic research, we referred the structured model of dimensions and components [10], as a builder for dimensions of modeling to be used in data collection through interviews. The third step is to design strategies for learning activities based on the findings of the RSL and compiled data from ethnographic study of users to design learning scenarios for the u-learning environment Youubi.

Phase II: The second phase comprises the prototype design of high fidelity of ubiquitous learning scenarios involving techniques of Design Thinking. To [15] Design Thinking is grounded in methods and models that emphasize, communicate, encourage and explain the features, capabilities and behaviors inherent in the human being, allowing their wishes, needs and experiences are the starting point to design solutions, products and services. Currently, there are several approaches to Design Thinking, however, for the development of this research, we adopted the proposal of the Hasso Plattner Institute of Design at Stanford (d.school), pioneered the use of DT in the middle academic [16].

Phase III - Consist of the planning and execution of the experiment to validate the hypothesis of this project. The results generated will be specified in the form of pedagogical strategies for ubiquitous learning environments that promote learning effectiveness with the use of ubiquitous technologies. These may be used as recommendations for improvement of current ubiquitous learning environments as well as in the design of new environments.

V. CURRENT STAGE OF THE PROJECT

In the case of a project in development, we describe in this section the first results found in the research.

A. First Results of the SLR

According to the research questions of Section 1, we define a set of relevant terms that guided the mapping of existing ubiquitous learning environments, their ubiquitous technologies employed as well as the pedagogical models used to promote ubiquitous learning. The organization of the SLR, follows the guidelines [17], in three stages: planning, execution and presentation of results.

For planning, the key terms for the preliminary search based on the problem of research on ubiquitous learning were initially identified to generate the search strings, according to the terms described in TagCloud of Figure 2.

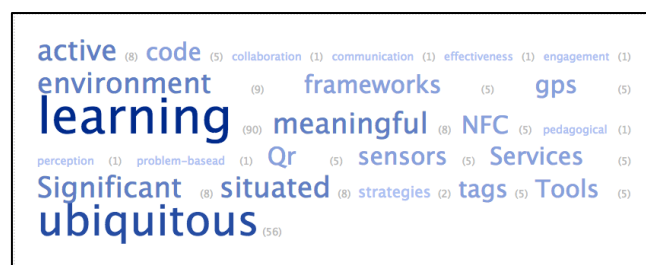


Figure 2. TagCloud words to search String.

After the search string definition, primaries studies were conducted in those chosen main databases in computing: ACM Digital Library (<http://dl.acm.org>), computer & Education, IEEEExplore (<http://ieeexplore.ieee.org>), SpringerLink (<http://link.springer.com>), ScienceDirect (<http://www.sciencedirect.com>).

In the implementation process, an automatic and manual search was performed on each digital library. Then, an iterative process was used to exclude non-relevant articles to the exclusion criteria.

The exclusion criteria were applied according to the analysis of the summary, keywords, full text screening and finally the duplicate jobs. Similarly, the procedures were performed until the final list as described in the Figure. 3.

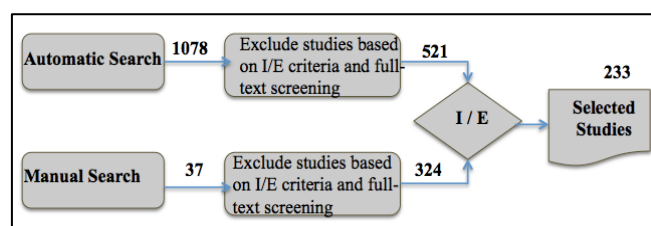


Figure 3. Process Research and Studies Selected.

Automatic and manual query took place between November (2014) to January (2015) and two researchers extracted the data. It is observed that the SpringerLink library, was the largest vehicle of relevant studies on ubiquitous learning. However, other vehicles were identified as relevant when the survey was conducted. The results for each digital library, conference and journal are shown in Figure 4.

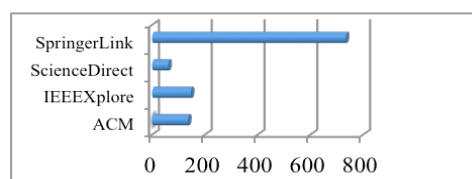


Figure 4. Total Found by Conference.

The ubiquitous learning architectures found in the preliminary findings of the SLR such as the location [18] Hello [19] and Cauls [20] showed no exceptional or different features of u-learning environment Youubi [10] as described in Table 1.

TABLE I. LIST OF ARCHITECTURE AND ITS UBIQUITOUS FEATURES.

TABLE CLASSIFICATION OF ARCHITECTURE MODELS				
Features Ubiquitous	1° Model (LOCAL)	2° Model (HELLO)	3° Model (CAULS)	4° Model (Youubi)
Tools	RFID, mobile device	QR code, camera, mobile device	RFID, mobile device	SmartPhone GPS, Google Maps
Immersion	High	High	High	High
Adaptability	High	Low	Low	Low
Invisibility	Yes	Yes	Yes	Yes
Located Activities	Yes	Yes	Yes	Yes
Education Dynamics	Yes	Yes	Yes	Yes
Interactivity	Yes	Yes	Yes	Yes
Type of Learning	M-Learning and U-learning	U-learning Activities	U-learning Activities	U-learning

In [21] and [22] is reinforced this context for education, in the sense that ubiquitous support can allow the development of educational programs, using dynamic information obtained from the physical context of learners. This scenery is recognized through the results shown in Table 1. The Ubiquitous Learning Environment Youtube was selected in this research as reference by support the same features. The important point in this process is related with the access the code and proximity the development team that are willing to collaborate to improve the environment, thus facilitating the construction process and gathering information from the real student's context.

Finally, the first phase of the filtering of the review articles is being completed and from these results, this research will be able to start the second phase.

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Increasing Student Engagement Through the Development of Interdisciplinary Courses:

Linking Engineering and Technology, the Sciences, and the Humanities

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Abstract — The changes in the defining ideas of the contemporary world, the exponential growth of knowledge, and the expansion of technological innovations have created a need for a critical examination of the convergences and connections between the Sciences, Engineering, and the Humanities. Today, there are areas of study so complex that they go beyond the confines of a single discipline. Examples of such areas include (1) the comparative study of concepts of mind, consciousness, and machines, (2) the critique of the technological culture through appropriate and alternative technology approaches, and (3) the questions surrounding cosmology, evolution, and beliefs. In response to this, we have developed interdisciplinary, team-taught, general education courses on artificial intelligence, appropriate technology, and the origins of the universe that respond to the above challenges, while fostering the ability of our students to use skill sets and concepts from different and divergent disciplines in order to examine such complex areas of study. The preliminary results indicate that, while there is a need for continuous retooling of the course model to better reflect the General Education goals and the university culture, this is a successful course model for our institution. The data also suggests that this type of interdisciplinary intervention in the beginning years of university study positively impacts the development of students' abilities in these areas.

Index Terms — interdisciplinary courses, student engagement, first year experiences, critical thinking, integrative learning

I. INTRODUCTION

The past few decades have witnessed an explosion in information in science and technology that directly impact our lives and call for an examination of the connections between Science, Technology, and the Humanities. These intersections form the crux of critiques of artificial intelligence, the appropriate use of technology, and the origins of life; three areas which influence our conceptions and our place in society and the world. While, technology and science are integral and formative parts of our culture, not neutral entities, they have the ability to alter how our senses inform us about the external world and help form one's own view of reality, structures of meaning, and identity [1]. Very few of the University of Puerto Rico, Mayaguez's (UPRM) General Education (GE)

requirements examine the reciprocal relationships between science/technology and society/culture or the associated convergences. To remedy this situation, our educational project, "The Convergence of Science, Technology, and the Humanities", aims to examine the convergences in our culture through a set of interdisciplinary team-taught, theme-based GE courses that enable students to explore the links between the sciences and the humanities, with the goal of improving our students' engagement in their own learning. Given the complexity of the three above areas, an interdisciplinary approach is needed for the study of their diverse elements [2 - 7], with Klein and Newell [3] indicating that such a format provides a base and process for examining topics, questions, or problems that are too broad to be dealt with by a single discipline or profession [3].

Scholars [8 - 11] indicate that colleges and universities are using interdisciplinary courses to enhance and focus on developing students' integrative skills, while addressing topics that are by their very nature intrinsically broad, multi-faceted and, therefore, beyond the scope of a single discipline. To be successful, these courses depend upon the integration of perspectives and tools from multiple disciplines for a more complete inquiry of the subject matter [9, 11, 12]. While there are concerns about the effectiveness and problems associated with team-teaching [9, 10, 13], in our project it became clear that if a teaching team maintains good communication lines and the members seek a deep collaborative experience, the development and offering of the course flows more smoothly.

Because UPRM is mostly a Science/Engineering university, the creation of interdisciplinary GE courses that examine the above mentioned intersections is an important addition to our GE curriculum. Professors from widely diverse disciplines are collaborating to develop and offer three interdisciplinary, thematic, team-taught GE courses that contextualize current debates and questions that inquire about (1) the expanse and limits of artificial intelligence (AI); (2) the ethical, social, and technical choices that distinguishes appropriate use of technology (AT); and (3) the theological, social, and scientific debates that arise in connection with the study of cosmology, evolution, and belief (CEB). Given the depth and complexity of these areas, an interdisciplinary, team taught approach is well suited and provides the best tools for considering these

topics [7- 9, 11, 13].

II. COURSE DESIGNS AND OUTCOMES

A team of three professors was assigned to each of the three thematic areas. Each team began designing the course format, syllabus, readings, assignments, and evaluation rubrics at least one year prior to offering the course. As part of this process, each team hosted a conference of visiting scholars who had expertise in both the specific theme and in pedagogical methods for interdisciplinary education. This included use of such interdisciplinary pedagogical methods as writing for learning, case studies, group research, and student led discussions [13 - 14]. The visiting scholars were presented with annotated draft syllabi of the courses for their responses, which further engaged the team members in a critical dialogue on course content, design, and pedagogy.

Two formats for the course were designed, both of which are based upon the mega-section concept and are cost neutral in terms of the number of students per professor. The first format, which was used in the AI and CEB courses, divided the students (up to 30 students per professor) into three separate sections. Each professor then met separately with each section on an alternating basis, with some general meetings for all participants scheduled during the course of the semester. The second format, used in the AT course and employed at some point in the other two, convened the entire class in a large classroom or auditorium. In all cases, for accounting and grading purposes each teaching team member was assigned up to thirty (30) students.

Due to the differences between the courses, the following presentation of the results (description, design, results) will be divided by course topic.

A. *AI: Mind, Consciousness, and Machines*

Core theoretical questions in AI research (and contemporary computer science and cognitive science in general) are core theoretical questions in the modern history of psychology and the philosophy of mind. An interdisciplinary course on AI, team-taught by a Computer Engineer, a Philosopher and a Psychologist, introduced a class of undergraduate students from diverse disciplines to the main areas that influence AI research, such as the rationalist/empiricist divide [15], the nativist/operationalist debate in psychology [16 - 17], classical computationalist models vs. connectionist models in Computer Science [18], neural nets and debates in Neurophysiology [19 - 20], as well as the basic premises of Computer Science [21 - 22], evolutionary Biology [23], Linguistics [24], Philosophy [25 - 26], Psychology [27 - 29], and Robotics [21, 30 -31]. This course has been offered twice (2010 and 2012). In the second offering, there were 17 enrolled students, with 80% of the students being from Engineering and the remaining from the Natural Sciences.

One of this course's main objectives was, through an introduction to diverse disciplinary perspectives on the topic of AI, to develop the students' critical thinking skills. Students were introduced not only to established paradigms, but to current debates and movements in the field, while the professors' job was conceived more as a facilitator to raise questions, rather than as a dispenser to introduce the students

to conventional professional wisdom. The professors quickly realized that the students needed instruction on general critical thinking skills. Forensic debates (in which the student was not aware ahead of time of which thesis they would be defending), mutual student grading and, of course, professorial debates were particularly well-matched to the interdisciplinary environment. The final grade distribution 29% -A, 5%-B, 12%-C, 18%-D, 0-F, (5 withdrawals, 1 incomplete) highlight both the benefits and the problems associated with this type of course.

The final course assessment activity was a general meeting with the students about the course. The students indicated that their writing skills had improved and that they developed greater understanding of what needed to be done to establish and defend a point of view. This is supported by the final grades in the class (i.e., the relatively high number of A's) and the professors' own observations. This was exciting, as professors initially thought that the most significant pedagogical achievement would be an increase in comprehension (owing to the diversity of the material). Increased comprehension was also evident, particularly in student reports, but they also developed a greater appreciation of the range of diversity in professional opinions; that academic and scientific disciplines generate disagreement as frequently and as productively as they do consensus, both inside particular disciplines and, of course, across them. This seemed to be a particularly valuable lesson so far as the students were concerned. The students also reported that they enjoyed seeing the professors interact and that the professorial debates were favorite class periods.

It was difficult to arrange the distribution of credit hours and classroom time, as well as registration, grading, and course organization for a team-taught, inter-departmental course. As the first group to offer a course, professors struggled with organization and subsequent courses learned as much from what went wrong as from what worked. The first time this course was offered, in 2010, it was organized around the concept that the students would meet separately with each professor for one of the scheduled class periods of the week, with periodic meetings of the complete group for the interdisciplinary discussions. The first course evaluation results, halfway through the semester, clearly indicated that the students preferred to meet with all three professors at the same time. This is the format that was followed in the second half of the 2010 course and the whole of the 2012 offering. The feedback from the students strongly indicated that this is the preferred meeting format.

B. *AT: Alternative and Appropriate Technologies: Technology for What? Technology for Whom?*

The overall goal of this course was to foster critical thinking about the humanity/technology relationship, and to inspire creative thinking about alternatives. The course enrolled 72 students (64 engineering, 8 non-engineering; 30 1st year, 22 2nd-3rd yr., 20 4th yr. or beyond) and was taught by faculty from Philosophy, Electrical Engineering, and General Engineering.

Using Schumacher's concept of Appropriate Technology [32] and elaborations by Willoughby [33] as the central theoretical framework, students critiqued practices of

technology both in the global North and in the global South. Additional ideas from Philosophy of Technology and elementary science were interwoven to encourage students to construct views beyond any single framework, and to elicit diverse views on what constitutes human progress.

Instead of attempting a detailed description of the course, professors provided a brief tour using electronic devices and media as a cross-cutting case. The students entered largely sharing the common view that technology is morally and politically neutral. This instrumentalist view is challenged by Albert Borgmann's theory on the endangerment of "focal things and practices" due to what he calls the "device paradigm" in which technologies provide goods and services invisibly, hiding the many consequences of our behaviors (e.g., we do not directly see carbon emissions when we turn on the lights) and erode lifestyles that reflect unity of effort engender human commitment [34]. A related idea elaborated by Héctor Huyke [35] is that over-availability of such devices produces distance between people, rather than nearness (e.g., think of a family at dinner, with each person on the phone rather than conversing with each other). Accordingly, the design of technology should take into consideration the strengthening of close human ties and foster meaning in life's activities [34]. Yet, introducing electronic devices in developing communities is often considered to be an "appropriate technology" [36]. However, the proliferation of these devices and their necessary infrastructure is generally managed by multinational companies whose principal motives are profit, raising questions such as those posed by Riley (e.g., should engineers resist global neoliberal economic policies?) [37], Practical Action (e.g., how is the community's wellbeing considered?) [38 - 39] and Willoughby (e.g., is the technology at a scale commensurate with the community's ability to manage and use it?) [33]. Parallel to these questions, mini lessons and exercises were presented to explore technical details of power requirements for operating such devices, and the broader environmental implications of diverse technologies for producing energy. In sum, students were able to reflect on the relative merits of seeking technological parity with the developed world, procuring better technological alternatives, and effecting behavioral changes to best promote quality of life and genuine wellbeing.

The principal assignments consisted of three written essays, in which students needed to apply critical thinking skills to (1) explain an important aspect of a theoretical framework on the humanity/technology relationship; (2) analyze a case from the perspective of that framework; (3) discuss a possible weakness of that framework; and (4) deliberate for or against the validity of the framework in a specific context. To evaluate students' critical thinking skills, an assessment rubric was developed based on these four elements. After the first essay was graded, students had an entire class session work in small groups to discuss the rubric with samples of their graded works, and a second class session for a plenary discussion summarizing the small group discussions.

Based on the rubric (10 pts. max.), the average scores on Essays 1 and 2 were as follows: Essay 1: (6.4, 6.6, 6.9); Essay 2: (7.1, 7.9, 6.9), where each triplet represents scores ordered by cohort (1st yr., 2nd-3rd yr., 4th yr. or beyond). For Essay 3, a group essay, the average scores were (8.0, 7.6), where the

pair represents scores ordered by groups with a (majority, minority) of 1st year students. These results suggest that there was general improvement in students' critical thinking skills as the course progressed, and that this improvement was most (least) demonstrated by lower class (upper class) students. We speculate that by being less encumbered by years of compartmentalized learning and teaching, entry level students are more motivated to freely investigate interdisciplinary questions critically. Although we are unaware of any studies that directly support this conclusion, our results cohere with those from a study of First-year Interest Group (FYIG) participants at UW-Madison, in which first year students choose to enroll in a set of theme-based courses. According to this study, "Faculty have also remarked that their FYIG students *often* outperform their upper class, and in some cases, even graduate students on some critical thinking tasks" [40, p. 248, emphasis on 'often' added].

Another positive outcome of the course is that several students were motivated to continue to be active in Appropriate Technology. Two students from our class took a special topics class about structural mechanics and building with bamboo [41]; one student started a "social business" with a limited profit motive and a commitment to employing fair labor and environmental practices [42]; one student plans a capstone design project in Electrical Engineering incorporating ideas of appropriate technology applied to the irrigation of a local bamboo farm; and nearly a dozen science and engineering students have subsequently chosen to take classes in Philosophy of Technology, Engineering Ethics, and general Ethics.

C. CEB: Cosmology, Evolution, and Belief

The course, "Cosmology, Evolution, and Belief," provides an introductory examination of the dynamic process of evolution of three different objects: the Cosmos (with their fundamental constituents and natural laws) [43], Life (from its origin to human beings) [44 - 45] and Belief [46 - 47] (from primitive cultures and ancient civilizations to present societies). In this course professors from Physics, Biology, and Humanities collaborated to present, discuss, and clarify these topics. The course is designed for first or second year university students. There were 64 total students enrolled in the course with 56% from the Natural Sciences, 21% from Engineering, and the remaining 23% from the Humanities. The student evaluation system was based on two exams (8th and 15th weeks), class participation, quizzes, homework, and attendance. Each professor used the last three evaluation methods differently.

With regards to the academic results, the average grades on partial and final exams, quizzes-works, and participation for the students who completed the course (there were three withdrawals) were 24/30 (exam 1), 21/30 (exam 2), 22/30 (other assignments), 9/10 (attendance), with an overall total average of 76%. All three areas utilized many bibliographic and audio visual references. The cosmology section used 12 references, which included the textbook *Introduction to Cosmology* [43], which was written specially for the course. The evolution component used 22 references, ranging from scientific articles to book fragments; and the belief section employed 12 references.

Formal quantitative assessment was not developed for this course. Although, professors offered an assessment test to gather students' background about the course topics. They also offered a survey at the end of the course to probe students' degree of satisfaction. The majority of the students were highly satisfied with the course. Some of them were more engaged with a specific subject matter, depending on their personal interests. Critical thinking and integration of topics were assessed on exams questions. Most students were able to integrate different views presented in class about the topics, which translates into the 76% grade average. However, a few failed to develop critical arguments in their exams, or refused to answer the questions altogether.

The course design was similar to the 2010 iteration of the AI course, in that it was originally divided into three separate sections with each professor rotating through each section and offering his lectures three times (during weeks 2-7 and 9-14). The interdisciplinary discussions were to take place in weeks 1, 8, and 15, when all registered students and professors would meet together to discuss, analyze and synthesize ideas. However, once professors concluded the first cycle in the eighth week, they decided to adopt a different approach for the remaining weeks of the course. All three sections were fused together and the professors attended all lectures. This new format promoted interesting discussions among students and all three professors during the classes. In the final course assessment, 75% of the students expressed that they preferred this second format. During the course, all three perspectives were taken into consideration while analyzing specific issues. For example, professors discussed the ethical and biological impact of transhumanisms and technology on the continued evolution of the human species [48 - 49].

III. CONCLUSIONS

The project's original goals were that an interdisciplinary perspective would help increase our students' engagement in their learning and, subsequently, their critical thinking skills, as well as the understanding of the links between the Sciences, Technology, and the Humanities and the preliminary results support this. While the assessment only measured the work during the course of one semester for each course, the students did demonstrate improvements in their critical and integrative skills during that time. This was observed in all three courses, through the use of class discussions and assignments.

All three courses surveyed the students at the end of each associated semester in order to gather information regarding their degree of satisfaction with the course format and subject matters and their views of their own understandings of the areas of study. The majority of the students were highly satisfied, with some going so far as to say that "For the first time in my 6 years in college I found a piece [of] hope for the system, thanks to you [for] having developed this course" and "It was an overall great experience and I'm glad we all had some part in it" (in reference to the CEB course). The students agreed on the positive impact of discovering the intimate relationship between the disciplines included in each of the three courses.

The team-taught format also demonstrated positive results in regards to the level of student engagement. In all three courses, student engagement was high, which was supported

by the increased level of class participation and fewer students using electronic devices during the class period. This was especially noted by professors in the 2010 iteration of the AI course and the CEB course. By changing the format of the classes from meeting in separate sections (with occasional interdisciplinary interventions), to one of all participants meeting together in one single section, not only were the students better able to perceive the convergences and divergences of the topics, but their levels of engagement in the class noticeably increased. As one of the professors observed, there was a notable increase in student attention, attendance, and participation as soon as they began meeting as a single section, instead of in separate sections.

However, organizing this type of course does present various difficulties during the course design and its subsequent offering. First of all, it requires extensive pre-course development, as well as good communications skills between the participating professors and the teaching teams needed to meet on a continual basis during the academic year before offering the course. In addition, each team of professors experienced a fairly steep learning curve to understand and learn each other's professional language, attitudes, and core beliefs. Further complicating the situation we confronted obstacles in regards to the administrative aspects. To offer such a course, a university needs to have well defined administrative procedures in regards to 1) teaching load, 2) publicity of the courses, and 3) student registration. We observed this while working on the course preparation and student registration for the course. Regardless of the obstacles, the whole process proved to be enriching, with one faculty member even remarking that he felt that the experience was like having an internal sabbatical.

IV. THE FUTURE

We envision that this model will be employed throughout the University to enrich the curricula and support better student engagement. To this end, professors from the Schools of Agricultural Sciences, Engineering and Business Administration are designing interdisciplinary courses along these lines. These curricular innovations will result in interdisciplinary team-taught courses between Engineering and Business, as well as a new multidisciplinary capstone course, which are scheduled for implementation on August 2015.

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Latinas' Resilience and Persistence in Computer Science and Engineering

Preliminary Findings of a Qualitative Study Examining Identity and Agency

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Abstract— Most professions have reached gender equity with the exception of computer science and engineering. To understand the mitigating factors influencing Latinas' enrollment and persistence in engineering and computer science, an interdisciplinary team of scholars at a majority Hispanic four-year institution has undertaken a three-year project to explore these phenomena. The following overarching question has guided us: What is the relationship among identity, resilience, and persistence of Latinas in computer science and engineering? The study was framed using a sociocultural theory of identity drawn from the work of Gee and from Holland, Lachicotte, Skinner, and Cain. Our findings suggest the majority of women encountered and dealt with some kind of adversity in their career trajectory. Their ability to overcome this adversity depended on many factors, such as the role of peer groups, family, and professors. Eighteen of the 26 participants referenced group participation phenomenon as beneficial to their success. They also identified spaces that accommodate group interaction including: the library, homes, local coffee shops, and university study areas.

Keywords—*women in engineering; narrative analysis; qualitative study; sociocultural theory of identity.*

I. INTRODUCTION

The disciplines of engineering and computer science have served as preeminent and prestigious fields of study, yet have been historically underrepresented in gender despite other professions reaching parity [1]. With engineering as “one of the few remaining of sex-segregated disciplines” [2, p. 1], only eighteen percent of engineering degrees are awarded to females with two percent awarded to Latinas [3].

Local and national pre-college outreach endeavors have addressed this disparity in the last 20 years, including the National Center for Women in Information Technology, the Computing Alliance for Hispanic-Serving Institutions, Grace Hopper Regional Consortia, CRA-W, ACM-W, and Tapestry. Although female enrollment numbers are far from parity (under 19%, with Latinas representing only 9% of the total number of females) in computer science and engineering, they would no doubt be worse without their dedication.

The disproportionately low share of Latinas earning undergraduate degrees in engineering is an indicator that the discipline could face its own crisis point. To resolve the crisis,

it is crucial to listen to the voices of Latinas already in the field. Our study was designed to further understand the ways that educational institutions may help recruit and retain these and other minority women in engineering and other STEM fields.

This study applies qualitative research methods to investigate the experiences, from their youth through university life, of Latinas toward enrolling and persisting in engineering studies. Located on the U.S.-Mexico border, the research site is a Hispanic Serving Institution where female enrollment in engineering is twenty percent --slightly higher than the national average.

To understand the mitigating factors influencing Latinas' enrollment and persistence in engineering and computer science, an interdisciplinary team of scholars at a majority Hispanic four-year institution has undertaken a three-year NSF-funded research grant project to explore these phenomena. The following overarching question has guided us: What is the relationship among identity, resilience, and persistence of Latinas in computer science and engineering?

II. THEORETICAL FRAMEWORK

We draw on a sociocultural theory of identity construction to understanding how participation in socio-cultural contexts mediates identity. In particular, we draw on the theoretical perspective of Holland, Lachicotte, Skinner, and Cain [4] who describe particular sociocultural contexts as “figured worlds,” or social configurations, such as family, school, and other social institutions. Holland et al. [4] describe figured worlds as “a socially and culturally constructed realm of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others” (p. 52). In a figured world, individuals shape subjective meaning of themselves as actors who participate and navigate as they move in, through, and out of these worlds throughout their lives; these social configurations shape how one makes sense of the world and how one perceives oneself in that world. This perception is how an actor “authors” herself—an embodied self in a particular social configuration [4, p. 32] where actors' participation and position can be one of privilege or subordination [4,5].

Using a figured worlds theoretical framework in their study of middle school girls of color in science classes and laboratories, Calabrese Barton et al. [4] focused their study on “identity work,” rather than identities specifically, and defined it as

actions that individuals take and the relationships they form (and the resources they leverage to do so) at any given moment and as constrained by the historically, culturally, and socially legitimized norms, rules, and expectations that operate within the spaces in which such work takes place. Individuals author possible identities through identity work over time both with and against the norms of the worlds they inhabit. (p. 38).

While we examined identity work in our investigation of three Latinas as they participated in similar activities as pre-college youth, for this paper we focus on their narratives.

Narratives or stories told to mediate identity construction in the figured world of engineering and computer science studies. It is through the stories people tell about their experience where we can come to understand how they make sense of their lives within this world. Through telling a narratives we are able to understand a number of things. For instance, we may understand the significance of events a narrator assigns to particular events, the value that have, the important people in narrator’s lives, the significance to be had from hearing particular stories and how the narrator understands herself within the frame of this figured world.

III. RESEARCH DESIGN

Twenty-six (26) participants were selected using purposeful sampling [7]. They were interviewed using an ethnographic method of deep interviewing developed by Seidman [8], which combines life history using focused, in-depth interviewing to provide rich descriptions of participants’ life experiences. These interviews provided research participants an opportunity to construct meaning of their life history in making their respective career choice, and their current experiences in navigating barriers and/or gateways as a female engineering student. Each interview lasted approximately 90 minutes. The three open, in-depth interview questions were:

- (1) What experiences brought you to engineering?
- (2) What has been your experience as an engineering student?
- (3) What it will mean for you to be an engineer?

Probing and clarifying questions are asked of the participants based on what they share in answering these questions. For example, they may mention a class where they were one of five females. The interviewer would then ask, “Tell me what that meant for you” or “Could you tell me more about that experience?” In this manner of collecting data, the descriptions of their life experiences were thick as they provided details of their experiences.

The team is in its final phase of analyzing these data using the following analytical methods: narrative analysis, constant comparative, and life charting. For this paper, the unit of analysis is the narrative, defined by narrative plot elements [9]. For this paper we purposefully selected narratives in which narrators included a crisis point where they wondered aloud if they identified as engineers. More than one third of participants presented what we termed a “narrative of uncertainty” due to the words narrators used, such as “doubt,” “not sure,” and “don’t know.”

Data were analyzed using an approach to narrative analysis that has a long tradition. It has been used in research for [10,11, 12] approximately five decades. This sociolinguistic approach to narrative analysis relies on linguistic markers to identify narrative structure. The following elements are found in narrative structure: a Setting (in which the narrator reveals the who, when, what, where of the story), a Catalyst (where the narrator identifies a the situation leading up to a crisis), Crisis or Problem (the narrator mentions an issue that complicates the situation), Resolution (the narrator says how the crisis issue was resolved), Evaluation (the narrator elaborates on the significance of the story), and Coda (closes out narrative). Analysis relied on linguistic cues, such as speech tone, rhythm, and vocabulary choice [13] as well as content to determine the structural elements of a narrative.

IV. FINDINGS

The findings from the data analysis of our larger study are: (1) negotiation of adversity in Latinas’ non-academic and academic lives; (2) being female in a male-dominated space; and (3) the development of engineering identity, which is informed by the roles of (a) affinity spaces; (b) supportive people; and (c) engineering-related artifacts and play experiences.

For this paper, we will focus on the negotiation of adversity in Latinas’ academic lives.

More than one third of participants volunteered what we termed a “narrative of uncertainty” i.e., they used particular phrases, such as “doubt,” “not sure,” and “don’t know” or questions (“I wondered if engineering was for me”). Our analysis pointed to recurring themes in Latinas’ narratives of uncertainty: 1) Crisis points revolved around events in lower division courses— what some of them call “weed out” or “gatekeeper” courses; 2) participants drew on their communities of practice to make sense of these difficulties; and, 3) a number of participants identified their mothers as the figure who confirmed engineering as the right career choice for them.

1) *“I wasn’t really sure that I was smart enough...”*

Many of the participants were among the brightest and most talented students in middle and high school, with some of them earning scholarships and/or attending engineering magnet high schools.

Early in their engineering coursework, participants began to question whether engineering was the right path for them.

Table 1 shows the courses in which participants told us they began to doubt themselves. In the second column, the courses where narratives of uncertainty are set are presented. Significantly, these courses are all lower-level courses, suggesting that participants' moments of uncertainty came early in their college career—not later.

Pseudonym and engineering major	Spaces of local struggles	Resources for resolving crises/struggles
Amber (Electrical)	Pre-Calculus (lower division course)	Her mother, school counselor
Autumn (Mechanical)	Physics (lower division course)	Self-motivation to become a NASA engineer
Briana (Mechanical)	Chemistry (lower division course)	Parents, sister, professor
Britany (Industrial)	Electro-Mechanical Systems (lower division course)	Change of major would delay graduation
Elena (Civil)	Statics (lower division course)	Upper division students; parents
Gabriela (Mechanical)	Calculus II (lower division course)	Her mother
Gina (Mechanical)	Dynamics (lower division course)	Her professor
Juliet (Computer Science)	Intro to CS	Her professor
Karla (Civil)	Didn't see the application of concepts in Statics and Mechanics of Materials (lower division courses)	Her family, especially her mother
Natalie (Civil)	Physics and Dynamics (lower division) Structural Analysis (upper division)	Self-motivation

TABLE I. SUMMARY OF NARRATIVES OF UNCERTAINTY

An example of one such narrative is Autumn's, a mechanical engineering major, who is now employed at NASA. She revealed that Physics I was when she doubted her identification with engineering.

[In] one of my classes, we were learning about moments and statics, equilibrium forces and things like that, and I'd never been exposed to that. So I was completely confused. I was really lost. And yeah, I was going back and forth thinking, this is pretty difficult. I'm not sure that I'm grasping these concepts and. "Is engineering really right for me?" You know? 'Cause I guess I'd gotten accustomed to everything comes easy, and it wasn't coming easy.

Like Autumn, all of the participants who volunteered a narrative of uncertainty pinpointed lower division courses as the moment when they began to wonder. Similarly, research has shown that lower division courses are a significant barrier for female students and students of color [14]. This finding suggests that colleges of engineering interested in retaining females might do well to target these (often large) courses.

2) *"If it weren't for those friends who are upper division students..."*

As noted above, narratives always contain a disclosure of how crises were resolved. Often narrators name other key people at this stage. Here, participants identified the resources and key people they turned to in order to resolve conflicts. Table 1 also shows the key people narrators named at the resolution stage of their narratives.

A few students drew on affinity groups [15], which served as support mechanisms that helped them navigate challenging coursework [16]. For instance, Elena constructed affinity groups with upper division students in a Statics course in which she needed guidance:

But that's what all the upper division students would tell me, "Just – just get through it. Just get to your upper division. Just keep fighting. Just keep working at it. And once you get to your upper division it's going to be a lot easier." So I think if it weren't for those friends that I had made who are upper division students, I don't think I would've done as well as I wanted to in the class afterwards.

Note that Elena's narrative is set when she is a lower division student, in a "weed out" course that may often lead to moments of uncertainty for many students.

Similarly, Gina, Briana and Juliet said that they relied on professors in moments of uncertainty. Gina said that she would often meet with her affinity group, and together they would visit the professor. A combination of these relationships signaled to Gina that engineering was the right space for her. She said that, when faced with difficult homework, she first worked by herself; followed by an internet search; then asked her friends; and, when doubts persisted, they asked a professor.

V. SIGNIFICANCE AND RELEVANCE

This paper contributes to the body of research on women's persistence and resilience in engineering, where they are significantly underrepresented. It confirms what other studies have shown, namely that gatekeeper courses posed a threat to these women's persistence in engineering [14]. However, the paper also adds new information regarding the ways in which successful women resolve and make meaning out of these experiences. Moreover, research has also shown that social support serves to curtail the loss of underrepresented students, particularly women, in STEM fields [17]. In this paper we drew on women's narratives to show the specific actors who

serve as support for undergraduates, namely their peer groups, professors and families.

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Making co-op work: An exploration of student attitudes to co-op programs

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Abstract— Engineering and computing at university both have a long tradition of co-operative education which plays a vital role in developing students' applied skills and giving confidence to both students and potential employers. Co-op education refers to relevant work experience integrated into a course. The main motivation for students in completing a co-op program, or *placement*, is in their increased employability skills; however, students cite other benefits such as increased interest in their subjects at university, improved grades on return from placement and support for career decisions. A study was designed to explore the reasons why students did not take a placement, and we considered both those students who tried but were not successful in securing a placement and those who did not apply for placements. The qualitative study revealed that students who applied but were not successful had in some cases limited their options by being selective in the placements for which they had applied. For some, it came down to excessive competition for the roles. For those that did not apply, stated reasons included anxiety about their abilities, sacrifices (such as giving up part-time paid work and apartments), concern about losing their study skills and difficulties in reconciling family and social commitments with the time requirements of full-time work. This paper explores the findings and asks how we can make co-op programs work for students.

Keywords— Professional Identity, Employability, Computing

I. INTRODUCTION

In the UK, there has been considerable interest in the prospects for computing science (CS) graduates when they leave university. A higher percentage of CS graduates are unemployed than the overall average. Indeed 13% of CS graduates are unemployed after 6 months, compared with engineering 9% and mathematics 9%, while the overall figure for all subjects 8% [1]. Undertaking a work placement during study has been found to enhance employability (for example [2], [3]). However, a recent report from the National Centre for Universities and Business (NCUB) highlighted the dwindling number of computing students undertaking placement, down from 30% to 26% [4].

Different models for student co-op programs or placements exist, however for the purpose of this study a placement is considered to be paid work with a company for a period of between 3 months and one year. The reduction in numbers taking a placement highlighted by the NCUB study relates

specifically to the 'standard' one year paid placement which normally attracts some academic credit, certainly some academic oversight for example, access to a placement tutor and pre-placement support. Before computing courses give up entirely on the one year model, which has been shown to be a good option for employers [5] the reasons behind the reduction in uptake should be explored.

This paper describes a study of second year computing majors at a Scottish university. The study was designed to explore the reasons why students did not apply for the one-year placement. Where students applied but were unsuccessful the study asked about their perceptions about why they had been unsuccessful to date in their applications.

II. BACKGROUND

The university has a one year paid placement which attracts academic credit, enabling students to graduate only 6 months after the non-placed students, and with significant industrial experience to complement their technical skills. The university places approximately 40 students every year which normally constitutes about a third of the second year student cohort. In addition, the university is active in a Scotland-wide paid placement project, e-Placement Scotland, designed to work with employers to create placement opportunities and advertise them across all Scottish universities and colleges [6]. These placements are most commonly 3 month summer placements and do not attract academic credit. The e-Placement Scotland project team organizes presentations at each university in Scotland with a view to promoting placements and explaining the application process. Project resources include an application website, CV advice and interview preparation techniques. The university itself encourages students to apply for both types of placement and to take part in pre-placement activity including CV workshops, mock interviews and mock assessment centers. To increase the quantity and quality of applications for placement, new interventions were designed. The main intervention was the introduction of a structured program, Placement Academy, run during the first semester, designed to prepare students to make applications and be prepared for interviews. Initially

there was a high level of engagement in the Academy events however attendance dropped off during the semester. The sample in this study comprises students who applied for placement and were placed, those who applied but were unsuccessful, and those who did not apply.

III. THEORETICAL FRAMEWORK

Student co-op education offers work based learning opportunities and has been found to be an effective way to provide relevant employment skills, experience and awareness of employer culture. The evidence that placements are valuable to students both in terms of employability and academic achievement is strong (for example, [4], [7], [8], [9]). Research suggests that student placements (at times referred to as work integrated learning, co-operative education and work based learning) enhance student skills, knowledge, competence and experience ([10], [7], [11]). Students gain relevant and paid employment whilst employers seek commitment, communication skills and specific aptitudes pertaining to degree type. Students who have taken a placement are at a distinct advantage over students who have not when applying for work after graduation [12]. Employers benefit from student placement too. Recent research suggests that graduate recruiters estimate 37% of graduate vacancies will be filled by applicants who have already worked for the organization as a placement student [13]. Employers cite other advantages including bringing new skills into an organization and having a specific task completed [5].

However, research in the UK shows there are declining numbers of students participating in placement [13]. Brooks and Youngson [12] suggest students do not see future remuneration in placements, 'long term benefits are not always appreciated with fewer students engaging in the process'. Lowden reports upon the high expectations of the employer, 'graduates need to demonstrate a range of skills and attributes that include team working, communication, leadership, critical thinking, problem solving and often managerial abilities or potential' [14]. His report acknowledges that these are often acquired through work placements and calls upon higher education institutions to create opportunities for student placements of 'significant duration' (p. 25). Docherty states that students are less geographically mobile than they were 20 years ago and are often unable to take placements that are too far away from their abode [13]. He further suggests that students are reluctant to move away from their cohort, and that they may need to maintain their paid employment and thus cannot risk a placement.

In a study of computing courses, declining participation rates were acknowledged in the National Centre for Universities and Business (NCUB) report, 'on average 26% of third year computing undergraduates- and 6% across all years – undertook a recorded work placement' [4]. In a study of higher education institutions in the UK, Banga & Lancaster found that placement staff cite a lack of motivation as the most significant factor (23% of respondents) in students not applying for

placement, followed by students not feeling prepared to apply (21%) and lacking confidence/ fear of rejection (21%) [15].

In terms of university interventions to prepare students for placement and encourage uptake, Feldmann and Sprafke note the lack of empirical research on how placement can be implemented effectively and they further point to the importance of longitudinal studies to gain deeper insights into student development of competences whilst on placement [16]. A longitudinal study following students onto and through placement into graduate employment may have benefits in providing reasons for students to participate.

Student motivations for taking a placement include to improve job prospects, support their career decisions and to earn money [5]. These are all positive reasons for students to apply. Less is known about the reasons behind those students who are eligible deciding not to apply and the factors that students themselves believe act as barriers to successful applications. Based on the literature review, the following research questions emerged:

(1) What reasons do UK students cite for not applying for a work placement? (2) What local and cultural issues lie behind students not going on placement?

IV. METHODOLOGY

A mixed methods approach was taken using both a quantitative and a qualitative approach. A questionnaire was designed, based on the findings of the literature review, to ask students in the second year of the course whether they had:

- **(Group A) Applied successfully for a placement:** students were then asked about the recruitment process and how they had prepared
- **(Group B) Applied but had not yet been successful in securing a placement:** students were asked about the number of placement jobs they had applied for and the nature of their applications to date
- **(Group C) No applications made:** students were then asked whether they had been actively engaged in the preparation activity and the reasons why they had not applied

Three separate questionnaires were used, based on the situation of each student interviewed. The questionnaire mixed factual questions about age, country of domicile and ethnicity combined with open questions about their experiences of placement. Specific questions were asked about a range of pre-placement activity that had been offered and about their experiences of applying. Placement data was uploaded to NOVI for analysis.

V. RESULTS AND DISCUSSION

During three separate interview sessions, all second year students attending class were invited to participate. In total, 71 interviews were conducted (n=71). Of these 19 had secured a placement, 18 had applied but had not yet secured a placement and 34 students had not applied for any placements. Overall,

90% of the participants were male, 10% were female; 63% of the participants were aged between 17 and 22, 26% were aged between 23 and 28; 10% were aged between 29 and 34 and; 7% were aged between 35 and 40. The characteristics of the three categories of students are given in Tables I and II.

TABLE I STUDENT CHARACTERISTICS: GENDER

Characteristics	Category		
	<i>Successful</i>	<i>No placement yet</i>	<i>Not Applying</i>
Female (n = 7) 10% of total	16%	11%	9%
Male (n = 64) 90% of total	84%	89%	91%
Total (n=71)	100%	100%	100%

TABLE II STUDENT CHARACTERISTICS: AGE

Characteristics	Category		
	<i>Successful</i>	<i>No placement yet</i>	<i>Not Applying</i>
Age 17-22	53%	50%	76%
Age 23-28	31%	17%	15%
Age 29-34	10%	17%	6%
Age 35-40	5%	17%	3%

Students were initially asked whether they had been aware of the possibility of placement before applying for the course. Of those that had applied successfully 53% had been aware, of those applying but not yet successful 56% had been aware. Of those that were not applying for placement 71% had been aware of placement opportunities. A larger percentage of students knew about placement but were not applying which suggests that publicizing opportunities for placement does not necessarily influence intention to apply for a placement. The data collected from each of the three categories is now explored.

A. Group A - Applied successfully

This participant group, who had applied and secured a placement, is of interest in this study as a means of comparing their responses with the other two groups. On average students in second year had applied for 4 placements.

Table III shows their responses to the question of whether they wanted to do a placement as part of their course.

TABLE III STUDENT RESPONSES REFLECTING PLACEMENT PREFERENCE

Statement	Student responses as %		
	<i>Strongly agree/ agree</i>	<i>Neither agree nor disagree</i>	<i>Strongly disagree/ disagree</i>
I wanted to do placement as part of my course	79%	21%	0%

Participants were asked about their level of engagement with the pre-placement preparation activity and 90% of students had attended placement presentations, the Placement Academy program or a mock interview with the careers service. Table IV reflects their engagement with preparation activity. Participants could select multiple activities.

TABLE IV STUDENT RESPONSES REFLECTING PRE-PLACEMENT ACTIVITY

Student responses as %			
<i>Placement Academy</i>	<i>Placement presentation</i>	<i>Careers Interview</i>	<i>No activity</i>
52%	52%	26%	10%

Students were asked if they thought there were any drawbacks to going on the one year placement and 17% said that graduating later than their peers was a drawback and 11% said that they would be out of synch with existing classmates. Childcare and 'current job retention' issues were mentioned but did not feature highly in this survey.

B. Group B - Applied but not yet successful in securing a placement

Students had on average applied for 6.5 placements and 63% had been for interview. Only one student said that he would not be applying for further placements. This student had already applied for 29 positions entirely through his own efforts and had instead decided to get some relevant work experience through a work-integrated professional practice course at the university. Taking this student out of the total placement applications, the average number of placements that had been applied for reduced from 6.5 placements to 5 placements.

Group B were asked whether they had wanted to do a placement as part of their program and Table V summarizes their results.

TABLE V STUDENT RESPONSES REFLECTING PLACEMENT PREFERENCE

Statement	Student responses as %		
	<i>Strongly agree/ agree</i>	<i>Neither agree nor disagree</i>	<i>Strongly disagree/ disagree</i>
I wanted to do placement as part of my course	94%	0%	6%

Participants were asked if they had taken part in pre-placement preparation activity and the responses are shown in Table VI.

TABLE VI STUDENT RESPONSES REFLECTING PRE-PLACEMENT ACTIVITY

Student responses as %			
<i>Placement Academy</i>	<i>Placement presentation</i>	<i>Careers Interview</i>	<i>No activity</i>
67%	50%	50%	17%

Asked about their motivations to apply for specific placements all students cited good experience and 83% mentioned future job prospects as a reason to apply.

C. Group C - No applications made

This group of students was also asked if they had originally wanted to do a placement as part of their course. The responses are given in Table VII.

TABLE VII STUDENT RESPONSES REFLECTING PLACEMENT PREFERENCE

Statement	Student responses as %		
	<i>Strongly agree/ agree</i>	<i>Neither agree nor disagree</i>	<i>Strongly disagree/ disagree</i>
I wanted to do placement as part of my course	41%	35%	24%

They were also asked about pre-placement preparation activity and their responses are given in Table VIII. When asked whether anything more could be done to help them be successful 35% mentioned advice related to the application process and 25% mentioned mock interviews.

TABLE VIII STUDENT RESPONSES REFLECTING PRE-PLACEMENT ACTIVITY

Student responses as %			
<i>Placement Academy</i>	<i>Placement presentation</i>	<i>Careers Interview</i>	<i>No activity</i>
26%	9%	3%	32%

The participants were then asked specifically why they had not applied for placement and their responses are given in Table IX. Students were able to select multiple reasons.

TABLE IX STUDENT PERCEPTIONS OF REASONS FOR NOT APPLYING.

Reason for not applying for placement	Percentage citing
Prefer to concentrate on degree	44%
Length of time taken to complete the course	29%
Already in work	29%
Placements not relevant to course	23%
Location of placements unsuitable	12%
Did not know about placement	12%
Not interested	12%
Unsure how to apply	9%
Value social interactions at university	9%
Financial reasons	6%

Table of student perceptions of reasons for not applying.

There was a chance to provide an explanation and students mentioned the following: worried about the level of knowledge that was expected of them, not yet ready and confident about applying and for some they had just arrived at university as direct entrants to the course and felt they had just become accustomed to the course and did not want to leave it so soon after arriving.

To reflect further on why the students had decided against applying we asked if students could see any drawbacks in undertaking a placement. Their responses are summarized in Table X.

TABLE X STUDENT PERCEPTIONS OF DRAWBACKS.

Drawback	Percentage citing
Length of time taken to complete the course	35%
No drawback	26%
Missing out on teaching	15%
Unprepared/ anxious	12%
Lose part-time work	3%
Finance – want to get graduate job	3%

When asked, in the future, what type of placement would suit them best, 82% of students stated that they would prefer a 3 month summer placement.

D. Discussion

Students in all three groups had participated in the pre-placement preparation activity and in all three groups over 40% of students had wanted to do a placement as part of their course. The group who expressed the biggest commitment to doing a placement were Group B who had been applying without success (94%).

This study shows that timing of the placement on a course is critical to student uptake. This echoes findings in the US [17]. It is clear from student responses that the one year placement following on from two years of study was a good model for students: they had consolidated knowledge and were more confident in their approaches to placement. Direct entry students either felt they were not yet ready or were concerned about leaving the course just as they had settled in to a study routine.

The findings contradict the perceptions of placement staff that students are not motivated, as reported in [15]. Instead there was anxiety about leaving the course (44%) and a perception that placement would be a distraction from concentrating on their studies (29%), with only 12% saying they were not interested in a placement. The following quotes from the study echo much of the sentiment surrounding placement uptake in year 2 of the course.

“It would increase course length overall. Could lack up to date knowledge relevant to course when you return”

“Worried about expected level of knowledge - didn't want to be unprepared, felt I lacked possible experience”.

Further to this, 29% of students note the problem of maintaining their current employment and issues with continuity, *“I was unsure how my work would be flexible about it”*.

Through analyzing data from all three groups it was apparent that certain advertised placements were popular and received many applications, and students were aware of the competitive nature of these placements. Although this did not deter students from making applications it was noted as a factor for failure to succeed. To increase their chances in a competitive situation participants stated that they would most value advice on making applications (35%) and gaining experience of interviews (25%).

When asked about the placements Group B participants had applied for, there was evidence of students being too selective in their applications. Most had applied for software development placements with specific and immediate benefit to their course of study, however many of the advertised placements related to IT support and network administration. Most of the companies mentioned were located in same city as the university.

In all groups there was a good level of engagement with the preparation activity (90% for placed students, 83% for those applying and 68% for those that were not applying). This preparation work included CV workshops, presentations from former placed students and mock interviews. Even students not applying found the activities useful and insightful.

E. Limitations of the Study and Further Work

The main limitation of the study is the focus on a single year of study. A further study exploring student attitudes across all years and the different geographical locations of placements would be useful in establishing more general claims for increasing placement uptake.

F. Recommendations

This study has highlighted the need for further research but initial observations for specific recommended actions would be:

- Encourage students to be less selective in their preferred roles by placing less emphasis on selection criteria when marketing placements.
- Encourage students to consider roles that are not specifically related to their degree choice.
- Continuation and further development of e-Placement Scotland and the Placement Academy program in terms of support offered to students.
- Look into offering travel reimbursement schemes for students who take a placement far away from their place of residence.
- Consider the possibility of childcare vouchers/ fund to aid the uptake of placements for students who have responsibility for dependents.

VI. CONCLUSION

Our study was designed to explore the reasons why students did not go on placement and our participants fell into three groups: those who had successfully applied, those who registered an interest and applied for placements but had not managed to secure a placement and finally those who did not apply for placements.

The study revealed that participants in all three groups engaged to some extent in preparation activity designed to increase uptake of placement. The study revealed that students who had not applied for placement had encountered both real and perceived barriers that included a preference to concentrate on their degree studies and, for the one year placement, the length of time taken to complete the course. For summer placements there was anxiety about their abilities, giving up part-time paid work and a lack of suitable placements available.

The experiences of students who registered an interest varied. Some students were overly selective in the roles they applied for, leaving only a narrow opportunity for a successful outcome. Some students had not undertaken the extensive preparation required for often quite complex and demanding application processes, while some students were simply unsuccessful through the selection process due to the numbers of applicants. The study captures rich data relating to each of these experiences

By capturing student perspectives, the study uncovers ways to increase participation in co-op education to the benefit of computing and engineering students. Two key elements are uncovered which can play an important role in increasing participation; communication of the benefits of situationally appropriate placements; and contextual pre-application preparation. While the data underpinning these elements

comes from students, the elements themselves are aimed at both students and employers.

The data from this survey highlights the local, social and cultural factors of running a student placement program. Diversity of placement options is crucial alongside knowledge of placement programs in a local context. It is essential to offer students considering a placement a high level of support and pastoral care.

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Perspectives on Volunteering for Initiatives for Women in Computing: a Case Study

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Abstract— Initiatives for women in computing exist since the 70's. However, little research has been done to study the effect they have on the women involved. Hence, this case study presents observations of the perceived value of the initiatives from the perspective of these women. This is a case study of one of the organizations contributing to this kind of initiative, the ACM (and its branch ACM-W), and how its volunteers see this work. The study is based on semi-structured interviews that were thematically coded and analysed. Results show that, depending on their generation, volunteers have different motivations and target their efforts at different audiences. Interviewees also reflected on how to further support women in computing. Finally, implications for future studies and lines of action are presented in the paper.

Keywords— Computing education, gender and computing, women in computing, voluntary work

I. INTRODUCTION

Women in computing, conscious and unconsciously, experience different difficulties during their career. Some of these issues are common regardless of the age range of the women, whereas others apply more to a particular generation. For this paper, we have chosen to follow the classification that Patitsas et. al used for their thorough presentation of the history of women in computing in the US. It is based on the time when women started their studies in computing: First Generation (60's-70's), Second Generation (80's-90's) and Third Generation (00's-10's). While the First Generation were *"simply getting on in a man's world"*, the Second Generation was preoccupied with *"being a woman in a man's world"* [1]. Members of the Third Generation, like the members of the other generation's, experience subtle unconscious bias: bias applied by people they interact with or by that member to herself, i.e. self-applied bias [1, 2, 3].

Women face these kinds of issues as students [4], as professionals in industry [5] and as professionals in academia [6]. Women may have to deal with an unpleasant and discouraging environment, e.g. women hitting the "glass ceiling", i.e. not being promoted to positions in the higher levels of their organizations. This has been known as "vertical segregation"[7]. These are some of the main factors for women

to quit their studies or jobs in the field: the issues accumulate and can cause a "death by a thousand paper cuts".

Low participation of women in computing results in a lack of diversity, which is very detrimental for organizations, as *"diverse teams are more effective: they produce better financial results and better results in innovation"*[8].

Thus, it is crucial that action is taken in order to support and keep women in the field. Initiatives for women in computing emerged (and continue emerging) as a response to this need. These initiatives were created mostly by women of the Second Generation, who shaped these movements primarily as a way to provide younger women with what they thought they would have needed when entering the field [1].

This paper introduces some perspectives from volunteers in women in computing initiatives on how and why women, not only from the Second but also from the First and Third Generation, are nowadays working together in the pursuit of gender equality in computing. Although these initiatives have been active since the 70's, little research has been done to study the effect it has on the women working in the initiatives. Our focus is on the particular case of the Association for Computing Machinery (ACM). After a summary of the background material in section II, we present the method chosen (section III) and some of the themes found in interviews with volunteers in the ACM (section IV). Finally, based on these results, we discuss future areas of work that aim at further supporting women in computing initiatives.

II. BACKGROUND

There are many organizations that aim at supporting women in computing. This paper focuses on actions taken primarily in North America and Europe, as issues faced by women differ depending on geographical area, e.g. low female enrollment rates in computer science is not an issue in some areas outside of our chosen regions [3].

There are organizations for women in computing that have been active for long and attract many women (and men), e.g. the Anita Borg Institute, opened in 1987 [1, 9], had the first

The Grace Hopper Celebration (GHC) of women in computing in 1994 [10]. In 2014, GHC had over 8000 participants [11].

In industry, companies are increasingly showing their concern about the lack of diversity in their teams by publishing their statistics related to their workforce (composed predominantly of white males) [12] and by starting different lines of action related to gender and computing. One of the latest examples of the latter is Google's campaign on unconscious bias [13].

In academia, universities are increasingly supporting initiatives related to gender and computing, e.g. by having committees focused on addressing gender-related issues (e.g. the Gender Equity Group at the Department of Information Technology at Uppsala University [14]) and by encouraging students to take part in student organizations focused on gender equity (e.g. the ACM-W Student Chapters, explained in more detailed below). Successful examples of program reforms and other changes may be found in the US, where universities such as Carnegie Mellon, Harvey Mudd and the MIT are seeing an increase in enrollment and graduation rates, thanks to their initiatives for women in computing, e.g. supporting female students to attend women in computing celebrations, and modifying study programs [15, 16, 17]. Similar actions have been taken in Europe, e.g. in Uppsala University [18].

Common ways of addressing issues related to gender and computing include providing women with scholarships and mentorship programs, networking opportunities (e.g. conferences, local groups, mailing lists), and positive female role models. These actions have been proved to be beneficial for their target audience [19].

The Association for Computing Machinery (ACM)

The Association for Computing Machinery (ACM) defines itself as *"the world's largest educational and scientific computing society, [that] delivers resources that advance computing as a science and a profession. ACM provides the computing field's premier Digital Library and serves its members and the computing profession with leading-edge publications, conferences, and career resources."* [20].

ACM-W, the ACM's council for women in computing, *"has been an active advocate for women in computing"* [21]. ACM-W's lines of action include the female student and professional groups network ("ACM-W Student/Professional Chapters"), a scholarship program for students to attend research conferences, and different kinds of support for the organization of regional celebrations of women in computing [21, 22]. ACM-W Europe is currently organizing the womENCourage 2015 Celebration of Women in Computing, an event that provides networking opportunities, role models and training in computing and gender-related topics [23].

III. METHOD

The qualitative study consisted of semi-structured interviews. 12 women that volunteer in ACM-W initiatives were interviewed.

The interviewees are the author's co-workers in her different roles as a volunteer within the ACM. This study was hence done with an insider perspective, conducted by one of the participants in the community: the author has in-depth local knowledge that was used for this case study [24].

The interviewees were grouped in the aforementioned generations: First and Second Generation (6 interviewees) and Third Generation (6 interviewees). We have made no division between the First and Second Generation, as several interviewees belonging to the former were -in some cases, also - studying in the late 70's and/or early 80's, thus making the division too blurry to be relevant to our study.

There was variety in the interviewed volunteers' experiences in voluntary work within the ACM, and in their knowledge of the actions that the ACM takes. This variety is related to the positions held within the organization: they ranged from roles in local representations of the ACM - by students at campus or professionals both from industry and academia (the aforementioned ACM Chapters)-, to senior professionals chairing committees at different levels and structures. All interviewees have participated in organizing a celebration for women in computing.

The core questions focused on why women join ACM-W initiatives, what was their experience as a volunteer and what could be done further, i.e. suggested future lines of action. Based on the answers, follow-up questions were asked.

The interviews were conducted mostly using videoconference. When not possible, email was the chosen alternative. They lasted 20 minutes on average and were all conducted in English. The researcher also took notes and recorded the interviews.

Notes from the interviews were read, and some themes were identified and assigned to categories. This was an iterative approach and the themes were refined with every iteration, which results in the final themes presented here. More themes will be identified following the same method.

IV. RESULTS

During the interviews, many different topics were raised. Work has, and still is, being done in further analysing the data and build on the conclusions drawn from it. Thus, the material to be presented in this paper had to be selected from the original available data set according to the following criteria: we have chosen to summarize the interviewees' statements on their motivation to join the initiatives, their target audience, and a few of their suggested lines of action. As, according to the interviewees themselves, there is a shortage of volunteer

time, we analyze what motivates volunteers and what they regard as relevant future work, in order to support focusing future efforts on increasing the attraction of supporters and collaborators of initiatives in women in computing.

Motivation

Almost all women stated the need to “*build a lasting sense of community, so that women no longer feel isolated and alone*”. Although the women of the Second Generation stated that they did not see low numbers in female enrollment during their studies, later in their career they did notice that “*too often, [they were] the only woman at the meetings at work*”. In contrast, interviewees of the Third Generation stated the low rates of female enrollment in their programs and, consequently, of a support network formed by peers that they found relatable: “*It’s fun to hang out with the guys but at some point you want to ask someone where to get a haircut and the guys can’t tell you that*”.

Women of both the Second and the Third Generation seemed to find their mentors a very valuable asset and a positive influence in their career, and thus they aim to provide the same for younger women: “*It’s not impossible to succeed in conditions with no role models and no support, but it’s very difficult.*”

Target Audience

When asked who they were doing this work for, or who they thought benefited from these efforts, interviewees referred to different groups. Another answer was “myself”: several women mentioned that they had developed different skills and broadened their network thanks to their participation in ACM-W’s initiatives. Some interviewees stated that efforts seem to focus on women doing their studies at a university level, though the volunteers also pointed out their work for women of the Second Generation and for a younger (the Fourth?) generation, mainly through -formal or informal- mentoring.

Proposed Lines of Action

It was commented that “*ACM-W succeeds tremendously well, with an all-volunteer staff.*” Due to the voluntary nature of the work, there was some concern related to the effort involved: “*[volunteers] donate service hours at a personal cost to themselves.*” It was considered important to reflect on actions aimed at “*prevent[ing] burn-out among project leaders.*”

Suggestions were discussed in the area of improving the organization in itself: training ACM volunteers in inclusive leadership and hiring paid staff to support the ACM-W volunteers were some of the ideas proposed.

The interviewees also commented on the need to broaden the scope of the current efforts, broadening the target audience to children and teenagers: “*raising awareness of the need to change the education system so that every child has the opportunity to be trained in computer science.*” Men should

also be involved in initiatives to support women in computing: “*after all, 80% of ACM members are men*”.

V. DISCUSSION

For this study, the author had an insider’s perspective as an ACM volunteer interviewing colleagues. This fact influenced the responses in aspects such as the level of detail in their explanations of ACM activities: the interviewees assumed that the interviewer already had most of this knowledge. Due to their collaboration in the organization, interviewer and interviewees had a more relaxed discussion than what may have been the equivalent of having a stranger asking the questions. This results in more honest answers.

If, according to our results, the motivation of these volunteers comes from the wish of providing themselves and others with a network, actions with this goal should be taken by relevant organizations, e.g. increasing the number of social events on and off campus for students, after-work activities for professionals. A network for whom? The Third Generation focused on the network at a university studies level, i.e. trying to get more female students in the field (and reducing their dropout rates), while the First and Second Generation also mentioned how important it was for them to have women breaking the glass ceiling and to establish a more gender-balanced environment at work.

A possible explanation of this difference is that the pool of experience from which the volunteers draw their material for mentorship and other related activities varies according to generation. As explicitly discussed with one of the interviewees, it seems very difficult to help women who are ahead of oneself in their career path. How could one know how to support them? The answer to this question is hard to find if we focus on advice and mentorship. However, other kinds of support, e.g. distributing information about events targeted at female academics, are possible for virtually any volunteer, regardless of age and level of experience. Reflecting on how to raise awareness of these alternative ways of volunteering for all volunteers is thus recommended.

Concerns related to volunteers potentially being burnt out may be addressed by the organization by including stress and time management in a volunteer training program. Another aspect of this plan, mentioned in the results section, is education related to inclusive leadership. This training may not necessarily be reduced to just the ACM: one way for other institutions to support initiatives in computing is providing similar training to the members of their community. However, our data shows concern about not only about time management but also about recognition: what value are we giving to work in initiatives for women in computing? Is the – lack of – recognition one of the factors that volunteers consider when deciding whether to devote a particular “free” time slot of their time to volunteering or to a different – more prestigious – activity? How is the organization where a

volunteer has a paid job supporting this volunteer's activities within, in the case of this study, ACM-W? Positive examples that answer this last question are flexible schedules that allow volunteers to attend ACM events, and even funding of a number of hours per week to work in gender and computing related activities.

Volunteering for initiatives for women in computing, and mentorship programs have clearly been seen by the interviewees as a great asset. How can organizations in industry and academia further support women and men for a gender-balanced environment? Having local initiatives, such as the aforementioned Gender Equity Group at the Department of Information Technology at Uppsala University, or a local ACM-W Chapter, provides women studying or working in an organization with a support group. It also allows them to take an active part in this kind of initiative, with the benefits stated above. Additional available options include, but are not limited to: funding attendance to celebrations of women in computing and - primarily for students - to research conferences, organizing local celebrations and networks, and providing the option to take part in a mentorship program.

The ACM provides institutions with material and support to start and maintain initiatives for women in computing. So far, women have been the main gender represented in the ACM-W team; the next logical step seems to pursue a mixed approach, i.e. targeting these efforts at both men and women. It could be argued that this is already underway. However, this is not a trivial step. Little has been studied about how to be a male advocate for women in computing: how do (wo)men perceive actions against sexism if they come from a man? What actions can a man take in order to "walk a mile" in the shoes of a woman in computing? It is crucial to involve men in initiatives such as the ones organized by ACM-W, as vertical segregation leads to a striking fact: most of the power in organizations is held by men. The inclusive leadership training mentioned in this section is one of the ways to provide men in these positions with the background necessary to support initiatives for gender equality in computing.

Although the ACM works on building the CS curriculum, our results show that volunteers believe that a more focused effort on educating younger students is needed in order for this target audience to be reached before it is too late.

Based on this study we suggest that future research in the area focus on the theory of communities of practice [25] and interpret how to build a better community for women in computing based on our results.

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Software Engineering Education –

Does gender matter in project results? – A Chilean Case Study

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Abstract— Teaching software engineering in a practical course in academia is considered one of the best strategies to help students understand what they will face in industry. Teamwork, coordination, communication are soft skills that are demanded in real life, but how to improve these courses to be more effective and yield better results is not clear. Software engineering – as with most computer careers – is known to be short on women, but the participation of women improves diversity to student teams. Women may have personal characteristics that are different from the ones we normally see among male software engineering students. Do, mixed gender software teams have better project results than one-gender teams? After assisting software engineering courses for four years, I observed mixed gender teams to be better. With this idea in mind I performed a case study where I analyzed the behavior and the results of software projects over nine semesters. The obtained results show that mixed gender teams were more effective and coordinated.

Index Terms— Software engineering education, gender influence, effectiveness, teamwork

I. Introduction

Software engineering (SE) is a discipline oriented to applying a systematic, quantifiable approach to the development, operation, and maintenance of software [1]. As any engineering discipline, it is tightly linked to the industry; therefore, the software engineering curricula used in computer science programs need to prepare students for the world of industrial software development [2].

Fox and Patterson [3] pointed out that while new college graduates are good at coding and debugging, employers complain about other missing skills that they think are equally important (e.g. working with non-technical customers, working in teams, etc.). The usual faculty reaction to such criticism is that they are trying to teach principles.

It is well known that the industry needs people able to work in teams to develop and maintain software. However delivering young professionals that are proficient in technical and operative issues is a great challenge for educational institutions [4] [5] [6] [7]. Begel and Simon [8] pointed out that universities are striving to prepare students for the industrial

scenario and to become lifelong learners, able to keep pace with the software engineering advances. Typically the universities tend to adequately teach the technical aspect of software engineering, but do not address operative issues such as managing projects/risks, defining/adjusting software processes, and performing teamwork.

Teams are the basis of software development organizations today, since the challenge and complexity of projects has made software projects unachievable for individuals. In this setting, professionals are not only required to have state-of-the-art knowledge and technical abilities. It is assumed that software will be built in cooperative and diverse teams, but the reality of software engineering teaching is sometimes different. Effective teamwork requires mastering specific abilities, such as leadership, coordination, conflict management and other skills. This implies that if higher education wants to meet the requirements of the students' future professional lives, it has to address the acquisition of such and have the technology to support the transference process. [9].

The participation of women in science, technology, engineering, mathematics programs and careers is disproportionately lower than that of men [10] [11]. Zeldin and Pajares [12] showed with a comparative study that social persuasion is one of the primary sources of self-efficacy beliefs for women in technology fields of study.

Women and men may have different goals when they participate in project-oriented courses; women's goals are more oriented towards teamwork and peer learning, than men [13]. In environments that are male-dominated, however, social learning strategies such as help seeking can be perceived as weakness [14], which may create situations that negatively influence the motivation, self-efficacy, and future engagement of students. Project-based learning presents opportunities for the pursuit of social learning goals, and evidence suggests that hands-on project activities contribute positively to the learning and satisfaction of both men and women [15].

Women are normally under-represented in IT educational programs and in the IT workforce [16]. But specifically in software engineering, there is not much reported on the gender difference. Nelson [17] stated in a recent article that diversity is important and that woman in computer science in general are

not encouraged to pursue a computer science degree. He also speaks about some case studies that helped increase the participation of women. Diversity needs to be increased and stimulated in all areas because it results in diverse points of view that are needed to solve different problems. In Chile, our reality is not formally known; there is only anecdotal information about gender subjects, with few factual data reports.

At Universidad de Chile, we teach software engineering using a hands-on methodology where students have to develop their projects and deal with the client in their own way. Of course they are not just thrown to the lions (clients). The lions are known (inside clients) and they have full support of the instructor's team.

In order to identify if there is a difference among the results of software engineering projects in academia related to gender, two hypothesis were proposed: mixed gender teams are more coordinated (H1), the participation of women in software engineering teams makes teams work more effective (H2).

In this case study I will show that software engineering teams that have female participation as team members are more effective and have better odds of achieving positive results.

II. Background

The wide use of technology creates very complex situations that professionals in IT need to be able to manage [19]. Typically, most of the situations that engineers find in practice differ from those they found previously. Therefore, engineers must be able to use engineering concepts that they have learned during their education to create solutions for real-world problems [4]. However, it is well known that the software industry is usually unsatisfied with the level of real-world readiness possessed by new engineering graduates entering the workforce [4] [20] [21].

Parnas [22] defined three steps required to produce software engineering programs: (1) define the possible tasks that a software engineer is expected to perform, (2) define a body of knowledge required for the software engineer, then (3) transfer such knowledge as a training program. This definition clearly identifies the need for transferring the most important knowledge to the students and also the skills required to use it in future developments. This definition is aligned with the role that Denning states for software engineers [4]. These definitions suggest that we need to address two main challenges: (1) identify and transfer the key knowledge to the students, and also (2) encourage students to develop the skills required to apply such knowledge in real-world work scenarios. According to Parnas [20] [21] [22], these challenges should be addressed through hands-on experiences that expose students to some frequent problems before they become stranded on their own.

There are also other researchers that identified challenges on other aspects of the transference process: teaching software processes with traditional methods (expositive lectures) [23] [24], educational challenges [25] and features of the development process or evaluating the work performed by the students [2] [26].

According to the selectivity hypothesis [27], males process information in a heuristic manner – paying attention to cues that are highly available and salient in the context. Females process information in a comprehensive manner, attempting to assimilate all available possibilities. In our problem solving and project development, the selectivity hypothesis implies that males and females will respond differently to different insights, which should impact problem-solving decisions. These differences imply that the information, the environment presents and how the environment presents information will impact on decisions and on how females and males interact and contribute to a project.

In this work, coordination will be measured as a coordination self-efficacy measure, where we define self-efficacy as the strength of belief that one can complete a task. The role of self-efficacy is especially pronounced for women in engineering programs [28]. In the social cognitive theory model of self-efficacy proposed by Bandura [29], three factors that contribute to self-efficacy are identified: mastery experiences, vicarious experiences (i.e., identification with role models) and social persuasion (positive feedback from others). Mastery experiences, of course, are what educational experiences generally seek to specifically provide.

Project-based courses reflect authentic engineering experiences as they facilitate a sense of domain mastery and thus lead to an increase in engineering self-efficacy [30]. Self-efficacy is also closely related to motivation, as a student's confidence directly impacts his/her course of action [30, 31]; self-efficacy in engineering and related domains is a prerequisite for both choosing an engineering major and persisting in it [28, 20]. Finally, engineering self-confidence and self-efficacy can vary with demographics; they are notably lower for women than their male counterparts [32, 32]. There is evidence that men show increases in self-efficacy (across a range of constructs) after taking project-based courses, particularly those in which they build a physical prototype, but no similar evidence was found for women [3].

III. Related Work

Glass [34] points out that when he entered the workforce in the late 50' there were no shortage of women practitioner's, but in the middle 80's something changed and the rates of women entering the computer science field in general dropped out. And we are still suffering and seeing that. In South America, things seemed to be a little bit different. Although there is no official data to refer to, people that were working in the field back in the day when computer science began in Chile, report that there was a shortage of women since the beginning.

Some authors propose single-gender classes as one of solutions for this issue [35] [36] [37] [38]. They report that one-gender classes make males or females perform better on overall courses. But all these authors were talking about courses in general and not about project courses, where students have to deal with each other and have to face the reality of dealing with a client. The main idea of the software project courses is to simulate the reality of what they will face

in real life when they start working in industry. In real life it is not feasible to choose to work just with one gender.

The Credit Suisse Research Institute [39] reports on an extensive analysis demonstrating the importance of having diversity on almost all company levels. In their investigation they even report that companies that have females on their board perform much better than companies that have only male board members

Burnett [40] reported an evaluation about the pluralism of gender related to spreadsheet use (feature-related confidence, playful exploration and usage in general). Her results show that there are differences in gender and that mixed genders completed each other in terms of accomplishment than one-gender teams.

IV. Experimentation Scenario

One of the last two software engineering courses at the computer science program at University of Chile is Software Engineering II (CC5401). It is a mandatory class for fifth year students (out of a six-year undergraduate program). For this study we monitored teams during nine semesters. The primary goal of this course is to teach students software engineering in a "hands-on" way, by resembling an industrial setting.

Students are put in teams of 4 to 7 students, according to their capabilities by a MBTI based tool, in use in the last five years [41]. Each student chooses the role they want to have on the team, and if more than one team member want to perform the same role, students have to agree among them.

The projects are real projects that have real clients and a problem that can be solved with information system software that should be addressed in the 15-week course time frame. The students must arrange weekly meetings with their clients and the course have four milestones where they have to deliver something tangible. In the first milestone, they must explain that they understood their client's problem, and show a mock-up solution of the software. In the second milestone they must show a demo of the software with the basic features that the client required. With the third milestone they must show the demo of the full software. And finally in the last milestone, they must deploy and deliver the software to the client. In each one of these milestones, the instructor evaluates student's presentations and the client evaluates the demos. After evaluations, students receive a grade between 1 and 7.

Teams are also supposed to use an iterative development lifecycle in each one of their milestones. And during the iterations they have to produce documents regarding user requirements, software requirements, design specifications, test cases and integrated tests.

In this context there are some challenges that are not minor, and they put some restrictions in our context such as:

- Type of student - 5th year students, neither used to and not prone to working in teams.
- Small projects - since the course has only 15 weeks, the projects need to fit this short time frame of development, and all the projects should have equivalent average size (around 100 function points).
- Real clients – clients are internal to the university, they

normally do not expect much of the project, and they do not fully commit with it.

- Technology – most projects are brownfield ones, meaning that students do not have much of a choice in the technology that will be used in implementation of the solution.
- Type of project – all developed products can be classified as Web information systems, and typically the complexities are similar.
- Roles – each team has defined roles (project manager, analyst, designer, developer and tester) and, depending of the size of the team, there could be more than one team member with the same role.
- Product quality – to guarantee the quality of the product, students should use some of the software engineering best practices and provide quality verification.

Trying to help students minimize these challenges, students have to meet their monitor weekly, and the monitor is someone outside the evaluation team. Students are assured that anything they say to the monitor will not have repercussions on their grades or on instructor perceptions of their team. Monitors lead the meeting, asking the students questions according to the milestones. They also assist students with guidance in technical and social problems that they may have. Monitors do not tell teams what they should or should not do. They are not project managers, coaches or scrum masters.

In this work, nine semesters of the software engineering course are reported (from 2010 until 2014). In total we had 151 students and only 16 of them were women (10.60%), 27 teams were formed and just 10 of them had women's participation. And due to the lack of women it was not possible to set up a software engineering team of women.

Methodology

In order to assess the students' self-efficacy (coordination), a formal peer-review assessment was conducted. Such assessment have been used and evolved in this course over the last seven years. The assessment determines how well each person fits with the behavior expected from a teammate. The students were assured that all opinions would be anonymous and that there would be no formal grades given based on that peer- assessment process.

The instrument used to perform the peer-reviewing process considers eight items that should be rated. The rates were indicated using a five-point Likert scale (from 'strongly disagree' to 'strongly agree') [42]. The evaluated items were the following:

1. He/she assumes the project as a team effort, providing support in project tasks.
2. He/she is able to seek help when problems are found.
3. He/she fulfills his/her tasks properly, working transparently and generating the most value out of each working day.
4. He/she demonstrates initiative to achieve project success.
5. He/she shows a communicative attitude facilitating the teamwork.
6. He/she has maintained good communication with client, generating value to project execution.

7. He/she demonstrates interest in improving performance on the execution of his/her activities and role within the project.
8. He/she is able to admit to mistakes and accept criticism.

These questions are interpreted through five concepts: commitment (1, 2), communication (4), coordination (5), attitude (3, 7, 8), contribution (2,6). These five concepts are our reading and interpretation on what is relevant to teach software engineer. Given the nature of the collected data, a research approach inspired by the grounded theory was chosen to conduct this study. According to Glaser and Strauss [43] grounded theory is the discovery of theory from data systematically obtained from social research.

In order to analyze the effectiveness of the teams, and validate our second hypothesis (the participation of women in

software engineering make teams work more effective) I took into consideration the final grades of software projects, considering mixed and non-mixed gender teams and the deployment and use of the software (successful project) as measures. Provided that the instructor, teaching assistant, course content and dynamics did not change during the observed semesters we can consider these teams comparable.

V. Results

Figure 1 shows women participation during the nine semesters being reported. Only sixteen female students enrolled in the software engineering course during the period being observed (approx. 10.6%).

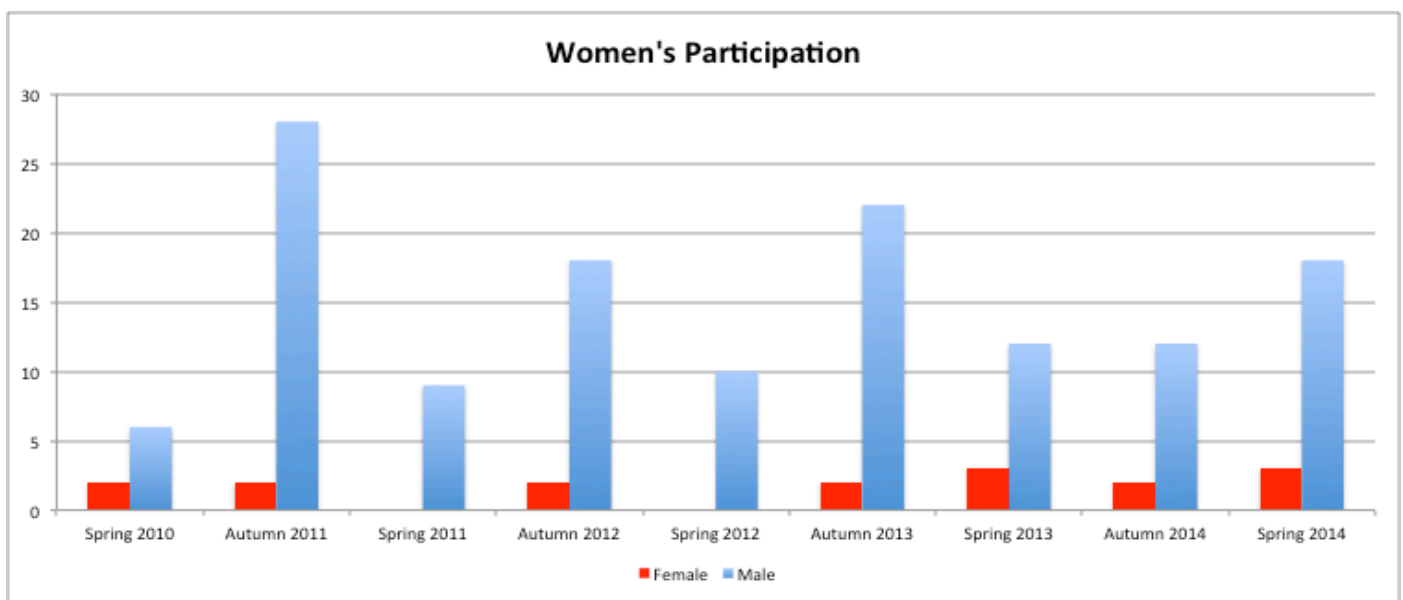


Figure 1 – Women's participation

A prior analysis of grades was performed with the students that were enrolled in these nine semesters to check if the female participants generally performed better than the males (in terms of grades). Only two female students were among the top students, and 15 male students that participated in this research were among the top students. We can say that the amount of top women participating in this sample is comparable with the amount of women participating in this sample.

In order to evaluate first hypothesis (teams that have women as team members are more coordinated) we used the results of the peer-reviewing process, as a way of self-efficacy perspective. Because they represent the teammates opinions, which probably are more accurate than the instructor, teaching assistant or monitoring opinion.

Figure 2 shows the obtained results for the peer evaluation and the concepts derived from the peer evaluation questions.

The results indicate that our hypothesis is aligned with the results that mixed gender teams have better coordination (in terms of self-assessment) than male only teams. The difference between mixed gender teams and male teams is 0.81; mixed gender teams are 20% higher in terms of self-perception than male teams. The other concepts have differences but they are not so significant as to be statistically valid (commitment 9.7%, communication 7.8%, attitude 9.6%, contribution 9.4%). The median of the concepts of the male teams was: commitment 5, communication 5, coordination 4, attitude 4, contribution 5 and collaboration 4; for the mixed gender teams the median values were: commitment 5, communication 5, coordination 5, attitude 5, contribution 5 and collaboration 5.

Looking in the roles performed by women in projects, there is no clear tendency; the women performed all the team roles that we have (project manager, tester, analyst, designer and developer); the only role that have just one female was the

designer; all the other have proportional female participation. So, the women roles are not a relevant data to our results.

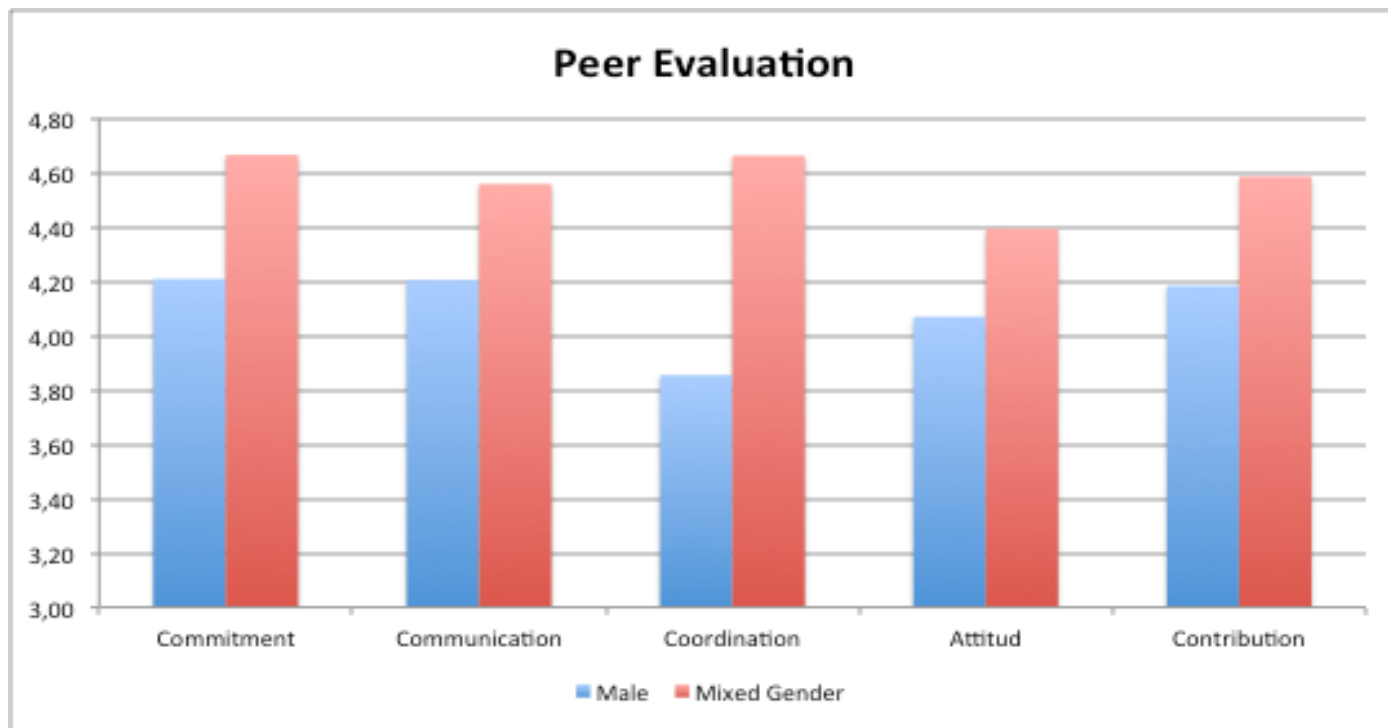


Figure 2 - Peer Evaluation

To analyze our second hypothesis (H2 - the participation of women in software engineering teams makes teams work more effective) the project grades and the software deployment were taken into consideration.

Figure 3 shows the project grades and the course final grades for male teams and mixed gender teams. The grades of mixed gender teams are 16% higher when we are talking about project grades and 13% higher when we are talking about final grades.

Figure 4 shows the project results. It also shows which projects were successful and which were used by the client (deployed) for the mixed gender teams. Figure 5 shows the same for the male teams.

The mixed gender teams have 10 projects. From these, 9 of them were deployed resulting in a success rate of mixed gender teams of 90%. The male teams have 17 projects and only 7 were implanted, so the success rate of male teams was 42%.

We conclude that the second hypothesis is aligned with our results, and that the participation of women on software engineering teams makes teams work more effective (H2).

In order to ensure that the data source used in this study is valid and reliable, the Cronbach's Alpha coefficient was calculated from the eight questions of the peer-review form, from the 138 respondents (total of 151 participants) and we had

a Cronbach's Alpha of 0.82. The closer Cronbach's Alpha coefficient is to 1.0 the greater the internal consistency of the items is in the scale. According to Gliem and Gliem [44], a value of Cronbach's Alpha of 0.8 from Likert-type scales is good and is considered a reasonable goal.

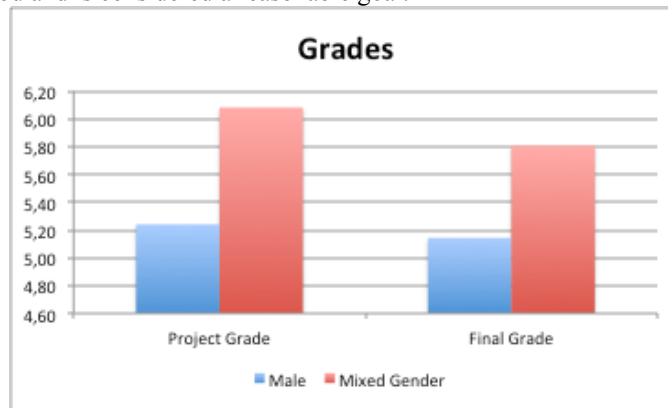


Figure 3 - Project grades

Mixed Gender Teams									
Year	2010	2011		2012		2013		2014	
Semester	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring
Team 2	✓								
Team 5		×							
Team 9		✓							
Team 11				✓					
Team 16						✓			
Team 17						✓			
Team 19							✓		
Team 21							✓		
Team 24								✓	
Team 27									✓

Figure 4 - Project Deployment for Mixed Gender Teams

Male Teams									
Year	2010	2011		2012		2013		2014	
Semester	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring
Team 1	✓								
Team 3		×							
Team 4		×							
Team 6		✓							
Team 7			×						
Team 8			×						
Team 10				✓					
Team 12				✓					
Team 13					×				
Team 14					×				
Team 15						×			
Team 18						✓			
Team 20							×		
Team 22								×	
Team 23								✓	
Team 25									×
Team 26									✓

Figure 5 - Project Deployment for Male Teams

VI. Threats to Validity

Analyzing the threats to validity of this case study, we found that the internal validity within the course is not a problem, since students may respond differently at different times. But, each time a student takes the course the project will be different. Cronbach's Alpha shows that there is consistency in the answers of students. The major threat regarding the conclusion validity is the quality of the data collected. The students are expected to answer the peer review assessment in the most truthful way, but sometimes students took the comrade behavior, and did not evaluate a colleague properly. Another threat is the project grades. To minimize this threat the grades are given by instructor, teaching assistant and client/user. The construct validity has one threat; the subjects are part of a course, where they are graded; this implies that the students may bias their data, as they believe that it will give

them a better grade. To minimize this threat at the beginning of the course the instructor stated that the peer review was voluntary and anonymous.

VII. Conclusions

In this paper we have described a case study comparing the results of mixed gender teams and male teams in student software projects in academia. Two hypotheses were proposed: mixed gender teams are more coordinated and are more effective. The results show that in our context our hypotheses are aligned with the outcomes.

This paper has two main contributions: unfortunately, we found that female participation in software engineering (CS degree) is not so different from studies in other countries [45]. The paper also contributes to finding that the mixed gender teams can improve the results of software engineering teams in academia. This is reportedly happening in other areas. Mixed-

gender teams offer more coordination and focus to student teams, help them focus their efforts on what really matters.

Mixed gender teams in software engineering education improves the results of software engineering teams in academia. Students learn to work on real-world projects with substantially better results.

The next step considers a more in-depth study on the gender subject, analyzing the recorded data from team meetings, an evaluation of which skills are increased in a mixed gender software teams in academia and why mixed genders perform better in terms of self-efficacy.

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Work/Family Attitudes of Computing Graduate Students

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Abstract—Work/family conflict is often cited as a concern for attracting and retaining talent in professional careers. STEM careers have been noted as particularly discouraging to professionals, especially women, for work/family concerns among other reasons. However, little research has explored the work/family attitudes of prospective professionals in these careers. This paper explores the work/family attitudes of graduate students in computing. Based on data from the Computing Research Association's (CRA) Center for Evaluating the Research Pipeline (CERP) 2011-12 nationwide survey of 1286 computing graduate students, our analysis explores at the aggregate and by sex, the connections between graduate computing education, work/family issues, and career expectations. The analysis of the data reveals work/family issues are important to those in advanced education planning careers in the field. Computing graduate students are strongly influenced by work/family issues in their decision-making regarding advanced computing education. Graduate computing students report high levels of knowledge of work/life strategies and express confidence about their abilities, and their likelihood, for balancing work and family. These findings should help graduate educators and prospective employers concerned with diversity understand the work/family concerns of computing students and future computing professionals.

Keywords—gender in computing; work/family attitudes; computing education; computing careers.

I. INTRODUCTION

Work/family conflict is increasingly cited as an area of concern for attracting and retaining talent in professional careers [1]. STEM careers have been noted as particularly discouraging to professionals, especially women, for work/family concerns among other reasons [2]. However, little research has explored the work/family attitudes of prospective professionals in these careers.

To address the lack of research in this area, this paper explores the work/family attitudes of graduate students in computing. Based on data from the Computing Research Association's (CRA) Center for Evaluating the Research Pipeline (CERP) 2011-12 nationwide multi-institutional survey of 1286 computing graduate students, our analysis examines at the aggregate and by sex, the connections between work/family

issues, graduate computing education, and career expectations. The analysis assesses several work/family influences on choosing graduate education. In addition, this study examines computing graduate students' knowledge of strategies to balance work and family and the level of confidence they have in their abilities to employ these strategies in their own lives. The findings of this research should help educators, employers and others concerned with diversity understand the work/family interests of current and prospective computing students and future computing professionals.

II. LITERATURE REVIEW

A. Gender, STEM Education and Career Intentions

A variety of important features of social and educational institutions steer women away from pursuing education and careers in STEM fields including lack of accurate career information, lack of encouragement, and gender and occupational stereotypes [3, 4, 5, 6, 7, 8, 9, 10]. Recent research suggests that work-family issues may be among those important aspects discouraging women from education and careers in STEM. Research on educational and career choices in STEM fields proposed a negative relationship between family-focus and interest in pursuing STEM education and careers for all students and, especially, for women [11, 12, 13, 14]. Other research [12] finds that concern over work/family balance issues in STEM occupations increases relative to non-STEM occupations as women proceed through college.

These findings suggest that students who persist in computing will exhibit less influence than most students from issues related to family concerns or other issues about balancing work with other aspects of life. Moreover, women in computing would be less concerned about work/life issues than the majority of women, and those in the more advanced levels, such as doctoral study, would be least concerned. Women with concerns about work/life issues likely would be filtered out of computing before even starting, or as they progressed through levels of education.

B. Work and Family Research

Prior theory and evidence suggests that work/family concerns impact students and professionals as they navigate through educational and career domains [15]. Some of this

work argues this impact is gendered; that men and women have different concerns and influences on their choices to pursue further education and professional careers [15]. Family-related issues, such as caregiving responsibilities and other family-oriented matters are perceived as an important aspect of female gender roles. As women enter previously male-only domains in the public sphere such as advanced education and professional careers, the private sphere often remains a female-dominated domain [16]. Even though younger generations have shown a more dual-centric (career and family) focus [17], when these spheres collide, women are more likely than men give primacy to family issues [18].

Computing is an interesting field in which to explore these issues. As a profession, computing suffers from serious underrepresentation of women [19]. Despite an especially positive job outlook, only a small proportion of those choosing to study computing at the undergraduate and graduate level are women [19]. Even fewer women choose to pursue careers in the field [20].

Recent research reveals many women in computing careers face difficulties in the workplace. One study showed a high rate of attrition for women who start computing related careers in the private sector. Hewlett et al. (2008) found that over 50% of women are gone within 10 years due to, among others issues, a masculine culture of work environments and the excessive time requirements of the work [2]. Also disheartening is that half of these highly qualified women leave their positions for jobs outside their STEM field [2]. It is these concerns about the prospects for work/family-friendly careers that may add to the propensity of women to opt out of pursuing further education and to choose alternate options for careers, even amongst those who have persisted in computing to the graduate level. Further salience of work/family issues is revealed in a study of female STEM faculty which argued that the institution of meaningful work/life policies would likely lead to greater satisfaction and, thus, retention of female scientists in academia [21].

Computing and other STEM careers are not alone in suffering from the loss of women due to work/family issues. Work/family balance issues have been cited as major factors in pushing women out of other professions such as law, medicine and business [22, 23, 24, 25, 26]. Research has also suggested that work/family concerns have influenced women to opt out of areas of study leading to careers in fields they perceive as incompatible with their family aspirations [1]. Given that work/family issues have affected professionals in other careers what impact, if any, might these concerns have on graduate students as prospective professionals in the field of computing? Do computing graduate students differ by gender in their focus on work/family issues?

III. HYPOTHESES

We hypothesize that work/family issues will be important to the majority of computing graduate students. If gendered expectations relating to work/family issues exist, we would expect to find that women are significantly more likely than men to report the influence of family/personal responsibilities and lifestyle on their decision to pursue graduate education in

computing. Similarly, if work/family gender differences maintain we would find women citing greater knowledge of work/life balance strategies and expressing significantly more concern, and less confidence than men, in their ability to achieve work/life balance.

IV. DATA AND METHODS

The data utilized in this analysis comes from the Computing Research Association's (CRA) Center for Evaluating the Research Pipeline (CERP) graduate student survey. Distributed during the spring of 2011 and 2012, the survey was completed by 1286 graduate students completing their degree program during the academic year from a broad range of computing departments at universities across the U.S. (N = 96 departments). We define computing departments as those offering graduate degrees in a computing discipline, including computer science, computer engineering and information sciences. A list of sampled institutions is available upon request.

The CERP survey assesses graduate students' professional experiences, their knowledge about professional development and the strength of their professional network as they progress towards a career in computing. The goal of the survey is to have students reflect and report on their experiences in their degree program; and to gauge students' plans for the future. These data allow us to explore at the aggregate and by sex, the influence of work/life issues on computing graduate students including the influence of family and lifestyle concerns on their decision to pursue further education, their knowledge of work/life strategies and confidence in their ability to achieve work/life balance.

We operationalize the measures of work/family focus as follows:

Education:

Family Concerns

- Did family or personal responsibilities discourage or encourage you in choosing to seek, or not to seek, a PhD in computing?

Lifestyle

- Did having the kind of lifestyle you want discourage or encourage you in choosing to seek, or not to seek, a PhD in computing?

For both education questions, respondents were given a scale from 0 = Not Answered, 1 = Strongly Discouraged, 2 = Somewhat Discouraged, 3 = Somewhat Encouraged, 4 = Strongly Encouraged, 5 = No Influence/Not Applicable. The resulting data were recoded so that "No Influence" = 0, "Any Level of Influence" = 1, and "Not Answered" = missing.

Careers:

Knowledge:

- Rate your current knowledge of strategies for work-life balance?

For the knowledge question, respondents were given a scale from 1 = None, 2 = Almost None, 3 = Some, 4 = Quite A Bit, 5 = Don't Know/Not Applicable. The resulting data were recoded so that "Some/Quite a Bit" = 1, "None/Almost None" = 0, and "Don't know/not applicable" = missing.

Confidence:

- How confident are you that you can successfully develop a satisfying work-life balance?

For the confidence questions, respondents were given a scale from 1 = Not At All Confident, 2 = Only Slightly Confident, 3 = Moderately Confident, 4 = Very Confident, 5 = Don't Know/Not Applicable. Resulting data were recoded so that 0 = "Not at all or Slightly Confident" (formerly 1 and 2) and 1 = "Moderately/Very Confident" (formerly 3 or 4). A response of 5 was set to missing.

Analyses of our key variables were performed on respondents replying to the gender question. This specification resulted in 727 valid cases for analysis, 517 men and 210 women.

V. RESULTS

Results from the CERP graduate student survey show that male and female graduate students in computing are remarkably similar in their knowledge and confidence related to career and family domains. Despite literature suggesting gender differences on work/family issues for prospective professionals in demanding careers, the data suggests no significant or substantial gender differences exist.

The descriptive statistics of the CERP Graduate Student Survey sample show a demographic profile of computing graduate students that is largely in line with the averages for graduate computing students at American universities. As Table I shows, they tend to be young and mostly male (a median age of 27 years old, 71% male).

Table I also specifies the family and caregiving status of respondents. The median age of graduate students is 27, about the age and time in their life cycle when they are starting to form families. 38% of respondents are either married or in a long-term committed relationship and 11% have the primary caregiving responsibilities for at least one child. Interestingly, there are no significant gender differences in those reporting primary child caregiving responsibilities (10.2% and 12.9% for men and women, respectively.)

While not affecting the majority of graduate students, work/life balance issues played a direct role for a substantial minority in the constraints placed on pursuing a career in computing. For instance, 23% of respondents reported that dual career concerns and the need to coordinate with a spouse/partner's job location constrained their own job search.

TABLE I. CERP GRADUATE STUDENT DEMOGRAPHIC PROFILE

	N	Categories						
		Men				Women		
Gender	727	71%				29%		
Age	693	Median Age of Respondents						
		27						
Race/ Ethnic	744	Hisp. Descent	White	AA	Nativ e Am	Asian	Pac. Islander	Other
		3%	41%	3%	1%	51%	.3%	3%
Family Status	726	Married/LT Relationship				Primary Caregiver of Children		
		38%				11%		

A. Work/Life Balance and Computing Careers

1) Knowledge of Work/Life Balance Strategies

Graduate students in computing rate their knowledge of work/life balance strategies high, with 84% of all respondents reporting they have "Some or Quite a Bit" of knowledge regarding work/life balance strategies. Knowledge in this area ranked sixth, behind knowledge in a range of job search elements such as resume writing (95%), job searching (93%), knowledge of career next steps (93%), job application knowledge (93%) and time management strategies (86%). Graduate computing students reported their knowledge of work/life balance strategies exceeded their knowledge in other key areas pertaining to their prospective careers such as developing a professional network (72%), effectively using that network (64%), working productively with a mentor (64%), effective teaching strategies (61%), negotiating a job offer (59%), mentoring students and interns (58%), finding their own mentor (53%) and their knowledge of the tenure process (51%). Knowledge of work/life balance strategies was ranked much higher than a variety of important career related factors. Less than half of computing graduate students reported knowledge of supervising students and interns (48%), new faculty expectations (47%), and appropriate volunteer opportunities (45%). The majority of graduate students reveal a lack of knowledge in research related matters such as developing research collaborations (44%), starting their research programs (41%) and obtaining research funding (34%). Contrary to expectations, there were no significant differences evident between men and women in their knowledge of work/family balancing strategies. As shown in Table II, more than four-fifths of men (83%) and women (87%) report that they have good knowledge of this important area of their life. Neither analysis of variance nor correlations showed any significant or substantial difference in the knowledge men and women have of work/life balance strategies.

TABLE II. KNOWLEDGE OF WORK/LIFE BALANCE STRATEGIES

	Male (% knowledgeable)	Female (% knowledgeable)	Correlation between gender & knowledge
How would you rate your current knowledge of work-life balance strategies?	83%	87%	-.05 two tailed significance = .27

2) Confidence and Work/Life Balance

Confidence runs high for graduate students. In general, graduate students report a high level of confidence for a variety of factors pertaining to their prospective computing careers. Graduate students see themselves as confident in setting career goals (87.4% saying they are moderately or very confident), managing their time (85.9%), planning steps for achieving their career goals (84.9%) and finding a job (83.9%). Out of the twelve factors, confidence in developing a satisfying work/life balance ranked as the fifth highest area of confidence (82.8%). Confidence in work/family balance ranked higher than confidence in other areas such as getting promoted on time (77%), developing professional networks (72.2%), teaching classes (66.9%), mentoring students (64.6%) and negotiating a job offer (62.6%). Graduate students pursuing research careers in computing had the least amount of confidence in their research prospects with 41.9% reporting confidence in starting up their research program and only 36.5% showing confidence in gaining research funding. Neither analysis of variance nor correlations showed any significant differences in the confidence perceived by men and women regarding work/life balance. Table III shows that approximately four-fifths of the women and well over four-fifths of men in this sample reported confidence in their ability to develop a satisfying work/life balance.

TABLE III. CONFIDENCE IN DEVELOPING SUCCESSFUL WORK/LIFE BALANCE

	Male (% confident)	Female (% confident)	Correlation between gender & confidence
How confident are you that you can develop a satisfying work-life balance?	84%	79%	.06 two tailed significance = .15

B. Work/Life Balance and Computing Education:

CERP respondents were asked a series of questions regarding influences on their decision to pursue graduate education in computing, ranging from the influence of undergraduate advisors to immediate employment opportunities. On average their strongest influences on educational decision-making were “the kind of work I want to do” (84%) and “the kind of lifestyle I want” (80%).

1) Influence of Family/Personal Responsibilities

Table IV shows that family/personal responsibilities played a role for the majority of students continuing in computing

further education (67%). Both men (67%) and women (68%) report these factors as an influencing their choice to seek a PhD in computing. According to both an analysis of variance and correlations, there are no statistically significant differences between males and females in relation to the influence of family or personal obligations on their decision-making related to pursuing a PhD in computing. The relatively high percentage for both males and females reveals the importance of this factor for the educational decision-making of computing students.

TABLE IV. INFLUENCE OF FAMILY/PERSONAL RESPONSIBILITIES ON DECISION TO PURSUE PhD IN COMPUTING

	Male (% influenced)	Female (% influenced)	Correlation between gender & influence
Did family or personal responsibilities discourage or encourage you in choosing to seek, or not to seek, a PhD in computing?	67%	68%	-.02 two tailed significance = .70

2) Lifestyle

Lifestyle concerns exert an important influence on PhD education choice. A majority (80%) of graduate students report their desired lifestyle was important for their choice to seek a PhD in computing. Analyses of variance and correlations reveal no statistically significant gender differences with respect to the importance graduate computing students placed on lifestyle issues when choosing to pursue advanced computing education. Here again the relatively high percentages for men and women (81% and 75%, respectively) reported in Table V suggest that these are concerns that influence most prospective computing professionals.

TABLE V. IMPORTANCE OF DESIRED LIFESTYLE ON DECISION TO PURSUE PhD IN COMPUTING

	Male (% influenced)	Female (% influenced)	Correlation between gender & influence
Did the kind of lifestyle you want discourage or encourage you in choosing to seek, or not to seek, a PhD in computing?	81%	75%	.06 two tailed significance = .16

DISCUSSION

The results show that male and female graduate computing students share largely the same influences on their decision-making regarding their intentions to seek a PhD in computing. Similar to undergraduate computing students [28], men and women graduate students do not differ in their perception of the role that family/personal responsibilities or the role that desiring a particular lifestyle played in their decision-making regarding pursuing graduate education.

Work/family issues matter to computing graduate students. Graduate students report a high level of knowledge about work/life balance strategies and have confidence they will be able to enact these strategies to achieve a satisfying work/life balance in their computing careers. No substantial differences exist between men and women on either levels of confidence or knowledge about work/life balance strategies.

CONCLUSION

Work/family issues are important to computing graduate students. This research shows work/family concerns influence both male and females in similar ways. Gender differences in work/family influence, knowledge and confidence do not appear in computing graduate students. These findings suggest that either gender differences have been overstated and/or STEM fields such as computing effectively filter out those with even higher levels of interest in balancing work and family. Further research comparing computing students who choose not pursue graduate education with those who do would illuminate whether or not significant differences exist in these populations with regard to gendered attitudes toward work/family issues. As evidenced by the results of this study, we suspect that those with very strong interests in work/life balance are filtered out of the field before reaching graduate level studies.

The findings from the present study reveal that work/life issues are of interest to the majority of prospective computing professionals, both women and men. Educators, employers and others interested in attracting and retaining more and diverse students into computing would benefit from taking these factors into account in their recruitment and teaching strategies. Stressing the availability of high quality, flexible jobs that allow for opportunities to develop a satisfying work/life balance would address some of the myths and negative stereotypes often associated with computing careers.

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Student evaluations of team members: Is there gender bias?

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Abstract—The ability to work effectively in teams is a critical learning outcome for engineering students. It is also among the ABET requirements and a skill desired by employers for it is integral to innovation, product development, and to a positive working environment. Many engineering courses provide students with opportunities to develop their team skills through projects, in-class activities, and other assignments. Peer assessment of team skills increases student accountability to teammates, helps students gauge what is expected from them, and assists instructors in assigning course grades; however, there are few studies examining whether gender bias occurs during peer assessment. This work aims to fill this gap, identifying whether gender bias exists in students evaluations of their team members. This study examines whether there are differences in how students evaluate team member course performance based on that team member's gender. We used a randomized experiment inviting 590 first-year engineering students to rate and evaluate a fictional team member. Using identical vignettes, except for the character gender, participants were asked to rate the fictional team member in terms of their skills and qualities. The results indicate that there is no difference in how students evaluate the fictional team members by gender; although there was some evidence of higher scores given to females on their contributions and punctuality. This absence of gender bias supports previous findings and open other research questions about the differences identified. As well as the evolution this absence of biases during the students' educational experience. These results suggest that peer assessments may be an effective method to provide students with additional feedback regarding team skills.

Keywords—team skills, peer evaluation, gender bias

I. INTRODUCTION

The engineering profession requires the interaction of multiple agents to develop integral solutions to problems. Engineers first must consider final users when designing such solutions. Furthermore, since the engineering expertise tends to be specialized, engineers from different disciplines have to work together to build better solutions. All this implies that the engineer must have the skills required to work in teams. This has derived on the authorities of the field recognizing teaming skills in engineering as a required characteristics of our graduates. For example, ABET has detailed that engineering graduates from its accredited programs must have “an ability to

function on multidisciplinary teams” [1] and the National Academy of Engineering has cited that “engineers need to work in teams to be effective” [2].

The ability to work effectively in teams is also a desired skill by employers. Teaming has been denoted as an integral part of product development, process improvement, and manufacturing activities [3]. Organizational researchers, have pointed out that teaming combines connection between people, listening of the views of others, coordination of actions and cooperative decision making; and this process involves the development of affective and cognitive skills which result essential to the success of organizations [3]. Edmondson [4] have stated that teaming is crucial to innovation because the teaming process brings together different participants to produce something new, their different skills and expertise can be enhanced with their interactions and therefore attain superior results.

Engineering undergraduate courses provide students with opportunities to work in teams. Borrego et al. [5] presented a literature review on how the knowledge about teamwork that has been derived from industrial and organizational psychology have permeated to the engineering education arena; and to what extent this interaction has been successful. The authors concluded that through the use of findings from psychology, engineering and computer science instructors can be able to develop strategies to minimize negative behaviors in teams and positively influence student teamwork outcomes. Shuman et al. [6] considering the extent to what teaming and other ABET required skills were prone to be taught and assessed, argued that project-driven classes, if properly structured, could teach students the necessary skills to work in teams effectively.

One strategy that has been used to measure the effectiveness of this training on teaming is peer-evaluation [7]. However, few is known about the interaction of these evaluations and other characteristics of the team members such as gender. In order to use peer-evaluations as a reliable way of measuring gains in teamwork skills, these evaluations should be first free of any bias. This work analyzes the extent to what students generate a biased evaluation of their peers based on their gender. Our research questions are:

A) Is there any gender bias on the preference to work in teams?

B) Which are the reasons that students give for choosing or not choosing working with students in teams?

C) Do students rate men and women differently in regard to performance on teams?

The evidence gathered here will help on designing strategies to teach teamwork skills in engineering education effectively considering any existing effects due to gender.

II. LITERATURE REVIEW

Most professions nowadays need their practitioners to be good team members. Therefore it is a skill that should be developed in the training of such professionals. Areas such as management, business and healthcare [8-10] rely heavily on the teamwork skills of its practitioners. Engineering is not the exception, since it requires a high level of interaction with either customers, other engineers, or other professionals.

In engineering education, students are exposed to different venues where they are able to increase their teaming skills. Since their first year, students are required to work in group projects [11], and this evolves up to more relevant endeavors such as capstone projects [12]. To ensure the effective learning of teaming skills among undergraduate engineering students, they need feedback on their development of these skills. One strategy to attain this is the use of peer assessment. Some of the advantages of using peer assessment include: increase of students accountability to teammates, prevention of "social loafing." Peer assessment also helps students know what is expected of them and how they will be evaluated [7]. Furthermore, it has also been documented that the use of peer assessment helps instructors addressing potential team issues [5, 13].

Other advantage of the use of peer assessment for instructors, is that it provides an additional measure of individual student's contributions to group work, therefore helps on the assignment of grades [7, 13]. Since grades can have significant implications for students in terms of their eligibility for programs or scholarships and future employment, it is important that the influence of peer assessment in their grades is as objective as possible.

Gender bias has been documented in a wide variety of working and academic situations. Snipes, Thomson and Oswald [14] presented an empirical investigation where they found gender bias in the evaluation of service quality, favoring males with higher evaluations. Other research analyzed whether there existed a gender bias in teaching evaluations of faculty members given by students. Even though there was no evidence of such bias, the author was able to document evidence that female faculty members were "subject to culturally conditioned gender stereotypes," since female professors were expected to offer higher levels of personal support than male professors [15]. An experiment performed by Moss-Racusin et al. [16] showed a strong evidence of a gender bias favoring males students when applying to laboratory position. The results pointed out that the female

students were seen as less competent by faculty reviewing the applications. Some other randomized experiments have proved the existence of gender bias in academic and professional settings. An study presented by Milkman et al. [17] showed evidence of gender and racial bias made by professors at U.S universities when it comes to reply to potential PhD students. Professors had a higher response rate favoring white males and lower rates of response to females and minorities.

This evidence of gender bias in different types of evaluations makes relevant to analyze the gender dynamics of peer assessment in student teams. Many research efforts have explored this effect already; however, their conclusions about the influence of gender on evaluations of others still show mixed results.

Different studies have identified a negative effect of gender, favoring male over female students. Scherpereel and Bowers [18] analyzed this dynamics in a junior level business class and reported that women team members self-rated themselves significantly lower than men after receiving peer feedback. In a controlled experiment, Heilman and Hynes [19] tested the level of credit given to women in a fictitious male-women dyad carrying out a project. The students assessing the dyads evaluated the female members as less competent, less influential and less likely to lead during the execution of the presented results, unless the ambiguity of the given information was reduced.

Also at the undergraduate level, some other works have reported an absence of gender bias in peer assessments of contributions to group work. Kaufman, Felder and Fuller [20] explored the differences between given and received ratings by gender in a peer rating system implemented among two chemical engineering courses at the sophomore level; their results concluded that there were no significant difference between the received ratings or the given ratings by gender, i.e. women and men received and gave similar mean ratings.

Falchikov and Margin [21] performed a meta-analysis of forty-eight quantitative studies in peer assessment. The authors compared the ratings given by the students and those given by the teachers across all studies and found a high correlation between peer and teacher marks. In a follow-up study the authors explored the effect of gender bias and found very small effect sizes when comparing the levels of peer assessment obtained by gender [21]. Tucker [22] explored the existence of bias in online self and peer assessment tools, with the analysis of 1,500 participants at two universities and following the methodology created by [21] they found no gender bias in six case studies, although in some of the cases they found also significantly higher ratings given to women when compared to men.

This contradictory evidence motivates this research to assess the level of gender bias in peer assessment at the

undergraduate level among engineering students. It is envisioned that the results obtained here will help shaping the educational experiences to overcome these barriers on teaching teaming skills.

III. DATA AND METHODS

The participants on this study were 590 first-year engineering students at a large research university in the Midwest. They were surveyed during a class of the first-year engineering program. The students were given vignettes about a fictional team member. The vignettes were identical, except for the name of the fictional team member, which was varied by gender. These vignettes were developed based on actual feedback from prior peer assessments from the students in previous editions of the course. An exemplar of one of the four vignettes used and its corresponding change in gender is shown below:

“Emily/Steve is an enthusiastic and helpful team member. She/He attends meetings on time and contributes to completing assignments. Lately, Emily/Steve has been distracted by a personal problem. She/he has missed 3 of the last 5 meetings. During the 2 meetings she/he attended, she/he spent most of her time texting...”

Two other names (Xin and Sanjay) were used to reflect the culturally diverse body of students at the school, ending up with a total of 4 names combined with 4 vignettes, and also The students were then required to do an evaluation of the fictional team member using a Likert scale for some characteristics. As well as expressing their interest on having the fictional member in their team and their reasons for it. The questions presented to them were:

Would you want to have a team member like [fictional team member name]: (Yes/No)

Why or why not? (Open-ended)

Please rate [fictional team member name] on the following items: (Likert Scale: 1-5)

- Is a reliable team member.
- Is a trustworthy member.
- Attends meetings regularly.
- Attends meetings on time.
- Contributes to completing the team’s assignments.
- Increases the quality of the team’s assignments.
- Creates a positive experience for other team members.

Information about the age or gender of the participant students was not available, but the collection of this information is envisioned as an improvement in future research endeavors. The final distribution of the male and female vignettes across students is detailed in Table I, where it can be seen that the amount of male and female vignettes distributed were comparatively close to each other (42% and 58% respectively). The vignettes were distributed randomly across students in a selected group which make this a quasi-experimental design.

TABLE I. DISTRIBUTION OF THE MALE AND FEMALE VIGNETTES.

Vignette Gender	Frequency	Percentage
Male	246	42%
Female	344	58%
Total	590	100%

We used data from this evaluation to verify if there was any gender bias on the preference of working with the fictional team member, and how he or she was graded. Results to our research questions are presented in the following section.

IV. RESULTS

This section describes the results to each of the research questions posed previously, the statistical tools used and specific considerations for each analysis are mentioned in each corresponding section.

A. Is there any gender bias on the preference to work in teams?

Since the vignettes were identical except for the name of the fictional team member, students were asked: *Would you want to have a team member like [fictional member name]?* Their answers only had two classes (yes/no) and when accompanied with the vignette gender classes, generated the cross tabulation presented in Table II.

A Chi-Square test failed to reject the hypothesis of independence between the gender of the vignette and its selection as a team member (Chi-Square test = 0.0134, P-value = 0.908). Therefore, there was independence between the gender of the vignette and their willingness to work with the fictitious student, i.e. they were equally willing to work with either the female and male fictional members. This supports Tucker’s [15] results about the absence of gender bias when using peer assessment. Absence of data about the gender of the students answering the evaluation limits further analyses by subgroups, such as identify if this lack of bias is consistent across male and female rater students.

TABLE II. CROSSTABULATION OF VIGNETTE GENDER AND PROPENSITY TO WORK WITH THE FICTIONAL CHARACTER.

		Want on Team		
		No	Yes	Totals
Gender	Male	144 (41.5)	102 (42)	246
	Female	203 (58.5)	141 (58)	344
	Totals	347	243	590
		%	58.8	41.2

Note: Quantities in parenthesis represent percentages within the No/Yes classes

B. Which are the reasons that students give to chose working or not working with students in teams?

1) Thematic coding of open-ended responses

When asked about why they accepted or rejected having a team member as the one described, they reported reasons related to the fictional member characteristics and also related to their own perception of the situation. This section describes the themes identified for either accepting or rejecting working with the fictional team member.

a) Reasons for Yes

When analyzing the 243 cases of yes, i.e. accepting working with the fictional member, 29 codes were identified, but only three of these codes were more recurrently mentioned (~50). The most prevalent code was that the fictional character “will try harder/improve,” followed by the fictional team member was “helpful” even though he/she was not collaborating as usual or expected anymore. The third most recurrent code was that the fictional member “still contributes” to the team. From these codes we observe that students agreeing to work with the fictional member put a higher weight on the first part of the description they received, and have the hope that he/she will be able to perform to those standards again.

Other characteristics the student mentioned about the fictional member to defend their decision were that he/she was enthusiastic and hard-working, and that “things happen” showing empathy for what the fictional teammate was going through. Figure 1 shows the word cloud obtained from the coded themes from the open-ended responses. No further analysis considering the vignette characteristics was performed.



Fig. 1. Wordcloud of reasons for yes.

b) Reasons for No

According to the open coding and thematic analysis of the open responses of the 344 students reporting that they would

not like to have the fictional member in their team. The most recurring code was the fictional member “poor attendance” with 145 occurrences. The second most mentioned code was that the fictional student “does not contribute/work” (102 students). The code with the third highest number of mentions was that the fictional student was not able to “separate work and personal life” (84 students).

Opposing to the arguments used by students accepting working with the fictional team member, those unwilling to work with him/her were more focused on the second part of the information provided. They did not make a tradeoff between the previous contributions of the team member but made the decision of continuing working or not based on his/her current situation. Also, the reasons for no mentioned by students, were more highly cited concurrently rather than alone, and the variety of reasons was also higher than those reasons mentioned for the yes. Figure 2 contains the word cloud generated with the codes for the students that did not want to work with the fictional member.



Fig. 2. Wordcloud of reasons for no.

It could also be argued that the main codes were based on information listed in the vignette (poor attendance, does not pay attention, does not participate, is helpful). However, there were many other codes where students extrapolated the information they received to more complex situations with particular consequences. For example, those accepting on working with the fictional member mentioned things such as he/she will try to improve and that the situation he/she lives is unfair. While those rejecting working with the fictional member cited things such as an extra load of work for the other team members, or causing bad scores due to his/her disengagement.

C. Do students rate men and women differently in regard to performance on teams?

To test this question we compared the ratings given to the fictional team members in the questions presented in the methods section, they included: reliability, trustworthiness, attendance, punctuality, contributions to team assignments, increments in quality of team assignments, and their creation of a positive experience for other team members. The general mean scores in each area are illustrated in Figure 3. The highest scored area was punctuality while the lowest was attendance, which was consistent with the vignette descriptions. The mean scores by gender are not presented here, since for the purposes of comparisons we chose to work with medians, due to the non-normal nature of the data.

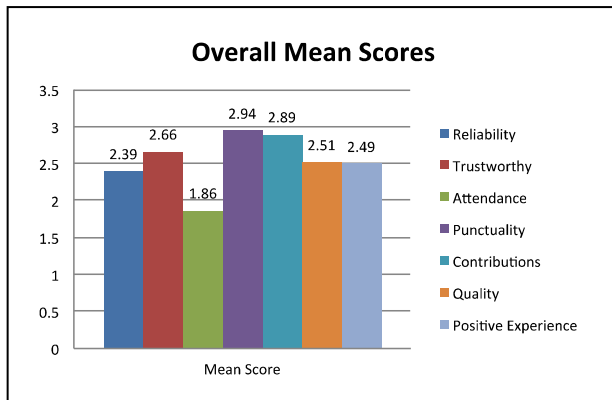


Fig. 3. General scores of the vignette characteristics.

The evaluations were made in a Likert scale (1-5, where 5 was the highest possible). We used a Mann-Whitney U test for the comparison of medians. This tool uses the mean sum ranks to compare the median score levels between males and females. The summary of the different tests for each of the described characteristic is presented in Table III. According to these results the only significant difference in the evaluation of students by gender was contributions (p -value<0.05) and punctuality (p -value<0.10). The identified differences favored females with a higher mean rank sum. Therefore, students gave better scores to females when compared to males in their contributions on team assignments and slightly better scores in punctuality to group meetings.

TABLE III. STATISTICS RESULTS OF THE EVALUATED AREAS BY GENDER

Evaluated Areas	Mean Rank Sum		Test Values		
	Males	Females	U	Z	p-value
Reliability	303.2	289.9	40415.5	-1.014	0.311
Trustworthiness	299.1	291.1	40881.5	-0.607	0.544
Attendance	303	290.1	40457	-1.015	0.31
Punctuality	280.4	305.4	38621.5	-1.845	0.065
Contributions	276.4	306.4	37569.5	-2.268	0.023
Quality	286.9	299.8	40128.5	-0.987	0.324

Positive Experience	306.9	287.3	39492.5	-1.469	0.142
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Effects sizes ranged from 0.024 to 0.093.

From these results we can see that women were better evaluated in contributions and punctuality. Since there was no evidence of a bias in the students' preference to work with the fictional member based on their gender, we also analyzed if there were any existing differences in the given scores depending on the student decision to work or not with the fictional member. In other words, if the student have decided not to work with the fictional member, we would expect the student giving lower scores to him/her.

From this analysis, the medians comparisons resulted as expected, most of the evaluated areas had lower scores for the fictional members that were not selected than those selected. The only area where there was no difference when considering their selection status was punctuality, i.e. the median evaluation for punctuality was not significantly different between the fictional members selected than those that were not selected. Our results support each other; having no difference in the evaluations of punctuality between selected or not selected fictional team members is consistent with the fact that even though there were some differences between males and females in punctuality scores there did not favor the selection of females better than males.

V. DISCUSSION

The absence of gender bias in our experiment is consistent with Tucker's [22] findings, whom reported effect sizes in the same range than those found here. A possible explanation for this may be related to the fictional nature of the team members presented. It has been shown that the nature of the commitment and the time span of a team project influences the students' efficiency communicating and making decisions [23], therefore, a lack of real commitment perceived by students may relate to the results obtained.

Also, Alfonseca [24] have reported that the different learning styles influence the efficiency of people when working in teams. Awareness of these differences can make place to being more permissive when working in teams.

Other possible scenarios for obtaining these results may be related to previous evidence about women working styles. Reference [23] have reported that women prefer to work in teams, therefore the perception of this trait can be reflected in the lack of differences among genders. Besides preferring it, women have also been reported as being better team players [23], which can be perceived by their peer evaluators. These propensity, perceiving women as more prone to work in teams and good at it, can also hide some leniency errors [7]. This would be an interesting area for further study.

Also, the only significant difference implied better scores for women in contributions and punctuality. Considering contributions, this is an insight that actually contradicts existing literature [19] that have pointed out that males are better rated in their contributions to the team. In terms of punctuality it is possible that a gender stereotype is influencing this results.

Among the limitations of this study is the lack of background information about the rater students. Having their gender, age or other descriptives would help on identifying any particular effects within particular groups. For example, identifying any existing bias supporting groups of the same or opposite gender as the rater. Also, the students underwent a teamwork training as part of their preparation for their first year in the program, therefore there may exist some mixed effects due to this training, and it would be interesting to have the assessment made before this training is given to verify if the present results hold.

In addition, there was a limited amount of vignettes and fictional team members to combine; increasing the amount of combinations could help on strengthen the results presented. This could include more names from ethnically diverse backgrounds, or vignettes with different proportions of good and bad information about the fictional team member. Finally, the fact that the students rated fictional members could have influenced the rater students' thoughtfulness to make their decisions. Therefore, we acknowledge that the fictional nature of the task may have an impact in our results.

VI. CONCLUSIONS

This work aimed to identify if there was any gender bias present when first-year engineering students decided if they wanted to work with a fictional team member or not. Based on quantitative analyses of our data, we conclude that there is no gender bias when accepting or rejecting to work in teams with these fictional members. Students accepted and rejected males and females fictional team members in approximately the same proportions. However, the rater students' gender was not known to analyze further relationships between their gender and their proclivity to accept or reject fictional team members of the same or opposite gender.

Students accepting to work with the fictional team member were more focused on the positive information they were given in the vignette. On the other hand, students who were not willing to work with the fictional team member were more focused on the information about his/her negative experiences, circumstances or actions which were presented secondly in the vignette. Students accepting the fictional team member were more empathetic of his/her situation, while students rejecting the fictional member usually projected their behavior as having negative consequences for the whole team.

We analyzed the scores given to the fictional team members in terms of their reliability, trustworthiness, attendance, punctuality, contributions, quality and positive experience, and there were no significant differences in their median scores by gender for most of them. The only areas where females were scored higher were contributions and punctuality. This opposes to Heilman and Hynes results [19] and at the same time that could be a signal of the presence of some gender stereotypes that usually judge women as more responsible than males when they are evaluated under the exact same circumstances.

VII. IMPLICATIONS AND FUTURE DIRECTIONS

Our results support the conclusions made by Tucker [22] about the absence of gender bias in peer assessment. However, at the professional level there is still evidence that some gender bias exist within professional organizations [25]. This discrepancy between the results obtained among college students and those drawn from professional practitioners call for further analysis about the evolution of gender bias attitudes among students. It is necessary to start unpacking the reasons why is this persisting if the training experiences of our students give other evidence. It would be interesting to explore if at some point the transfer of "unbiasedness" from the collegiate experience to the post-graduate professional experience is not happening. A promising strategy to start analyzing this inquiry would be to generate longitudinal analyses that would allow to observe the trends and changes among students during their college life and their experience after graduated.

Other strategies that could be explored is the connection of teamwork efforts in class with work in industry. It has been documented that it is required that the training of our engineers needs certain level of fidelity where we connect "the similarity of the training situation to the students' present and future working conditions" [6]. Other future directions in this line include the analysis of working teams in industry to verify if the gender bias reported by literature holds when it comes to peer assessment. Making connections between classroom teaming skills and professional engineering practice is essential among our graduates, and this is why we suggest that more inquiries in this line are necessary.

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Women in STEM: The Impact of STEM PBL Implementation on Performance, Attrition, and Course Choice of Women

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Abstract—Women are underrepresented in STEM fields, and their attrition from the STEM pipeline begins in high school. In this study, the performance, attrition, and course selection of women in mathematics and science subjects were examined in a school where STEM Project Based Learning was introduced. A four-year longitudinal study was conducted. Data from high-stakes tests, course taking patterns, and retention were examined. Results indicated that these women's scores improved in mathematics and science, and more females opted to take physics than did males. Moreover, female student attrition was lower than that of males and decreased markedly after the introduction of STEM PBL to the classrooms. These results indicate that implementing STEM PBL activities in classrooms is promising for improving female participation in STEM.

Keywords—STEM, gender, Project-based Learning, high-stakes tests

I. INTRODUCTION

The purpose of this study was to examine how science, technology, engineering, and mathematics (STEM) project based learning (PBL) affected the success of high school women in mathematics and science using a four year longitudinal study. PBL and cooperative work have been linked to an increase in motivation [2,3]. Moreover, advanced course taking practices in mathematics and science have been shown to influence the pursuit of a post-secondary STEM career [4].

The driving question focusing this study was: Are there differences between the males and females in achievement, retention, and course selection before and after their teachers implemented STEM PBL activities over a four year period?

A. Women and STEM

The number of people who received a STEM degree in college has declined in the United States. The percentage of STEM degrees awarded in the United States in 2002 was less than the average for STEM degrees awarded outside the United States [5]. Interest in STEM and the pursuit of STEM careers have been deemed vitally important in the preservation of the United States' role as an international leader and innovator [6]. Within the United States there was a disparity between the number of women and men in STEM majors and professions [7]. Women comprise over half of the population in the United States, yet they have been underrepresented in STEM professions. While women have gained nearly equal employment in many non-STEM professions, such as law (47.62% women) and business (41.45% women), they have remained a minority population in STEM careers, such as engineering (20.94%) and computer science (20.56%). Women, if interested and engaged in STEM, could play a major factor in positioning the United States and themselves for greater opportunities.

The increased involvement of women in STEM professions could have benefits for women on an individual level as well as for the nation as a whole. Students who graduated with degrees in one of the STEM fields reaped the benefit of higher paying jobs with those employed in STEM professions earning 26% more than their peers earned in non-STEM professions [8]. Employment opportunities were also better for STEM professions with projected job growth of STEM related careers at 17% by 2018 in comparison to 9.8% for non-STEM careers [8]. The nation could benefit from greater female involvement in STEM professions because women could offer a new voice and perspective within these predominantly male fields [9]. The fact that the number of STEM degrees, particularly in Computer Science, Engineering, Mathematics, and Physics,

have been overwhelmingly earned by men, indicated that there was a large segment of the population within the United States that could be engaged in STEM [10]. The focus then turned to answering questions of when and why women have chosen to not pursue STEM careers as well as what can be done to remedy this issue.

Identifying the time period in which women's interest began to shift away from STEM is important in determining the point at which the greatest gains can be made. In early grades the scores of boys and girls on science and mathematics standardized tests were equivalent [11]. Additionally, it has been shown that women's STEM achievement levels did not differ much from men's achievement levels in middle school [12]. In high school, the gap between men and women's performance on mathematics and science related assessments has become evident. When considering scores from 42 countries participating in the Program for International Student Assessment (PISA), males were found to perform better than females in mathematics and science [13]. The percentage of males outscoring females in high school mathematics and science has decreased in the past 30 years, but unfortunately the difference between scores of males and females has remained fairly stable for the last 20 years [14]. While many state tests mandated by No Child Left Behind have shown that the gender gap has been minimized or erased, these tests were also shown to fail to evaluate the complex problem solving skills required to be successful in STEM majors and careers [15]. The international differences in gender performance and the somewhat inconclusive results on state tests have forced researchers to more heavily investigate what was happening (or not) in high schools that may be further indicators as to why there existed a gender gap in STEM professions.

Apart from standardized testing, the type and number of advanced courses taken in high school can be an indicator of student ability and interest in subject areas. Students who completed challenging coursework in high school were more likely to complete a college degree [16], and those who completed Advanced Placement¹ mathematics were more likely to major in STEM related fields when compared to those who did not complete the courses [17]. In 2013, 49% of Calculus AB and 41% of Calculus BC test takers were women, but women were still a small minority of the total number of students who took Advanced Placement Computer Science A (19%), Physics B (35%), Physics C: Electricity and Magnetism (23%), and Physics C: Mechanics (26%) courses [18]. The choices that women made in high school about the advanced coursework that they completed gave insight into why the number of women who earned undergraduate degrees in mathematics was similar to the number of men who earned mathematics degrees, while a large gender gap was still evident for computer science and engineering degrees [19]. High school was evidently a turning point for many people, and in particular for women, in their ability and pursuit of STEM course work.

After high school, the gap between men and women in STEM professions was solidified by selection of a major. The

percentage of women entering STEM fields after high school was much lower than the percentage of men entering the same fields [20]. Adding to the gap, women were more likely to switch from a STEM major to a non-STEM major during their first year of college when compared to their male peers [21]. For those who took more STEM courses, women's attrition rates were higher than men's rates [22]. While some STEM majors such as Biology saw a minimal difference in attrition rate, others, such as Computer Science, saw an extreme drop in the proportion of women [21]. This loss of students in STEM majors was considered to be a "leak" in the STEM pipeline and was a loss of potential innovation and leadership.

Women either avoided or dropped out of the STEM pipeline for various reasons. Stereotype threat was identified as a factor that may have inhibited the success of women in quantitative STEM pursuits. Stereotype threat caused an individual to act in a stereotypical way, regardless of their ability or interest, in order to preserve the group stereotype and his or her membership in it [23]. The negative implications of stereotype threat became evident during standardized test taking, in which women who were faced with challenging mathematics problems may have begun to doubt their ability to successfully answer them because of the stereotype that cast women as inferior math students. Stereotype threat can reduce the achievement of students on standardized tests even if they were academically gifted [23]. Informing women about stereotype threat was shown to be an effective means of reducing the achievement gap between men and women on mathematics tests [24]. Women who fell prey to the stereotype that math was for men could view themselves as outsiders in their math classes. While men looked forward to mathematics classes, women did not feel very comfortable in mathematics classes, were usually afraid to ask questions [25], and were less confident in their ability to do mathematics [26, 27]. Following stereotypical gender paths could force capable women out of the STEM pipeline.

While the stereotype that math is for men may prevent capable women from pursuing STEM, general differences have been found to exist between men and women that could have made a career in STEM less appealing to women. Women were found to be more interested in people and social life [22]; therefore, the science and mathematics curriculum was irrelevant to many of them [28]. Women were more motivated by communal goals (opportunities to work with or help others) than men traditionally were, and this posed a problem when many STEM professions such as engineering and computer science were not seen as fulfilling those communal goals [29]. Women may have found the role of the stereotypical scientist, viewed as someone who spends their life in a lab with no outside interests, as being unattractive or unaccommodating. However, these stereotypes have been changing; the idea of being a scientist and "a real person" has become more acceptable. This new image of scientists might motivate women to pursue science careers [30, 31]. The current lack of female scientists was an issue because women lacked role models and colleagues to inspire or support their STEM aspirations [31]. The women that pursued STEM in spite of these stereotypes and lack of role models have paved the way for women in the future to have what they did not. These

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stereotypical views of women and STEM professions have been evolving and by doing so may form a bridge eliminating the gap between the two.

B. Project Based Learning

What is project based learning? A review of the diversity of definitions found several consistent components [32]. In project based learning, students are presented with challenges that require an interdisciplinary solution that ultimately results in some form of tangible product or presentation. In order to complete the task, students engage in problem-solving, design, and investigation. Teachers facilitate the group work but do not control it. This approach to learning is exceptionally different from the traditional teaching method and offers students real world applications of the knowledge that they are gaining in school.

The introduction of PBL activities in classrooms had a number of favorable results. PBL helped increase student motivation, especially when the teachers were motivated to use PBL themselves [3]. Students were more prone to learning new concepts when they knew that learning these concepts would help them complete their projects [2]. Moreover, PBL taught students teamwork, research [33], presentation, and management skills [34]. PBL also instilled internal motivation in the form of perseverance after having failed a few times before eventual success and increased awareness of the interrelatedness of what students were learning [35]. PBL made learning “varied and fun” (Ravitz, 2008, p. 4), and allowed students to explore their learning in depth. The exploration process encouraged creativity [35], and inquiry [36] resulting in deep understanding.

In STEM PBL, students worked collaboratively to complete a project and “to seek out the answers for their questions” [3]. During the STEM PBL process, students followed an inquiry based approach and an experimental design to reach their goal. PBL applied to STEM subjects “provides the contextualized, authentic experiences necessary for students to scaffold learning and build meaningfully powerful STEM concepts” [1]. Students had to play an active role in their own learning, which led to self-actualization and intellectual growth [36]. Women usually preferred depth in whatever they learned [2, 28]. Therefore, it is possible that STEM PBL would encourage these women to take advanced STEM courses and pursue STEM careers.

C. Women and STEM PBL

Females have not benefitted as much from traditional instruction as males have [26]. “Women have a greater interest in people than in things... and may respond more positively to ideas in context than in isolation” [22]. Therefore, the use of cooperative groups and scientific inquiry was suggested to increase the representation of women in science careers [28]. Female students enjoyed cooperative learning because they also perceived it as a chance to interact and improve their social skills [2]. Projects that focused on creating solutions that make the world a better place and help others could also increase the interest of women in STEM fields [9, 37]. Therefore, new methods for teaching mathematics and science that focus on opportunities to think and to discuss ways of

improving the world, like STEM PBL, might increase women’s motivation to attend mathematics and science classes. STEM PBL has provided this because it is based on contextualized projects and teamwork.

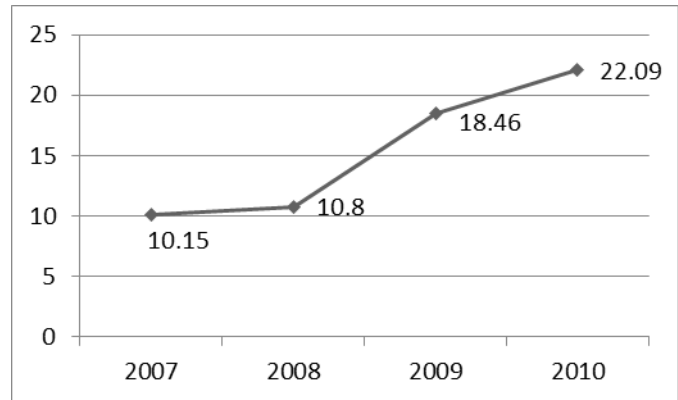
II. METHODOLOGY

Mathematics, science, and English standardized test data were collected over four years from a school district where professional development on STEM PBL was the major focus. The first year of data, in which the teachers had not received any professional development on STEM PBL, served as the baseline. The professional development on STEM PBL took place during the summer between the first and the second year and was sustained throughout the second, third, and fourth years. Throughout the second, third, and fourth years teachers were assisted and guided in the design of PBL activities and were given feedback on their lesson designs and implementations during classroom observations.

A. Participants

The students were chosen from the high school where the teachers most effectively implemented STEM PBL. These teachers were observed each year for STEM PBL implementation and given scores ranging from 1 to 5 on 27 items divided into six main categories. A mean score of 3 on each category was considered an average implementation; therefore, adding the means of the six categories, a total score of 18 was considered an average implementation. By the third year, these teachers were considered to be above average in STEM PBL implementation and were closely grouped across the six indicators (see Figure 1).

Fig. 1. Teacher’s mean level of STEM PBL implementation.



The same students were tracked for four years of high school, starting in grade 9 and ending in grade 12. When these students were in grade 9, the teachers had not yet been exposed to PBL training and, therefore, neither were the students. In grades 10, 11, and 12, these students participated in various PBL activities in their mathematics and science classrooms. For all analyses, the 08-09 ethnicities were used because they were the most complete set of ethnicity data during the four years. The problem with ethnicities is that they are self-

reported and students bubble their own ethnicity. Therefore, ethnicity varied from year to year. Some variation, though minimal, existed for Hispanic students who may have initially selected Hispanic and changed to White in a subsequent year, or vice-versa. There were no variations in responses from Black students; however, there were some years when an ethnicity was not selected.

In the first year of score collection, there were 186 students in grade 9. Because of the high attrition rate in the district, only 127 of these students remained in school for four years. Out of the 127 students, 24 did not have scores for all years and, therefore, were removed from the data set. The final sample size was 103 students with 52 females and 51 males. This was a loss of 59 students in four years. However, what is noticeable is that 34 students of the 59 left in the first year, and only 24 of the starting 186 left in the second, third, or fourth year. To compare the results obtained in this study to the broader literature, a search was conducted using ERIC EBSCO and ERIC CSA using the search terms “girls or females or women” and “high school and STEM or science or math” for the publication year 2010. The search yielded 113 unique articles. Of the 113 articles 23 were reports from the Center on Education Policy and did not contain data disaggregated by gender, 16 others could not be located, four were dissertations that did not report academic improvement, 37 were qualitative reports without aggregation of findings or estimates of improvement, and 15 were quantitative studies that did not disaggregate results by gender. Of the remaining articles only one provided sufficient information to compute effect sizes for the results. Therefore, the benchmark effect sizes are based only on a single study with our Cohen’s *d* estimates of effect for our study. The estimated change in ability and coursework plan from grade 9 to grade 11 in females’ math was 0.0 and .423, in females’ science was .239 and .821, in males’ math was .296 and .345, and in males’ science was .471 and .334.

B. Procedures

Mathematics, science, and English Texas Assessment of Knowledge Skills (TAKS) scores and course matriculation data were collected for each of the students in each of the three years. Students are allowed to take their exit tests in grade 11, and as a result, a lot of students did not have TAKS scores for grade 12; therefore, grade 12 scores were not included in the study. Because there is no state test for science in grade 9, only grades 10 and 11 TAKS science scores were considered. Moreover, English scores were included to provide a basis for comparison because STEM PBL was not used in these classes, and the STEM professional development did not focus on English learning objectives. Therefore, changes in mathematics and science should be uncorrelated with changes in English scores when the changes are attributable to the STEM professional development. Data were analyzed using significance tests, graphs, confidence intervals, and Cohen’s *d* effect sizes.

C. TAKS

In Texas, during the years of the study, students were administered TAKS exams in the spring of each year. Students took the mathematics portion of the TAKS each year starting in

grades 3 through 10; after grade 10 students were required to pass the Exit Level mathematics TAKS in either grade 11 or 12. Students took the science portion of the TAKS in grades 5, 8, 10, and Exit Level (either grade 11 or 12). Students took the English portion in reading from grades 3 through 9 and in reading and writing (ELA [English and Language Arts]) in grade 10 and Exit Level. In mathematics and science, the test items were multiple choice items. On the 10th grade and Exit Level ELA tests, two additional question formats were included: a) open-ended short-answer questions and b) a written composition. TAKS tests were not timed so students were permitted the time they needed to complete the test; some even stayed after regular school hours to finish. Seniors needed to pass the Exit Level TAKS test in order to graduate from high school [38].

III. RESULTS

A repeated measures MANOVA was used to determine whether the scores for each gender had changed over time in mathematics, science, and English. The change in test scores in mathematics was statistically significant for both males ($p_M < .001$; partial $\eta^2 = 73\%$) and females ($p_F < .001$; partial $\eta^2 = 65\%$). The variation in mathematics test scores was 73% accounted for by being male and 65% accounted for by being female. Based on the previous analyses, the means for both genders increased statistically significantly over the years ($F_1 = 33.7$; $F_2 = 36.6$; $F_3 = 41.3$; $M_1 = 34.5$; $M_2 = 36.9$; $M_3 = 43.8$). The males’ means were slightly higher than the females’ means at the beginning of the study. With the introduction of PBL to the classes, the gap between gender means narrowed. However, in the third year the gap in score means between genders increased slightly again in favor of males (see Figure 2).

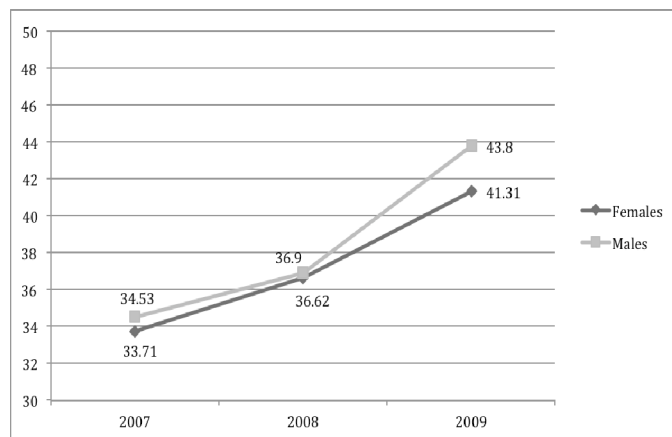


Fig. 2. The means of mathematics scores for males and females over three yrs.

In science, the change in scores was statistically significant for both females ($p_F < .001$; partial $\eta^2 = 28\%$) and males ($p_M = .044$; partial $\eta^2 = 7.9\%$). The effect size for the females was reasonably large and nearly three times as large as the effect size for males. While the difference for males was statistically significant, the obtained effect size does not merit much

interest. The rate of change in females’ scores was larger than the rate of change in males’ scores; however, males still performed better. One reason may be because the males had a higher starting mean ($M_1 = 40.39$) than females ($F_1 = 34.9$); therefore, females had more room for improvement and narrowed the gap ($M_2 = 41.8$; $F_2 = 38.3$) (see Figure 3).

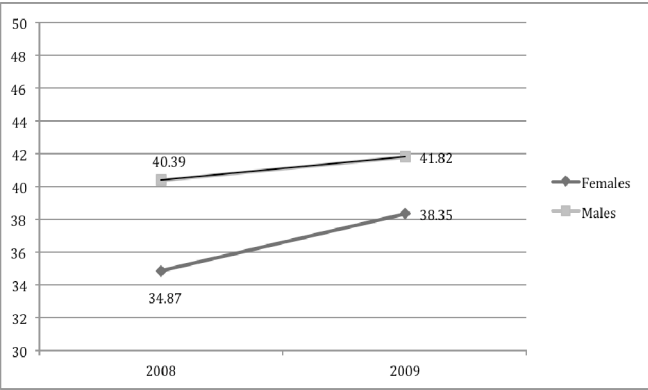


Fig. 3. The means of science scores for males and females over two years.

The science scores show the least growth over time. When considering females by ethnicity there was modest growth for all females regardless of ethnicity (see Figure 4). The obtained effects were small but consistent for Black, Hispanic, and White, 0.19, 0.13, and 0.14, respectively. There may be more possible explanations but one stands out. The science test is not administered in 9th grade but in 10th and 11th. Therefore, the base year or inception of STEM PBL was not estimated but instead it was the middle year or second year of the intervention. So the comparison might not indicate the magnitude of the growth as compared to mathematics or English.

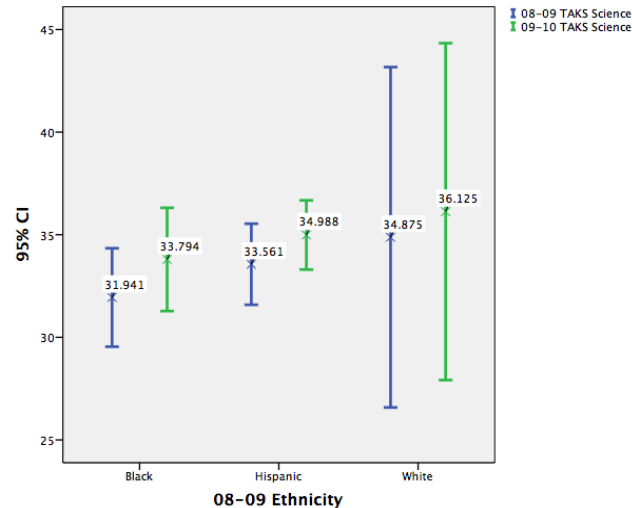


Fig. 4. 95% confidence intervals for females by ethnicity for science scores.

For females and males English scores increased statistically significantly over time ($p_F < .001$; partial $\eta^2_F = 96\%$; $p_M < .001$; partial $\eta^2_M = 85\%$). For the first two years, the changes in the means of the two genders were fairly similar ($M_1 = 32.3$; $F_1 = 32.0$; $MM_2 = 46.1$; $F_2 = 46.4$). Due to the change in the test from assessing reading to assessing ELA, the magnitude of the effect was over estimated. However, there was a slight decrease in the females’ means in English during the last year ($M_{F3} = 45.0$) and the gap between the means of males and females widened slightly in favor of the males ($M_{M3} = 46.4$) (see Figure 5).

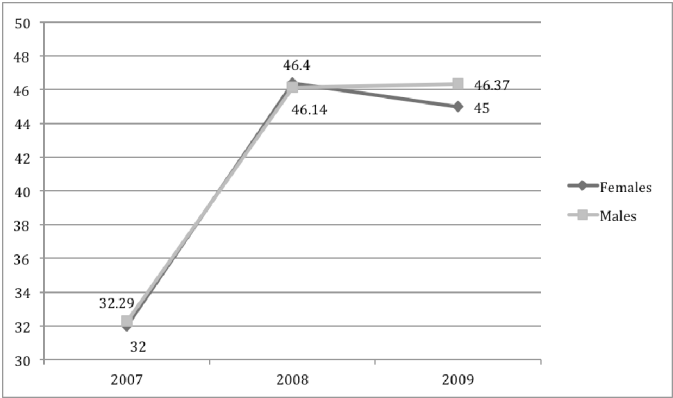


Fig. 5. The means of English scores for males and females over three years.

All the students took the following mathematics and science courses, which were required: Algebra I, Algebra II, Geometry, Biology, and Chemistry. Around half of the students, 51% of the females and 50% of the males, chose to take Principals of Technology I (PTI), which was an engineering course. Only 16% of the males chose to take Physics, while 42% of the females took Physics. Sixty percent of females and 68% of males chose Precalculus, and 16% of females and 26% of males took AP Calculus. The choice to take AP Biology was 16% for females and 14% for males (see Figure 6).

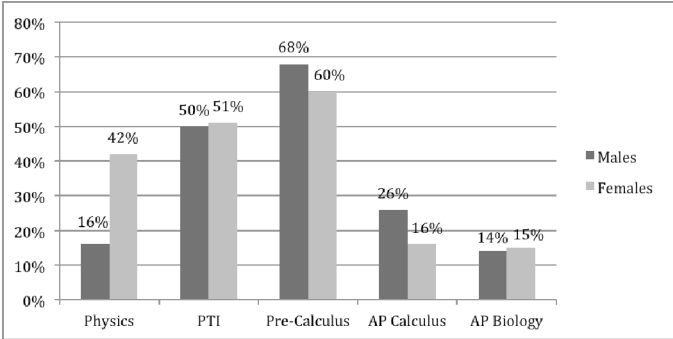


Fig. 6. Percentage of males and females who chose to enroll in classes.

When the study began, in grade 9, there were 186 registered students, 87 females and 99 males. Out of the 186

students, 153 students (82%) were registered for the second year in grade 10 (85% females, 79.8% males) in addition to 18 new comers, resulting in 171 students in grade 10 for that year. In grade 11, 148 of the 171 (86.5%) remained at this high school (87.6% females; 85.5% males), with an addition of 25 newcomers to make a total of 172 students. Out of the 172 students, 151 (87.7%) stayed (93.7% females; 82.6% males), and 28 newcomers registered to give a total of 179 students in the fourth year. The overall trend was that females were increasingly retained over the four years whereas males had a consistent attrition rate (see Figure 7).

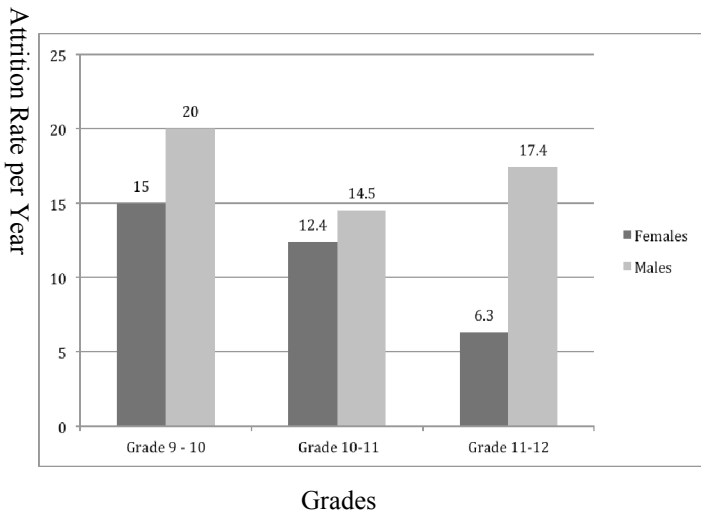


Fig. 7. Percentage of male and female attrition from one grade to the next.

To determine the impact of STEM PBL for females by ethnicity, the 95% confidence intervals were calculated and shown in Figure 8. The overarching message was that there were no initial differences between ethnic groups. There was greater variation in the scores for White females while Hispanic females had the smallest variation. However, for females across the ethnic spectrum, their scores increased longitudinally. There was a statistically significant difference between the 07-08 and 08-09 school years and 09-10 for Black and Hispanic females. By the end of the 09-10 school year there was no difference in scores evidenced by ethnicity. Hispanic females experienced the greatest gains with statistically significant differences in each of the three years favoring the subsequent year. That is, STEM PBL benefitted females within ethnic groups similarly, and by the third year all females were on par. While some groups exhibited greater gains, all groups showed practically important growth. The Cohen's d effects for Black, Hispanic, and White were 1.13, 1.08, and 0.61, respectively.

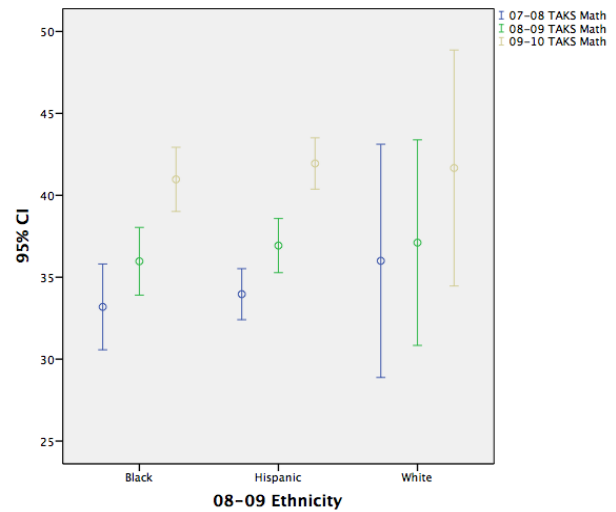


Fig. 8. 95% Confidence intervals for females by ethnicity on mathematics performance longitudinally.

Finally, the comparison between performance by gender would answer the question, "Did STEM Project-based Learning afford females the opportunity to bring their level of performance equal to that of their male counterparts?" The results showed that females and males started out fairly equal in mathematics. By the end of the three years both groups showed statistically significant gains from year 1 (See Figure 9). However, at no point in the longitudinal study did one group outperform the other; that is, they both showed important gains each year that were close to equal. The Cohen's d effect for females and males longitudinally was 1.06, and 1.05, respectively.

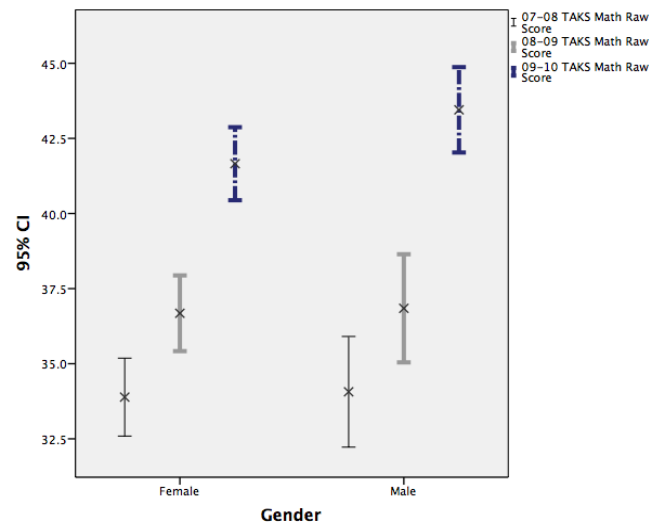


Figure 9. 95% confidence interval by gender for mathematics performance longitudinally.

IV. DISCUSSION

There were several interesting results that could point to the benefits of STEM PBL for both genders but especially for narrowing the gender gap in performance and interest in STEM fields for females. Firstly, the increase in science and

mathematics scores cannot be attributed to maturation because the females' science and mathematics scores means increased in the last year while their English language arts (ELA) scores decreased. PBL activities were only introduced in mathematics and science classes and not in English classes. Therefore, one possible explanation for mathematics and science improvement in the third year is the use of STEM PBL activities in these classes. Moreover, these PBL activities were more developed in the last year because the teachers had more experience with these kinds of activities after having implemented similar activities the previous year as well as continuing professional development and classroom support for refining and implementing PBL lessons. The rate of change of English scores was in a different direction from the rate of change of mathematics and science scores, indicating that the underlying causes of change were different for math and science as compared to English.

The literature indicated that females were usually found to perform better in English, while males usually performed better in mathematics and sciences [13, 14]. However, in this study, even though the males outperformed the females in science, the females' science scores improved much more than the males' science scores. If males have greater interest than do females in STEM courses, it would be expected that performance of females would increase a small amount, if any. This indicates that the active STEM PBL lessons may have contributed to the narrowed gap between females and males in science. In English, however, the males' scores improved more than the females' English scores but not to a practically important degree. These analyses in total show that females did not show improvement in all subjects nor to the same degree. It was unlikely that the increase in females' scores in science was due to a school initiative to improve TAKS scores overall. If that were the case, it would be expected that females would improve their English scores accordingly, particularly in view of the fact that females have shown greater interest in English than science courses and fields of study.

The profound increase in both females' and males' test scores in English from grade 9 to grade 10 can be attributed to the change in testing style in English TAKS from reading to ELA. In grade 9, students were only tested for reading and only had to answer multiple choice questions. On the other hand, in grade 10 students were tested for reading and writing as well as answering essay style short answers and writing a composition. The subjective nature of these short questions and composition sections may have contributed to improved scores because students could receive partial credit for the short answer questions.

A second interesting result was that the percentage of females who left the high school decreased over the years. One could argue that the majority of students who lose interest in high school and leave do so after their first year. However, the percentage attrition for males leaving this high school was consistent and did not decrease like the percentage attrition for females. STEM PBL activities seemed to have stemmed the attrition of females in the high school in the study. Therefore, STEM PBL activities may attribute to retention of girls in high school.

The third interesting result was the STEM course selections made by students. The greatest differences in course selections between males and females were in Physics, where the number of females who chose to take physics courses was almost three times the number of males who chose physics, and in AP Calculus, where the number of males who made the choice for AP Calculus was higher than the number of females. In comparison to a similar study [39], around 25% of men and women took Physics in high school and 7.4% of the women and 8% of the men took AP Calculus or an equivalent course. Moreover, less than 10% of the students took Precalculus, compared to 60% or more in this study. STEM PBL might have been a contributing factor to the choice of taking Physics, Precalculus, and AP Calculus for both males and females. This result is harmonious with prior study results showing that females were more interested in STEM courses and fields when they were able to see benefits to individuals and to society rather than just experiencing the course content outside the possible applications of interest to them.

Females' mathematics and sciences scores increased over the years with the introduction of STEM PBL to the classes. Moreover, the attrition of female students decreased with the years. Whether PBL was the direct cause for the increase in scores and decrease in attrition cannot be answered by one study alone. More studies are needed to follow females that are exposed to STEM project based learning and to track them through post secondary education. Studies that involve both performance and attrition in STEM courses and majors combined with surveys or interviews that give insight into the reasons both males and females persist or drop out of STEM majors would be particularly useful in understanding the problem and searching for possible solutions to the STEM pipeline issues related to all students, particularly females.

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Examining the Relationship between Faculty Teaching Practice and Interconnectivity in a Social Network

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Abstract— The study reported in this paper examined the connectedness of STEM faculty to others both within and across academic departments who might be potential resources for diffusion of Learner-centered practices, and the impact of participants' social networks on their Learner-centered beliefs and practices. The research question under investigation was: To what extent is the degree of social connectedness among faculty within and among STEM departments related to the degree of implementation of Learner-centered practices? Participants were recruited from Physics, Chemistry, Mathematics departments, and from departments in the College of Engineering. The sample began with 21 randomly-selected faculty from each department engaged in the STEM instruction of first and second year engineering students. The second level consisted of the colleagues identified by the first level as people they utilize as resources for improving their instruction. The connectedness of faculty in the network was examined using network analysis, focusing on both number of connections, and depth of connections. Attitude and Observation Protocol measures were used as outcomes. Results show that faculty classified as Learner-Centered had deeper and more extensive social networks. Results are discussed in terms of the need for intra- and inter-departmental faculty professional development experiences that both introduce and encourage faculty to trial new tools and techniques, but that also run for the long-term, supporting collaborative organizations of faculty working together to transform early engineering experiences.

Keywords—learner centered, instruction, professional development

I. INTRODUCTION

Recent research has shown that learner centered practices are infrequently used in engineering pedagogy. Learner Centered instruction is defined by the American Psychological Association as comprising a set of cognitive and metacognitive factors, motivational and affective factors, developmental and social factors, and individual differences (see Table 1) [1]. It is assumed, generally, that to be learner centered, pedagogies need to simultaneously address key concepts, skills, and dispositions in a domain, *and* account for the knowledge,

predilections, and social characteristics afforded by students in a manner that is dynamic, adaptive, and personally relevant.

In a recent meta-analysis of 119 studies across grades K-20, Cornelius-White, found that learner-centered variables such as non-directive verbal interactions, incorporation of higher-order thinking, encouraging learning and challenge, and adapting to individual and social differences correlate significantly with cognitive and affective student outcomes (e.g., mathematics achievement, science achievement, participation, motivation, and others). Relationships among these variables average $r=.34$, indicating that the overall influence of learner centered practices accounts for about ten percent of desired outcomes--a significant relationship [2].

The hypothesis underlying the study reported here is that faculty practices are the primary mechanism by which potential changes in student learning and motivation are effected. While faculty attitudes may support practical change, and while student beliefs and attitudes may mediate their learning behavior, it is precisely the conditions of learning that are responsible for the nature and extent of learning, *and* students beliefs about, and self-regulatory strategies recruited while learning. One of the problems in studying learner centered practices is that they cast a fairly wide net. Many different pedagogical techniques may be employed effectively and be called "learner-centered." As such, learner-centered instruction can be thought of as heuristic—incorporating rules of thumb that can be used in the moment to tailor instruction to the needs of students. The following heuristics have been shown to be effective in structuring learner centered pedagogical environments[3.] As can be seen, learner-centeredness requires a shift from presenting content to enervating and supporting the actual learning modalities and outcomes for students.

Table 1. American Psychological Associated Learner Centered Psychological Principles

Cognitive and Metacognitive Factors Nature of the learning process: The learning of complex subject matter is most effective when it is an intentional process of constructing meaning from information and experience. Goals of the learning process: The successful learner, over time and with support and instructional guidance, can create meaningful, coherent representations of knowledge. Construction of knowledge: The successful learner can link new information with existing knowledge in meaningful ways. Strategic thinking: The successful learner can create and use a repertoire of thinking and reasoning strategies to achieve complex learning goals. Thinking about thinking: Higher order strategies for selecting and monitoring mental operations facilitate creative and critical thinking. Context of learning: Learning is influenced by environmental factors, including culture, technology, and instructional practices.
Motivational and Affective Factors Motivational and emotional influences on learning: What and how much is learned is influenced by the learner's motivation. Motivation to learn, in turn, is influenced by the individual's emotional states, beliefs, interests, and goals, and habits of thinking. Intrinsic motivation to learn: The learner's creativity, higher order thinking, and natural curiosity all contribute to motivation to learn. Intrinsic motivation is stimulated by tasks of optimal novelty and difficulty, relevant to personal interests and providing for personal choice and control. Effects of motivation on effort: Acquisition of complex knowledge and skills requires extended learner effort and guided practice. Without learners' motivation to learn, the willingness to exert this effort is unlikely without coercion.
Developmental and Social Factors Developmental influence on learning: As individuals develop, they encounter different opportunities and experience different constraints for learning. Learning is most effective when differential development within and across physical, intellectual, emotional, and social domains is taken into account. Social influences on learning: Learning is influenced by social interactions, interpersonal relations, and communication with others.
Individual Differences Factors Individual differences in learning: Learners have different strategies, approaches, and capabilities for learning that are a function of prior experience and heredity. Learning and diversity: Learning is most effective when differences in learners' linguistic, cultural, and social backgrounds are taken into account. Standards and assessment: Setting appropriately high and challenging standards and assessing the learner and learning progress - including diagnostic, process, and outcome assessment - are integral parts of the learning process.

1. The actions of the instructor focus on students learning as opposed to presenting material.
2. In ethically responsible ways, instructors share decision making about learning with students. Teachers control less, but students are involved more.
3. Content is used to build a knowledge base, to develop learning skills and to foster learner self-awareness of their abilities. Teaching approaches account for students' learning modes and strategies.
4. Instructors and students, together, create learning environments that motivate students to accept responsibility for learning.
5. Assessment activities are used to promote learning and to develop self and peer assessment skills, not to evaluate performance primarily.

Unfortunately, research shows that learner-centered practices are used only infrequently by post-secondary STEM faculty [7]. Part of the problem concerns the fact that an instructor's perception of student-centered pedagogy may not align with the reality of their classroom practice. Ebert-May et al., for example, reported on results of a national biology professional development program consisting of 6-12 days of workshops on scientific teaching over three years [4]. While faculty engaged in the professional development self-reported they were using a student-centered learning strategy, observation of their practice revealed that, in reality, three-fourths were lecturing with instructor-centered teaching. The authors maintain that the professional development was not sufficient to sufficiently change the nature of their teaching practice. So the majority of participants, had not actually progressed into a true embodiment of learner centered practice. Ebert-May et al., hypothesized that a possible reason for the lack of efficacy of the intervention was lack of social support for their changing beliefs, thus hindering their translation into new classroom routines and activities.

In support of this general hypothesis, McKenna et al., studied engineering faculty developing student-centered conceptual change instructional methods. Faculty worked collaboratively with learning scientists to promote effective task and instructional sequence design. The researchers found that the greater the extent of collaborative reflection between engineering faculty and learning scientists, the greater the shift toward student-centered practices[5].

Other researchers (e.g., Borrego et al.) have used Everett Rogers' model of diffusion of innovations to characterize faculty change through professional development [6] [7]. They found that faculty tend to only progress through the earliest stages of change: *awareness* and *interest*, and tend not to move to actual practice. The key issue here is that, without change in students' learning experiences, little chance of improving learning and motivational outcomes exists. Alternatively, if

change occurs too slowly, it may be so ineffective, it may take years or decades for instructional practices to catch up with students needs. Altogether, this paints a pretty bleak picture of faculty practice and faculty development. However, Borrego et al., also cite confining evidence that providing support *in the form of collaborative interactions among faculty* during the third and fourth *decision* and *trial* stages of can provide a successful progression to the higher stages of diffusion of innovation.

A. Social Network Analysis

Recently Judson & Lawson studied the degree of faculty connectedness in high school STEM teachers [8]. They recorded the degree to which teachers served as resources for others, in a addition to seeking out others for assistance in improving their instruction. They found that the degree to which individuals served as sources of information—i.e., where others came to them for help, strongly predicted their implementation of constructivist pedagogies. In the current study, these practices, assessed on the Reformed Teaching Observation Protocol [9] are deemed close analogs to Learner-centered practices as defined by the APA and Weimar.

These findings suggest that social support for faculty is a key mediating variable determining faculty practice. There have been many articles reporting how faculty, particularly adjuncts and teaching faculty feel unsupported and isolated in University STEM departments [10]. Where practical change occurs, research has shown that collaborative professional development can be one of the key design elements of the effort [4].

This study examines the extent of faculty social networks across University STEM departments, and the relationship between faculty connectedness with their learner centered attitudes and classroom practices.

B. Research Question

The research question under investigation was: To what extent is the degree of social connectedness among faculty within and among STEM departments related to the degree of implementation of Learner-centered practices?

II. METHOD

A. Participants.

Twenty-one different instructors (13 Engineering, 4 Physics, 2 Mathematics, and 2 Chemistry) across nine departments were chosen for the study. All instructors teach at a large, urban, Southwestern University in the United States. Faculty participants were randomly selected from the list of faculty teaching required STEM courses for freshman engineering students. Two participants hailed from the Mathematics Department, four from Physics, four from Chemistry, four from Biomedical Engineering, two each from Freshman Engineering, Electrical Engineering, and Civil Engineering, and one each from Materials Science, Computer Systems, and Mechanical/Aerospace Engineering. Faculty were provided small stipends as compensation for their time.

This study utilized four data collection methods: Faculty interviews, faculty surveys, observation protocol scores and qualitative classroom observations

B. Interviews

Each faculty member in the study participated in one one-hour semi-structured interview focused on their practice, and on the supports and barriers they encountered in their efforts to improve their practice. Interviews consisted of twenty-four questions focusing on topics of teaching practices, teaching resources used, teaching environment, course and departmental policies, self and departmental evaluations, and departmental and interdepartmental collaboration. Interviews were audio-recorded upon permission.

The Glaser and Laudel approach to qualitative content analysis was chosen to analyze the interview data. Qualitative content analysis is a theory-guided method that extracts *qualitative* content using units of meaning originating from the same theoretical framework that guided the *quantitative* data collection. The goal of this analysis was to determine contextual and potentially causal factors in the qualitative data that “mirrors” the quantitative [11]. Specifically, we used this method to ascertain the common resources faculty used to support instruction, and then determine the extent to which use of resources supported Learner-centered instruction as defined by the quantitative measures (below).

A key portion of the faculty interviews involved a set of questions focusing on the social network related to instruction within which each participant operated. Three questions were asked:

1. With whom do you collaborate regarding improvement of instruction?
2. With whom do you discuss teaching-related topics? and
3. Who comes to you to discuss instruction?

The interviewer probed instructors to create a comprehensive list of others, both within their department and outside their department. Responses also indicated that several faculty rely on colleagues outside their university for information and support. A total of eighty-three persons were nominated using this process, across all participants. These responses were then entered into an adjacency matrix, where connections between any two nominees was coded as 1, and lack of connection was coded as 0.

C. Approaches to Teaching Inventory (ATI)

In addition to the interview, each instructor completed a twenty-two item revised edition of the Approaches to Teaching Inventory survey to measure faculty perceptions about their own teaching. The ATI is a valid and reliable self-reporting tool designed by Trigwell and Prosser assesses the extent to which faculty teach with an approach toward

Table 2. Total, Mean and Standard Deviation of the Number Of Connections Nominated by Participants Across Academic Departments.

	Civil Eng.	Comp. Sys.	Mat. Sci.	Mech. /Aero.	Elect. Eng.	Math	Fresh. Eng.	Chem.	Phys.	Bio Eng.
Mean (S)	2.2 (1.5)	1.8 (1.5)	2.0 (1.7)	1.25 (0.5)	1.5 (0.7)	1.0 (0.8)	5.1 (5.9)	1.8 (2.3)	2.3 (2.3)	3.0 (4.0)
Total	6	4	6	4	2	4	13	7	15	19

instructor-centered knowledge transmission versus student-centered conceptual change [12]. Items on the ATI fall into four dimensions: 1) Conceptual Change Intention, measuring the degree to which instructors are aware of, and support the development of student understanding in the class (e.g., I see teaching as helping students develop new ways of thinking in this subject); 2) Student-Centered Strategies, measuring the extent to which instructors utilize pedagogical strategies that focus on student learning (Teaching in this subject should help students question their own understanding of the subject matter); 3) Information Transmission, the extent to which the instructor emphasizes getting information to the student (e.g., I think an important reason for running teaching sessions in this subject is to give students a good set of notes); and 4) Teacher-Focused Strategies (e.g., My teaching in this subject focuses on delivering what I know to the students). The first two dimensions promote Student-Centered classroom practice, while the latter two promote Teacher-centered classroom practice. Reliabilities of the subscales range from $\alpha = .73$ to $.75$. Of course, it was expected that all instructors will incorporate some beliefs from each of these 4 dimensions to more or less degree in their own teaching perspective.

D. Classroom Observation Protocol and Qualitative Observations

For each course, three classroom observations were conducted for a total of 63 observations. Sections to be observed were randomly selected from the list of required freshman engineering courses taught in each department. The Reformed Teaching Observation Protocol (RTOP) was used after each observation to identify specific teaching practices associated with reformed teaching. The RTOP is a classroom observational protocol that quantitatively characterizes the extent to which faculty implement student-centered behaviors in their own classroom practice. It has high reliability and validity. Published reliabilities of RTOP subscales are: Lesson Design and Implementation ($\alpha = .915$), Propositional Knowledge ($\alpha = .670$), Procedural Knowledge ($\alpha = .946$), Communicative Interactions ($\alpha = .907$), and Student/Teacher Relationships ($\alpha = .872$).

The overall RTOP has a reliability of $\alpha = .954$. As classroom practice can vary across days and specific learning objectives, RTOP scores for each participant's three observations were averaged to gain a typical view of their practice, resulting in a single set of scale scores for each

participant. In addition to RTOP scores, qualitative classroom observation field notes were gathered during each course observation including details about class environment and student-instructor interactions. The classroom observation field notes were used to provide relevant information in conjunction with the reformed protocol results and to provide any needed context when examining the relationship between the classroom teaching practices as reflected in the RTOP score and the teaching beliefs reflected in the instructor interviews and survey responses [9].

E. Social Network Analysis

Social Network Analysis is a set of analysis techniques that characterize the number and type of connections among members of a social system. It uses mathematical concepts from graph theory to map the links (relationships) between nodes (people). Any adjacency matrix listing the connections among individuals can be turned into a vertex-edge graph, which illustrates visually, the density of connections within and cross-connections across departments. We follow the method of Judson & Lawson [8] who used this method fruitfully to predict the relationship between high school STEM teacher connectedness and dimensions of the RTOP.

III. RESULTS

Figure 1 below shows the connectedness among all participants and the persons participants nominated those with whom they engaged in collaboration, or conversations about teaching quality. Both the density of connections within departments, and the connectedness across departments are of importance here. It is clear from the area comprised of each department in Figure 1 that Bio Engineering, Freshman Engineering, and Physics have many players involved in the design and implementation of first year instruction for engineers. It is also clear from the density of connections in each department that the interconnections among members of Bio Engineering, Physics and Freshman Engineering is higher than the other departments. What is also apparent is that there are few connections across departments.

Table 2 presents the mean number of people nominated by participants whom they felt they either collaborated with, or whom they had regular contact with regarding teaching or course improvement. A quick glance shows that colleagues in Bio Engineering, Freshman Engineering, and Physics do have many more reported connections than faculty in other departments. A few participants in departments, most notably

Figure 1. Vertex-edge Graph of the Connecteness of Faculty Participants

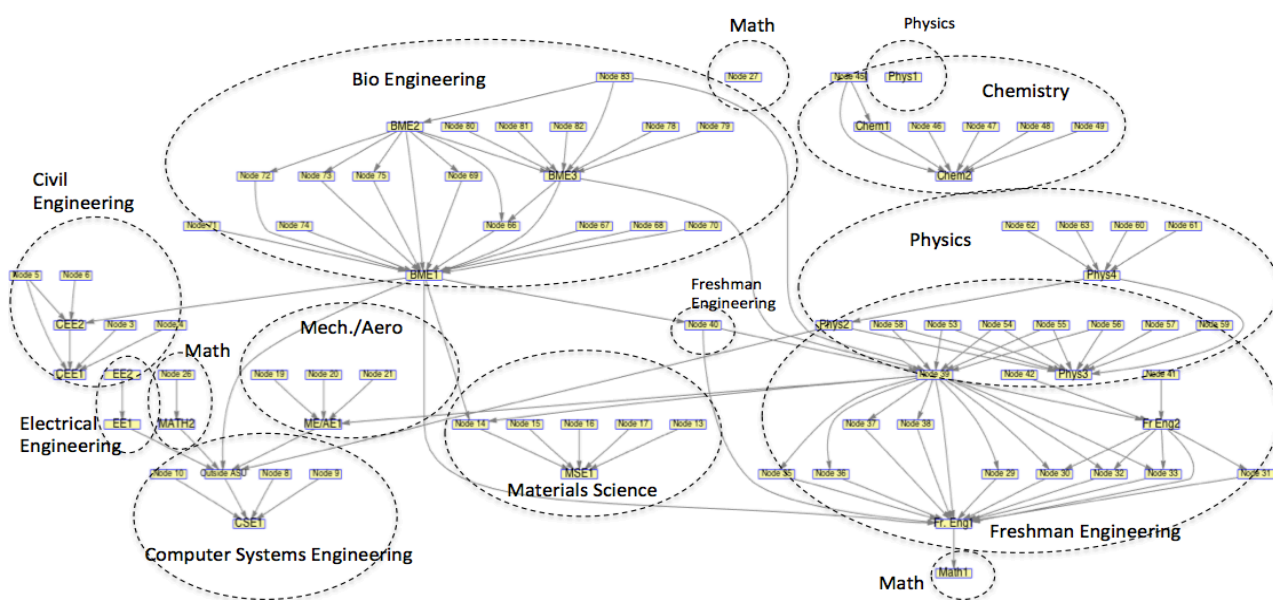


Table 3. Pearson Correlations between degree of connectedness and dimensions of Faculty Learner-Centered Attitudes (ATI) and classroom practice.

Concept Change Intention	Student-Focused Strategies	Info. Trans.	Teacher Focused Strat.	Conceptual Change/Student Focus	Info. Trans./Teacher Focus	Lesson Design/Impl.	Prop. Knowl.	Proc. Knowl.	Com. Inter.	Student/Teacher Rel.	RTOP Total Rating
.236	.374	-.322	-.181	.357	-.289	.704**	.084	.629**	.493*	.572**	.594**

*p<.05

*p<.01

ATI Dimensions: Conceptual Change Intention, Student-Focused Strategies, Information Transmission, Teacher Focused Strategies, Conceptual Change/Student Focus composite, Information Transmission/Teacher Focus composite.

RTOP Dimensions: Lesson Design and Implementation, Propositional Knowledge, Procedural Knowledge, Communicative Interactions, Student/Teacher Relationship, and RTOP composite.

Mathematics, Mechanical/Aerospace Engineering, and Electrical Engineering, appear to have few, if any connections at all.

To test the hypothesis that more connected faculty, on average, engage in more learner-centered practices, scores on the ATI beliefs instrument and RTOP observational instrument were correlated with degree of connectivity for each participant (see Table 3).

As can be seen, correlations are moderate to high across most dimensions of learner-centered faculty beliefs, and classroom practice. The direction of relationships are all in

the expected direction, indicating a positive relationship between connectedness and learner-centeredness in general, and a negative relationship between connectedness and teacher-centeredness. RTOP scores were generally very strongly related to connectedness, with *lesson design and implementation* showing the strongest relationship. This dimension focused on strategies that account for students' prior knowledge, engagement of students as members of a learning community, encouragement of alternative modes of investigation and problem solving, and using students ideas to help direct the lesson. The second highest correlation centered on procedural knowledge, a dimension emphasizing rigor of ideas, multiple representations, and engagement in hypothesis building and testing. The least correlation centered on *propositional knowledge*. This dimension focused on the subject matter knowledge of the teacher, the abstractness of the content, connections to other disciplines, and the coherence of the conceptual understanding promoted by the lesson.

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It is also important to note that none of the ATI dimensions were significantly correlated with connectness. While technically this indicates no systematic relation between the variables, the relatively small number of participants in the study yields relatively low power. With an earlier study showing significant positive relationships between ATI and RTOP scales, we feel there is still merit in reporting these correlations as consistent with theory. However, it is the overall pattern of the relationship, not each individual correlation that should be examined.

IV. DISCUSSION

Results indicate that faculty connectness is at least moderately correlated with learner-centered attitudes, and relatively strongly related to learner-centered practices.

These findings echo those by Judson & Lawson, who found that the indegree of high school teachers' social networks related strongly, at about the same magnitude as the present study, with their RTOP scores. These were interpreted as indicative that constructivist teaching practices, a close analog to learner centered practices, are highly related to the degree to which teachers are seen as resources by their colleagues [8].

The authors report that, in a social network, the degree to which an individual is seen as a resource, where their colleagues come to them for assistance, is an indication of their leadership. Moreover, the number of people in a network with large indegree indices indicates closeness of collaboration. Friedkin & Slater suggest that such sources of advice and creativity can be more influential in the social network than more formal leadership roles [13].

In summary, the research reported in this paper provides further evidence that faculty culture is moderately to strongly related to quality practice—at least as a mediating variable for learner centered instruction. Faculty with more connected social networks displayed higher scores on conceptual change and student focused attitudes, and lower scores on information transmission and teacher focused attitudes, than faculty with fewer connections. Moreover, faculty with larger social networks scored highly on all learner-centered variables with the exception of the propositional knowledge subscale on the RTOP. Some caution must be urged here. None of the correlations for faculty attitudes were statistically significant. However, the strong correlations for faculty practice variables lends support for our original hypothesis.

We are currently surveying nominees *not* in our original sample, to further examine the connectness across the entire network. With this larger set of data, we hope to be able to determine factors of social collaboration that relate to improved instruction and student outcomes across the larger community of faculty.

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Preparing for an Academic Career – the Engineering Faculty of Tomorrow

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Abstract—To prepare our interested graduate students for careers as engineering educators, a three year graduated teaching experience has been developed combining face-to-face teaching experience with a seminar and workshops to provide some formal training in STEM higher education instruction.

The department's "Academic Careers" seminar provides an introduction to the three major aspects of the academic career – teaching, research and service. Students also enroll in our Preparing Future Faculty and Professionals Program (PFFP). In the graduated teaching experience, students work first as teaching assistants, then as a member of the instructional team for a course helping to develop and deliver instructional materials and then, in the third year, the students have full teaching responsibility for a significant segment of that course. Feedback is provided to the students from seasoned engineering educators.

Participation in these experiences allows our students to begin their academic careers with confidence. To date, five students have completed this program; there are four students currently in the program. The training program is more completely described in this paper together with program assessment information from former participants, both graduate students and their undergraduate students, and how the program has been modified based on these assessments for the current participants.

Keywords— *teacher training; higher education; graduate students; academic careers*

I. INTRODUCTION

There are a variety of ways by which an engineering graduate student in – say, Electrical Engineering – who's interested in a career as a university professor in EE, can obtain valuable training for a faculty position while working on one's Ph.D. research. Some of these ways include nationwide programs such as the Preparing Future Faculty (PFF) program, to programs developed specifically within engineering disciplines at particular schools, and to various mixtures of both models. The teaching program at Marquette University in Electrical Engineering is an example of the mixture model.

The PFF program began in 1993 as a joint effort between the Association of American Colleges and Universities and the

Council of Graduate Schools [1]. Marquette University and the University of Wisconsin at Milwaukee (UWM) were selected to form one of the original seventeen regional clusters. From 1993 to 2003, Marquette and UWM served as a central hub for other colleges and universities in Wisconsin for PFF-related events and programming. Since 2003, the Marquette University Graduate School has continued the PFF program at Marquette, providing funding for significant PFF programming including an impressive list of workshops on teaching topics.

Over the years, the PFF program has been adopted – either completely or with local modifications – at over 45 doctoral institutions such as Purdue University and the University of California-Los Angeles. Faculty from the University of Cincinnati describe the organization of their PFF discipline specific engineering program covering the planned PFF activities, preliminary results, and program benefits [2]. The faculty from the University of Cincinnati revisited their PFF implementation after twelve years to determine how to modify it for the modern future faculty needs [3]. Another example of modifying an existing implementation of a PFF program is discussed by faculty from Clarkson University and Northwestern University [4]. They present their current PFF program and describe multiple changes they have made. They have made their general PFF program specific to engineering which allows them to build a series of presentations covering the following topics focused for engineering educators: hiring, tenure, teaching, curriculum reform, grant writing, and service. They also discuss the various types of engineering educational institutions at which future engineering faculty might consider employment.

Other institutions have presented alternative or supplemental programs that are based on or are similar to the PFF program [5-10]. In addition to their PFF Program, the University of Cincinnati also had a Science and Technology Enhancement Program and developed a study plan to determine how participating in the program had an effect on the students [5]. Another group of faculty does not mention having a PFF program, but they discuss a course in faculty development [6]. The course covers topics such as lecture preparation, ethics, course content, teaching methods and techniques, and other

key components relating to daily faculty’s duties. A “teaching apprenticeship” program at the University of Notre Dame incorporates direct teaching experience with informal meetings to expose the students to engineering education research and practice [10].

In addition to the studies on the implementation and content for programs devoted to training future faculty, there have been studies on the expectations of the future faculty [11-15]. Faculty from the University of Washington introduce their Engineering Teaching Portfolio Program and interview the fifteen graduate students who participated in the pilot offering [7]. The participants are graduate students who are interested in a faculty career and are asked to discuss what they perceive to be the daily responsibilities of a faculty member. Alternatively, another group interviewed graduate students and requested that they reflect on the research mentorships they had [12]. Specifically, they wanted the graduate students to focus on how their research mentorship helped prepare them for a faculty career. These discussions are insightful because they show misconceptions that current faculty did not realize future faculty had and help pinpoint areas that might need to be clarified for future faculty. This would ensure the future faculty would have a good expectation of the career path ahead of them. It would also be more likely to produce effective faculty members.

Lastly, there have been multiple evaluations by faculty of their current future faculty training programs [16, 17]. Faculty from Virginia Tech interviewed former participants in their Teaching Fellowship program to evaluate the effectiveness and success of their program. The feedback they received from the fellows was collected and a list of modifications to the program has been identified [16].

This paper introduces another method for faculty development, focusing on the teaching development aspect. The program was developed specifically to provide appropriate teacher training and experience to students in the department’s fellowship program supported by the Graduate Assistance in Areas of National Need (GAANN) program of the Office of Postsecondary Education, Department of Education. The teacher training program followed in our department combines our PFF workshops with a department seminar course and a three year progressive teaching experience that is the heart of this program.

II. PROGRAM OVERVIEW

The goal of our program is to prepare our interested graduate students for careers in higher education in electrical engineering; three aspects of which are teaching, research and service. To accomplish training in teaching, we have developed a three year progression of teaching experiences in conjunction with a seminar course and workshops used to provide some formal instruction in pedagogy with emphasis on STEM disciplines. The graduate students who receive fellowships in our program are competitively selected from

among those in the department who express interest in academic careers.

There are three phases of face-to-face classroom teaching practice – first as a general cohort teaching assistant, second serving a support role as a member of the instruction team for a course and finally taking on the instructor role for the course. Each phase takes place in one or two semesters of three consecutive academic years.

Simultaneous with the teaching practice, students participate in the department’s Academic Careers (AC) seminar course as well as the university’s Preparing Future Faculty and Professionals (PFFP) program. These two activities mesh together to provide instruction in research-based pedagogy and andragogy techniques. Both the seminar course and the PFFP workshops provide supportive learning activities to promote well-rounded faculty by addressing not only teaching but also the research and service aspects of an academic career. Participation in these experiences is intended to foster confidence in our students when they begin their careers. To date, five students have completed this program; there are four students currently in the program. In the following sections, a more complete description of the program is provided. Program assessment information from former participants, both graduate students and the undergraduate students they taught is also discussed together with how the program has been modified based on these assessments for the current participants.

III. PROGRAM DETAILS

As mentioned in the previous section, formal instruction on teaching together with classroom based experiences are incorporated into all three years. Table I shows the focus for each component of the teaching training -- face-to-face (F2F) teaching practice, the department’s Academic Careers Seminar (AC) course and Marquette University’s PFFP workshops—for each of the three years. In the first year, when students are working as teaching assistants, students will receive most of their instruction in educational practice through the seminar and the PFFP workshops. In the second and third years, as the student’s level of responsibility in the classroom increases, the AC and PFFP continue to provide timely resources for education and also begin to incorporate activities to address the research and service aspects of the academic career.

Table I: Teaching Training Yearly Schedule

<i>Program Year</i>	<i>F2F Teaching Practice</i>	<i>Primary focus – AC and PFFP</i>	<i>Secondary focus – AC and PFFP</i>
First	General TA	Educational Practice	Research (Publications, Presentations)
Second	Instruction team member	Educational Practice	Research (Proposals, Funding)
Third	Lead instructor	Practical support (AC)	Academic Job Search, Service

The Academic Careers weekly seminar is a one credit course taken by the students each semester. Students in the teaching program also participate in the Marquette University Graduate School PFFP Certificate Program. Students will generally attend between three and five two-hour PFFP workshops each semester. Every attempt is made to coordinate PFFP workshops with AC topic discussion to reinforce and/or practice the concept. Students are awarded a notation on their university transcript upon completion of the eight PFFP Certificate Program requirement.

Focus for the instruction in teaching in the Academic Careers Seminar is provided through the textbook by P. C. Wankat and F. S. Oreovicz, *Teaching Engineering* [18]. Topics covered include the “how-tos” and pros and cons of various teaching styles - lecture, project-based, co-operative learning and learning styles; the definition of various student learning styles and how to incorporate strategies to accommodate them within the course learning experiences; how students develop intellectually; teaching with technology such as the use of course management systems for quizzes, surveys, on-line and hybrid teaching modes; syllabus and test creation; grading issues and academic honesty; and others. Supplemental materials from the ASEE, the IEEE, and current papers drawn from archival sources (journals, proceedings, etc.) are also used.

Students implement at least two different learning assessment methods from *Classroom Assessment Techniques*, by Cross and Angelo [19] and summarize the results with improvement recommendations. Students learn to incorporate activities to promote student achievement of the “A through K” list of attributes of successful engineers required by the engineering accreditation agency, ABET, into their teaching. Senior EECE faculty members share their expertise on effective teaching in this seminar.

The eight PFFP Certificate Program requirements include completing workshops and classroom instruction activities in (1) Theory and Research on Effective Teaching in Higher Education; (2) Specific Teaching Skills; (3) Obtaining Feedback on Teaching; (4) Assessing Student Learning; (5) Teaching with Technology; (6) Applying and Interviewing for Positions; (7) Obtaining External Funding and (8) Teaching Portfolio. Students automatically meet PFFP requirements 1, 2, 3, 4, and 8 through their department teaching experiences; requirements 5, 6 and 7 are met through participation in the PFFP workshop program co-sponsored by Marquette University’s Center for Teaching and Learning. Regularly scheduled PFFP workshops include “Effective Course Design”, “Syllabus Construction”, “Learning Objectives,” “Assessing Student Learning.” Every effort is made to dovetail the topic schedules of the Academic Careers seminar and the PFFP workshops so, in the AC seminar, the concepts of the workshops can be more fully explored and tried out, if possible.

The face-to-face classroom experience starts when students serve as half-time (10 hours/week) teaching assistants with grading responsibility in one of the electrical engineering undergraduate laboratories or for an electrical engineering class during their first year in the program. They hold a minimum of three hours per week of office hours for the class to which they have been assigned to provide assistance to students. All teaching assistants work directly with the instructor assigned to teach the laboratory or course. The course for which the student will serve as instructor in the third year is selected by the project directors together with the student and her/his research advisor prior to the second year of the fellowship.

During the second year, the student serves as part of the instructional team for the course for one semester to both observe the day to day classroom instruction by an experienced faculty and to work collaboratively with that faculty member to develop curriculum materials such as lecture notes, electronic resources, handouts, homework assignments, tests, supplemental reading, etc. to support pedagogy for the course. These materials are used by the student when, in the third year, the student assumes responsibility for that same course including appropriate instruction, grading and grade assignment, and supervision of any assigned teaching assistants. The same faculty member from the second year serves as the student’s teaching mentor for this third year experience.

During the third year instructor experience, the faculty member monitors the student’s classroom performance to enhance their presentation skills and ensure proper coverage of course material. The teaching mentor visits the classroom daily during the first two weeks of class; if satisfactory progress is noted, visits are then conducted weekly for the next month and then every two weeks. Each visit is immediately followed by a meeting of the student with the mentor to review. The mentor provides feedback to the student about handouts, exams, and homework and project assignments to ensure that course objectives are met. Formative assessment of teaching performance with frequent feedback is stressed. In addition to regular recurring review by the teaching mentor, students’ teaching is evaluated by two senior faculty members via the EECE Department Peer Review of Teaching program to provide additional guidance and support. Summative and formative assessment occurs when students are evaluated at the end of the semester by the students through MOCES – Marquette University’s Online Course Evaluation System. The MOCES data is reported to the Chair and compared to department, college and university averages. Each student is required to complete an annual “Graduate Student Activity Report” (GSAR) modeled after the Faculty Activity Report at Marquette University at the end of each academic year, listing their teaching work, their research work, and their service work. This teacher training provides baseline information on teaching performance from

which the students can build on as well as develop strategies to affect such improvement.

Research, service and finding the first academic job are also covered in the Academic Careers seminar and the PFFP workshops. Topics such as best practices to supervise/mentor graduate students, responsible conduct of research, research methodology, technical writing, presentation skills and proposal writing are covered. The students develop written statements of their teaching philosophy and a personal research statement; these statements are included in their teaching portfolios. Other aspects of the interview process are discussed – such as suggested questions for the interviewee to ask so that they have a good feeling of how they will fit into the new department.

The students develop and maintain a professional portfolio through which they document their teaching and research abilities. They attend an educational conference in their three years as students, such as the ASEE annual exposition or the ASEE North Midwest Section conference or the IEEE/ASEE Frontiers in Education conference (FIE). In addition, students are encouraged to also perform some type of service to the profession.

IV. ASSESSMENT AND PROGRAM MODIFICATIONS

The five graduates from the first cohort of students who participated in this teaching training program were recently surveyed. From this first cohort, two are employed in university teaching positions in engineering (one tenure-track, one full-time adjunct); of the three who are employed full-time in industry, one is an adjunct faculty member in an electrical engineering program teaching one class per semester, another has just this semester taught an EE course as a part-time instructor for the first time. All of this first cohort report that the teaching experiences in the program were of significant value to them; two of them have specifically taught their “third year course” again using some of the materials they developed during their training.

Recommended changes/improvements to the program focused primarily on the Academic Careers seminar. It was suggested that the AC seminar be used to discuss the experience of the people currently going through the 2nd and 3rd year instructor roles to provide “real-time” feedback for the student teachers as well as insight for students who are getting ready for these experiences. It was also recommended that discussion and/or instruction be added to the AC seminar for several more modern teaching modalities such as synchronous hybrid distance-education classes, asynchronous video lecture classes, and completely online self-paced classes, all of which seem to require vastly different teaching strategies than those used for traditional lecture formats. In addition, it was recommended that the appropriate use of prepackaged course material (lectures, quizzes, other supporting material) available from the book publishers also be covered because it was felt that for a novice lecturer prepackaged material can be

most effective and time efficient and open educational resources (OER) are also normally good starting points for developing one’s own material.

Another recommendation from the first cohort involved carefully choosing and scheduling the courses for the third year teaching experience. For the first cohort, two required junior level program courses and one senior level elective course were taught by the “student teachers” during a single academic year. Even though all students were mentored by full-time faculty as described, some of the undergraduate students expressed dissatisfaction with multiple exposures to inexperienced teachers. Due to this, it was recommended that, as much as possible, the scheduling of multiple same-level classes taught by program students during the same academic year be avoided if possible.

Additional assessment from the directors of the program also provided recommendations – most importantly for the third year teaching experience. It was felt that to have the full responsibility for a course is too burdensome for the students in the program because during that same year, students are expected to also complete the dissertation research, writing, and defense.

Virtually all of the recommendations from our first cohort have already been or will be shortly incorporated into the teaching program for the second cohort of students who are currently within the first or second year. An even closer connection has been made between the concepts and schedules of the PFFP workshops and the AC seminar so that the AC seminar can supplement the PFFP workshops with specific examples of how the topics of the workshop translate to STEM disciplines – what’s the same, what’s different – and now serves as reinforcement for PFFP topics. Also, in the AC seminar, attention has been directed to learning about the flipped classroom and the creation of appropriate supporting materials for the flipped or on-line class. All the current students in this second cohort are creating appropriate modules as narrated slide presentations and/or video presentations for a single topic in each of three different classes; a three-phase power module for Circuits II (sophomore year), several VHDL modules for the digital electronics course (sophomore), and a mathematics review module to prepare students for the Linear Systems class (junior). These materials will be used by the students when they assume responsibility for the instruction of those topics within the named course. By incorporating the flipped classroom technique in the third year experience, we are able to (a) reduce the workload for the students in their final year of the program while (b) still giving them significant “solo” teaching experience and (c) possibly reducing the perception of our undergraduate student of multiple exposures to novice teachers. These materials may then be used by the students when they assume the faculty role – just as many of our first cohort students have done.

V. CONCLUDING REMARKS

The three year graduated teaching experience that has been developed which combines face-to-face teaching experience with a seminar and workshops to provide some formal training in STEM higher education instruction has proven to be very successful for our program. Almost all of the first group of students who participated in this program have either become faculty or have taught part-time in an electrical engineering program at a university or community college.

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Innovative Faculty Cohort Hire at the University of San Diego

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Abstract—The University of San Diego (USD)’s NSF ADVANCE grant, AFFIRM (Advancement of Female Faculty: Institutional climate, Recruitment and Mentoring), focuses on addressing issues related to race and gender for faculty in Science, Technology, Engineering, and Mathematics (STEM). Although a majority of undergraduate students majoring in most STEM disciplines at USD are female, there are not nearly that many women faculty. As part of the grant proposal, the AFFIRM team was promised two new faculty positions by the Provost. In Fall 2013, the team met with the Dean of the College of Arts and Sciences and the Dean of the School of Engineering and the idea of hiring a faculty cohort to facilitate mentoring, diversity, and interdisciplinarity emerged and was approved. Over 200 candidates from diverse backgrounds applied. The candidates that came for on-campus interviews were so impressive that the Provost and Deans agreed to additional hiring opportunities, leading to a cohort of eight female faculty in the STEM fields including four women of color. In this work-in-progress, we discuss our innovative cohort hiring process, and share feedback from members of the cohort, and lessons learned. This innovative process could serve as a model for other campuses.

Keywords— *ADVANCE; cohort hire; interdisciplinary; female faculty;*

I. INTRODUCTION

As part of the University of San Diego (USD)’s NSF ADVANCE grant, AFFIRM (Advancement of Female Faculty: Institutional climate, Recruitment and Mentoring), we are focusing on addressing issues related to race and gender for faculty, particularly those in Science, Technology, Engineering, and Mathematics (STEM). Typical approaches to diversifying faculty have not been successful suggesting more innovative approaches are needed.

Although a majority of undergraduate students majoring in most STEM disciplines at USD are female, there are not nearly that many women faculty. A goal of the grant was to promote opportunities for women in STEM fields and have a more representative faculty. In 2014, the team achieved a milestone towards this goal when a cohort of eight women faculty in STEM disciplines was hired. In this work-in-progress, we discuss our innovative cohort

hiring process, feedback from members of the cohort, and lessons learned. This process could serve as a model for other campuses.

II. HIRING PROCESS

A. Cohort Hire Idea

In the proposal to NSF, the AFFIRM team was promised at least two faculty positions in STEM and Social/Behavioral Sciences by the Provost. After that Provost left, the Interim Provost honored that commitment.

In Fall 2013, the third year of the grant, the AFFIRM team met with the Deans of the College of Arts and Sciences and the Shiley Marcos School of Engineering as well as the Vice Provost for Inclusion and Diversity to discuss and formulate a method of advertising the new positions. Both deans had started in Fall 2013. The idea of hiring a faculty cohort to facilitate mentoring, diversity, and interdisciplinarity emerged and was enthusiastically approved. Typically science and engineering faculty position advertisements are written tightly and prescriptively, but the team, with the support of the administration, tried something different.

Cohort or cluster hires have been used to diversify faculty and appear in several universities best practices for hiring faculty policies. Institutions including the University of Illinois Chicago and North Carolina State find that these types of hire improve the retention of faculty of color, enhance socialization, and reduce feelings of isolation [1, 2]. Other work points to the importance of obtaining a critical mass of faculty of color to help build community and increase retention [3]. Such hires are becoming more common although there is not currently much published peer-reviewed literature on this topic.

An invitation was sent to all eligible departments inviting them to be included in this hiring effort. All departments that accepted the invitation were listed on the ad, filed a recruitment plan, and included discipline-specific language as needed. Of the eligible departments, only Psychological Sciences chose not to participate. A copy of an advertisement is shown here and was available online [4]. Note that candidates were asked to provide additional

information (shown in bold) beyond what is typically requested.

Job Advertisement

The University of San Diego (USD) invites applications for a cluster of new Assistant Professor positions in STEM (Science, Technology, Engineering, Mathematics) and/or Social Sciences associated with a funded National Science Foundation ADVANCE grant initiative (<http://www.nsf.gov/crssprgm/advance/>). The positions will begin in September 2014 and may be housed in one or more of the following departments:

Biology, Chemistry and Biochemistry,
Marine Science and Environmental Studies,
Mathematics and Computer Science,
Physics, Sociology or
the Shiley Marcos School of Engineering.

The successful candidates will:

- hold a Ph.D. in a STEM or social science discipline, and
- have demonstrated a commitment to teaching and research, mentoring undergraduates, and fostering a climate of inclusion and diversity.

It is anticipated that these faculty members will work as an interdisciplinary cluster to build opportunities for faculty/student collaborations and promote interdisciplinary strength within the undergraduate core curriculum. We endeavor to build a cohort of teacher-scholars who will offer a strong contribution to the diversity and excellence of USD through teaching, scholarship, service and collaboration.

Please submit by January 15th to WEBSITE:

- Your curriculum vitae.
- Statement of teaching philosophy.
- Your research statement/plans.
- A statement addressing the following:
How do you envision yourself working as part of an interdisciplinary cohort?
How will you promote interdisciplinary collaborations in the undergraduate curriculum?
Explain your approach to, and experience with, mentoring female students and students from under-represented backgrounds.

Have four recommenders submit letters of recommendation to AFFIRMsearch@sandiego.edu by the deadline. At least one of the recommendation letters should specifically address teaching and one should specifically address your track record in terms of mentoring female students and students from under-represented backgrounds.

B. Applicant Pool and Interviews

Two hundred seventeen applications were submitted. The racial/ethnic distribution of the applicant pool is shown

in Table 1. In the pool, 45% of the applicants were women, 48% were men, and 7% declined to state.

TABLE I. DEMOGRAPHICS OF APPLICANT POOL

White (not Hispanic or Latino)	47%
Asian	28%
Hispanic or Latino	10%
Black	4%
Two or more Races	2%
American Indian or Alaska Native	1%

The AFFIRM team reviewed responses to the mentoring and interdisciplinary portions of the applications. Two AFFIRM team members commented on each file and made a recommendation of whether the candidate satisfied the initial criteria. Applications that passed this screening were forwarded to individual departments to be evaluated in whatever manner is customary in that department. Departments were asked to select up to three individuals for on-campus interviews.

The Provost agreed to allow each unit to interview up to two candidates. Candidates were required to meet with both Deans, the Vice Provost for Diversity and Inclusion, and members of the AFFIRM team, in addition to the customary meetings. These interviews occurred over a three week period concluding in early April. Each department was then asked to forward to the Dean their selected candidate(s) with a brief rationale. The AFFIRM team met in late April and given the strength of the candidates made the recommendation to hire as many as possible, without ranking candidates. Representatives from the AFFIRM team then met with the Deans and Provost.

C. Final Cohort

The candidates that came for on-campus interviews were so impressive that the provost and deans agreed to additional hiring opportunities. The Provost agreed to fund another line and three departments used open lines. Two departments (Mechanical Engineering and Psychological Sciences) hired women outside of the AFFIRM search who were invited to join the cohort. This brings the total size of the cohort to eight, four of whom are women of color.

These new assistant professors are in the departments of chemistry and biochemistry, biology, industrial and systems engineering, mechanical engineering, environmental and ocean sciences, mathematics and computer science, and psychological sciences.

III. FEEDBACK FROM THE COHORT

Members of the cohort were interviewed during their first semester at USD by the evaluator for AFFIRM. Highlights of these responses are included here.

A. Response to Advertisement

Respondents were asked to describe their reactions to the ad that was placed for their position and why they chose USD. The faculty offered the following comments:

- Wanted a teaching oriented college
- Attracted by the San Diego location
- Attracted by the quality faculty that already had positions in the department they were applying to
- Appreciated the interdisciplinary focus of the cohort
- Only expected that there were going to be two or three hires but like the cohort aspect
- They had some questions about who made the hiring decision. Was it the Chair, search team, AFFIRM, provost or who?
- Saw the ad as an effort to encourage women faculty of color in STEM but not exclusive to them.

B. Interdisciplinary Aspect of the Position

The faculty offered comments that coalesced around several general themes regarding the interdisciplinary focus of the AFFIRM initiative.

1) The interdisciplinary approach offers opportunity

- Interested in exploring the possibilities both for research and teaching
- “Collective work is at the core of my beliefs”
- If incorporated into my teaching it becomes a way for students to understand how a particular subject area has applicability in other STEM disciplines—could attract underrepresented students to the field.
- Could help our students in the job market
- Having AFFIRM being part of this hire shows there is a commitment to supporting ambitious research
- I *need* to work with faculty in other departments in order to do my research.
- I came from an interdisciplinary approach and it was very productive.
- Interdisciplinary work is the wave of the future; more journals are encouraging it.
- Excited about working with other members of the cohort on grants. Some have already begun conversations.
- Seen as a way to address more academically rich and challenging research questions and go for larger grants. Different backgrounds can stimulate creativity and create an environment that is conducive to research.
- Interdisciplinary collaborations really work for some faculty. Her work is so interdisciplinary that it was hard for her to find a job because universities don’t know where she fits.

2) The interdisciplinary approach also presents some challenges:

- Unfamiliar with that kind of work, not sure how it will work...

- Not sure what it really means in practice. “I’m trying to figure it out”. “Not sure the AFFIRM team knows how it will work either”. “How will AFFIRM develop interdisciplinary collaborations? Feel like it is being left to us to figure it out”.
- “I don’t really want to be pigeonholed to do interdisciplinary research”.
- Not enough time as it is to do my own research. Would need a shortcut to learn about other disciplines.
- Universities prize interdisciplinary focus but they don’t know how to put it into action. Not sure where the support will come from.
- The Chair’s support for interdisciplinary research will be very important. Some felt they had a supportive Chair and that their Chair honors team teaching.
- The orientation could be just a “token” or ideal; not actionable
- When thinking about the tenure process, seems like it might present problems. Tenure decisions are stressful. Not sure how interdisciplinary research will impact tenure

Others felt they were unlikely to work within the cohort as they sought out collaborators because they would want more expertise than the new faculty were likely to provide.

- More likely to reach out to national labs, professors at other universities or even USD professors but they would be folks with more experience than the new cohort of faculty.
- Not sure there is a structure in place to support the approach

C. Cohort Aspect of the Initiative

Everyone interviewed thought the cohort was a great idea, although some were more positive than others. They made the following comments:

- Cohort is great
- Wonderful colleagues who are going through the same transition that each of us is going through
- Difficult to transition to a faculty anyway so this arrangement would help
- Nice individuals but not really interested in being too involved, too busy.
- Coming in with a cohort of people really helps.
- Some individuals explained that they had already begun to have conversations about research.
- Several live in the same faculty housing and that is boosting their interaction.

D. AFFIRM Mentors

The AFFIRM grant provides for a departmental mentor and an outside of department mentor. Initially, the members

of the cohort were assigned only a departmental mentor. All felt that the mentoring was working and reported that they met formally on a routine basis with their mentor—some met also almost daily on an informal basis. From their perspective, having a mentor inside their department offered tremendous advantages. They explained they had discussions on the following:

- goal settings and planning
- department culture
- clarification on who to ask about issues
- discussion of teaching, students, class info, course materials, grade distribution
- tenure
- debrief what department expects
- research
- type of service
- what's going on and what to expect
- honesty and helpfulness

Everyone was aware that a mentor outside the department was going to be assigned as part of AFFIRM. Most thought that might be helpful. Some felt it could really be a help to get to know others at the university but they were also concerned that the culture outside their department might be very different and thus the advice may not always be that helpful. Many faculty also mentioned the support they receive from the Associate Dean of Arts and Sciences who is a coPI on the AFFIRM grant.

IV. LESSONS LEARNED

This type of cohort hire had never been done at USD before and therefore the process was very much a “just-in-time” approach. There was a steep learning curve that at times caused some confusion and breakdown in communication between the AFFIRM team and the departments that were hiring. Additionally, we did not start advertising for the positions until January which may have limited our pool. We believe any future cohort hires will run more smoothly and with a more typical timeframe because of our experiences.

Another lesson learned by the AFFIRM team is how essential it is to have good relationships with the administration to influence hiring practices. Having a coPI that is an Associate Dean and supportive Deans was invaluable. It was also important that the Provost's promise of new hires was obtained in writing since the Provost left soon after the grant was funded. The AFFIRM External Advisory Board (EAB), which includes a Provost with extensive experience with ADVANCE grants, was also helpful in the process. During their annual meetings with upper administration, they stressed the need to make progress on the promise of new hires.

The AFFIRM EAB praised this effort and its impact “This grant has provided USD with a new paradigm for establishing a hiring process that more closely meets the goals of this university. The interdisciplinary work of the new hires presents an opportunity for USD to move in

directions that represent a modern approach to the way science is done. This can only be viewed as a tremendous accomplishment. It certainly shows administrative buy-in to the goals of AFFIRM. It is no surprise that this set of hires is bringing positive attention to USD, and top universities around the country are looking to mimic it.” Articles on the cohort were published in the Chronicle of Higher Education and on the USD website [5, 6].

The AFFIRM EAB gave several recommendations to help insure the success of the cohort and future hiring at USD. Specifically, they recommended that “departmental structures be reviewed to ensure that the new faculty are treated fairly as they pursue tenure. The interdisciplinary work that the new faculty perform may not fit into the traditional career paths of faculty, and thus may be more difficult to evaluate. Allegiance to departments must be well-defined so that faculty understand their teaching commitments. This new approach is being carried out largely by untenured faculty. This could be a dangerous experience for the new faculty. As part of the mentoring this new cohort receives, we recommend that senior faculty who have experience with interdisciplinary research participate regularly.” In addition, they recommended that the USD administration “review the procedures that were used in this last search with a view as to institutionalizing them for future hires. If USD continues this implementation with the result of substantially increasing diversity of its faculty in the next few hiring cycles, it would position USD as a unique university.”

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Tailor-Made: Meeting the Unique Needs of Women of Color STEM-SBS Faculty Through Mentoring

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Abstract—Women of Color faculty have some of the worst outcomes of all other faculty in terms of attainment of tenure and promotion. They are much more likely than others to leave a university, file suits for discrimination and face hostile work environments and classrooms, and leave academe. It is to a university’s and society’s benefit to retain talented women of color and remedy these negative outcomes. This paper seeks to address the unique concerns and issues of Women of Color through the custom tailoring of mentoring programs based upon qualitative data analysis. Best practices and strategies will also be explored.

Keywords - Mentoring; STEM; African American; Latina American; Native American; Women of Color

I. INTRODUCTION

The underrepresentation of women of color (WoC), or AALANA (African American, Latina American, and Native American) female faculty in STEM (Science, Technology, Engineer and Math) and SBS (Social and Behavioral Science) disciplines at predominantly majority-group institutions in the U.S. is of great concern. Of faculty positions at the end of the first decade of this century, American-Indian women held 0.6 percent, Latinas held 4.0 percent, Asian American held 7.0 percent, while European-American women held 78.2 percent [3]

Delgado and Stefancic [10], Thomas and Hollenshead [20], and Cooper and Stephens [7] point out WoC faculty’s unique challenges in higher education. Compared to their majority-group female colleagues, WoC face additional barriers based on the intersections of race/ethnicity and gender. They live with multiple marginality [6,9,20,21]

The lack of effective mentoring contributes to the STEM-SBS WoC faculty’s low retention and advancement rate. Therefore, there is a need for RIT to establish mentoring programs that takes STEM-SBS WoC faculty’s unique circumstances into consideration.

II. LITERATURE REVIEW

Some form of mentoring is usually in place for new hires in many professions. Mentoring entails pairing up an experienced employee (the mentor) with a junior colleague (the mentee).

Working with a mentor can be invaluable preparation for a young professional. A mentor can help a junior employee learn about and adapt to an organization’s culture. He or she also can help a mentee get ahead by offering career advice [16]. Therefore, it would seem reasonable to expect mentoring to be beneficial in the professoriate where faculty are on probation longer than in almost any other profession and many WoC (women of color) faculty say they feel like they are on indefinite probation. However, it is well known that WoC are disproportionately denied access to mentoring due to the fact that academia has traditionally been dominated by majority-group males.

WoC in academe live with multiple marginalities [21]. Marginalization of women faculty, in general, persists as a result of exclusionary practices that foster a de facto segregation. This situation restricts opportunities for developing both formal and informal mentoring relationships by female faculty. In addition to gender marginalization, due to racial and ethnic marginalization, WoC face inequities and other obstacles in the pursuit of their career aspirations. As a result, they often develop feelings of isolation.

Many WoC recognize that mentoring and networking are important to their success [20]. However, in light of their extremely small numbers in STEM (Science, Technology, Engineering, and Mathematics) fields, they need much encouragement and support in order to survive; hence the need for the college and university administrators to provide WoC faculty with quality mentorship programs. Moody [17] believes “[M]entoring is *essential* for under-represented women in male-dominated fields..” Furthermore, she points out that “Mentoring has two dimensions: a senior person in the organization assists and advises a junior colleague regarding his/her career advancement and, secondly, provides to her less advanced colleague social/psychological support to enhance the mentee’s sense of well-being.”

A mentor should be “someone who will help you grow, move forward, challenge you, push you to be your best and...is going to advocate for you and your organization,” says Lacey Leone McLaughlin, director of executive education at the Center for Effective Organization at the University of Southern California’s Marshall School of Business [16]. The word “mentor” has its origin in Greek mythology. Mentor was a friend of Odysseus. The latter chose Mentor to educate and support his son, Telemachus, when he left for the Trojan War.

The term “mentor,” adopted in English, means someone who imparts wisdom and shares knowledge with a less experienced colleague. There are informal and formal mentors. The former provides informal mentoring that occurs naturally and is capable of providing significant benefits to both the mentor and the mentee due to the insights it provides to each. Alternatively, a formal mentor takes mentoring to the next level (a structured approach), expanding its usefulness, going beyond that of a single mentor-mentee pairing to enhance its value and effectiveness. There is evidence that mentoring benefits the mentee, the mentor and the organization. Therefore, in academia, effective mentoring has the potential to contribute to the career success of all faculty members. However, the mentoring model adopted by an institution is very important. It should have sufficient flexibility to adapt to the needs of the faculty without compromising the integrity, structure and quality of the program.

The MIT Report on the Initiative for Faculty Race and Diversity [14] recommends the need for establishing formal mentoring programs in all schools and departments, with training given to both mentors and mentees. Yolanda Flores Niemann [18] further emphasizes, “effective mentorship is critical to the success of women of color.” According to Christopher K.R.T. Jones, the Bill Guthridge Distinguished Professor of Mathematics at the University of North Carolina and a former recipient of the national Compact for Faculty Diversity, “African Americans and their under-represented faculty still receive little or no serendipitous mentoring. That’s an unconscionable gap that I see across the country. Formal mentoring programs, I agree, are the answer [17].”

It is very critical for an institution to provide a mentoring program that fits its institutional culture. The main mentoring models are: the traditional one-on-one, group-(or network) and peer-mentoring. At the University of Washington [25], for example, a network-based (or group) mentoring model is found to be appropriate for that institution. They did not find the one-on-one, single-mentor model to be an effective means for mentoring their junior faculty. They found a network of multiple mentors more beneficial than one-on-one mentoring to achieve the desired outcomes.

A. Institutional Context and Background

Founded in 1829, Rochester Institute of Technology (RIT) was an early pioneer in practice-based and cooperative education. Today, RIT is home to approximately 18,000 students (predominantly STEM majors) and is the third largest technical institution of higher education in the United States. Over one thousand full-time faculty (n=1068) support the academic and research enterprise in this tuition-driven, student-focused university. In 2014, women full-time faculty constituted only 32% of tenure-track faculty; 24% and 33% within STEM and SBS (Social and Behavioral Sciences) disciplines, respectively, and 40% overall.

RIT obtained an NSF ADVANCE IT project award (NSF ADVANCE 1209115) in 2012 entitled, *Creating Opportunity Networks for Engagement and Collective Transformation: Increasing the Representation and Advancement of Women Faculty at RIT* (or, simply, ADVANCE RIT).

ADVANCE RIT is an effort across RIT’s nine colleges, which includes STEM and SBS disciplines. The goal of the project is to increase the representation and advancement of women STEM and SBS faculty represented across ethnic, social, and cultural backgrounds. Over the past five years, RIT’s incoming classes have improved in quality and diversity and increased in size (20%). The faculty has become significantly larger, and less diverse.

III. METRODOLOGY

The present study entails analyzing data from two focus groups, consisting largely of tenure-track STEM-SBS WoC faculty, conducted at RIT during the spring of 2013. Participants were self-selected from a wide e-mail call, using the well-known snowball non-probability sampling technique. This approach was selected given RIT restrictions on providing race demographic data. Therefore, there was no way to identify prospective participants who identified with WoC groups. A scripted invitation that outlines the purpose of the project was sent out. It pointed out that the focus group discussion would be audio-and-video-recorded and that participants’ confidentiality would be preserved so that they could not be identified outside of the research group. Seven STEM-SBS WoC faculty, from science, math, and technology, participated in the focus-groups; four in one and three in the other. The focus group participants consisted of assistant professors and associate professors but were primarily junior faculty members. The participants have been at RIT for an average of four years.

A qualitative analysis of data obtained from the two focus group transcripts was performed using the constant-comparative method [4]. This enabled identification of patterns in the data sets to reveal similarities and differences.

The analysis entailed a three-phase approach. The first phase (open coding) permitted identification of ideas, themes, and issues. The second phase (focused coding) produced a reduced set of related ideas, topics and themes, and the third phase allowed for the identification of concepts that ties into the emic themes [19] that cut across the two focus groups.

IV. FINDINGS

As the research and analysis progressed, themes emerged from the meaning they represented for the subjects. In other words, the more prominent the themes were for an individual subject, the more likely it would be that they would attribute meaning to them in one or more area of their lives. Furthermore, prominence may be determined by the affect a subject uses when discussing it, or by the relative numbers of occurrence through the interview. Themes may also emanate through the wording of the interview when cross-referenced with ethnographer’s field notes and journals. In these cases, the notes may provide connections between theory and theme, creating an entirely different notion. The themes, as described by the subjects, were analogous with very personal events or social forces such as family influence, mentoring, networking in lieu of mentoring, creative mentioning, unique demands of

AALANA female faculty, or the power of education. More importantly, however, these themes granted a greater understanding about the role and function or lack of effective mentoring at RIT.

"It would be nice but right now I don't have an official constant go to person. It would be nice to have."

In general, this faculty member does not have a relationship where a senior member has taken an active role in her career development. She is not experiencing a process by which an individual of superior rank, special achievements and prestige is instructing her, counseling, guiding and facilitating her intellectual and career development. Furthermore, she is not being socialized to the rules of the academy by a senior member. She does not have someone who is accompanying her along her career to promotion and tenure. Her career development is not been viewed with a broad eye, seeing where she has come and where she is headed. For this respondent, mentoring has not empowered her to advance her career and receive tenure and promotion.

"...and I can't really pinpoint a specific thing. Just, you walk into a room sometimes and you are like, well this is odd or awkward and it takes a while to warm up. But that shouldn't be the feeling right. You should be able to walk into a room on this campus and feel like you are accepted. So no one does anything specific...but it's just a feeling you get when you walk into a room sometimes that, "hey, maybe I shouldn't be here."

The above respondent has gained entry into RIT and the profession but she finds that the environment is chilly and unwelcoming. This chilly environment may hinder her from attaining greater mobility and rewards. Her objective was focused on gaining entry into the academy and now she is being less successful in cultivating a mentor or mentors. This respondent might benefit from more than one mentor. Having several mentors would empower her more and give her more options. This might include a mentor who has interpersonal abilities or technical specifics in her profession for broad-based experiences. One mentor may make the initial contact in establishing a relationship with another mentor.

Kanter [15] noted that the centrality of power within formal organizations, along with obscure political structures, provide the means by which power mobilizes and distributes resources. Most white men want to maintain formal and informal positions within the power structure. They do this by establishing alliances with peers and sponsors. Peers and sponsors are therefore exceedingly important for women and AALANA women in particular because their sponsors, alliances, and peers are often more limited than those of males. In short, AALANA female faculty need access to the power structure that is available to majority demographics.

From stereotyping to tokenism, women of color face unique realities in the academic community. The above respondent feels excluded from communications and interpersonal activities that play an important part in promotion and tenure. This exclusion is also caused by their low numbers and their lack of entry into the formal and informal networks that provide support and opportunities to their white colleagues.

"So you have to sit there and think, is it just me? Honestly, there aren't enough of us on campus to be able to ask someone else besides you, "do you get the same vibe?" Who are you gonna ask?"

In view of the very small number of RIT's STEM WoC faculty, it is not surprising that the participants talked about a feeling of isolation and not belonging at this university. Much has been written about the negative sociological consequences of being the so-called "token" minority [20]. And there is the heavy load to be borne by being the tokenized numerical minority for performing service while having teaching and research responsibilities.

Racism and sexism are problems that concern and influence the behavior of AALANA female faculty. AALANA female faculty face a number of obstacles that make it difficult to achieve tenure and promotion. The two most prevalent obstacles they face are gendered and racial discrimination. The combination of which has been referred to as "double jeopardy" or the "double bind." Scott and Alexander [2] describe this double jeopardy when referring to African American women in particular, as: "preventing black women from formal networks such as higher educational training, and informal networks in which social relationships could possibly generate career benefits."

"Sometimes I think it's about being a women on this campus. Sometimes I do think it's about race. But no one ever says anything right?"

Although none of the respondents in this study had the benefit of a mentor in the traditional sense, all felt that mentoring was important and have or would like to assist others by being a mentor themselves. Many are involved in what can be defined as a history of relationships which have fostered individual growth. Some of these relationships are long-term, structured, formal and planned while others are spontaneous, short-lived or informal. One respondent stated:

"I have to agree with your definition of an advocate now that I'm thinking about it. So my department chair I would say is an advocate. Sometimes a mentor but not on the level of the other two, the formal and informal. If I need something he would definitely go to bat for me. Not personally, but yes definitely professionally."

Whereas the RIT STEM-SBS WoC faculty focus groups' participants recognize the value of a mentor, there appears to be some confusion concerning a formal versus an informal mentor and how either one may be able to help them to achieve career success. Not all of the participants said they have a formal mentor; however, they all said they have at least one informal mentor. One participant stated that she has a good relationship with her *mentor* whom she referred to also as her *advocate* due to the good relationship they have developed. She states that this person is her department chair. However, in order for faculty mentoring to be successful, the University must have an internal structure that supports an effective formal mentoring program. In addition, it is important to recognize the difference between a department chair-faculty relationship and that of a mentor-faculty relationship.

The department chair's focus is on achieving the goals and objectives of the department and the university while the latter is on developing the mentee professionally and personally. This distinct difference in their roles should preclude pairing new faculty with their department chairs in a mentoring program.

The lack of effective mentoring led to the creation of the P&T Smarts (informal) and P&T SMARTS (formal) program. These efforts grew out of the need to use a bottom-up management approach. A bottom-up management approach begins at a detailed view, with various segments combined to create a larger structure with a higher-level view. This approach gathered input from junior faculty at the lower levels as planning and decision-making are conducted. The nature of the P&T Smarts (informal) and P&T SMARTS (formal) missions most likely will achieve sustainable change that will build trust and communication. The loss of a substantial number of AALANA faculty at RIT points to the need to go beyond current programs and practices that the Institute currently provides and develop new programs that specifically target AALANA women to address the unique issues and needs they have as WoC faculty at a predominantly white institution.

A. *P&T Smarts (informal)*

This P&T Smarts will be facilitated by Dean Hector Flores (Graduate Studies Office) with the partnership of experienced faculty that will engage in informal mentoring and guidance. The process leading to tenure and promotion at an academic institution is sometimes fraught with tension and uncertainty. The purpose of P&T Smarts (informal) is to build a community of support and strategic thinking around issues of tenure and promotion. Experienced faculty and administrators will facilitate regular discussions on the various issues confronting faculty, engage in deep discussion about *smart* strategies and help develop a sense of common purpose and support that can eventually lead to a sustainable pipeline for success and a stronger community of teachers and scholars. Hands on exercises will be conducted as appropriate on issues ranging from networking, building relationships, to best practices to write and present scholarly work, building a strong and balanced promotion and tenure portfolio, etc. The only requirement for joining P&T Smarts is to commit 1-2 hours a month for reading or other assignments as appropriate.

B. *P&T SMARTS (formal)*

Under the leadership of Dr. dt ogilvie, Distinguished Professor of Urban Entrepreneurship, Former Dean of Saunders College of Business, and founder of the Center for Entrepreneurship (CUE), a CONNECT Provost Grant, Promotion & Tenure Strategies for Minority-women Academics at RIT for Transformative Success (P&T SMARTS) was funded with the primary goal to actively help non-tenure and tenure AALANA women faculty develop successful careers at RIT. It helps to retain them through a multi-faceted strategic approach that offers advice, feedback, guidance, and best practices that reflect a deep understanding of the unique issues and challenges that AALANA female faculty face.

Activities fall into several categories: mentoring and sponsorship, research and writing productivity, teaching

effectiveness classrooms that exhibit racial and/or gender oppression, time management, work/life balance, and professional SMARTS. Workshops will be designed to convey valuable information to the participants and provide training in how to develop and inculcate the skills into the faculty member's repertoire. This will be accomplished by improving communication, increasing transparency, providing consistency, and adding measures of accountability into the process.

Another important aspect of P&T SMARTS is the mentoring of the AALANA-Women faculty. Our model advocates that the participants develop a strategic mentoring plan, which entails that in addition to any mentoring provided by their units and mentoring by the team members, they develop a broad base of mentors for various aspects of their careers and look for cross-mentoring. That means they may look for writing mentors, teaching mentors, work/life balance mentors, mentors from their racial/ethnic group and mentors from other racial/ethnic groups, etc.

V. CONCLUSION

The unique experiences of WoC female faculty are often rendered invisible within the academy, obscured by scholarship devoted to either women as a whole or all people of color. The present mentoring initiatives at RIT have failed to capture the intersection of gender and race/ethnicity where the unique needs and experiences of women of color reside, silenced and masked within these contexts.

The lack of effective mentoring contributes to the WoC female faculty low retention rate and advancement rate. Therefore, there is a need for RIT to establish mentoring programs that takes STEM-SBS female faculty's unique circumstances into consideration.

The WOC social science research component seeks to remedy this oversight by giving voice to this subpopulation. Through implementation of the P&T Smarts (informal) and the P&T SMARTS (formal) seeks to tackle the lack of effective mentoring specific to women of color faculty by looking to the bottom-up approach to improve outcomes for female faculty as a whole.

By having examined the characteristics, lived experiences, perceptions, policies and institutional outcomes of women of color STEM-SBS faculty at RIT, unique barriers and catalysts to promotion and tenure and advancement are identified. The P&T Smarts (informal) and P&T SMARTS (formal) strategies or interventions will address these barriers.

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The Role of Collaborative Inquiry in Transforming Faculty Perspectives on Use of Reflection in Engineering Education

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Abstract— During the 2014 – 2015 academic year, engineering faculty members and students at California Polytechnic State University (Cal Poly) met monthly in a collaborative inquiry dialogue group to discuss the role of reflection in transforming engineering education. This project is part of the larger Consortium to Promote Reflection in Engineering Education (CPREE) headed by the University of Washington. In this paper we describe the activities of the Cal Poly group involved with CPREE and how these activities have transformed the thinking and actions of participants. Collaborative inquiry dialogue involves self-organizing individuals into a small group to address a compelling question through repeated cycles of experimentation and reflection on the results of that experimentation. In this context, the faculty members involved (including the authors of this paper) have been meeting to discuss how use of reflection in the classroom and/or in a collaborative inquiry dialogue amongst colleagues might lead to transformation in engineering education practice and outcomes. The dialogue group serves as a safe container that allows for the possibility of transformational insights by participants – insights that change their view of themselves, the world, and their relationship to it.

Using a qualitative self-report methodology in the tradition of an action research paradigm, we (the authors) reflected on what we believed we had gained from the collaborative inquiry dialogues. Broadly we have noticed that participation in the collaborative inquiry dialogue has led us to reconsider what reflection is and what it could be, to develop a greater appreciation for the role of reflective practices in engineering education, and to better recognize when reflection is occurring (and when it might not be) such that reflective behaviors can be encouraged and practiced. We also began to challenge

assumptions we had made about our teaching practices and have noted that the collaborative inquiry provides an environment in which development of new thinking is possible.

Keywords—collaborative inquiry; reflection; faculty; transformation

I. INTRODUCTION

In recent years there have been numerous calls to reform engineering education [1-5]. Most recently, Goldman and Sommerville [6] called for a significant reform not just to the content and pedagogy of engineering education, but to its very culture. They describe the engineering culture as rigid and focused on knowledge rather than on the human beings who operate within the engineering educational system.

We argue here that engineering culture might be altered toward a more human-centered perspective if more faculty, staff and students could be encouraged to reflect critically on the assumptions they hold about the nature of engineering education. We believe a change in culture of this sort would not only be a positive development, but would involve a transformation in both the quantification of the current system (i.e. better prepared students, more diverse students and faculty, etc.) and in its qualitative nature (i.e. the way that faculty, staff and students interact within the system, how power is shared, and how individuals are motivated to thrive). To this end we are engaged in an effort to promote critical reflection among engineering students and faculty with the

hopes that it leads to a transformational change in the state of engineering education at Cal Poly.

We did not embark on this voyage alone. In 2013 The Leona M. and Harry B. Helmsley Charitable Trust collaborated with the University of Washington to create the Consortium to Promote Reflection in Engineering Education or CPREE. CPREE is a consortium of 12 partner institutions ranging from very high research, large public universities to community colleges. The goal of this consortium of institutions is to encourage engineering faculty to incorporate reflective practices in their classrooms, thereby increasing the number of engineering students who have encountered reflection in their academic careers.

As a member of the consortium, Cal Poly not only seeks to encourage faculty to incorporate reflective practices throughout the engineering curriculum and across multiple disciplines, but we also aim to leverage funding from the CPREE initiative to facilitate a collaborative inquiry dialog within the College of Engineering that may lead to the transformational change described above. Our strategy to accomplish this goal is to engage a critical mass of engineering and non-engineering faculty and students in a collaborative inquiry on the role of reflective practices in bringing about transformation within the higher educational system. We acknowledge that we are participants in this system; systemic transformation therefore implies self-transformation. The technique of collaborative inquiry and its impacts on the first group of faculty and students (thus far limited to engineering disciplines) to participate at Cal Poly will be described later. First we begin with a brief discussion of reflection in engineering education as a transformative process.

II. REFLECTIVE PRACTICES IN ENGINEERING EDUCATION

Reflection is something that we are generally aware of and might even claim that we use on a regular basis. But arriving at a succinct definition of the concept is not trivial. According to the work of Moon [7], our common understanding of the concept of reflection involves three attributes: 1) that reflection is directly tied to learning and the representation of that learning, 2) that we reflect for a purpose, and 3) that it involves consideration of complicated issues for which there is not a single obvious solution [8,9].

The first significant advocate for reflection in education was perhaps John Dewey [8] who saw it as a crucial process for resolving dilemmas that one faces in every-day life. For Dewey, reflection is “Active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and further conclusions to which it leads . . . it includes a conscious and voluntary effort to establish belief upon a firm basis of evidence and rationality” [8, p.9]. Dewey believed that reflection was a process that could be used to serve education, but that it was limited to a purely individualistic and cognitive process. Habermas [10] extended Dewey’s thinking on reflection to

suggest that reflection is an emancipatory process that leads towards truth, freedom and justice.

Later Kolb [11] would position reflective practice within his larger experiential learning cycle. Kolb situates reflection as a process that brings the ‘concrete experiencing’ of events to the level of ‘abstract conceptualization’ as shown in Figure 1. The capacity of reflective judgment is necessary in order to achieve this level of abstract conceptualization. Kolb himself hypothesized that certain individuals might be better suited to particular aspects of his experiential learning cycle, leading to the possibility of preferred learning styles. Furthermore, he also postulated that one could develop ability in any one of the four domains of his learning cycle, including reflective observation. King and Kitchener [9] operationalized this thinking into their seven-stage developmental model of reflective judgment. Within their model, only the final two stages of development are designated as truly reflective, making the ability to make reflective judgments the most advanced stage. In their thinking, therefore, they saw reflective judgment as something that was not attained by everyone and was for most an adult activity. While the lower stages of their model are characterized by knowledge acquisition and reasoning ability, they posit that reflective judgment involves comfort with ambiguity and the lack of an expert solution to a given dilemma.

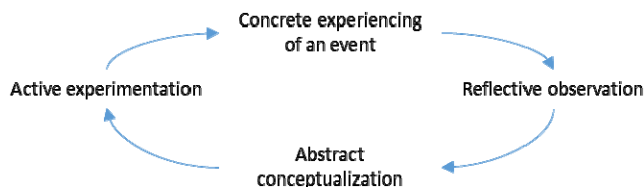


Figure 1: Kolb’s Learning Cycle [11]

Turning from a theoretical examination of reflection we can study how reflection is used in practice in engineering education. In their review of the engineering education literature, Turns, *et al.* [12], found relatively few publications related to the use of reflection in engineering education. They note that Ambrose [13] calls for greater inclusion of reflection in engineering curricula. Beyond this more general appeal, there are isolated cases of engineering education researchers recommending the use of reflection for various learning outcomes [14-19] and as a component of service-learning projects/activities [20-22]. Why there should be such a general dearth of reflection in engineering education, considering that the idea of reflection has been commonplace in higher education since the time of Dewey, is an interesting question. However, it appears that engineering education has largely been resistant to the inclusion of reflective practices. Perhaps this is because engineering has been defined by the content of the discipline and the expertise of the educators, rather than on a more holistic foundation as is found in the social sciences. Or perhaps there is a collective belief system among engineering educators that reflection is neither appropriate to engineering nor attainable by engineering

students. Regardless, based on the extensive history of reflection in education in general, we believe there is ample room for the inclusion of reflective practices in engineering education and the study of its impact. At Cal Poly we have chosen to explore reflection and reflective practices through a process known as collaborative inquiry.

III. COLLABORATIVE INQUIRY

Collaborative inquiry is a technique used by educators around the world to leverage participant experiences in order to address a captivating question of interest to the participants. It is a strategy derived from the work of John Heron [23,24]. Collaborative inquiry is generally a small group discussion process in which a group of peers frame and work to answer a captivating question through repeated cycles of reflection and action. It is a method both for conducting participatory research and for facilitating adult learning through experience [25]. Participation in collaborative inquiry is both voluntary and consensual [26]. The methodology “rests on the epistemic assumption that human experience is most validly understood when people are politically full participants in decisions so that they can most fully engage as their authentic selves leading to valid experiences” [26 p. 251]

Collaborative inquiry as a process can take different forms and Heron himself does not claim to have possession of the sole description of the method [24]. Bray *et al.* [25] argue that there are four important phases to collaborative inquiry extending over months, if not years, of discourse: forming the group, creating the conditions for inquiry, acting, and making meaning. Depending on the time scale of the collaborative inquiry group, the first two stages may be merged into one. In forming the group it is important to seek out both a diversity of participants and participants who are intrinsically compelled to answer the captivating question. The conditions for inquiry require a democratic sharing of power where all are free to contribute as they see fit. Acting involves testing out hypothesized models of reality, followed by both personal and group reflection in order to make meaning of the results of the hypothesis test in such a way that assumptions may be challenged and altered in the mind of the individual.

Collaborative inquiry is closely aligned with the theory of transformative learning [27,28]. Transformative learning as a theory is interested in the development of adult learners to change their frames of reference by critically reflecting on their assumptions and beliefs and consciously making and implementing plans that bring about new ways of defining their worlds [29]. Collaborative inquiry can be used as a technique to create the conditions largely considered to be essential to successful transformative learning. These include creating a democratic space in which participants are free from coercion, share power equally, and establish norms of inquiry that involve both hypothesizing alternative models of reality and also testing those models in the real world. Together these attributes of collaborative inquiry guide the individual to engage in critical reflection on personal assumptions and epistemologies. It is this critical reflection which leads the individual participant, through group dialogue, to change themselves and how they relate to the captivating question.

A key facet to successful collaborative inquiry is the contribution of experienced facilitation. Experienced facilitators will be knowledgeable with the principles of collaborative inquiry. They will be able to fluidly work with the group dynamics and simultaneously be able to critically reflect on the impact of their own assumptions, values and actions on the group and on the discourse related to the captivating question. Herron [30] and later Alcántara, Hayes and Yorks [26] identified a systematic structure of three modes of facilitation and six dimensions of facilitation (Table I). No one mode is ‘correct’ in collaborative inquiry. Rather it is important that the group experience a range of facilitative modes across all dimensions in order to maximize the richness of the experience of the collaborative inquiry group.

TABLE I. MODES AND DIMENSIONS OF FACILITATING COLLABORATIVE INQUIRY [26]

Dimensions	Modes		
	Hierarchical	Cooperative	Autonomous
Planning	Decide on process and content of group’s learning	Negotiate and seek agreement on what participants will learn and the process by which they will learn	Affirm group as it plans its own learning process
Meaning	Illuminate and make sense of participants’ actions and experiences for them	Partner with the group in the generation of understanding emanating from the process	Allow and support participants in the generation of their own meaning making
Confronting	Raise group’s level of self-awareness by pointing out behaviors and other issues affecting experience	Consult with group members, and invite them to raise each other’s awareness of the dynamics affecting their process	Create a climate for group members to practice confronting and consciousness raising
Feeling	Choose the methods of managing feelings and emotions to suit the purposes of the group	Work with the group to elicit views on and handling of feelings and emotions	Give group space to manage its own affective dynamic
Structuring	Design and supervise group learning methods and activities	Construct learning methods and exercises with group members	Delegate group control over the design and supervision of their learning
Valuing	Initiate care for group members, and commit to creating a climate that values each person	Build a community of value and mutual respect with participants	Entrust to the group the affirmation of self and others’ worth

IV. COLLABORATIVE INQUIRY AT CAL POLY

Beginning in September 2014, a group of 15 faculty from the College of Engineering at Cal Poly began the process of collaborative inquiry together. This collection of individuals represents a varied cross-section of the disciplines present in the college and includes faculty of all ranks including non-tenure track. Importantly, our collaborative inquiry involved ourselves as research subjects and coresearchers in the

tradition of an action research paradigm [31-32]. Experiments were situated in our own lives, rather than on 'others'. The group meets for two hours each month in a shared space within the campus library, having met a total of eight times by the writing of this paper. Over this period of time, several engineering undergraduate students have joined us in the inquiry.

It is worth mentioning that some members of the group had been meeting together for several years within a collaborative inquiry framework to examine the concept of change models in higher education, while other members of the group were entirely new to the process of collaborative inquiry. For the collaborative inquiry group described in this paper, the captivating question was "What is the role of reflection in transforming engineering education?" Our collaborative inquiry group is facilitated by Mr. Roger Burton, a change consultant for large corporations for more than a decade. Roger arrived at Cal Poly several years ago as part of a nascent partnership around research questions of sustainability. Prior to working on the CPREE project he had been facilitating the collaborative inquiry group on change models in higher education for about 5 years.

The collaborative inquiry group meets monthly for a two hour period. Meetings begin with a 'check-in' during which participants have an opportunity to share anything on their minds which may prevent them from being fully present in the ensuing discussion. The purpose of this ritual is to set down whatever is distracting one's attention. Things that people say can often be evocative, the discipline involves listening attentively and refraining from responding to whatever is said. It is the quality of the attentive listening that creates the safe environment for authentic reflection and self-change. We then move to a discussion of the previous meetings' homework and reflection on the results of the homework. The homework encourages participants to actively engage in reflection in their own lives and to observe the consequences of this reflection. What follows next is a discussion which typically centers on ideas of reflection in practice, transformation, and the relationship between the two. Finally the meeting is concluded with proposals from the participants about the homework for the next gathering. In this way, homework followed by discussion followed by homework, the participants are cycling through action and reflection as is crucial to a successful collaborative inquiry.

V. FACULTY AND STUDENT OBSERVATIONS

During the period of the collaborative inquiry and prior to the writing of this paper, we asked faculty participants to engage in a sort of reflection on their experiences in collaborative inquiry. Specifically we asked them the following three questions:

- a) In what ways has the collaborative inquiry group led to discourse that you might not have otherwise engaged in?
- b) What have you learned about reflection as a result of your experiences in the collaborative inquiry group thus far?

- c) In what ways have your understandings, ideas, assumptions, motivations, etc. been transformed by the collaborative inquiry group?

This section is a synthesis of the members' responses to these questions. Participant names have been replaced with pseudonyms.

For the first question, many of the participants noted that they had engaged in a dialogue around reflecting on reflection, something that they would not have otherwise done in their daily activities. Abigail observed that her participation in a collaborative reflection activity was ironic, given that she has requested that her students reflect in her courses, but she has not done it herself. For some this meant considering questions such as what it really means to reflect, how and when an individual reflects, and where reflection originates.

Participants have noted the creation of a cooperative environment in which it is safe to discuss challenging pedagogical and philosophical questions. For Charles the collaborative inquiry was a place to engage in critical thinking in a public way, something he has had neither the time for nor felt sufficiently safe to do in the past. Zhuang pointed out that we all come from different disciplines, backgrounds and levels of comfort with reflection, but all the collaborative inquiry participants are committed to improving engineering education. Because of this shared purpose all the participants respect each other and are able to engage in a dialogue that might seem "odd" in any other setting. The overall shared purpose comes from the group being self-selected and has enabled everyone to speak freely without fear of embarrassment, ridicule or censure.

For some, the collaborative inquiry led to a questioning of their own motivations for using reflection. As Sara remarked, "My participation in CPREE has helped to clarify that I tend to use reflections as a way to peer into student thinking and to have a 'conversation' with them."

The collaborative inquiry group has also allowed some to "back away" from the details of what they are teaching and to focus on the broader context of student growth and learning. In this way the regular meetings of the collaborative inquiry group invigorates a personal transformation into being a better educator.

As for what participants have learned about reflection in the process, question b), a common refrain was developing new models of what reflection is, its many benefits, and the many ways of using reflective practices in the classroom. Some noted that they had come into the collaborative inquiry with what they thought were well-established definitions of reflection in their minds, only to find that the collaborative inquiry dialogue led them to question what reflection was and what it could be. Even with these varied meanings of reflection, it is clear to many of the participants of the inquiry that we have a long way to go to identify the measurable benefits of reflection and reliable means of teaching it.

At least one participant noticed that in discussing reflection he came to realize that reflection was a method by which to make meaning from his experiences and that through reflection his experiences could be applicable beyond the immediate context of the original experience. This may have implications for engineering education as the practice of engineering does involve application of the same knowledge in differing contexts.

Another refrain among participants was the realization that students might not always reflect in an honest way when prompted by the instructor, but might instead provide a reflection that they think the instructor wants to hear. As Sasha reported:

“The students are simply writing what they think I want to hear or about a ‘transformation’ that they think I want them to undergo. I came to understand this well when we as a group forced ourselves to engage in reflective practices which possibly gave me insight into the experiences of my students. It seems to be a significant challenge for facilitators to create an environment where participants feel safe to share potential vulnerabilities when reporting on their reflective practices and what insights or personal transformations might have occurred.”

Finally, examining what assumptions and motivations have changed for participants, a wide range of responses were gathered suggesting that participation in a collaborative inquiry can have divergent meanings for each participant. George became more conscious of the need to reflect himself in order to bring transformation into the classroom for his students:

“A common denominator I gathered from our discussions is that a reflection involves thinking about our own experiences. This in turn made me think more about my experiences as an educator and what I want my students to achieve. It became clear to me, that in order to improve my effectiveness as an educator, I first need to reflect upon myself – thinking about my experience in the classroom – and identify possible changes I can implement. Reflection then leads to transformation – change I will implement – to provide students with a transformative experience.”

Abigail added that she has also learned “that faculty members play a conditioning role around the effects that ‘reflection’ has on the student. Their role includes the assumptions they hold about power in the classroom and the purpose of reflective activities. When the assumptions are unexamined, the influence is even stronger.”

Zhuang experienced a range of emotional responses to the collaborative inquiry. On the one hand, he acknowledged that the inquiry dialogues forced him to examine his own assumptions about reflection and even engineering education more broadly. But on the other hand, he now has more doubts about how to encourage students to reflect and how to determine the benefits of reflection. Zhuang recalls that:

“... while doubt is a negative emotion, it is appropriate here because I initially was overconfident about what I ‘knew’ about reflection. It’s not that I now know less ... it’s that I now know what I don’t know. I make fewer assumptions and that means I have to face more unknowns.”

Charles has begun to re-consider his motivations for teaching. He had originally been a teacher who wanted to excel in the classroom, to dazzle students with “ah-ha” moments. The collaborative inquiry has made him realize that teaching and learning is about the students’ lives in a significant way.

Some are challenging assumptions that reflection is a thing, but instead are seeing it as a process that we may be engaged in continually, either consciously or unconsciously. Others have come to recognize that in order for students to experience transformative learning it may be necessary for faculty to undergo a similarly profound transformation. Sasha illustrates this perspective when she says:

“facilitators must also reflect and be open to changes that occur in their views and themselves and their interactions with the world that are made apparent by this reflective process. It is only from this open vantage point that they can reasonably attempt to create the necessary safe environment in which their participants can also engage in the reflective process.”

Some participants have even observed that the collaborative inquiry is in itself an intervention in the traditional engineering education culture and that through this inquiry we are calling into question our identities as “experts”, our purpose in teaching, and our habitual practices and assumptions. This has encouraged some to engage more deeply into research on reflection, not merely practice. Sasha, for example, stated:

“I am interested in looking at what factors would influence the validity of collected reflective artifacts. In this way, I think the rigor of my future explorations will be improved. I am also feeling an increase in motivation to study this and find ways in which to get my students to authentically reflect on their experiences.”

Lastly, one faculty participant noted that the collaborative inquiry dialogues are a place to relax our expectations, to open up and to simply be human. This reinforces the notion of collaborative inquiry as a genuine exploration of the human condition as suggested by Heron [24].

The student participants in the collaborative inquiry, some of whom are authors on this paper, contributed to our thinking about the impact of the collaborative inquiry as well. One student, Michael, pointed out that normally there is a significant power differential between students and faculty such that he would not feel safe having a conversation with faculty about pedagogy. But in the collaborative inquiry group, he felt at ease to discuss pedagogical practices

including use of current models in educational practice from Mezirow and Argyris for example.

Armando observed the value of the collaborative inquiry in promoting free discourse not just about reflection, but about the challenges of engineering education. He particularly enjoyed hearing how faculty struggle with the larger issues within the context of their everyday activities. He offers that “[the] freeform discussions not only expand my horizons, but also remind me of the power of simply taking the time to sit down and talk with others.”

Michael also found that even in classes where reflection is not assigned, he still needs to reflect because for him reflection was a key aspect of developing as a human being, not just as an engineer.

The student authors concurred that the CPREE collaborative inquiry group has provided an environment where it was okay to reassess their preexisting notions and, perhaps, to change their mind.

VI. FUTURE DIRECTIONS OF INQUIRY AT CAL POLY

Currently 15 faculty and 4 students have participated in the collaborative inquiry group on reflection and transformation in engineering education at Cal Poly. During the next year we aim to increase the number of faculty participants to 35 and recruit as many as 25 student participants. One of the challenges we will face in reaching this goal is that we must reach out to faculty who might not otherwise consider themselves proponents of change in engineering education. To encourage people to participate we will provide modest stipends for participants during year 2, and will provide books on reflection practices to participants.

Another challenge will be managing collaborative inquiry groups with so many potential attendees. While not every participant will attend every collaborative inquiry meeting, having several dozen people participate simultaneously in collaborative inquiry groups may not be feasible. To overcome this obstacle, we may need to break up into smaller, parallel collaborative inquiry groups facilitated by faculty who are currently participating, also known as a federated collaborative inquiry [25]. Each collaborative inquiry group would begin with the same approximate agenda, but would be autonomous in the sense that the group members drive the direction of the group.

Lastly, we intend to recruit a diverse population of students to join the faculty in collaborative inquiry. To achieve this, we are establishing working relationships with several student organizations (e.g. Society of Women Engineers, Society of Hispanic Professional Engineers, Society of Black Engineers and Scientists, among others) such that we can recruit inquiry participants from their membership. Small stipends will also be provided to the students to compensate them for their participation.

VII. CONCLUSIONS

In the College of Engineering at Cal Poly we have initiated the process of a collaborative inquiry into the relationship between reflective practices in and out of the college classroom and transformative learning. Collaborative inquiry is a process that democratically explores the experiences of participants through repeated cycles of action and reflection. It is a powerful qualitative research methodology that treats participants as agents of change rather than simply objects to be studied.

We have carried out several collaborative inquiry dialogues amongst our group of engineering faculty and engineering undergraduates. Through these dialogues we have gained much insight into the meaning of reflection, its role in our professional and personal lives, and how it can be used to help our students experience a more transformative educational experience. Specifically faculty observed that they were engaging in a conversation that they would not otherwise have had due to the collaborative inquiry, nor at the depth of thinking they experienced. Faculty also noted that they were developing new models of what reflection was and how it could be used in various settings. They were also becoming more attuned to the conditions that were necessary to elicit honest responses from students completing reflection activities as part of their courses. They realized that transformation for students might require that faculty themselves undergo a transformative process through regular reflection on their part. In other words, in order to enable change in the students, the faculty would have to undergo a change process themselves.

Students too contributed to the collaborative inquiry process and the findings in this paper. In particular they noted that the collaborative inquiry created a space that was safe for them to enter into dialogue with faculty despite the ever present power differential. They appreciated hearing faculty perspectives on the challenges facing engineering educators, and they enjoyed being challenged to reassess their preexisting ideas and even to change their minds.

Cal Poly will continue its collaborative inquiry into the 2015-2016 academic year, with plans to expand the number of participants to 35 faculty and up to 25 undergraduate students. The hope is that by increasing the extent of dialogue among and between participants we can affect change in the College of Engineering that would make the educational process a more human-centered endeavor.

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Teaching computer programming

Practices, difficulties and opportunities

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Abstract— It is highly recognized that difficulties involved in teaching programming in an introductory course, arise from the cognitive process complexity that is necessary for developing this ability. Previous studies on the best first programming language or the best first programming paradigm have been conducted. Even, the most appropriate integrated development environment (IDE) for novice programmers has been inquired, and the most appropriate problem solving strategy to teach to write computable solutions has been researched. From the investigation in a sample of Bogota universities, and from a holistic perspective, this paper presents an overview of the most common practices and difficulties in teaching these courses, providing important information to help diagnose possible weaknesses in the current process of teaching as well as providing some elements to consider in the design of new strategies, resources and planning criteria for these formative scenarios.

Keywords— *Computing education research, teaching computer programming, introductory programming, programming pedagogy, novice programmers*

I. INTRODUCTION

Providing a suitable environment for learning computer programming for beginners is a topic of ongoing research since the 1970's [1], [2], even though it has been the focus of attention literary from the birth of electronic computing at the end of the Second World War [3].

Making computer programming learning more effective is socially important for the learner, as well as the novice programmer, the software industry which has held a growing demand in the quantity and quality of professionals, and for instructors and teachers interested in increasing the number of computer programming students by forming competent and competitive programmers.

There are elements that typically integrate the basics of the teaching-learning process in computer programming such as the languages, paradigms and programming environments, in addition to problem solving skills as a central focus of the process. Since the findings introduced in this paper, we invite readers to consider such elements within an integrated approach, given that they have usually been studied

individually and not as a set of variables that constitute the teaching environment.

Studies have been done regarding the most suitable language for teaching computer programming [4]-[6], as well as research on the most suitable integrated development environments [7]. However, the research conducted in this paper is an opportunity to fully consider additional elements involved in teaching programming, not only from the educational background, but also from the technological components with the perspective of problem solving skills.

This paper presents characteristics about teaching practices in introductory computer programming courses for undergraduate programs offered in Bogotá, in 2013, and it is organized as follows. Based on background revision, Section II presents the elements that typically build up a process of teaching computer programming and the role they play on it. This presentation structure serves also to show the results of this study. Section III introduces the methodological issues of this research, Section IV shows the results and their analysis and, the last section, shows some conclusions and recommendations associated with research findings.

II. TYPICAL COMPONENTS IN TEACHING COMPUTER PROGRAMMING

Part of the educational foundation of computer programming refers to Piagetian constructivism, but puts greater emphasis on Papert's constructionism [8], that is, an approach in which the world and knowledge are constructed and constantly reconstructed through personal experience, recognizing the inherent dynamics of reality and conceptualizing intelligence as an adaptation to the changing environment.

Papert [9] emphasizes the dynamics of change, learner's autonomy and an ecological or systemic vision of the learning process. All of these taking into account the competence of learning how to learn [10], which is also a key component in computer programming courses.

In this first section, components building up the set of the teaching computer programming practice are identified and explained. These components are those which have traditionally been taken into account in previous inquiries, such as programming languages, development environments, programming paradigms and problem solving strategies. Nevertheless, they have been frequently addressed isolated from their environment and other conceptual elements, but also isolated from situational elements [10], all of them integrating the computer programming teaching environment as object of study.

A. The role of the programming language

Although by 1956 the FORTRAN programming language [11] was created, and by 1960 the ALGOL programming language appeared at the computer scenario [12], it was only until the 70s that a programming language was designed [13], [14], that even its success in teaching (an learning) computer programming, it was not effective in the development of commercial applications, or at least not as much as Cobol [15], [16] that was created in 1959. Since 1970, some researchers [4]-[6] stated that the first step in teaching programming is the choice of the first programming language or suggest that it is a key element [17]. Those researchers develop their academic discourse around the programming language [18], [19].

The teacher is exposed to risks when teaching programming courses for novices in which the emphasis is on the programming language. One of the risks is that the novices focus their attention on syntax issues and not on the computational semantic power of the language, which at the end of the day is what allows to build solutions using computer programs. This approach prevents novices to understand that the main role of a programming language is to serve as a mean to express computational solutions proposed in the training exercises. Moreover, choosing a standard de facto language in the industry offers the advantage of training the student to develop skills that the market is looking for. However, it can also generate a bias of the concept of the student regarding the futility of learning other languages [20] and, besides, it can reduce the environment in which students develop the ability to learn to learn [10].

While the artificial language is an unavoidable element concerning the teaching of computer programming, especially for novices, the research that was conducted found that perhaps it should not be a decisive element in teaching practices. This should not be understood as a statement that teaching programming language concepts and structures are inappropriate [21] - [23]. The aim of learning programming language concepts and structures is to develop skills and competences to understand a wide range of artificial languages.

B. Computer programming development environments

Computer program development environments available today highly contrast with those available in the early years of computer programming. The interaction between the programmer and the computer during 1960's and 1970's was

minimal. At the present time, computer and programmer are very close. As other users, computer programmers during 60s and 70s had a punched tape or a deck of punched cards as a computer interface. Privileged users had a TTY terminal to edit files and issue commands. The process used to be linear and composed by five separate phases, e.g., editing, compiling, relocating, executable code generation and, if everything was correct, execution (Fig.1). Through the use of either control cards or control lines, the programmer issued commands to the computer (or the computer operator at the computer center) to determine what program or programs should be executed on the (source) file.

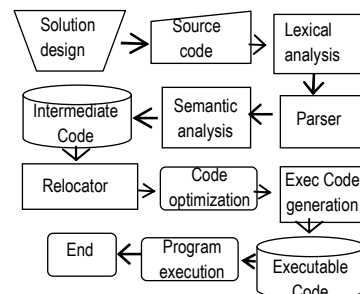


Fig. 1 Linear process of editing source code, compiling, understood as lexical analysis, parsing, and semantic analysis. Then a relocation phase, optionally going into a code optimization phase and, finally, generation of executable code and its execution.

The advent of microcomputers in the late 1970s and their consolidation in the next decade, brought the development of programs which allowed the programmer to edit the source file and, from the same program options menu, invoke the compiler, without any human intervention.

Contemporary IDEs, also known as suites or studios, are programs in which software tools or programming tools have been packaged [24]-[26]. Software tools such as: text editor (often specialized in creating visual aids on lexical and syntactic elements of a programming language), a compiler, with all its phases from the lexical analysis to generation of executable codes, a debugger and a program to design GUIs (graphical user interfaces) [27] share the same user environment. This increases the complexity of using the same IDE application and implies that the novice user adds another task to the process of learning computer programming: learning to use an IDE.

There may be different IDEs available for each of the operating systems. Let's say that the programming language (C, for instance) maintains constant between different operating systems. When using that programming language (C) in a Linux operating system there are a plenty of IDEs available. Moving the source code to iOS®, Android® or Windows®, just for the sake of reference, does not guarantee that the same IDE is available in the new environment. On the other hand, some IDEs may be more suitable for commercial usage, while others may be fitter for academic purposes. Besides, because of its nature, IDEs are not standard for all programming languages.

The use of a programming language can determine the use of a defined range of IDEs because there is not a universal

IDE. This, in turn, can generate an impact on the learning process since, empirically, it is known that students can direct their effort to understand the use of IDEs and overlook learning how to program a computer, or override learning the programming language itself. Therefore the choice of IDE is also an issue to consider.

Thus, the linear process of computer program development, an offline process from the perspective of the programmer, became an interactive process (Fig. 2). The expectation was that this new interactive process would improve software production leading to a final software product fulfilling at least high-quality standards, in terms of error free, well-documented, clear source code, leading to reductions in maintenance costs.

Usage of IDEs facilitated in part the interaction between the (learner) user and the computer, but a risk in this case has been the assumption that learning to use the IDE by the student is intuitive and therefore not time-consuming or exhibiting minimal difficulties [28], besides, the assumption that the learner is able to distinguish that learning to use the IDE is only a means to construct computer programs.

C. Programming Paradigms

A programming paradigm can be understood as a set of practices to solve computable problems, design its models and translate them into computer programs, practices that are adopted and used by a community of programmers over a period of time, based on the concept of Kuhn [29]. Consequently, the paradigm determines the style of programming, the time that the program testing can take, the results of software metrics and possibly the programming language in which it is (or have to be) encoded.

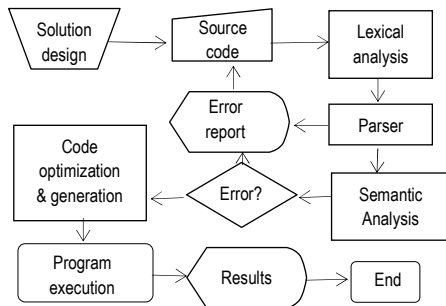


Fig. 2 Description of the interactive process of computer programs development, which by means of an IDE app, offers to the programmer the software tools that are supposed to be sufficient to build

Available literature shows no general agreement on the classification of programming paradigms, and even some documents tend to interpret these paradigms as a criterion for classification of programming languages or only identify them as "approaches" [30]. In this article, a tripartite categorization is adopted, and it is based on the criterion of how the solution to a computable problem is defined:

i) Imperative paradigm: in which the expression of the operation to be performed is privileged, i.e., how to do it; ii) declarative paradigm, in which the expression of what is sought is privileged, i.e., what to do; and iii) a third category in which other guidelines are grouped to privilege other

concepts or emphasis is made in the abstraction of other elements in the context of the computable problem (Table I).

TABLE I. PROGRAMMING PARADIGMS

Category	Programming Paradigm
Imperative	Free Structured/Modular Procedimental Object Oriented Event Oriented
Declarative	Logical Programming Functional Programming
Others	Heuristics Agent Oriented Concurrent (by processes) Aspect Oriented Rule based Restriction based

Thus, free programming called as *spaghetti* programming, is essentially an imperative form, in the same way that the structured programming paradigm refers to procedures and modules. The object-oriented programming paradigm and the event-oriented programming paradigm are categorized also within the imperative paradigm category.

The paradigm of logic programming and functional programming are classified under the category of declarative programming paradigms.

While the concept of object-oriented programming can be traced back to 1966 [31], it is at the beginning of the 1990s when the tradition in teaching programming in the structured paradigm is challenged by the object-oriented paradigm [33]. And an analog academic discussion to that given in the selection of the programming language, develops in the arena of programming paradigms, especially in the confrontation between the paradigm of structured programming and the paradigm of object orientation (OO).

It is not under discussion if the OO paradigm should be taught, since the software industry demands this skill. The discussion focuses on when it is more appropriate to introduce it. Literature shows that the OO paradigm produces better performance in students when they learn it before the structured programming paradigm [32]. Students who first learn the procedural paradigm, experience serious difficulties, in some cases insurmountable when changing to the OO paradigm [33], [34]. That is not to say that learning the OO paradigm is less difficult than the procedural paradigm [35], [36]; so it is recommended to do it gradually [36], [37], starting from the object-oriented paradigm gradually and then, if necessary, move to the paradigm of structured and procedural programming.

Nevertheless, there are studies that suggest that there is no significant difference concerning the order in which programming paradigms are taught, the difference mainly relies on the language that is used for novice programmers [38].

D. Problem solving strategy

Despite the extensive development of programming languages and programming paradigms, some researchers insist that neither the programming language, nor the programming paradigm or the integrated development environment are important elements in teaching, but rather the design process and concept-oriented on problem solving, not on paradigms [39] and that all students should be taught to program computers as an extension of the knowledge they already possess, that is mathematics.

Therefore, it is recommended that instructors include strategies for develop problem solving skill, in the classical sense, by induction [39], and through the use of top-down approach, with verifiable practical results [40]. This means that the programming learning environment is not restricted to the software applications of integrated development environment (IDEs), but involves the development of cognitive processes and improve competences on real world understanding, also. Algorithmic thinking is just one of those skills steps related to those processes and competences.

E. Other elements involved in teaching computer programming

As in any teaching process, the issue under study: the programming language paradigm or IDE, is not the sole determinant in the success of the teaching process. Some studies have pointed out motivation as a key element to be considered and strengthened in any teaching process [41]. A three-level hierarchy of the difficulties in teaching/learning Java programming language has been proposed [42], within these categories, difficulties in teaching programming can be examined. The first level establishes three criteria: (i) cognitive difficulties, (ii) programming difficulties and (iii) image difficulties (or perception).

In the second and third levels, within the cognitive difficulties, teaching strategies are identified (classes, tutorials and laboratories), learning style (comprehension and memorization) and motivation (genuine interest, prospects of career and family pressure). Programming difficulties themselves are grouped into difficulties regarding multiple processes (translation, algorithms, coding), educational skills (problem solving, precision) and multiple skills (syntax, structure, semantics, style). Finally, the criterion for self-perception difficulties (or perception) is comprised of interest (creativity, enjoyment when performing the task), reputation (public image and career), and finally, pace of instruction (academic year, course intensity and evaluation).

III. METHODOLOGY

A research study was conducted in order to unveil the practices developed by teachers and the difficulties in teaching computer programming in undergraduate programs in some universities in Bogotá, and those features related to students' learning processes; finding useful information for the design of new teaching strategies, teaching resources and planning criteria for courses in the academic area of teaching computer programming [43].

A literature review was carried out to establish the advances of research on the topic (typical elements conforming computer programming teaching) in order to contextualize and guide the study. The study was conducted based on a qualitative research approach. An instrument for collecting data was designed and an analysis on teaching practices was conducted.

A. Sample Determination

As the main interest of the study relies on characterizing teaching practices in introductory courses on computer programming, different universities in Bogotá with academic programs that include this type of courses were identified. The academic programs that were taken into account were the ones registered and recognized by the Ministry of National Education of Colombia. As a criterion of homogeneity for the sample [44], within this group of programs, we identified those courses in which the main goal is to teach the fundamentals of computer programming, establishing such courses as units of analysis [44]. In the sample, we identified introductory courses to programming within programs of Systems Engineering, Environmental Engineering, Industrial Engineering, Electrical Engineering, Mathematics and Computer Technology.

After identifying the courses, universities and programs were invited to participate in the study and, by sampling volunteer participants [44], we included the teachers that teach the introductory courses as subjects of inquiry, in order to gather the information required to characterize their teaching practices, and other useful items for analysis. Since the research study is an in-depth case study, it required at least 6-10 cases [44]. The study involved 17 courses (units of analysis) belonging to 8 academic programs from Universidad El Bosque, EAN, Fundación Universitaria San Mateo, Universidad San Martín, Uniminuto, Fundación Universitaria Konrad Lorenz, Universidad Manuela Beltrán and Universidad Central.

The methodology for data collection was based on the actions and skills of the actors involved in the programming teaching process. It included the implementation of a structured interview with twenty-two questions for teachers who were asked about their teaching and assessment practices, bearing in mind resources, tools, paradigms and languages used for teaching programming, as well as the difficulties encountered in the process. The texts of the interviews were transcribed for further information processing.

B. Information Processing

From the initial research question: What are the practices and difficulties in teaching introductory courses on computer programming?, the analysis of the information was developed in three stages. In the first stage, called encoding, the gathered information was organized under initial criteria previously established from the axes of inquiry obtained from the interviews and the research purposes. They allowed us to obtain an overview of the information and the data collected. In the second stage, called analysis, similarities, relationships and differences were recorded, which consequently led to the

emergence of the categories of analysis. In a third stage, and taking into account the conceptual framework that was presented in the state-of-the-art revision, the results of the research were outweighed and contrasted to finally describe the findings in each category.

C. Classification Stage

In this stage, we selected, classified, cut and coded all interview texts in accordance with their relevance to each of the defined criteria and sub-criteria (Table II).

TABLE II. BASE ANALYSIS CRITERIA

Base Analysis Criteria	Subcriteria
Teaching/learning context	Contents Teaching strategy Assessment strategy Learning goals
Tools and resources	Development environments Programming languages Others
Paradigms	
Difficulties	
Strategies for improvement ^a	

^a Emerging criteria

The criterion "Teaching/Learning context" groups information that provides a general characterization of training environments. The criterion "Tools and resources" includes information related to the languages, programming environments (IDE) and other resources used in the courses. The criteria "Paradigms" and "Difficulties" are considered to be part of the research interests. "Strategies for improvement" is emerging as a possible category.

D. Analysis Stage

This stage was developed in two different phases. In the first, called "screening" [45], initial relationships were found in the information contained in the criteria, by listing and mixing, they gave rise to the categories of analysis.

The second phase called "*web of relationships and final categories*" [45], common elements, relationships and differences in the information within categories and subcategories were sought, finding a web of concepts that when observed in the light of all elements that constitute a process of teaching and learning computer programming, become the final categories of information that serve as a basis for the interpretation of results. Table III shows the final category structure resulting from this stage.

The categories related to languages and programming paradigms, development environments, solving problems skills and difficulties in the process are intended from the objectives of the study and data collection.

In this case, finding that teaching practices that characterize the context depend mainly on languages, paradigms and selected IDEs, the "Teaching/learning

context" category and its subcategories mingle with the "resources and tools" category, yielding the "Other teaching practices" category, which together with "Opportunities for improvement" gather what teachers say and reflect on their practice.

TABLE III. FINAL ANALYSIS CRITERIA-RESULTS CATEGORIZATION

Base Analysis Criteria	Subcriteria
About programming paradigms and languages	As a guide of concepts, contents and learning goals. <ul style="list-style-type: none"> • Java. • OOP and Structured Programming. As a guide of preferred IDEs <ul style="list-style-type: none"> • Java As a guide of learning strategies <ul style="list-style-type: none"> • Java As a guide of languages and preferred paradigms. <ul style="list-style-type: none"> • Java, PHP, C++, Python, UML, C#, HTML5. • OOP, Structured Programming, Procedimental, Dynamic, By Blocks, logical and Functional. As a language linked to a paradigm <ul style="list-style-type: none"> • Java and OOP
About development environments	For Pseudolanguages and Flowcharts. For OO Languages To modellings
About solving problems skills	As a teaching strategy As a teaching goal As a difficulty As an opportunity
Difficulties in the teaching process	Cognitive Of programming process Of image and perception Other difficulties
Other teaching practices (emerging)	Other contents Other learning strategies Other assessment strategies Other tools and resources
Opportunities for improving (emerging)	Changes of the courses Motivational Didactic Other improvement strategies

With the structure of final categories, an overview concerning the teaching practices and difficulties presented in the teaching environment of computer programming is provided. Additionally, these categories allow teachers and researchers to address such difficulties and reflect on them from an integrative perspective.

E. Interpretation Stage

Having organized the results into categories and subcategories [45], we proceeded to identify the role of paradigms, programming languages and development environments, how problem solving is discussed, and some features of the teaching process that are considered as debilitating. In the final stage called intense analysis, which deals with one category at a time, in terms of the conditions of variation, interactions, strategies/tactics and consequences, useful information was found in order to design new teaching strategies. The interpretation process ended with the

integration of categories building answers to the research question and establishing the conclusions of the study.

IV. RESULTS ANALYSIS

A. *The role of programming languages, programming paradigms and development environments*

Some teachers mentioned structured programming and even 'dynamic programming' as the paradigm of their choice for teaching. However, many reported they adopted the object-oriented programming paradigm, because it provides "better logic and organization", understanding them as the ability to provide a solution, because it allows the reuse of code, and even, because "it is more focused on the real world" in the sense that this skill is demanded in the labor market. For the same reasons, the language that is usually referred as the first language in teaching computer programming is Java. The use of this language should be evaluated by the inherent uncertainty of its 'durability' in the market, and because of the restriction or bias the students are exposed to by learning a unique tool for computer programming.

Other languages that appear during teaching practices are 'pseudo-code', as a first step for writing algorithms, PHP for web development environments; C# and C++ for the applicability of the language in various environments. Python is mentioned because of its simple and easy-to-learn syntax.

As for programming environments and preferred tools to support learning, some teachers mentioned the use of Notepad, Notepad++ and SublimeText in the early stages of learning, so that students understand that it is not always necessary to use development environments such as Eclipse or Netbeans.

Teachers also argue that using computer programs such as Notepad++ prepares students for an eventual and less traumatic transition to operating systems different than MS-Windows. In the panorama, other tools like BluJ, DFD, StarUML, NetBeans, DevC++ and Visual Studio have appeared.

It is worth noting that the predominance of Java and the object-oriented paradigm becomes more important when planning instruction. While reviewing responses from teachers when asked about programming languages, as it was expected from the state-of-the-art revision, the programming language defines several contents and learning objectives for the courses, becoming then the goal and not the means, relegating problem solving strategies to a second instance. In this regard, the next section shows how this issue was confirmed.

B. *Problem Solving*

In general, problem solving is mentioned as an important learning goal, combining other skills such as analysis, abstraction and solutions design. However, when reviewing the prevailing teaching strategies used in instruction, none of them relates to the development of skills to problem solving. This seems to agree with the fact that teachers mentioned dealing with problems, analyzing them, design and implementation of solutions to real world problems using a programming language, as the relevant difficulties students show when learning to program a computer. As a result,

teachers suggest that course didactics must provide means to develop this capability.

C. *Weakening agents in the teaching process.*

Regarding the inquiry on practices, some facts were perceived by teachers as debilitating agents for the learning process: students fail to devote to study and need more autonomous practice. These seems to be either because they work by day and study at night, which restricts their available time and, thus, they should allocate time between classes, or because students do not assume responsibility to manage their time yet.

In relation to educational skills, determined within the constraints of programming per se, in the third hierarchical level the set of difficulties in teaching Java programming language [42], teachers mentioned other debilitating factors in the process, such as lack of skills in mathematics and logic associated with the difficulty to abstract. Besides, they mentioned students show deficiencies to read and understand texts in Spanish (including poor knowledge of spelling in Spanish and scarce skills in text composition), problem analysis and students' refusal to read in English. In the same hierarchy of difficulties, those called perception, the lack of basic knowledge in mathematics, vocation and love for programming, also seem to prevent success in the learning and teaching process.

Given these debilitating factors, this study asked for pedagogical strategies. Results allowed to identify that those used in teaching programming courses are closely similar to those used when teaching math courses: an exhibition of topics provided by teachers, possibly with visual aids to visualize and outline solutions, followed by experiments on the computer in scenarios called "laboratories". There is no reason to think that these practices vary significantly in other universities in Colombia.

In the "laboratories", teachers repeat what was taught in class and assign sets of exercises to be done by students outside the classroom. Solutions to such exercises are assessed based on their performance or progress (direct approach), or by means of "tips" given by the teacher and, by delivering the solution, or by means of teacher-led workshops and guided practices (indirect approach). Other formative didactic activities such as class projects, programming marathons, quick response contests and programming challenges were also found.

These findings confirm the need to develop the ability in students to solve problems in computer programming courses. It seems that teaching practice by itself does not lead towards this aim. Teaching program focuses rather on mastering the use of programming languages and software tools. Furthermore, the teaching strategies that seek to develop problem solving skills are not present during teaching practices. These issues are recognized as major drawbacks in students, which directly affect their performance in computer programming courses.

D. *Other Teaching Practices Found*

The learning goals and assessment strategies stated in the inquiry were reviewed, and a clear correspondence with

educational and expressed difficulties were found, because the learning objectives that appear as major in the courses are the construction of computer programs using paradigms, languages and specific programming environments, understanding and applying the concepts related to them. In a few cases, it is sought to develop social and emotional skills such as teamwork.

The fact that the practice of examining students (quizzes) at the very start of each class is justified because it "forces (students) to devote at least 20 minutes before class to review the topics studied" is worth highlighting. This follow-up process and other coercive means implemented by teachers arise as an answer to a set of external situations to the very exercise of teaching that are expected to be solved by asking the teacher to "motivate" their students. Other summative assessment practices such as oral defenses, presentations and exams are included. Other formative assessment strategies also appear as extra class exercises, labs and research exercises. Other teaching contents are the algorithms and the writing techniques, software architecture, graphical user interfaces and in some cases databases.

It was notorious to observe in responses received from teachers that no mention was made of the incidence of the use of a specific operating system in the teaching of computer programming. It was not mentioned the reading of the source code as a competence or as a learning activity, which is one of the skills that the ACM Computer Science Curricula 2013 [46] states as *core-tier1*, which means, as one of the basic or core competencies.

E. Opportunities for improvement

From the emerging categories, improvements in the teaching-learning process proposed by teachers such as the inclusion of activities in courses to develop logical-mathematical skills, modelling and problem solving, focusing didactics on drilling-practice and assessment for rewards may be emphasized.

Other teachers suggest leveling up students in algorithmic, mathematics, reading and logical comprehension, either before or at the beginning of the course. Additionally, they suggest incrementing the number of hours devoted to courses as a way to improve, given that insufficient time was also stated as a debilitating issue for a complete and integral accomplishment of syllabus objectives.

As stated before, the landscape of practices and difficulties in teaching computer programming must be analyzed from a holistic perspective, observing the cause-effect relationship between them and the pedagogical thinking behind that generates such a scenario. First, it is clear that the hidden curriculum understands computer programming as a mechanical task, so the consequence is that programming courses design is task-oriented and not to the skills of solving problems and modeling computational solutions. However, this reality is not recognized by teachers because while they are the architects of said reality, they demand students to have superior abilities. On the other hand, paradigms, languages and development environments are used as necessary tools in the task of programming, but the

possibilities that they offer as learning resources is not considered, adding another useless load to the teaching process.

The panorama of practices and difficulties also reveals that it is not possible to achieve success in teaching programming if it is not seeking to develop skills throughout (or prior to) the students' learning process; skills that are also important for other disciplines and also for a student's life. Then it is recognized that the times assigned to programming courses will never be enough to achieve it.

V. CONCLUSIONS AND RECOMMENDATIONS

Since computational thinking is a nuclear academic competence of the XXI century [49], [50], considering a possible generalization of the results found in other scenarios not dealt with during this research, teaching computer programming needs to be deconstructed and redesigned. First, the development of skills for problem solving, communication, mathematical thinking and learning how to learn should precede, or at least to be paralleled with the intention to teach programming. This would mean that computer programming courses should not be taught early in the curriculum, but perhaps as said skills are being acquired (or already have been) later throughout a student's formation. Second, it is necessary that IDEs, paradigms and languages support the development of such skills, analyzing its relevance to the implicit cognitive processes in the skills being sought, apart from the criterion of popularity or market demand for use. Third, it must stop using transmissionist teaching strategies oriented to the task, for which it is also necessary that curriculum designers, principals and faculty members think about what "being" an engineer means, and how computer programming supports this essence. To understand this, and making students understand it too, adds motivation and autonomy to their learning process.

Once the results of this research have been presented, it can be stated that the difficulties in teaching computer programming, and the non-achieved objectives in the process of instruction, resulted from the design of courses, which do not take into consideration the didactics oriented towards problem-solving skills development, logic, understanding and abstraction of real world, written expression and/or appropriate use of natural language.

Additionally, student evaluation should stop being used as a coercive instrument to become a true assessment method of teaching and learning, and therefore, capable of monitoring the development of the skills described above. Then, the challenge is to teach computer programming by having students develop "learning to learn" skills, or as it is expressed in the ABET, the "recognition of the ability to learn throughout life", to solve problems and express solutions in an artificial language remains the same as from the beginning of the 1970's [12], [47], [48].

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Teaching-learning methodology for Formal Languages and Automata Theory

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Abstract-Formal languages and automata (FLA) theory have fundamental relevance to the base of knowledge in the computer science area, especially focusing on scientific education. Usually presented by a discipline, the teaching-learning process of FLA is characterized by the high level of abstraction, and it is considered difficult due to the complexity of language formalisms. As support for the learning process, tools have been used to simulate language formalisms. However, the simulation is not enough to reinforce the construction of an abstract concept. In this paper, we present an FLA teaching-learning methodology based on the development of simulators as an approach to clarify the formalism for the students. Through developing their simulators, students are exposed to the data structure and algorithms to handle the formalism. Consequently, students have the opportunity to make the concept concrete.

Keywords - *Methodology, Formal Language and Automata Theory, Learning Tool; Visualization; Cognitive Load; Education; Computing.*

I. INTRODUCTION

Formal languages and automata theory have fundamental relevance in the computer science area. To a graduate student, especially those who have the academical career as a life goal, it is considered an important knowledge acquired. It is usually presented in a course where the high-level of abstraction characterizes the teaching-learning process of it, and it is seen as difficult due to the complexity of language formalisms.

A common way to exemplify the formalism is using sketches to make a visual representation of an abstract concept. Besides that, drawing take too much time and make usage of static images do not help with the interaction between student and formalisms. For this reason, many tools were used to support the teaching-learning process, and all of them are able to generate a visual illustration of a formalism.

Additionally the use of simulation tools generates an interactive form from an abstraction and helps students to understand the logic behind the visual form. On the other hand, the simulation is not enough to reinforce how the construction of a formalism is done. The teaching-learning process needs to be helped by software capable of formalism interaction, enhancing the learning logic; it still needs to be capable to

demonstrate how to create a formalism with programming languages and paradigms.

Several tools have been developed to present formalisms structure [1], [2], [3], [4], [6], [5], [7]. They help the learning process contributing to build a concrete knowledge, minimizing difficulties faced by students with the high level of abstraction [8]. The tools by themselves are not enough, the different perspectives of teaching and developing require methodological approaches to organize the usage of mechanisms to support the teaching-learning process [9].

The experience of modeling a simulator provides the opportunity to the student write their understanding of a formalism in a code architecture [9]. As a result, providing challenges and making connections to different representations of a common abstraction as a Finite Automata and Turing Machine, as many others that can be developed into a common structure.

The main goal of this paper is present a formal language and automata theory teaching-learning methodology based on constructionism [10]. In our methodology, students are exposed to data structure and algorithms, developing their simulators as an approach to clarify the formalism in favor of knowledge construction. Consequently, students have the opportunity to make the concept concrete.

As a result, different years, before and after the methodology application, students' grades were collected and compared yearly. The positive results are observed in students' grades, besides their increasing interest and motivation in learning.

In order to present this teaching-learning methodology, this paper is organized as follows: Section 2 presents some tools available in the literature; Section 3 presents the methodology proposed, and a brief description of a developed simulator, a tool to represent and visualize formalisms and their operations; Sections 4 presents the results of the methodology application; Section 5 presents the final remarks.

II. RELATED WORKS

This area covers many classes of formal languages like presented by Chomsky hierarchy [11]. It can be divided into topics where each topic explains and present a formalism with the necessary theory and implementation guidelines.

The formalism is related to language, grammars, and regular expression recognition with finite automata. Apart from Turing, Mealy, Moore, Norma, and Post machine; besides the automata variance with determinism, non-determinism, and push-down automata [12].

Our course introduces this area to students, from raw to complex, teaching about:

- 1) Finite state automata and regular grammars;
- 2) Push-down automata and context-free grammars;
- 3) Linear-bounded machine and context-sensitive grammars;
- 4) Turing, among other machines, and phrase structure;

We use, as a guide, the course topics to compare different formalism simulators. Analyzing each one with their conceptual-implementation. As conceptual understanding, students need to be taught about the theory to represent and solve problems with machines and grammars. In the other hand, the implementation understanding represents the knowledge to create a data structure capable of formalisms recognition [9].

JFAST [1] is a Java finite automata simulator focused on visualization and interactivity to active learning techniques to improve mastery of difficult concepts. It is characterized an easy-to-use graphical software tool for teachers and students, with an emphasis on the introductory level of finite state machine topics. The simulator goal is enhancing teaching effectiveness in this subject, particularly for less advanced computer science students, on the other side, the simulator is limited for automaton representation.

JFLAP [2] is a theoretical computer science framework written initially in C/C++ and after that ported to Java. It was built to design and simulate several variations of finite automata, push-down automaton, one-tape Turing machines and multi-tape Turing machines. Besides that, **JFLAP** allows the conversion between grammars and regular expressions if they are equivalent by Chomsky hierarchy [11]. **JFLAP** is one of the most complete tools developed in this area, it is capable of several conversions from one representation to another.

In the following we present some of the supported conversions [13], [14].

- 1) nondeterministic finite automaton to a deterministic finite automaton;
- 2) nondeterministic finite automaton to a regular expression;
- 3) nondeterministic finite automaton to regular grammar;
- 4) regular grammar to an automaton;
- 5) nondeterministic pushdown automaton to a context-free grammar;

Visual Automata Simulator (VAS) [3] is a tool for simulating, visualizing and transforming finite state automata and Turing Machines. It is characterized to be an application capable of creating and simulate any deterministic or non-deterministic finite automata, as well as Turing Machines. The tool present a complete implementation about Turing Machines and finite automata, but could be improved if others representations were implemented to be used by advanced computer science students.

Auger [4] and **FSM** [5] are simulators that can visually represent a finite automata to grammar recognition, both of them are limited by the finite state automata and regular grammars which represent the lowest level of complexity on Chomsky hierarchy [11]. **FSM** stands out compared to **Auger** because it is an on-line application.

Automatograph [6] is a deterministic finite automata simulator and is a beta software, still in development, which have been used to help in the teaching-learning process with regular grammars and finite state automata. The goal of the application is to validate characters chains with an automaton created by the user and showing the steps of recognition until the automaton reach the final state.

Deus Ex Machina (DEM) is a simulator capable to provide a generic platform for designing and running different kinds of automata, such as finite state, push-down, linear bounded automata and Turing, registers and vectors machines, apart from, Markov algorithms. It was built on an icon-based interface where students can sketch an automaton using vertex and edges. The software implements step-by-step run, showing how a given input string is processed as the execution of the automaton. Besides that **DEM** includes save, load and print functions for all representation [13].

A cellular automata simulator [7] is described as a compiler that have been developed for high-speed simulation. Cellular automata are a way to understand and simulate the behavior of complex systems; this simulator is an example of a particular usage of automata to help to understand the usage in a case studying. It is characterized as a temporal and discrete spatial system, capable of updating many cells at high speed with high precision.

As presented there are many tools capable to represent the formal languages and automata theory formalism, and usually the authors present the tools focusing on a feature available. They spent much time creating an icon-based interface to interact with the student, showing how the formalism work, but do not present a way to build it. Also, tools are not bound to a methodology [9]. It is important to use a tool like a support to the teaching-learning process, but an adequate methodological approach is needed to improve the teaching and the learning part, providing a better understanding of the subject.

III. METHODOLOGICAL APPROACH PROPOSED: SIMULATORS CONSTRUCTION

Making an analogy to the learning process of data structure and programming language, the capability of understanding an abstraction or a formalism are the most difficulty faced by the students [16]. On the other hand, the highest level of abstraction it is correlated with the programming concept and their theoretical relations [17]. Comparing this points with the formalism faced in formal language and automata theory, we discover that the abstraction, as a step to conquer knowledge, need to be helped by educational software or simulations tools, in the order to simplify and create a visual representation of an abstraction concept. The methodological teaching approach underlies the teaching-learning process and is responsible to guide the knowledge providing strong personal development.

In the following we present a Simulator to illustrate and explain the proposed methodology appliance. The purpose of

this section is to demonstrate, through a simulator developed by a student, how specific and deep knowledge was acquired in the classroom. Focused on finite state automata, regular grammars, Turing Machine and phrase structure.

The stated Simulator is an application based on Multi-Formalism Modeling, and it was developed by a student in JavaFX [15], known as a multimedia framework developed by Oracle Corporation based on multi-platform and web applications development. The current version of the framework allows desktop, browser and mobile development, and it is compatible with Smart TVs, video games, and Blu-rays players. Besides that, JavaFX can be executed by the common JRE or JavaME.

The simulator has a visual icon-based interface to interact with the user. The software front and back-end work together to create, represent and simulate formalisms. The first screen of the simulator is presented in Figure 1, where the user

can choose to simulate finite automata or multi-tape Turing Machine.

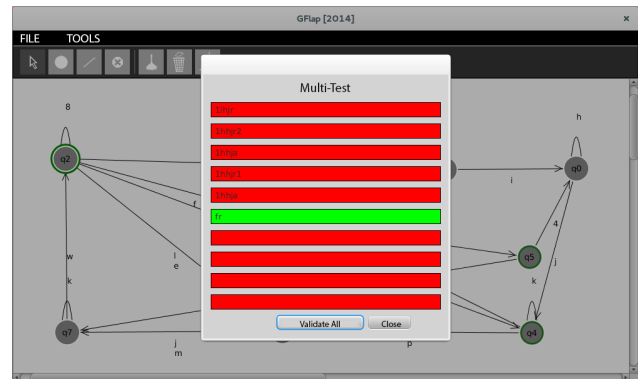
The tool is capable of working with deterministic and non-deterministic finite automata, regular grammar and expressions, beyond single tape or multi-tape Turing Machines. Apart from the main functions, the software is capable of step-by-step solution, multi-test, regular grammars test and conversion from regular grammar to finite automata, and vice-versa.

Additionally, the student who developed the simulator created a history of tested inputs and a random automaton generator. Besides that, the software allows save images and XML files that can be opened on JFLAP [2].

At next, we present two examples to illustrate the usage of the simulator. The first one is an example of a multiple input test and the second one is a conversion from finite automaton to regular grammar using a random automaton. The result is depicted in Figure 2 and Figure 3 respectively.



Fig. 1. Start screen of the simulator



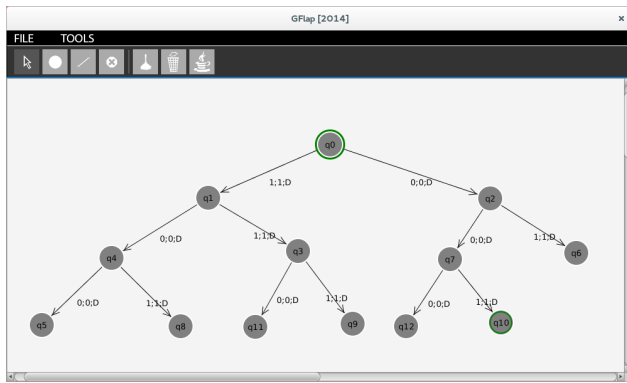


Fig. 4. Turing Machine example

The Turing Machine, single and multi-tape function, Figure 4 and Figure 5, are currently in development by the student. The final software will contain the formalisms from two complementary subjects, Formal Language and Automata Theory also to Theory of Computing. The result will be used to encourage the new students on the development, on the way to understand the formalisms in an easier and more didactic approach.

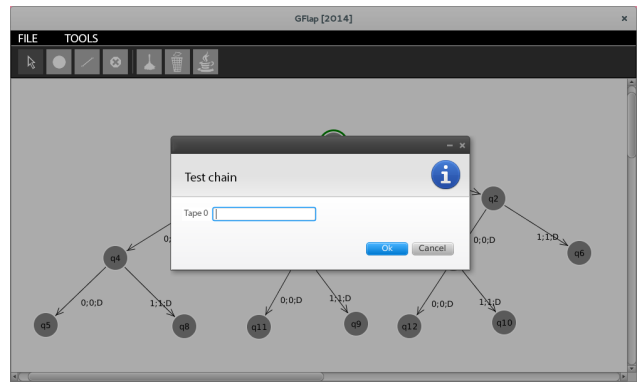


Fig. 5. One tape input for turing machine

For a final example of usage, we present, in Figure 6 to Figure 13, a full string recognition on a non-deterministic automaton previously presented as a random automaton. The string tested is "1ihj2r". On each step of recognition, if the single character is accepted, the color will be changed to blue, else the recognition will stop. The same rule is applied in each state if automaton state amend the last state will turn green, else stay gray and the recognition process stop.

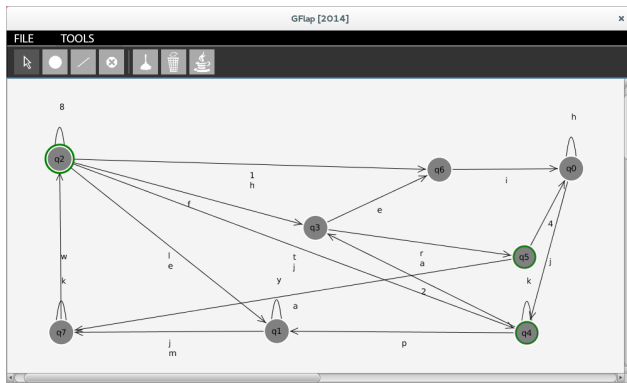


Fig. 6. Deterministic finite automaton

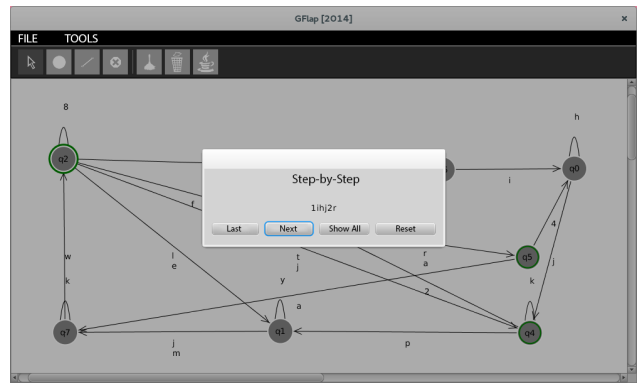


Fig. 7. Step-by-step run on random input

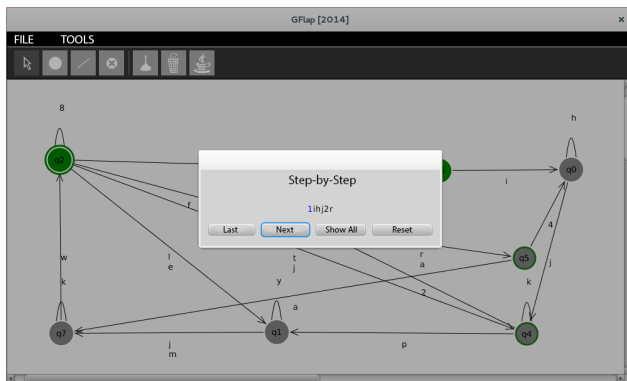


Fig. 8. Step 1, accept "1"

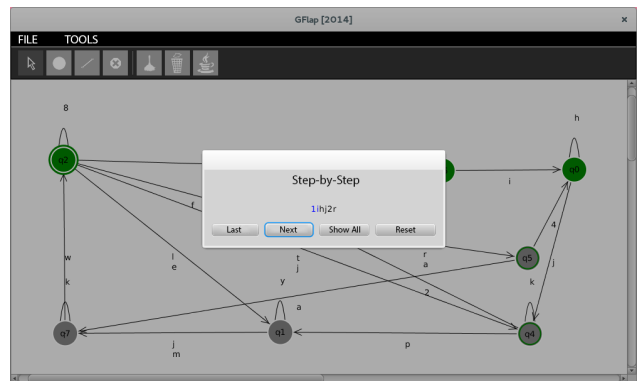


Fig. 9. Step 2, accept "i"

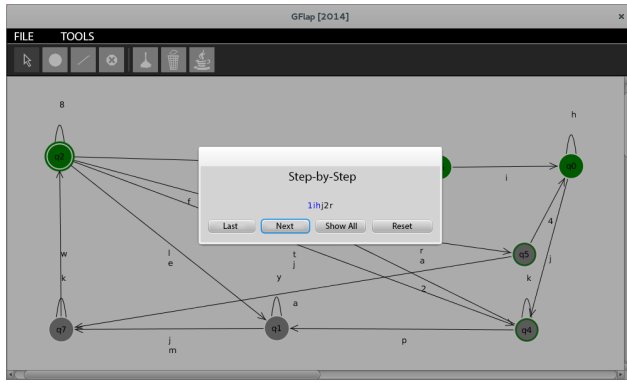


Fig. 10. Step 3, accept "h"

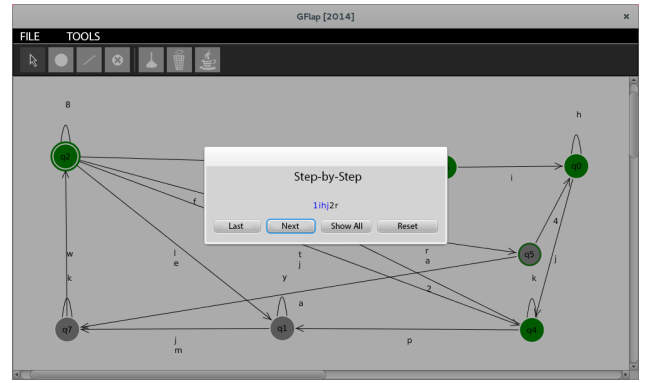


Fig. 11. Step 4, accept "j"

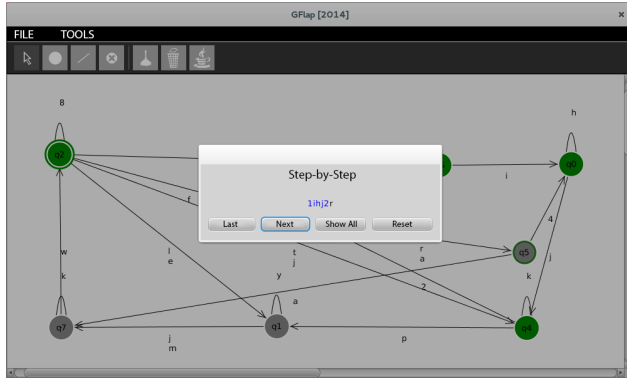


Fig. 12. Step 5, accept "2"

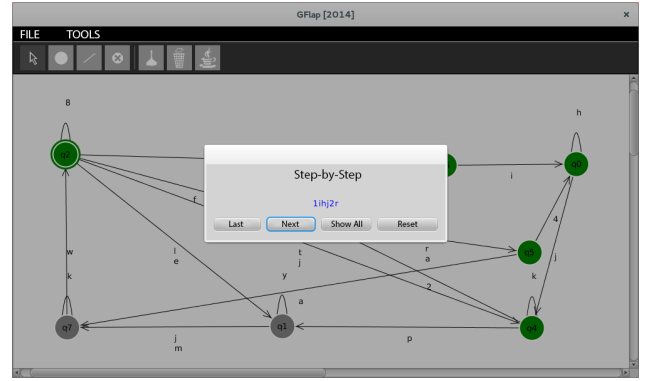


Fig. 13. Step 6, accept "r", accept character chain

IV. APPLIANCE RESULTS

The ease of understanding the abstraction and the formalism construction are possible by interaction with the finite automaton and the regular languages. The icon-based interface enables the interaction with the tool and allows visual operations, structure changes, and real-time viewing results. As a result of simulator development, different years, before and after the methodology appliance, students' grades were collected and compared yearly, and they are depicted in Figure 14 and Figure 15.

These results support the teaching-learning methodology, once it is fundamental for students in the computer science area, and it involves formalism recognition and languages generation that are used in compilers and programming languages. The positive results are observed in students' grades. We separate the results in year grades (Figure 14) and simulator grades (Figure 15).

At Figure 14, is presented an over years time-line, considering classes from 2012 to 2014, presenting students' grades. We can verify that the grades have become, on average, higher, compared to previous years. The final grade for each student presented above is an important factor to understand the results because the formula helps to see why a student has a bad or good grade at the end of the subject.

The minimum grade to approve a student is 05.00 of 10.00 points. To reach the points students are evaluated with one theoretical test on each trimester and the simulator presentation at the end of the semester. The student grade is the average of all evaluations made during the semester, but we use a clause

to make the average or not. First of all, we check the grades, and if both grades, tests, and simulator, are greater than or equal to 05.00, we sum grades and make an average. Else, the final grade is the lowest grade between test and simulator. The formula is presented at next.

$$test(T1, T2) = \frac{T1 + T2}{2};$$

$$final(T1, T2, SIM) = \frac{test(T1, T2) + SIM}{2};$$

$$grade(T1, T2, SIM) = \begin{cases} final(T1, T2, SIM), & \text{if } test(T1, T2) \geq 5.0 \\ & SIM \geq 5.0; \\ lowest(test(T1, T2), SIM), & \text{otherwise;} \end{cases}$$

Considering the formula, the results shown in Figure 14 does not focus its values on A-concept (grades between 8.0 and 10.0), the trend line denotes that the values are higher in its means, which shows that over the years more students are approved. The higher number of approved students is a result of the teaching-learning methodology, which made them more focused and stimulated in classes.

Besides the main results, we can observe an increase of students with grades between 3.0 and 4.0 in the years 2013 and 2014. Each case has examined separately by the teacher,

and it was concluded that these students, in particular, made an incomplete development of the proposed simulator. Despite the fact that the student has achieved good test scores, the

final grades clause give to that students the lowest grade, in this case, the simulator grade.

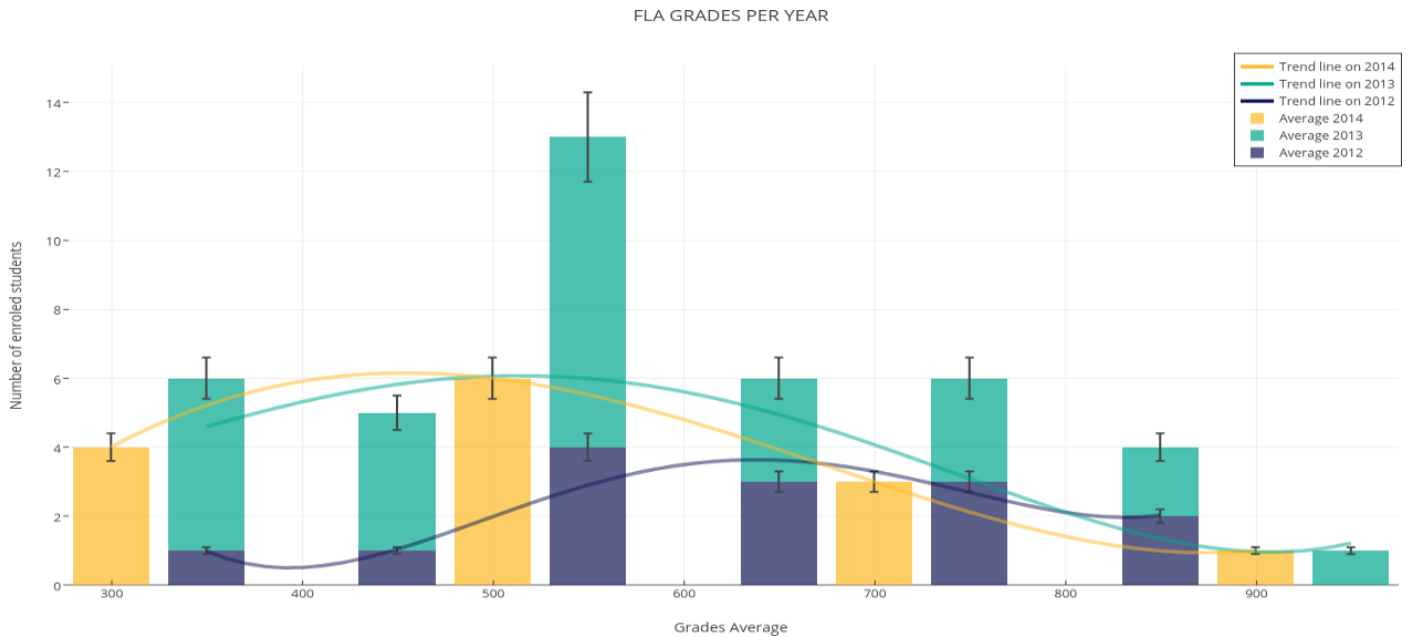


Fig. 14. Application based on Multi-Formalism Modeling

In Figure 15, is depicted the students simulator grades. The values follow a distribution that results in an arc on year 2014, while for 2012 and 2013, results are close to a sinusoidal line with growth between grades 3.0 and 5.0, which features a lower average between these years and less favorable values.

In both cases, Figures 14 and 15, we emphasize that the number of students between the years is not constant, which

changes the size of graphics and the position of the trend lines. However, to make any analyze we just considered the percentage of median results.

Having the discussed statistical analysis and the results depicted in the graph in Figure 14 and 15, it proves that the teaching-learning methodology is crucial to knowledge construction process.

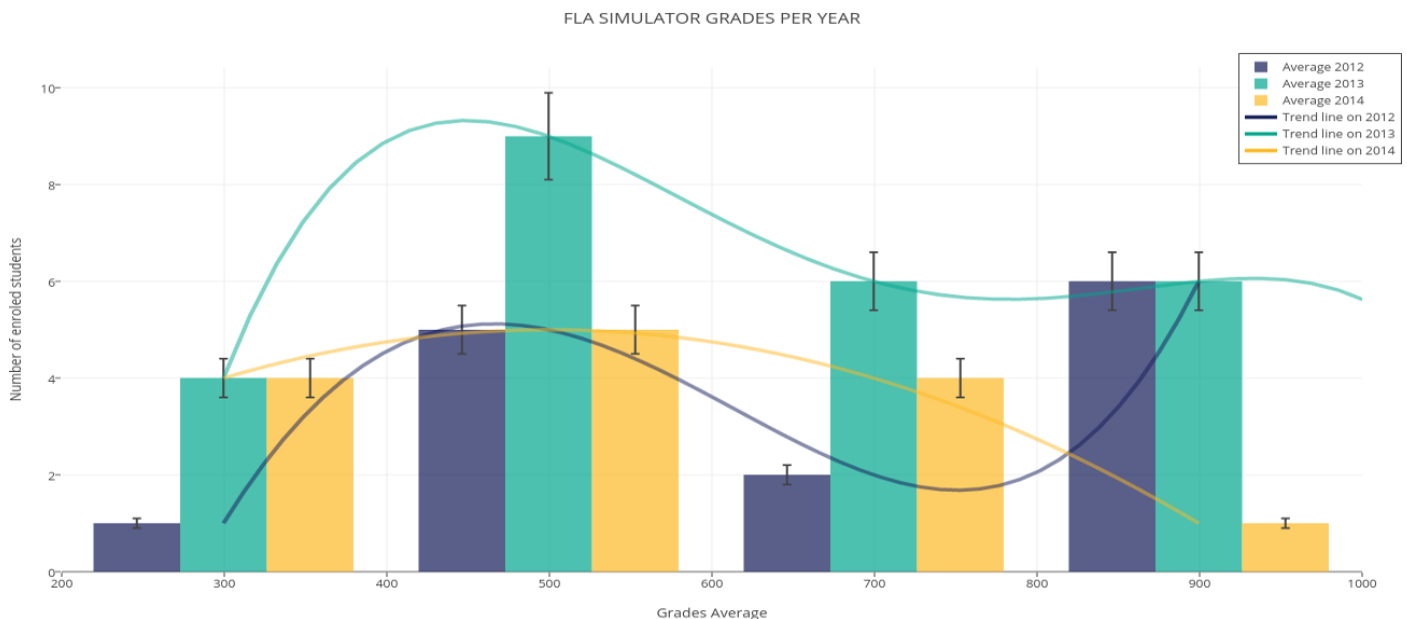


Fig. 15. Application based on Multi-Formalism Modeling

V. CONCLUSION

In this paper, we present a teaching-learning methodology to support the formalism model construction about formal languages and automata theory. According to the methodology proposed, for each topic about the subject, the teacher must propose a simulator development as classwork or homework to guide the student on formalism understanding.

In order to present our methodology, we use a developed simulator, based on Multi-Formalism Modeling and it was developed by a student in JavaFX [15]. The simulator had a visual icon-based interface to interact with the user and was built to support students understand of FLA formalisms. The visual resources and the programming logic to built it aids the student to learn abstract concepts easier, in comparison to imagining how formalisms work and how they are represented.

This methodology was applied at São Paulo State University (UNESP), applying the methodology proposed during four years, considering the current year, 2015. Our evaluation consisted in compare students' grades yearly, before and after, the methodology appliance.

The ease of understanding and building the abstraction represented by the formalism are possible by the interaction with the formalism. User interaction is possible by defining operations, changes in the structure and real-time viewing results. It is intended to follow this proposed teaching methodology with the next class of LFA and extend the teaching-learning methodology to Theory of Computing, aiming to incorporate formalities related to context-free languages, context-sensitive languages, and recursively enumerable languages.

In general, the positive results are observed in students' grades and their evaluation. Also, according to the teacher, the students have shown interest and more motivation.

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An Online Introductory Computer Programming Course Using Matlab: Design Steps and What to Expect

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Abstract— The usefulness of online and hybrid delivery methods in education has long been realized and with the advancement of computer and communication technologies and the Web based authoring tools, their effectiveness have been further extended. We are at a point that online and hybrid course offerings for undergraduates are quickly becoming an integrated and regular part of engineering departments' course offerings. Many institutions are offering online courses, as part of their regular schedule. In this paper, based on our experience that started with hybrid delivery and ultimately extended to a full online offering, we will present a set of recommended steps that can be used as a guide by those who are interested in designing an online introductory computer-programming course. We will then present a set of observations that we feel needs to be considered and discussed by the research community. The paper will include examples of students' comments, which were received in teaching evaluations, for hybrid and online offerings.

Keywords—online; computer programming; e-learning; hybrid delivery

I. INTRODUCTION

We are at a point that online and hybrid course offerings for undergraduates are quickly becoming part of institutions' strategies, as a way of providing more flexible course offerings to students and with the hope of some cost savings in the long run. We are also witnessing that a growing number of institutions are moving toward offering complete online undergraduate degrees and a degree in computer science is on the top of their list. In this paper, based on our experience that started with hybrid delivery and ultimately extended to a full online offering, we will present a set of recommended steps that can be used as a guide by those who are interested in designing an introductory computer-programming course.

In our previous works [1]-[3], we presented a hybrid e-learning approach to enhance distance learning. In this work, we describe our online development plan based on the hybrid approach. We first start with brief background information. Online learning has affected the traditional distance-learning format by transforming it from a static paper or videotape-based delivery to a more dynamic format by adding/substituting the web as the delivery media. While some studies reported high levels of student satisfaction with web-based course delivery [4]-[7], others found that students preferred the more familiar classroom-based environment [8]-[9]. Some of the difficulties associated with web-based learning, as reported by students going back a decade ago, still

exist. They include: the feeling of isolation due to a lack of interaction with peers or faculty; lack of prompt feedback about processes and progress in the course; and a need for students to better manage their time in order keep abreast of the course requirements [10]-[11].

In this paper we will present a summary of our implementation plan, which includes design and delivery considerations that can/should be considered by those who are interested in starting an online course development. The recommendations are general and can be used for any course. We will also discuss the unique aspects and challenges associated with designing a Matlab programming course versus a C++ course. Based on our experience, using various delivery methods and components for the past five years, we will then present a set of observations that we feel needs to be considered and discussed by the research community.

II. IMPLEMENTATION PLAN

A. Background

Perhaps the biggest difference in design and production of an online course versus its face-to-face counterpart is the amount of resources that it requires and the long payoff time for the allocated resources. In order to design a high quality online course, one needs to have access to an instructional designer or knowledge about instructional design concepts, consider hardware and software requirements, various learning styles, and ethical issues, among others. The biggest challenge for those who are considering designing an online course, for the first time, would be the challenge of anticipating all possible problems and issues that may occur during the delivery of the course and include preventive means in the initial design. The luxury of adjusting the flow of the course, which exists in a face-to-face course, is not part of an online delivery methodology. Based on the aforementioned observations and assumptions, we believe the best way to produce a high quality online course is to start from a face-to-face delivery, produce a hybrid delivery model, and finally move to an online production. Of course, this process takes a long time but the product will have a higher quality with less problems.

B. Design Considerations

The design process for an online course is a resource intensive task. The following were identified/recommended for this process.

- Goals and objectives of the course should be identified and an online delivery should be recognized as one of the approaches that can be used to achieve those objectives. This means that not every course should be delivered as an online course.
- Course objectives should be mapped to learning materials (video/audio/reading) and assignments.
- The web interface for the course plays an important role. It should be designed with the help of instructional design experts.
- Course materials should be designed to be short and precise and lengthy video/audio/reading material should be avoided. The length of a typical video segment should be limited to 20 minutes and should be followed by a link to a set of assessment questions or a worked-out video problem. In this approach, a typical face-to-face lecture is converted to two (15-20 minutes) video segments, each following with a set of assessment questions.
- Design test banks for quizzes and exams.
- In order to promote participation and eliminate/reduce the sense of isolation due to lack of interaction that is usually associated with online courses, a discussion forum should be set up for the course. It is recommended that each week includes its own discussion forum. Students should be encouraged to participate in these forums. Guidelines for how to use the forums including what can or cannot be posted should be provided.

C. Delivery Considerations

A welcome email should be sent two weeks before the start of the course that should include the following points.

- Inform students regarding course delivery methodology and the requirements for student participation. It is important to point out that a reliable Internet connection is a requirement for the course.
- Textbook requirement and ways to contact the instructor.
- Information about the course technology, including the course management system, which will be used for the course, any hardware-software requirements and/or recommendations such as webcam, headset, Matlab student software, etc.
- Date that the course website will be accessible.

D. Site Considerations

The course website should be designed so that the pages are not cluttered and are easy to navigate. Figure 1 illustrates the home page of our online Matlab offering for the summer session.

- The site includes links to information videos about the course and how to effectively use/navigate the site.

- Links to Homework, quizzes, exams, and discussion forums, which can also be accessed from the weekly page links.
- A link to late submission folder for cases that warrant such permission. Like the traditional offerings, late submission should be allowed as an exception with possible penalty.
- Weekly pages should include objectives, links to the learning material, homework assignments, discussion forum for that week, quizzes, Q&A session, and course resources. Figure 2 illustrates a sample weekly page of our online Matlab offering for the summer session. In this example, some of the video lengths are greater than the recommended 20 minutes. We are planning to edit and modify for the next offering.
- We are planning to include a 3-minutes video/audio summary of the topics covered for the week that will be placed at the top of the weekly page. This is to make sure that students can identify important topics that are going to be covered for that week.

III. STUDENT AND COURSE ASSESSMENTS

The following integrated, but separately assessable components were used in the assessment process:

- Homework assignments include exercises, related to the reading material, and programming assignments.
- Weekly quizzes were given with a 24-hours period of accessibility. Quizzes are timed programming assignments and are designed in such a way that allocated time would be enough for someone who has studied the required material. For the next offering of the course, we are requiring a webcam to be connected during the quizzes so that random still shots are taken and sent to the instructor. We believe that this will increase the integrity of the assignments.
- Weekly quiz questions are randomly generated from a quiz bank, related to the topics covered.
- Exams include conceptual questions and programming questions. Like quizzes, students are required to have a webcam connected during the exam, for the next offering of the course.
- Conceptual questions are randomly generated from a test bank and include multiple choice and true-false questions. This part is worth 20% of the exam grade and is designed to be accessible to students for a period of several hours, anticipating students from different time zones.
- Programming questions for exams are given at a set time; those who are at a different time zone are accommodated by providing them with alternative times.
- Although some online offerings require proctored exams, having such a requirement would not be an easy task for everyone, especially international students.

It should be noted that the assignments for an online course should be comparable with its face-to-face counterpart course and they should not overwhelm students.

IV. REMARKS AND CONCLUSION

Matlab has been designed as a tool for simplifying technical calculations/simulations. It has not been designed to be a “programming language.” With this in mind, some basic programming rules such as variable declarations, have been relaxed. This constitutes a challenge in conducting a programming course using Matlab, so that it does not turn into a “teach-a-package” course. Therefore, if one looks at Matlab from a purely computer science point of view, it would not be the first choice to teach a programming course. Another difficulty that we faced was the limited available resources in using Matlab as a “programming language,” versus the wide range of books that are published for use with general purpose programming languages. Reference [12] was selected as the course textbook from a limited textbook collection based on the aforementioned criteria.

Student ratings for the course have revealed several interesting points that can be further studied to analyze the current models used for online teachings and the reliability of student ratings and evaluations. Using an identical course structure with two different group of students in two summers, revealed noticeable differences in students’ evaluation. The difference was even more significant for a regular semester offering of the course. Students taking the course during the summer session had a much higher rating for the course than those who took it during the regular semester. We have identified two factors or possible explanations. The first factor is the GPA (Grade Point Average). Students with higher GPA had a more positive opinion about their experience. The second factor, we suspect, could be related to the decision process. Summer students wanted to take the course online and they saw the online offering as a huge convenience. Students, who took the course in the regular semester, were given only the online offering option and perhaps did not see this as their own choice. Even including extra help with the course did not help their performance or attitude toward the course. We are hoping to be able to present these data during the conference presentation of the paper, after the IRB (Institutional Review Board) approval. We believe this point needs to be further investigated by the research community. Finally, based on our experience we are recommending that the research community assess the idea of offering different online

versions of the same course to accommodate different learning styles and backgrounds.

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Course Home

Read the [welcome message](#) for the course.
Watch the [Course Introduction videos](#).

Course Utilities

1. Course Information ([Syllabus](#), [Schedule](#), [Course Introduction Videos](#), [Chapter Objectives](#))
2. [Course Technology Orientation](#) (Site Structure, Course Tech. Overview, MATLAB Remote App, Screen Cast)
3. Course Recourses
 1. [Recorded Textbook Lectures](#) (2nd Edition)
 2. [Short Supplementary Videos](#) by Instructor
 3. [Sample Programs](#)
 4. [Program Elements](#) (detailed video(flv); [AdobeLink](#))
 5. [Program Check List](#)
4. Weekly Schedule
[Week 1](#) | [Week 2](#) | [Week 3](#) | [Week 4](#) | [Week 5](#) | [Week 6](#)
5. Weekly Discussion Forums related to current topics in the course:
[Week 1](#) | [Week 2](#) | [Week 3](#) | [Week 4](#) | [Week 5](#) | [Week 6](#)
6. Homework Drop Boxes:
[Week 1](#) | [Week 2](#) | [Week 3](#) | [Week 4](#) | [Week 5](#) | [Week 6](#)
7. Quizzes and Exams:
[Week 2](#) | [Week 3](#) | [Week 4](#) | [Week 5](#) | [Week 6](#) // [Exam 1](#) | [Exam 2](#)
8. **ALL LATE SUBMISSIONS** (late submissions are graded if prior arrangements have been made)
9. Programming Solutions: [Homework](#); [Quizzes](#); [Exams](#)

Fig. 1. Home page of our online Matlab offering for the summer session

```
5/26 - Quiz #1 (accessible at 9:00 PM)
5/27 - Quiz #1 (click to access. DUE: 11:55 PM)

Chapters 4 & 5 Objectives:
- Manipulating Matrices
- Problems with two variables
- Special Matrices
- Two-dimensional plots
- Subplots

Read chapter 4 & 5
Chapter 4 Textbook Recording (47 min)
Chapter 5 Textbook Recording (22 min)

5/27 - Quiz #1 (click to access. DUE: 11:55 PM)

6/1 - Exercise Problems for chapters 4 & 5 - 4.1 (1-4), 4.3 (1,3,5), 5.1(1,2), 5.2(1-5) from Practice Exercise sections
6/1 - Programming HW Problems - (4.6(modified); 5.1(modified); 3.16(modified); 5.17))

Chapter 6 Objectives:
- User defined functions
- functions with arguments
- functions with output and input parameters
- Anonymous functions

Read chapter 6
Chapter 6 Textbook Recording (part 1; 27 min)
Chapter 6 Textbook Recording (part 2; 15 min)

6/1 - Exercise Problems for chapter 6 - 6.1 (1 & 7 only) from Practice Exercise sections
6/1 - Programming HW problems - (6.3; click on the link to access the drop box)

*****

5/29 - Optional Q&A - Adobe Connect Session (6:00-7:00 PM); (click the link to connect) Email your questions by 9:00 AM (5/29)

Post Questions or Programming Problems in the forum: Course Questions/Programming Problems
Program Elements
Course Resources
```

Fig. 2. Sample weekly page of our online Matlab offering for the summer session

Programming Education for Primary Schoolchildren Using a Textual Programming Language

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Abstract— In this research, a Textual Programming Language (TPL) is used in programming education for primary schoolchildren because of the following reasons: (1) it is more practical to use the programming languages similar to the ones used for developing real applications, (2) typing statements could be easier for primary schoolchildren than generally thought, (3) there exist programming environments such as Processing that are easy to use and produce very attractive graphical outcomes. Teaching material for programming education with Processing was developed. In this teaching material, cartoons were used to explain difficult concepts. The learners who use this teaching material were supposed to draw some computational figures with chosen colors. Trial experiments of programming education using this teaching material was conducted to a cohort of seven primary schoolchildren (six 4th grade and one 5th grade children) in two consecutive weekend classes (one hour each). Since the authors' aim of this programming education was to create a sense of fun and excitement in the children and inculcate a desire to engage with computing, the motivation of the children was assessed using the questionnaire based on the ARCS (*Attention, Relevance, Confidence, and Satisfaction*) motivation model. The results were encouraging and suggested that TPLs could be used in programming education for primary schoolchildren.

Keywords—programming education; primary school; textual programming language; Processing

I. INTRODUCTION

Programming education for primary schoolchildren has been adopted in many countries in recent years. In the growth strategy approved by Japanese Cabinet in June 2013 [1], there was a statement saying, “In addition, the government will establish framework to continuously cultivate practical IT human resources through industry-university-government cooperation by the end of next fiscal year and promote IT

education including programming education from the compulsory education stage.” The “compulsory education stage” in Japan means primary schools and lower secondary schools. In the lower secondary schools, “measurement and control by programming” became a compulsory topic in the subject of Technology Education in 2012, therefore, programming is already compulsory. Though there are not many primary schools that have classes in which programming is taught, there are many after-school and weekend classes for primary schoolchildren throughout Japan that teach programming¹. In fact, Japan is not a front runner with regard to programming education for primary schoolchildren. The UK introduced a new national curriculum which includes practical experience of writing computer programs in 2014². Also, in Australia, primary schools began teaching students how to computer code in 2015³. Some other countries including USA, UK, Estonia, New Zealand, Israel, and Korea have already adopted programming as a formal subject in primary education, or are seriously considering doing so.

Many programming languages for programming novices have been developed. Some of them are Visual Programming Languages (VPL) in which composing elements of programming are represented with blocks or tiles that can be manipulated with mouse movements. Examples of VPL include Scratch⁴, Squeak Etoys⁵, Alice⁶, and Viscuit⁷. Others

¹ For example, <http://techkidscamp.jp/>, <http://coderdojo.jp/>.

² <https://www.gov.uk/government/publications/national-curriculum-in-england-computing-programmes-of-study/national-curriculum-in-england-computing-programmes-of-study>

³ <http://www.australiancurriculum.edu.au/technologies/digital-technologies/Curriculum/F-10>

⁴ <https://scratch.mit.edu/>

are Textual Programming Languages (TPL) in which traditional textual representation of program source codes are used. Examples of TPL include Processing⁸, Arduino IDE⁹, and IDLE (Python GUI)¹⁰.

VPLs are very popular in programming education for young children like primary schoolchildren and secondary schoolchildren, because they do not require knowledge of programming syntax and provide an environment where compile-time errors are nonexistent [2]. There is also a report saying that VPLs can form long-term opinions about the enjoyment of programming in the mind of children compared with conventional programming languages [3].

Though VPLs have such merits over TPLs, they also have some limitations such as not giving advanced students the opportunity to improve their skills, or allowing students to acquire bottom-up development process (selecting commands, and then combining them for desired effect). Though VPLs are widely used in programming education for young children, they are not widely used for professional software development. Therefore, at some stage, students should change the language to TPLs. However, it has not been acknowledged when TPLs should be introduced to the young children. Therefore, in this research, it was investigated if TPLs could be used in the programming education for upper primary schoolchildren.

In this research, a TPL is used in programming education for primary schoolchildren because of the following reasons: (1) it is more practical to use the programming languages similar to the ones used for developing real applications, (2) typing statements could be easier for primary schoolchildren than generally thought, (3) there exist programming environments such as Processing that are easy to use and produce very attractive graphical outcomes.

Teaching material for programming education with Processing was developed. In this teaching material, cartoons were used to explain difficult concepts. The learners who use this teaching material were supposed to draw some computational figures with chosen colors. Trial experiments of programming education using this teaching material was conducted to a cohort of seven primary schoolchildren (six 4th grade and one 5th grade children) in two consecutive weekend classes (one hour each).

Since the authors' aim of this programming education was to create a sense of fun and excitement in the children and inculcate a desire to engage with computing, the motivation of the children was assessed using the questionnaire based on the ARCS (*Attention, Relevance, Confidence, and Satisfaction*) motivation model.

This paper is organized as following. In the next section (section II), it is shown that VPLs are extensively used in the

related works. In section III, the approach of this research in which a TPL is used is presented. In section IV, the trial experiment of programming education is presented. In section V, the analysis of the programming education is presented. In section VI, conclusions of this paper are presented. Finally, in section VII, authors' future research is presented.

II. RELATED WORKS

Since after-school and weekend classes of programming education became popular worldwide recently, the number of papers concerning programming education in K-12 have been increasing. Smith, Sutcliffe, and Sandvik [4] reported on the first year of Code Club in 1000 UK schools. Code Club is a network of after-school programming clubs for primary schoolchildren in the UK founded in 2012. Technically-adept volunteers collaborate with teachers in the club, and adopt Project-based pedagogy. Their aim is not to develop skills. Instead, they try to create a sense of fun and excitement in the child participants and inculcate a desire to engage with computing. In the Code Club, they use Scratch [5] as the programming environment because of (1) ease of use by primary schoolchildren, (2) the range of media resources easily available, and (3) the support for saving and sharing projects via the Scratch website. They reported that the participants could appropriately use the concepts such as user input, control statement, and parallel execution.

MacLaurin [6] reported on a new visual programming language (VPL) for young children called Kodu which was integrated in a real-time 3D gaming environment. The purpose of introducing this new programming language was to provide a new "first programming experience" that mirrored the early PC era: play games, fix them up, and eventually create your own from scratch. Touretzky et al. [7] described a three-stage method of teaching programming to children beginning with Kodu, and progressing to Alice and Lego Mindstorms NXT-G. The idea behind this three stage method was that though highly introductory programming environment offers novices a smooth path to early success in computing, their limited expressiveness must inevitably lead to their abandonment in favor of more powerful conventional languages. They conducted a pilot study with these VPLs in a five-day computer camp for 31 children aged 10-17. They found that at least for older students, it could be better if they used more powerful programming formalism.

As seen in these and other papers, almost always, VPLs are used in programming education for young schoolchildren. Despite many positive impacts of VPLs, they also have some negative sides. Meerbaum-Salant, Armoni, and Ben-Ari [8] pointed out that students learning to program using Scratch show some bad habits that are contrary to recommended programming practices. Moreno and Robles [9] reinforced this allegation by analyzing 100 Scratch projects they downloaded. They found that the majority of these projects contained bad habits of (1) not changing the names of the characters assigned by the programming environment, and (2) repeating code in the same project, sometimes even in the same character programs.

Duncan, Bell, and Tanimoto [2] wrote up meaning and potential impact of learning programming by young students in

⁵ <http://www.squeakland.org/>

⁶ <http://www.alice.org/>

⁷ <http://www.viscuit.com/>

⁸ <http://www.processing.org/>

⁹ <https://www.arduino.cc/en/Main/Software/>

¹⁰ <http://www.python.org/idle/>

a comprehensible fashion. Because many countries are promoting programming education for young students now, this kind of research has acute importance. They collected arguments for and against the idea of teaching programming to young students. They discussed cultural factors, the change of school curricula, whether young students are really gaining computational thinking or they are just moving around blocks of commands to find good positions haphazardly in their projects, teaching and learning tools. In the discussion of teaching and learning tools, they categorized 47 tools into 5 levels (level 0 through level 4). Among those levels, Level 2 are for the age range of 8 to 14, and, interestingly, a few TPLs are included in this level.

Booth and Stumph [10] compared visual and textual programming environments used for Arduino in the context of end-user experiences. In their paper, the textual programming environment is the default Arduino programming environment, and the visual programming environment is Modkit Alpha Editor¹¹. The eleven participants in their experiment were not young children, instead they were adults of mean age 36.18. Their findings were: (1) when using a visual environment, participants felt more confident modifying a program than creating one, but creating programs made them feel more confident than modifying existing ones when they employed the textual environment, (2) visual environments provided a more positive experience, (3) coordination barriers proved to be more challenging aspect for participants in the visual environment than the textual environment, (4) both environments are not perfect and may be perceived as unsupportive or confusing.

III. USING VISUAL PROGRAMMING LANGUAGES

As can be seen from the previous section, VPLs are almost always employed in programming education for young children. It is especially true in Japan. To the best of our knowledge, VPLs such as Scratch, Viscuit, and Squeak eToy are used in most of the reports about Japanese programming education for young children. One reason for this could be the peoples' belief that typing English words required in TPLs was too difficult for the children because they did not learn English in primary schools. However, it is not that clear if typing English words are too difficult for Japanese primary schoolchildren.

Duncan, Bell, and Tanimoto [2] suggested that TPLs could be used in the programming education for students aged between 8 and 14. Also, some papers suggest that programming languages should be switched from VPLs to TPLs at some stages of advancement because most professional programmers use TPLs [2, 10]. Booth and Stumph [10] suggested that task type mattered in learners' self-efficacy rating, and TPLs would be better for writing programs from scratch.

From all these conditions and suggestions, it was felt that TPLs had merits over VPLs when being used in programming education for young schoolchildren. Of course, if practical programming languages such as C, C++, Java were used with

professional IDEs such as Eclipse, it would be too difficult for young schoolchildren, but there exist TPLs for programming novices such as Processing [11, 12].

The TPL chosen for teaching programming to primary schoolchildren was Processing. Processing's editor and display windows are shown in Fig. 1. It is a Java based textual language initiated by C. Reas and B. Fry that facilitate the development of visual projects [11]. The best thing about Processing is that though programming is text-based, the outcomes are not text-based, instead, these are visually attractive artworks. Besides this fact, Processing has many characteristics that make it suitable for being used in programming education for programming novices such as: (1) not requiring creation of Classes, (2) not requiring the codes for creating windows for visual programming, (3) providing many statements for drawing shapes such as ellipses and rectangles, (4) providing a way to check the spelling of reserved words by colors, (5) providing simple ways of making animation.

The authors have been using Processing in introductory programming courses for non-computing majors in universities, and have been assessing the motivation of the students [12-16]. The artworks that students could create were very attractive for the students, and they kept high motivation while learning programming. Therefore, it was authors' expectation that the primary schoolchildren would also express the same enthusiasm for programming with Processing.

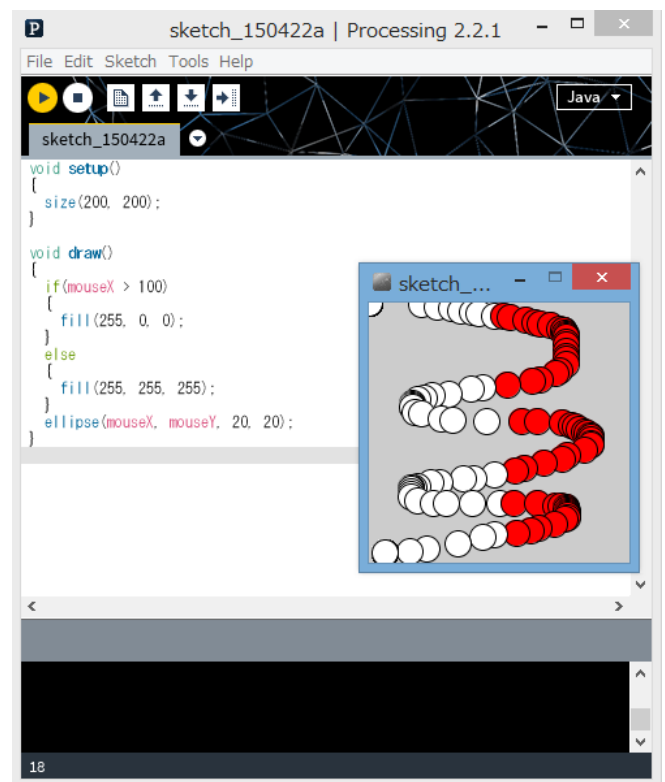


Fig. 1. Processing's editor window and display window.

¹¹ <http://www.modkit.com/>

IV. PROGRAMMING EDUCATION FOR PRIMARY SCHOOLCHILDREN

One of the authors has been teaching programming to primary schoolchildren in some weekend classes using robots and VPLs. Two others have been using Processing to teach programming to non-computing major students in universities. The curriculum and the teaching materials for teaching programming to the primary schoolchildren were determined from the experiences of these members of authors. The curriculum is shown in TABLE I. It is designed in such a way that the schoolchildren can understand the concept of programming, and can keep their motivation high throughout the classes.

TABLE I. CURRICULUM FOR THE PROGRAMMING EDUCATION

No.	Contents
1	What is programming
2	A tool for programming (Processing)
3	Statements used in Processing
4	Size of the display window
5	Positions in the display window (coordinates)
6	Drawing points
7	Drawing rectangles and ellipses
8	Coloring the shapes
9	Using variables
10	Changing behavior based on conditions
11	Repeating the same things
12	Program that generates movement

One of the characteristics of our teaching material is that cartoons are used. An example of the cartoons is shown in Fig. 2. The cartoons are there to explain difficult concepts in an easy-to-understand manner. There are three main characters in the cartoon: an apprentice witch called Momo, a soft toy called Kumao, and a professor. Momo always tries to lay an enchantment on Kumao to do something, but without much success. The professor explain why it doesn't work properly to Momo. In the cartoon, enchantment is a metaphor for programming.

The reason for teaching programming to young schoolchildren has been discussed in some papers. Some argued that there were two reasons: enabling students to understand what programming is all about, and enabling them to possess computational thinking (CT) which will be of use regardless of a student's career [2]. Others argued that their intent was to create a sense of fun and excitement in its child participants and inculcate a desire to engage with Computing, with skill development a secondary concern [4]. Our aim is similar to the last one. Since negative experiences, such as poor teaching, have a very strong and lasting impact on their interest in computer science career [17], enabling students to have positive experience during programming education is very important. For this reason, assessing the motivation of the participants while learning programming was thought to be important in this research.

In the past, the authors had been analyzing motivation of the learners in programming education using the authors' original questionnaire based on the ARCS motivation model [12-16, 18]. The ARCS motivation model was introduced by J. M. Keller [21-23]. This model has four factors (*Attention, Relevance, Confidence, and Satisfaction*), and each factor has three lower categories. Therefore there are twelve lower categories in total. The authors developed the questionnaire (ARCS assessment metric), and each question item in the questionnaire was designed to ask if each of the twelve lower categories in the ARCS model was satisfied. Each item was presented using a five-point Likert scale where answer 5 always corresponded to "agree" and answer 1 to "disagree". The lower categories and the corresponding question items of the questionnaire are shown in TABLE II. Though the question items in the table are in English, actual question items were in Japanese.



Fig. 2. A cartoon used in teaching materials

The authors conducted a trial experiment of programming education using this teaching material in two consecutive weekend classes (one hour each) in November 2014. Seven primary schoolchildren participated in the classes. Among those, six children were 4th grade and one child was 5th grade, four females and three males, only one student had previous programming experience. Those children could type Japanese words, could use a mouse, and had no problem operating personal computers. The weekend classes were conducted in a computer room in a primary school. The children used the notebook-computers the authors provided.

In the first class, Topics No. 1 through No. 6 in the TABLE I were covered. At the beginning of the class, programming concepts were explained using the cartoons. When the children drew the figures in the display window, they needed to know the units of distance and the concepts of coordinates. Distance and coordinates are measured in pixels, but the children did not know what pixels are. Therefore, authors prepared a compact microscope so that the children could actually view the three colors in a pixel and understand what pixels are.

TABLE II. THE QUESTION ITEMS IN THE QUESTIONNAIRE

<i>Attention</i>	
A1	Perceptual arousal: Did the programming education give you a pleasant surprise?
A2	Inquiry arousal: Did you feel that you wanted to learn more during the programming education?
A3	Variability: Could you study without getting bored because there were variations in the learning content?
<i>Relevance</i>	
R1	Familiarity: Did you feel that the learning content was familiar?
R2	Goal orientation: Did you understand the goal and the importance of the learning?
R3	Motive matching: Did you have chances to select the learning methods that were suitable to you?
<i>Confidence</i>	
C1	Learning requirements: Is the goal you should reach clear?
C2	Success opportunity: Did you have an occasion to feel that you had written your programs well?
C3	Personal control: Did you feel that you wrote your program well because of your efforts and ability?
<i>Satisfaction</i>	
S1	Natural consequence: Did you have occasions to use your newly acquired knowledge?
S2	Positive consequence: Were you happy when you made a good program?
S3	Equity: Was your accomplishment fairly evaluated with a consistent standard?

In the second class, Topics No. 7 through No. 9 were covered, but No. 10 through No. 12 could not be covered. At the beginning of the class, a review of the statement for defining the dimension of the display window was conducted. After that the children drew ellipses and rectangles, and moved them together using variables.

The ARCS assessment metric survey was conducted three times: middle of first class (after Topic No. 4), end of first class (after Topic No. 6), and end of second class (after Topic No. 9).

V. ANALYSIS

A. Computer Skill and Knowledge

Authors' particular concerns were if the schoolchildren could type English words correctly and fast. At first the children were claiming that they could not type English words as fast as typing Japanese words since they were used to typing Japanese words. But soon after that, they stopped saying that. They seemed to get used to it. Another concern the authors had was if the children understood the concepts of coordinates and pixels. The children seemed to understand these concepts after they viewed the pixels on the display using the compact microscope. Actually they enjoyed viewing the liquid crystal display using the compact microscope.

B. Scores of Four Factors and Sub-Level Categories

The results of the ARCS assessment metric conducted three times during the experimental weekend classes are shown in Fig. 3 and Fig. 4. Fig. 3 shows the mean scores of the four factors in the ARCS model as well as the mean score of all (four factors combined). For each factor, there are three bars corresponding to the three surveys conducted during the

weekend classes. An asterisk (*) indicates that the difference is statistically significant ($p < 0.05$).

For all of the four factors, it would appear that the score went up from first survey to second survey, and it went down from second survey to third survey. It is already known that the motivation of students fluctuate as the course progresses depending on the teaching contents and study environments [15]. Since first two surveys were conducted in the same class, study environments such as instructor, support staff, temperature of the room and so on, were the same. Only the teaching contents were different. The topics taught before the first survey were: What is programming (the cartoons were used here), Processing interfaces, Statements used in Processing, and Sizes of display window. The compact microscopes were used by the children to view the pixels on the screen during this time. The topics taught between the first survey and the second survey, were: Coordinates in Processing, and Drawing points. The students vigorously entered commands in the editors and changed the arguments during this time. Comments were also collected in the questionnaire, and all the comments in the first survey and second survey were positive, expressing enjoyment of the activities and gladness for being able to learn what programming was.

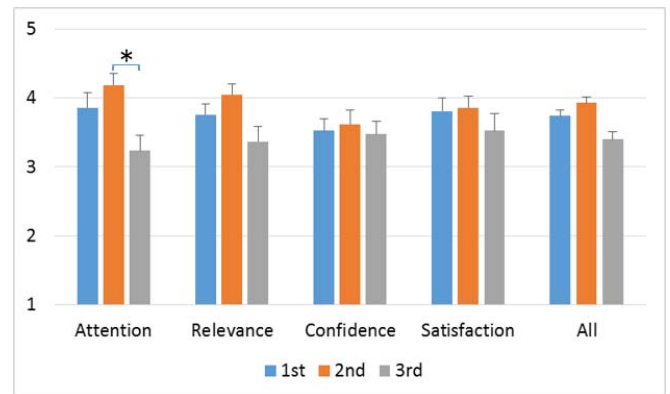


Fig. 3. The scores of the four factors

The third survey was conducted at the end of the second class, and the result was different from the previous two in that the scores appeared to be lower than those of the first and second survey. Especially, the third score of *Attention* factor went down from the second score by almost one point. In the second class, the children drew shapes with different colors, and moved the shapes together using variables. There were also, differences in learning environments in that a different instructor taught the children, and the number of support staff was less than that in the first class. Students' comments also indicated the drop of the scores. Four students gave positive comments expressing enjoyment, but two said "I do not have any particular thing to say." The last one said "It was fun, but it was hot here." This fact suggested the importance of the learning environments such as teaching skills of the instructors, number of support staff, and temperature of the room.

Fig. 4 shows the mean scores of the 12 question items corresponding to the 12 sub-level categories in the ARCS

model. Most of the sub-categories indicate the same tendency as the aver-all tendency shown at the rightmost group in Fig. 3. Categories C-2, and S-3 indicate different tendency. The score of C-2 went up from first survey to second survey, and to third survey. The question associated with C-2 (Personal control) was “Did you have an occasion to feel that you had written your programs well?” The answer to this question does not depend on the learning environment. Therefore, it could be that the students were confident with drawing the figures even if they did not feel comfortable with the learning environments. The score of S-3 did not go down from second survey to third survey. The question associated with S-3 (Equity) was “Was your accomplishment fairly evaluated with a consistent standard?” In the case of these weekend classes, evaluation meant the words of encouragement and praise. Therefore, it could be that the instructor and the support staff might have offered words of encouragement or praise to the children, even though other environments were not so attractive to the children. From this, it could be said that though the motivation of the children during programming education is influenced by the learning environment, some motivation factors (such as Personal control and Equity) might be less influenced by them.

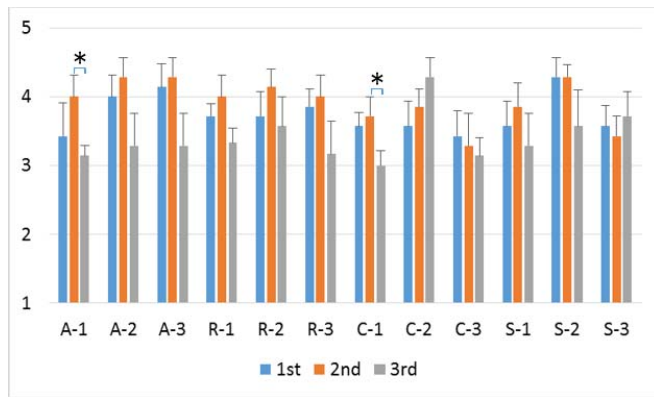


Fig. 4. Change of the scores of the sub-level categories

C. Comparison with previous research

The results of four ARCS assessment metric surveys are compared in Fig. 5. Here, the bar graphs are arranged in such a way that the scores of the four factors in the same survey can be compared easily. In each group of bars, from left to right, there are bars of *Attention*, *Relevance*, *Confidence*, and *Satisfaction*. In the figure, (a) is the result of this research, (b) is the result of programming education for primary schoolchildren with robots and a VPL [18], (c) is the result of an in-house training (programming) of new employees in an IT company [19], and (d) is the result of a programming course for non-computing majors in a university [20].

As can be seen in Fig. 5, the four graphs (a)-(d) display a similar pattern of bars. Almost always, the scores of *Attention* and *Satisfaction* are above the scores of *Relevance* and *Confidence*. It is only the third survey in this research which displays a different pattern. One reason to this would be the small number of samples. Therefore, it is not possible to say anything strongly, but observing that the *Attention* score is the

lowest in the third survey, it would be possible to say that Topics No. 7 through No. 9 of the teaching material should be improved. It can also be noted that the scores of first and second survey of this research (a) is not less than the scores of the previous research. This is an encouraging result because this result suggests that the primary schoolchildren could enjoy working on TPLs and use them to learn programming.

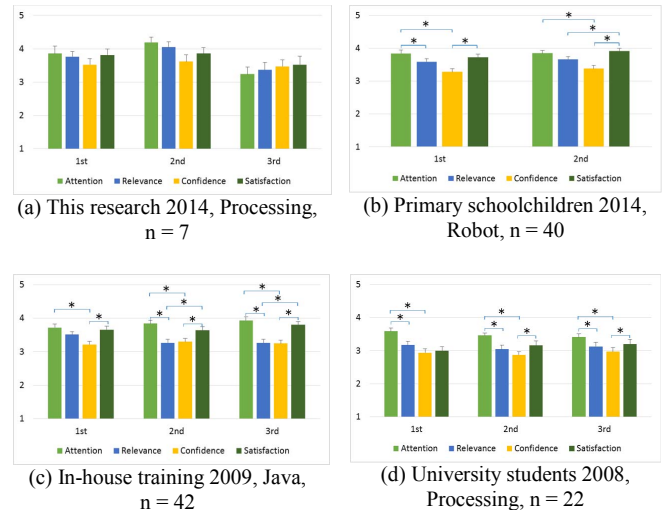


Fig. 5. Comparison with previous research

VI. CONCLUSIONS

In this research, using TPLs in programming education for primary schoolchildren was proposed, and teaching materials with a TPL was developed. The characteristics of this teaching material used includes (1) Processing programming environment which uses TPL, (2) cartoons are used to help children understand difficult concepts in programming. A trial experiment of programming education using this teaching material to a cohort of seven primary schoolchildren (six 4th grade and one 5th grade children) was conducted in two consecutive weekend classes (one hour each). Though 12 topics were prepared in the curriculum and in the teaching materials, the last three topics including conditional branch could not be covered due to the time shortage. The authors' aim of this programming education was to create a sense of fun and excitement in the children and inculcate a desire to engage with computing. For this aim, it was important to know the motivation of the participants in the trial experiment, and therefore, motivation of the participants in the class was assessed using a questionnaire based on the ARCS motivation model.

From the analysis of the motivation, the following findings were extracted:

- Primary schoolchildren of 4th grade and above can type the statements without much problem.
- Primary schoolchildren of 4th grade and above can understand the concepts of coordinates and pixels.

- Depending on the teaching materials, primary schoolchildren of 4th grade and above would be able to enjoy programming in Processing.
- The learning environments such as teaching skills of the instructors, number of support staff, and physical environment would influence the motivation of the children to learn programming.
- It could be that there are some sub-level categories in the ARCS motivation model that are not influenced by the learning environments.

VII. FUTURE RESEARCH

In the trial experiment in this research, there were only seven participants and only two weekend classes were used. Therefore, in future research, it would be necessary to test and confirm these findings extracted from this trial experiment in weekend or after-school programming classes with more students and for a longer period. Also, it would be necessary to compare TPLs and VPLs as the programming language used in the programming education for primary schoolchildren.

In the teaching materials used in the trial experiment, cartoons were employed, but the effects of the cartoons were not monitored. Therefore, in future research, we plan to include many more cartoons in our teaching materials and to monitor the effects of them.

In Japan, programming education is not yet compulsory in primary schools. Therefore, programming is taught in weekend classes or in after-school classes to the schoolchildren who are interested in programming. If programming education becomes compulsory, the ways of teaching programming might have to be changed regardless of the types of programming languages. Making programs and viewing the results on the screen or on the other gadgets would not be enough. We would have to devise ways to keep motivation of the children high during the programming education. Cartoon would be one of them, and compact microscopes would be another. Therefore, in future research, we would like to develop activities that would keep motivation of all schoolchildren high during programming education.

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A Proficient High Level Programming Program as a Way to Overcome Unemployment Among Graduates

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Abstract—Unemployment has been a major concern in recent years. This is particular true for young people and in the case of Portugal for youngsters with a Higher Education degree. In this paper we describe the program “Acertar o Rumor”, a two years program to reconvert unemployed graduates in Engineering and Exact and Natural Science in experienced Java programmers. Particularly, we focus on the Programming courses of the program, where the two main programming paradigms, the procedural and the object-oriented, as well as principles and technologies for developing enterprise systems were taught. We describe the main methodologies and approaches followed and report the very positive results obtained with the first edition of the program till now. We finish the paper by proposing some recommendations and improvements for further editions.

Keywords—Unemployment; Human resources reconversion; Computer Science Education; Programming learning

I. INTRODUCTION

Unemployment is a major problem that the XXI century people face. Eurostat estimates that there are more than 23 million of unemployed people in Europe and this is especially true for young people. World specialists say that while this situation is not solved the economic crisis is not over too. Almost one quarter of people under 25 years old in Europe belongs to this group and in Portugal more than one third. In our case this is particular hard for youngster with a Higher Education Degree [1, 2].

One solution for these people has been to look for a job abroad and emigrate. This brings long-term social and economic consequences. On the other hand there is still a shortage of employees with digital skills across Europe. One of the Europe 2020 Strategy pillars, which aims at the growth of the European Union (EU) by 2020, is the European Digital Agenda. It “proposes to better exploit the potential of ICT in order to foster innovation, economic growth and progress”. In order to promote employment in this field, and in jobs requiring digital skills, the Grand Coalition for Digital Jobs and Skills was created. Among its objectives are:

“Training and matching for digital jobs (...)

Awareness raising – to attract young people to ICT, which offers rewarding and enjoyable careers to both women and men;

Coding - to raise awareness on the importance of coding skills [3].”

Many universities have postgraduate training programs in many subject areas, including ICT. Many of the programs involve ICT applied to a specific area. We can find examples applied to medicine, teacher training, engineering and more [4, 5, 6]. Also there are programs that were designed in a partnership with industry. Examples include [7, 8, 9].

All these factors contributed to the University of Coimbra (UC), namely the Department of Informatics Engineering, in a partnership with the company iTGROW, that aims to attract, select and complement the training of young engineers through a program of training on-the-job and to promote the development of skills valued by the IT market through trainees’ exposure to the best practices in the field of software engineering, to design a program for unemployed Masters in the areas of Engineering and Exact or Natural Sciences to reconvert them in experienced Java programmers. This program is called “Acertar o Rumor” (Adjusting the course, in a free translation) [10].

In this paper we start by describing the program “Acertar o Rumor” and its main principles. Then we describe the group of students that has been selected. After we move on describing the main courses of this program, namely Introduction to Programming in Java, Advanced Java Programming and Project. We focus on the methodologies used, the approaches followed and analyze the results obtained from the application of two efficacy surveys. Finally we present some conclusions of this first experiment.

II. ACERTAR O RUMOR PROGRAM

The program “Acertar o Rumor” is designed as a two-year program, with a first year of regular classes at the University of Coimbra and a second year of an internship at one of the companies that is enrolled in the program. This program aims to train graduates that have difficulty finding a job in their prior field of expertise in technical programming. It is strongly focused on the development of high-level Java programming

skills. At the end of the program, the trainee is able to implement a computational application, based on a set of well-defined specifications. As generic skills to be developed, we highlight: analysis and synthesis; organization and planning; problem solving; group work; autonomous learning; adaptability to new situations; creativity; concern about development quality and sustainability.

An entry requirement to the program is to have an undergraduate degree, or an equivalent one, in Engineering or Exact and Natural Sciences, or a foreign degree recognized by the Scientific Committee of the Department of Informatics Engineering as meeting the objectives of such a degree in any of the above mentioned areas. In duly justified cases, holders of an academic, scientific or professional curriculum vitae that is recognized as attesting the capacity to carry out the program by the Scientific Committee can also apply. It is expected that these candidates have strong potential to programming, since they were trained to employ mathematical reasoning in their field of expertise.

In order to keep teaching quality reasonably high, only 20 candidates are accepted in the program every year. The candidates must go through a very selective recruitment process, which includes individual interviews, problem-solving tasks in a team and logical and mathematical exercises, in order to assess their potential to become programmers, as well as their motivation and ability to learn new concepts. After the acceptance to the program, the candidate enrolls in the program at the UC and has access to the Internet, to an e-mail account and other facilities, such as printing room, library and canteen.

The training program is very intensive. As such, trainees have to work as in a full-time job in a total of 40 hours per week. Also they have to work in an open space scenario, similar to the way many IT companies usually do. The structure of the program plan is shown in Table I. The program includes both a theoretical basic training in some important IT areas and a theoretical plus intensive practical training on programming techniques, supplemented with a final project. The courses Introduction to Programming in Java (IPJ) and Advanced Java Programming (AJP) provide the necessary support for developing applications with some complexity using the Java programming language and up to date programming technologies. The courses Operating Systems, Databases and Network Communications and Internet Technologies provide complementary training on the specific topics and run simultaneously with the IPJ course, each one at a time. The Project is the last course in the program, before the internship, and allows the application of the programming concepts introduced in the earlier courses in the context of a broader practical application.

The final rating of each course, except for the Project, is calculated based on the weighted average of the grades obtained in two main components, a continuous assessment (50%) and an exam (50%). Project grade is obtained based on the quality of a presentation and a final report, with a public discussion of the results obtained.

TABLE I. ACERTAR O RUMO PROGRAM PLAN

	Course name	ECTS ^a
1 st semester	Introduction to Programming in Java	23
	Operating Systems	1
	Databases	1
	Network Communications and Internet Technologies	1
2 nd semester	Advanced Java Programming	22
	Project	22

^a. European Credit Transfer System.

All these courses take place in the first 10 months of the program, from October to July. A student can only be approved in the curricular part and get the diploma if he/she achieves the approval in all courses. The student that does not obtain approval in any of the courses that precede the APJ course is unable to continue the program and does not have access to any kind of certification. The same happens to a student who, despite having had success in the first four courses, does not get approval in the APJ course.

III. THE TRAINEES GROUP

The group of selected candidates for the first edition of the program, out of 120 candidates, was made by 20 elements, 13 male and 7 female, or 65% and 35% respectively. Their ages were between 24 and 45 with a mean of 33.2 years. The selection process involved a set of written tests and an interview.

Four of them (20%) had got a Master Degree and 16 (80%) an equivalent pre-Bologna Degree (5 years College degree). The curricular areas of the corresponding degrees can be seen in Table II.

In terms of professional experience it varies a lot, since they have also diverse ages and it goes from no experience at all (these trainees have just finish the respective degrees) till 17 years of experience (just one case).

TABLE II. PREVIOUS TRAINEES' COLLEGE EDUCATION AREAS

Degree	Area	Number
Equivalent	Architecture	1
Master	Biomedical Engineering	1
Equivalent	Chemical Engineering	1
Master or Equivalent	Civil Engineering	5
Equivalent	Clinical Analysis	1
Equivalent	Eletrotechnical Engineering	2
Equivalent	Journalism	1
Equivalent	Management	1
Equivalent	Mathematics Teaching	6
Equivalent	Physics Teaching	1

IV. THE CORE PROGRAM COURSES

A. Course Introduction to Programming in Java

IPJ corresponds to the subject matters covered in the first two semesters of introductory programming courses of the UC Informatics Engineering (IE) degree, at the Bachelor level. It covers both the procedural and the object-oriented paradigms.

This course corresponds to 36 hours of work per week during three months (the first component), during which trainees learned the basic of both paradigms, plus a period of five weeks (the second component), where students had to develop a small Java project. In parallel, trainees had in turn one of the other basic courses (Data Bases, Operating Systems and Network Communications and Internet Technologies) in a schedule of just 4 hours of lectures per week and lasting 5 weeks each one of them, to complete the 40 weekly hours.

The course objectives are to acquire a sound knowledge of the principles of procedural and object-oriented programming using the Java programming language as a vehicle. The syllabus is shown in Table III.

In the first 12 weeks, the course was divided into lectures and lab classes. The first ones took 8 hours per week, lectured by a teacher of the Department, while the remaining 28 hours were the labs, where trainees solved a set of proposed programming problems supervised by tutors (experienced Java programmers recruited among the best Master and PhD students of the Department) applying the concepts taught in the lectures in a closer match. It was also the responsibility of the teacher to supervise the group of tutors that helped her running the course and organize their work. In the last 5 weeks, there were 16 hours per week of lab classes, accompanied by the tutors. The rest of the time the trainees had to work in the final project by themselves.

Part 1 (the procedural paradigm) took about 6 weeks and culminated with the first written exam. Part 2 (the object-oriented paradigm) took about 5 and a half weeks and ended with the second written exam. Part 3 ended with the public defense of the project and the final exam.

Cycles were introduced till the 2nd week and trainees showed no difficulties till then, but with this topic some revealed them, special the weaker ones. Because of this and before starting designing their own methods and to reinforce both cyclic structures and the method concept, the teacher decided to introduce graphical functions at this point of the

course. This was not explicit stated in the course syllabus, but proved to be an effective strategy, as gave the opportunity to train cycles more and, on the other hand, to visualize concepts. Diverse students learn differently and the teacher decided to capitalize on this approach [11, 12]. These problems also helped them to improve algorithm development. Also the use of arrays and matrices, which were not difficult for them, helped to clarify the cycle concept, due to its iterative nature.

It was quite difficult to do the shift from the procedural to the object-oriented paradigm. Particularly the concept of inheritance and the design of a class hierarchy was quite hard to apply in concrete problems. Object-oriented analysis and a brief introduction to Unified Modelling Language (UML) were presented next. The teacher decided to move them here, because she felt they needed to start designing problems more correctly from an OOP (Object Oriented Paradigm) point of view. But they revealed again many difficulties. In UML she introduced class diagrams and three types of relationships: association, aggregation and generalization [13, 14].

In Java containers the teacher introduced the general concept of the Java Collections Framework, but only referred to Generics and ArrayLists.

GUI was not in the initial syllabus plan, but the teacher thought it would be important to have some knowledge for the construction of concrete applications in the future. Thus, she have done only an introduction to Java Swing and let them explore it better during the project.

The project consisted of developing a multimedia kiosk for their local Town hall. It should provide information about the main tourist attractions, events, accommodation offers and restaurants of the municipality. It should have a GUI and menus in Portuguese and English allowing to switch between the two at any time. The application should take also into account two types of users with diverse privileges.

Course evaluation consisted of two components: A continuous component and a written exam, each contributing with 50% to the final grade. The continuous component would also be the sum of two subcomponents, the work in class during the course and a final project. Both contributed equally to this continuous component. The exam component could be attained as a single exam at the end of the course or as the sum of two equally weight exams done during the semester, one on the procedural part and the other on the object-oriented part.

TABLE III. INTRODUCTION TO PROGRAMMING IN JAVA SYLLABUS

IPJ syllabus	
<i>Procedural paradigm</i>	<i>Object-oriented paradigm</i>
A brief introduction to computer architecture Data types and operations Sequential structures Conditional structures Iterative structures Functions	Objects, classes, attributes and methods Encapsulation Inheritance Polymorphism Abstract classes and interfaces Java containers Object-oriented analysis Introduction to Unified Modelling Language

The work in class grade had an average of 79.3%. The average grade of the first exam was 74.4% and the second one was 73.5%. Only 14 students out of 20 (70%) tried the final exam and from this only 5 (36%) increased their mark. The average grade of the exam was 64.3%. This was not because the final exam was more or less difficult than the previous exams, but probably because, as they mentioned, they were quite exhausted after finishing the project. The average grade of the projects was 91.8%, extremely high as compared to that of regular Bachelor level courses. In fact the final quality of all projects was very high with four close to excellent and included features that were not requested, such as talking menus, sophisticated protection inputs, etc. The final grades' average was 80.2%.

There was a strong positive correlation between the continuous evaluation grades and the final grades of the course (0.94), which reinforces the idea that the teacher perception was quite correct as she knew very well each trainee performance and difficulties due to the relative small size of the class and the close relationship between teacher and students. This kind of teaching/learning strategy is one that the teacher defends for the learning of programming and that has given proven results in our programming courses of Design and Multimedia and IE degrees [15].

It was observed by the teacher that these students performed in class much better than IE Bachelor students. On one hand probably because they were very highly motivated, had experienced recently unemployment and the course evaluation scheme put a very high pressure on them. On the other hand, they were clearly better equipped in terms of mental tools, like problem-solving skills, critical thinking, etc., than the younger ones. This clearly favored the learning of procedural programming. On the contrary, when compared with the same IE Bachelors, they revealed more difficulties in learning the object-oriented paradigm. This may be due to the fact that they were older than the others in average, and so new skills are more difficult to learn, or because the time to learn them was shorter and time is needed to shift from a programming paradigm to another.

B. Course Advanced Java Programming

The aim of the AJP course is to give students a strong understanding of what is an Enterprise System, and how to

design and build enterprise applications using state of the art commercial frameworks, in particular, Java Enterprise Edition (JavaEE). Enterprise applications are characterized by their web-targeted technology, the large numbers of users and amount of data they have to handle, their distributed nature, and the need to enforce important quality attributes such as security, performance, availability, modifiability, maintainability and testability. The syllabus of the course is shown in Table IV. The definition of the syllabus was a process that involved consulting the industry, in order to understand which are the most valuable technical competences, and the Department Bachelor and Master courses on Distributed Systems and Systems Integration respectively.

The AJP course has a 14 week-long program. Each week students had 8 hours of lectures and 28 hours of lab classes. Lectures were critical to provide students with an initial understanding of what are enterprise systems, and the “mechanics” and tools of enterprise software development projects. Lab classes were used for developing software. Students had a total of 8 short projects to develop during the full length of the course.

Course staff was composed by a teacher of the Department and six tutors, which are industry experts and seasoned developers. Besides providing assistance to students in lab classes, tutors also reported on student progress and commitment. Course faculty opted for a coaching approach when dealing with students, providing guidance for students to accomplish their milestones by themselves. Tutors also maintained a daily record of what was happening in their classes. This diary served as a communication mechanism between faculty and everyone had to read it before their classes and write on it afterwards. Among the most important information on the diary was: discussion of the overall progress of students; identification of struggling students; major problems solved and how; open problems; comments and questions for faculty body. Since, every faculty was alone with the class, this diary was essential for guaranteeing that students got the same feedback from all teachers and that teachers were up-to-date with the class progress and problems.

TABLE IV. ADVANCED JAVA PROGRAMMING SYLLABUD

APJ syllabus		
Overview Enterprise systems and technologies Multi-tier architectures Web applications Topics on web technology Java Servlets Java Server Faces Beans Enterprise beans Message-drive beans Context and Dependency Injection Persistence Java Persistence API JP Query Language	Programming enterprise web applications Application structure and architecture Exception Handling Concurrency and synchronization Transactions Web services SOAP – JAX-WS REST – JAX-RD Advanced web applications AJAX Web sockets	Security Secure web applications Secure enterprise applications Supporting technologies Web server Application server Databases Resources Java Message Service Development, build, testing and deployment technologies Enterprise system management

The development of web and enterprise systems cannot be learned without a strong emphasis on practice, since it is mostly based in a few strong, but general, programming concepts and characterized by a steep learning curve on frameworks and technologies. Thus, this course was structured to demand a strong commitment from students to self-learning and learning-by-doing. Besides the 8 hours of lectures per week, students had to develop 8 software projects with diverse sizes and complexity in the 14 weeks period. Each project focused on different subjects and had different learning and evaluation objectives. Projects gave students the chance to put into practice the concepts and technologies discussed in lectures. In each assignment, besides the regular objectives, the teacher defined additional challenges for top students. This optional "Go further" section was, for the greater part of the class, considered as being mandatory, which was a great indicator of the quality and commitment of this group of students. Projects were planned for groups of 2 students. Groups were defined by the faculty, with the aim of preventing the same group of students of working on more than one assignment together, making sure that in each assignment there were new groups.

The course had no written exam, the evaluation was divided in two components: projects and continuous assessment. In each project, the teacher evaluated the work being produced and the individual performance of each student. The evaluation of the work focused on grading the legibility of the code, the robustness of the code and software, the modularity of the solution, the correctness of the solution, the fulfillment of the assignment requirements, the overall structure and software architecture, and the existence of tests. On the individual side the teacher graded the effort of the student and his/her contribution to the project and the acquired competences.

Regarding continuous assessment, the tutors graded students in each lab class in terms of their assiduity, participation, and demonstrated acquisition of knowledge and competences.

Students also completed a self-evaluation of their performance for each project. This was a supportive instrument to help understand the students' perspective on how efficient the work on the projects was for achieving their learning objectives.

The objective of the first project was to diagnose the students' proficiency in Java programming. As a result of this assignment the teacher introduced two changes to the syllabus of the course that correspond to areas where students demonstrated difficulties or a complete lack of knowledge and that were not covered in IPJ: Exception Handling and Design Patterns.

The lowest grade of the course was 70% and the highest 90%. The average was 79.2% and the median 80%. In this analysis we left out the data of one student that did not conclude the course. These were very rewarding results. Furthermore, when comparing the correlation between the continuous assessment grades, gathered by tutors in lab classes, with the final grades, we observed a correlation coefficient of 0.85, which is a good indication that tutors were

able to work very closely with students and get to know and evaluate them very well.

Another aspect that it is interesting to evaluate is the impact in learning and in grades of the policy of blind pairing students for each assignment and defining new groups for each assignment. The chart in Figure 1 shows the relative performance of the 3 lowest and the 2 top performing students. It is immediately clear that top performers have a much unwavering performance, while low performers struggle and evidence high fluctuations. By crossing the information about the groups of students in each project and this chart, we concluded that:

- When Top Performers had lower scores, they were paired with low performing students. But, most of the times, pairing with low performers did not affect the best students' scores.
- When Low Performing students had lower scores, they were paired with other Low Performers.
- When Low Performer were paired with Top Performers, their scores improved drastically. A quick consultation of the course diary showed that these students benefited from the guidance and expertise of their colleagues and, at the same time, found themselves in a position where the quality of work, required by their colleagues, was higher.

During the course, it became clear to the teacher that students had to handle a large quantity of new information and concepts very quickly. If they failed to keep up with the new knowledge, there was not much room for recovering. Mainly because, in each project, the teacher introduced new concepts, but assumed that previous ideas had already been put to practice and assimilated. Thus, the rhythm of the course was high. To cope with this problem, the teacher gave more time for the execution of some projects, on which he knew that students would have the opportunity to revisit previous concepts. To one student, this was not enough. A student, which had already been struggling since the previous introductory course, was not able to recover and failed. On the other hand, a student that had recently been a new mother, and had to miss 4 weeks of classes in IPJ, was able to recover and finish the course successfully. Students had an additional difficulty, programming web front-ends. Initially all students had none or a very low knowledge of HTML, CSS and JavaScript. Since, the syllabus of the course did not include front-end programming, the teacher decided that the best way to cope with this problem was to do short workshops on the lab classes. The objective of each workshop was to get students familiarized with the tools and mechanics of front-end programming. Of course, workshops were not enough by themselves, students still had to further explore, study and practice by themselves.

One area of the course that still has a large room for improvement is Software Testing. Although it was mandatory in every project, students were never able to deliver thorough test results. Furthermore, the large majority had no structured testing methodology in place.

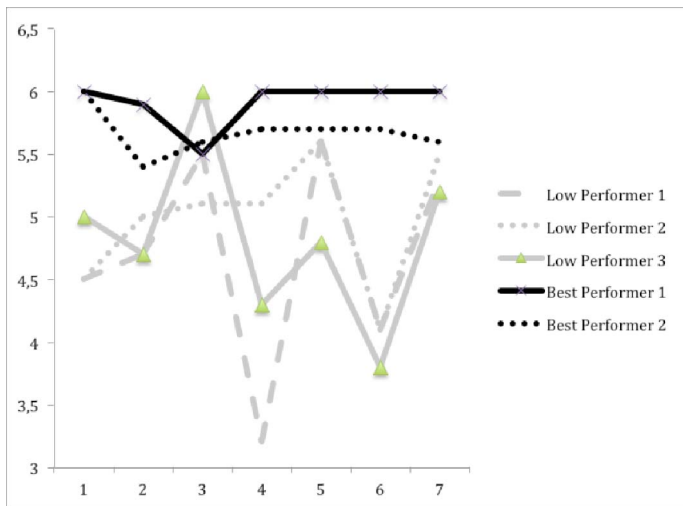


Fig. 1. Individual scores of the 3 lowest performing students and the 2 best performing students in the projects.

C. Project Course

The goal of the Project Course was to allow the students to develop an application in a very autonomous way, with very limited intervention of the teachers. The project was proposed by one of the companies involved in the course and consisted of developing a recruiting management software to a company, with different levels of users. The application to be developed was described in terms of mandatory and optional software requirements. The mandatory requirements consisted of opening of accounts for different type of users, search and opening of positions, and job applications, matching of position and application, notifications, generation of interview guides, interview feedback about an application and reporting. In addition, the software should allow a candidate to search for information about job openings and submit its application through an automatically generated web-page. The optional requirements consisted of LinkedIn integration and advanced reporting. The students were also free to add other optional requirements.

The students were split randomly into groups of two. A teacher was assigned to not more than 3 groups of students. Each group could seek advice from the teacher not more than 1/2h per week. At the end of the course, they submitted the code and a report and discussed, individually, the implementation with the teachers. The assessment was based on the number of mandatory and optional requirements that were performed as well as the quality and usability of the final application.

Individual grades ranged from 55% to 90%, with mean 76.55% and standard deviation 8.05%. Only in two groups there was the need to differentiate the grade between the group elements.

V. INTERNSHIP

Each student that concludes the first phase of the course at the UC is allowed to do an internship of 12 months in one of the companies that accepted to be involved in the program.

The goal is to acquire skills about software development in a realistic environment by integrating a team of developers working on a real application. Each company provided one or more internship proposals and was responsible for integrating, accompanying and reporting the progress of the intern. A teacher from the University also met the intern once per month. The internship was paid by the company, minimum 750 Euros per month.

A total of 10 companies from Coimbra, Lisbon and Porto accepted to be in the program and submitted 24 internship proposals, which were validated by the program coordination. The proposals consisted of web-portals development, web-services integration, ERP integration, and development of particular applications, such as maritime solutions, smart meters, biomedical sensors and games. The students went through the proposals during a week and ranked all of them. The matching between students and proposals was solely based on their grade, that is, the student with the best grade was assigned to his/her first choice, and the student with the second best was assigned to his/her first choice that was not yet chosen, and so on.

VI. SURVEY RESULTS

During the second year of the first edition of the program two surveys were passed to access the efficacy of the program – one for the trainees and another for the companies involved. First we analyze the one of the trainees that was anonymous.

By this time one of the trainees had left the program for personal reasons. 89.47% of the trainees answered the questionnaire, 41% females and 59% males. 47% were from Exact Sciences, 35% from Engineering, 12% from Social Sciences and 6% from other areas. The questions asked can be seen in Table V and Table VI.

To the question “What of the following technical issues taught during the training phase at UC are being used in the internship?” they answered: SQL 20%, JAVA 21%, Web RESTful Services 10%, Java Persistence API and JP Query Language 12%, Automatic tools: compiling, application server, repository and mapping between object model and relational 21% and Testing and Debugging 16%.

To the question “Are there other knowledge that you think should be taught during the training phase to ease your integration in the internship?” they referred: HTML5, CSS3, JavaScript, WebServices, jQuery, maven, Junit, Mockups, more on SQL, more on software testing, design patterns, more on Networks, Repository management, Agile development, development of scalable code, projects with bigger teams.

When questioned if they would recommend the program to a friend 94% said yes against 6% that did not recommend it.

Trainees’ final comments include:

“The program Acertar o Rumor is, from my point of view, an innovative method of people reintegration in the labor market.”

“I feel that I have made the right choice in participating in the program.”

TABLE V. TRAINEES' QUESTIONNAIRE ANSWERS

Question	Very Good	Good	Reasonable	Weak
How do you classify the process of internship assignment in the end of the program?	35%	53%	12%	
How do you classify the interaction with the organizing team of the program?	35%	59%	6%	
How do you classify the adequacy of the training to the work being done in the internship?	12%	76%	12%	
How do you classify the level of integration in your internship team?	8%	12%		
How do you classify the importance of the internship tasks to your professional development in IT?	71%	29%		
How do you classify the accompaniment that has been done by the UC supervisor?	24%	23%	35%	18%
How do you classify the accompaniment that has been done by the company supervisor?	47%	41%	12%	
How do you classify till now your experience in the program	53%	47%		

TABLE VI. TRAINEES' QUESTIONNAIRE ANSWERS

Question	Totally Agree	Agree	Disagree	Strongly Disagree
Content sequence was coherent.	41%	53%	6%	
Contents were adequate for the internship.	29%	53%	12%	6%
The time for doing the activities was sufficient.	23%	59%	18%	
Proposed activities were useful for learning consolidation.	47%	53%		
Contents are applicable in the internship context.	47%	47%		6%
Themes were interesting.	59%	41%		
Activities were motivating.	41%	47%	6%	6%
I felt involved in the activities.	71%	23%		6%
Evaluation methodology was adequate for program objectives.	6%	71%	23%	
Provided texts and papers allowed to deepen knowledge.	23%	65%	12%	
References were useful.	18%	70%	12%	
Provided support documentation was adequate.	24%	35%	41%	
The pedagogical team motivated me.	35%	59%	6%	
The pedagogical team was present when I had doubts.	23%	71%		6%
The pedagogical team fostered my participation.	18%	70%	12%	
The pedagogical team gave timely feedback, contributing to my learning in a suitable way.	6%	56%	31%	7%
The pedagogical team revealed interest in my difficulties.	19%	69%	12%	
The pedagogical team was clear when intervening.	12%	76%	12%	
The pedagogical team supported me solving problems.	18%	76%	6%	

"It was an interesting program where I learned a lot (...). From the beginning, with a practical emphasis and with the intention of integrating in a work team, it was a very enriching and rewarding experience. The general feedback is more than positive."

The survey for the companies had a 61.11% of participation. The questions asked can be seen in Table VII and Table VIII.

To the question "What of the following technical issues taught during the training phase at UC are being used in the internship?" they answered: SQL 14%, JAVA 20%, Web RESTful Services 18%, Java Persistence API and JP Query Language 16%, Automatic tools: compiling, application server, repository and mapping between object model and relational 16% and Testing and Debugging 16%.

To the question "Are there other knowledge that you think should be taught during the training phase to ease your integration in the internship?" they referred: more on databases and SQL, design patterns, more on testing and debugging, reuse, Angular, React, Bootstrap, JQuery, transactions, distributed applications and communication and organization skills.

To the question "What competences do you think "Acertar o Rumor" trainees have?" they answered: Motivation to the job 16.4%, Commitment: extra effort when needed 14.8%, Team

work capacities 16.4%, Assertive communication 6.6%, Analysis, synthesis and problem-solving capacities 9.8%, Organization and planning 8.2%, Autonomous learning 14.8%, Adaptation to new situations 11.5% and Other 1.6%.

From the point of view of the trainees we can see that they classified as Good or Very good or as Agree or Totally agree the majority of the questions asked and 94% would recommend the program to others.

TABLE VII. COMPANIES' QUESTIONNAIRE ANSWERS

Question	Very Good	Good	Reasonable	Weak
How do you classify the process of internship assignment in the end of the program?	55%	45%		
How do you classify the interaction with the organizing team of the program?	18%	82%		
How do you classify your trainee?	64%	36%		

TABLE VIII. COMPANIES' QUESTIONNAIRE ANSWERS

Question	Yes	No	Without opinion
Is it probable that you want to maintain collaboration with trainees after the internship?	82%		18%
Is it probable that you participate in future editions of the program?	82%		18%

From the point of view of the companies we can draw similar conclusions and that 82% intend to maintain the collaboration with the trainee after the internship, thus coping with unemployment, and the partnership with the UC (see Table VIII).

VII. CONCLUSIONS

In this paper we described a program developed in partnership between the University of Coimbra and iTGROW to reconvert unemployed Engineering and Exact and Natural Science Masters into experienced Java programmers. In what concerns the core courses of the program, from the observations in the classroom and the results obtained, it is possible to say that this was a very good experience in terms of teaching and learning, both for the teachers as well as for the trainees.

Two efficacy surveys were passed, one for the trainees and another for the companies involved in the partnership. The results show that both value the program quite well in several dimensions. This has led us to recommend the program for further editions. At the moment the second edition of the program is already running and the recruitment phase of the third is starting. However, we also recommend some improvements and minor changes.

One thing that should be improved is the unbalance between the IT basic courses (Operating Systems, Databases and Network Communications and Internet Technologies) and IPJ during the first term. It would be better to have some practice in the former and have 4 hours more per week to accommodate it, for instance. Otherwise concepts will remain quite vague and they are important too, especially to APJ and to the Project. On the other hand a small reduction in the IPJ labs would not affect them much in our opinion. Other changes already made were small adjustments in AJP in order to accommodate companies' requests.

But this experience also led to other reflections. One is that the Java programming language could be easily replaced by another one, like C# for instance, if this issue was felt necessary by the companies in the program. Also we think that this approach could be applied to other subject matters, like it is the case of a training course on Web Technologies that the Department is designing at the moment. Although in a shorter format and less ambitious, the goal is to provide extra ICT skills, for unemployed graduates of several curricular areas.

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Engineering University-Industry Projects: A Design for Six Sigma Framework

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Abstract— As the world's economy becomes global, graduate workforce readiness is increasingly necessary. There has been a gradual shift in industry expectations of graduates from exhibiting academic expertise in a chosen discipline to a commercially adroit candidate with a strong command of, and immediate ability to apply, a broad range of skills deemed essential in the workplace [1]. With the globalization of technology and the rapid changes in the way companies do business, it is becoming imperative that graduates start performing and processing from their first day on the job [2]. Design for Six Sigma (DFSS) is an approach that can be helpful in pushing towards better-prepared graduates for the workforce. This study aims to use current student project work to analyze preparedness, particularly in terms of students' abilities to organize and communicate their thoughts. Preliminary findings show that more needs to be done in institutions of higher education to align the process of executing projects in universities with what is widely employed in industry.

Keywords—Six Sigma; Design; Engineering Communication; Design process

I. INTRODUCTION

Design is a major component of engineering and managing the process of designing is equally an important component. As defined by ABET, Engineering design is the process of creating a system, component, or process to accomplish a goal. Furthermore, ABET outlines the criteria in engineering design that research institutions must contain. Some of these features include: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, in addition, realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics and social impact [3].

In meeting these criteria, the use of a design process has been widely used in undergraduate curriculums with iterations ranging from a circular diagram to a block diagram of the design process [4]. Given the range of design processes available, there is no clear path on which design processes should serve as a baseline for higher institutions to follow in design classrooms. Given the emphasis on Six Sigma processes in industry, this study uses Design for Six Sigma (DFSS) as a framework to examine how students' engagement of the product development process within product design incorporates elements of DFSS. To accomplish this, our research question posits:

What elements of Design for Six Sigma (DFSS) are present in third-year engineering students' written work during a problem-solving design task?

II. CONCEPTUAL FRAMEWORK

A. Design for Six Sigma

Six sigma is a quality philosophy at the highest level, concerning all processes, and a quality measure at the lowest level. The term "sigma" refers to standard deviation, σ . Standard deviation or variance, σ^2 , is a measure for the dispersion of a data set around the mean value, μ , of this data. Six Sigma then stands for six standard deviations from the mean [5]. The Six Sigma methodology provides the techniques and tools to improve the capability of, and reduce defects in, any process. Originally developed as a set of practices designed to improve manufacturing processes and reduce defects, its application was subsequently extended to other types of business processes [5]. Six Sigma is often associated with the Total Quality Management (TQM) principles made famous by W. Edward Deming's 14 points theory. Deming's philosophies have been used in several industries with a focus on customer satisfaction and continuous improvement of systems [6]. Six Sigma DMAIC (Define, Measure, Analyze, Improve and Control) first appeared in 1979 when the Motorola organization wanted to take the TQM principles to the next level, which is how and when the Six Sigma methodology and DMAIC methodological framework were both born [7]. The DMAIC approach is used and a proven successful schema by many Fortune 500 companies in multiple sectors including General Electric, Dow Chemical, United Technologies, Motorola and Ford Motor Company as well as many others. These companies have invested over one billion dollars and have put hundreds of thousands of employees through the Six Sigma certification program [8].

There is recent research looking into the use of Six Sigma methodologies, on a par with industry, as a way to measure several aspects of academia. These areas include recruitment improvement strategies, attrition, and graduation rates among engineering students [9]; [10]; [11]; [12]; [13].

Over the years, Six Sigma has evolved immensely to not only consider products and services from a problem-solving, process improvement lens but to also as a way of looking at the engineering design process. Rather than focusing on streamlining a product or process to reduce defects, eliminate mistakes, or save money via Six Sigma, Design for Six Sigma

* Best in this context means the most reasonable solution

** P2:1 – Phase 2 Item 1 on the list from Table 1

(DFSS) is a methodology that can be incorporated at the onset of a design or process. Furthermore, it can be used to develop a new design, enhance innovation, or to reduce the need for redesign of an entire process and thereby prevent downstream errors [8].

Defined as a driver of unique synergy between engineering design principles and applied statistical analysis methods, DFSS adds another layer to product development called Critical Parameter Management (CPM). “CPM is the disciplined and focused attention to the design’s function, parameters, and responses that are critical to fulfilling the customer’s needs” [14]

B. Product Development Process

An effective product development design process combines the use of tools, best practices, and project management in the design process. This relationship between the design process and project management is critical to the success of an engineering design project. These critical parts are all used and taken into consideration at every stage in the DFSS process [14].

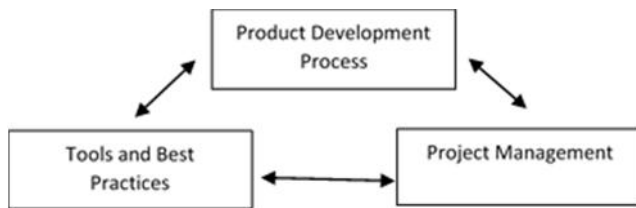


Figure 1: Critical Components in Successful Product Development [14]

During design development, modeling takes place between the first and second phase [14]. Using DFSS in the Concept, Design, Optimize, and Verify (CDOV) process, we will focus on the measure of students’ engagement of the product development process in these two defined areas. While there are four phases of DFSS, our study will focus on the first two phases. Within each of these phases (concept phase and design phase), there are four major characteristics to accomplish the task of product development. Figure 2 describes these characteristics.



Figure 2: Important aspects of the Concept and Design Phase in DFSS

III. METHODOLOGY

This study employs content analysis [15] using the DFSS framework (phases 1 and 2) to analyze limitations, assumptions, and engineering thinking of final responses for 14 student teams modeling activity tasks.

A. Setting

The setting for this study is a public research university in the western United States with a focus on engineering and applied science. This university is also one of the top public universities in terms of salary potential and ranked as one of the top engineering schools in the United States, serving approximately 2,600 engineering undergraduate students with an average class size of 33.

B. Participants

With a class size of approximately 55 students, the participants in this study were grouped into 16 teams of three or four chemical engineering students each; the class is a junior-level heat transfer course. In 14 of the 16 teams, all students consented to be a part of the research study. (See Appendix)

C. Task

Teams of three to four students worked on developing a mathematical model to predict the thermal sensation of touching kitchen utensils for a company that needed guidance selecting new materials for utensil handles. As they developed a model to make this prediction, the student teams wrote two memos. The first memo was an internal document describing detailed model development and highlighting the important physical properties (e.g., thermal conductivity, density, thermal diffusivity) that governed thermal sensation. After feedback from the course instructor (acting as project manager for the teams), each team revised their model, developed a working spreadsheet to predict thermal sensation for new kitchen utensils, and wrote a second memo to their client at the kitchen utensil company. This memo provided: 1) details of the team’s mathematical model (including assumptions and simplifications) that would allow someone who deals with utensil materials in the company to predict the touch sensation that a person would experience when using a utensil made of a given material at a given temperature; 2) a list of thermal and physical properties necessary for prediction of utensil sensation; and 3) a description of desired property values that a candidate material should have for use in developing a new product line. It also included thermal sensation predictions for material properties recommended for the new product line.

D. Data Analysis

The student teams’ memos were read by both authors and analyzed for key ideas of the design process. After the first coder analyzed the data, the second coder analyzed the data independently. Both coders then met to discuss differences and resolved them when necessary to come to an agreement on the evidence we proclaimed as the artifacts. The artifacts included the student’s recommendation memo and the final design proposal, classroom videos, and transcriptions.

Data analysis was conducted using a deductive coding strategy using the four major characteristics of DFSS in the concept and design phase using a preset category [16]. Since Six Sigma has its own language, we define the language of the requirements for successful exhibition of the phase 1 and 2 deliverable in Table 1.

* Best in this context means the most reasonable solution

** P2:1 – Phase 2 Item 1 on the list from Table 1

Design for Six Sigma	Definition
Phase 1:	
1. Gathering the voice of the customer data	Gather customer requirement
2. Refine and Rank Voice of Customer (VOC)	Prioritize customer requirements
3. Integrate and Align VOC with Voice of Technology (VOT)	Consider and align customer desires with feasibility from a design perspective
4. Generate system concepts	Idea generation
Phase 2:	
1. Identify and Resolve “conflicting requirements” using VOC data	Manage and confirm customer request against best idea generated and select best design
2. Construct subsystem Noise Diagram	Identify limitations and assumptions of the design
3. Select best concept	Select best idea
4. Generate a spatial integration model	Create a spatial model of best* design

Table 1: DFSS concept and design phase and definition

IV. RESULTS

The data below (Figure 3) shows the result of coding 14 student groups' data. One group scored 6 out of 8 with the mean score being 3.5. The assumption phase was defined by all 14 groups while selection of the best idea generated scored second highest while the creation of a spatial model of the best design scored third highest. The weakest area for the students was the customer related memo portions. Tying their work back to the VOC was a challenge for most of the students and explicitly acknowledging and addressing customer requirements was also weak although sometimes insinuated, communicating this information in the memo written to the customer was not obvious. Below is an excerpt from Team #10, which shows an exhibition of an explicitly stated P2:1**:

From the attached data, the group determined that wood would be the best material to use for the new product line as it would decrease the sensation range.

Below is an example of an explicitly stated P2:2:

We are assuming that we only looking at the contact area of the fingertips and the material of the spatula. We assume that when the finger is depressed against the material it is sufficiently depressed so that it can be accurately portrayed as a flat plate.

Team	P1:1	P1:2	P1:3	P1:4	P2:1	P2:2	P2:3	P2:4	Total/8	Grade/70
1			X		X	X			3	55
2		X		X	X	X		X	5	67
3					X	X		X	3	45
4			X			X			2	55
5					X	X	X		3	68
7					X	X	X		3	70
9	X		X		X	X			4	70
10	X	X			X	X			4	70
12						X	X		2	66
13						X	X		2	70
14	X			X	X	X	X		5	70
15	X		X	X	X	X	X		6	70
16	X		X	X	X	X			5	63
17				X		X			2	70

Figure 3: Student results based on Design for Six Sigma Requirement for Concept and Design phase

V. DISCUSSION AND IMPLICATIONS FOR THE CLASSROOM

Analyzing the third-year engineering students' written work using DFSS shows that organization of thought and communication of findings were the two main challenges for students. The ability to present design ideas and to make recommendation in an effective way to the client during a problem-solving design task is important to the idea itself. An idea that is communicated effectively can make the difference in acceptability. Deciphering what the students were trying to communicate is an area of opportunity that can be improved in the teaching of a design process with attributes such as communication which has been mentioned by many research studies [17][18]. A process like DFSS can be employed to improve the communication of data, results, and interpretation of customer requirements in student projects for industry focused assignments. Furthermore, using DFSS as a process for design can enhance the student presentation of their ideas and help organize these ideas in a systematic way. Defining roles and responsibility in project-based assignments in the classroom environment might offer students the opportunity to practice leadership and project management. For example, in designing a system, a systems engineer is necessary to monitor the cohesiveness of different components. Having such roles and responsibility defined can potentially be of value to students to gain different perspectives over the term of their schooling. The DFSS methodology has strength in all these areas where students can benefit. Given that DFSS is widely known in industry, it can serve as a learning tool in university-industry, problem-based learning environments in higher institutions.

* Best in this context means the most reasonable solution

** P2:1 – Phase 2 Item 1 on the list from Table 1

VI. FUTURE WORK

We plan on expanding this work to include several of the team conversation and data to understand the team dynamic in the idea generation phase and analyze this data to see how the student team employed the customer requirements in their brainstorming activity through the recommendation phase.

VII. APPENDIX

This study is based on the work of Dr. Tamara Moore which was published in the *Journal of Engineering Education*: Moore, T. J., Miller, R. L., Lesh, R. a, Stohlmann, M. S., & Kim, Y. R. (2013). Modeling in Engineering: The Role of Representational Fluency in Students' Conceptual Understanding. *Journal of Engineering Education*, 102(1), 141–178. doi:10.1002/jee.20004

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* Best in this context means the most reasonable solution

** P2:1 – Phase 2 Item 1 on the list from Table 1 IEEE Frontiers in Education Conference

Perspectives on Engineering Design Learning: Realities, Challenges, and Recommendations

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Abstract- Design is considered by most to be the central activity of engineering. Also, it is known that engineering programs should graduate engineers who can design effectively to meet social and environmental needs. Though the role and perception of design across a wide range of educational institutions have improved markedly in recent years; however, both, design faculty & design practitioners argue that further improvements are necessary. One of the defining characteristics of design is that there is rarely a single correct answer to an engineering problem but, rather, an optimal or acceptable solution leading to a final design, presented as the best possible balance between technical as well as non-technical constraints. These non-technical constraints typically involve economics, politics, social and environmental issues, ethics, etc. And, while professional practitioners generally accept this understanding of design, students, by enlarge, tend to interpret the engineering design process as an unambiguous and clearly defined process supported by rigidly applied principles and processes of “the scientific method.” Students’ vision and mis-concepts of design do require proper alignment with prevailing conditions on the ground. Undoubtedly, the start of any design course should be preceded by exposure to *design thinking* and related processes. The paper reviews the role of design in engineering programs, and outlines the current research on how *design thinking* processes could be taught and learned. It explores also the currently most-favored pedagogical model for teaching design, namely: Project-Based Learning (PBL). The paper identifies several contexts for PBL, along with some available data on its success. Finally, the paper raises some of the questions that should be answered to identify the most effective pedagogical practices of improving design learning.

Keywords—*Design education, design thinking, convergent & divergent thinking, project-based learning, the hybrid approach, team environment.*

INTRODUCTION

Design is widely considered to be the most distinguishing activity of engineering. It has also long been understood that engineering institutions should graduate engineers who could

design effectively to meet societal needs. Historically, engineering curricula have been based largely on an “engineering science” model, referred to as the “Grinter Model”, in which engineering is taught only after a solid basis in science and mathematics. The resulting engineering graduates were perceived by industry and academia, at the time, as being “ill-prepared” for the practice. Despite steps taken to remedy the situation, through greater industry-academia collaboration; both design faculty and design practitioners argue that further improvements are necessary. Design faculty across a range of educational institutions still feel that the leaders of engineering schools (deans, department heads, tenured faculty) are unable or unwilling to recognize the intellectual complexities and resources needed to support good design education.

Fortunately, more and more educators are becoming aware of the issues of design, and steps are being taken world wide, to address the concerns of industry at large. One approach has been to form “symbiotic” partnership between industry and academia through senior capstone projects.

The capstone course has evolved over the years from “made up” projects devised by faculty, to industry-sponsored projects where companies provide “real” problems, along with expertise and financial support. In fact, design courses, in general, have emerged as a means for students to be exposed to some flavor of what engineers actually do; and also, could learn the basic elements of the design process by being involved in real design projects. There have even been formal proposals for curricular goals and assessment measures for design-based curricula. This argument is driven by a widespread notion that the intellectual content of design is consistently underestimated [1].

This paper reviews research on *design thinking* as it relates to how designers think, learn and make decisions, which is an important reason why design is not easy to teach. *Design thinking* is, in general terms, complex processes of inquiry and learning that designers perform in a systems context, making decisions as they move forward, often working collaboratively in a social setting, and eventually arriving at an optimum solution. The paper, also, focuses on the most favored pedagogical model for teaching design, namely: *project-based*

learning (PBL), as an effective way for students to learn design by experiencing design as active participants. The paper closes by making recommendations for ways to enhance design learning.

ON ENGINEERING DESIGN THINKING AND LEARNING

What does “design” mean in an engineering context? What are the qualifications of a designer? Can design be taught? And if so, who can teach it? These questions will be addressed in the paragraphs that follow.

Relevant Definitions, Thoughts and Processes: *Engineering design* as stated by Dym et al. in 2005 is: “a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints” [1]. This definition presents design as a thoughtful process that depends on systematic, intelligent generation of design concepts and the specifications that make it possible to realize these concepts [2]. Sheppard’s characterization of what engineers as designers do: “They scope, generate, evaluate, and realize ideas” [3]. In the context of engineering design, *creativity* is important, but it is not design! *Design problems* do reflect the hard fact that the designer has many constraints that may positively or negatively affect the outcome of the design, i.e., the designer has a client to satisfy and for whose benefit the item/artifact and/or project is being developed.

There are several approaches to characterizing *design thinking* and *design processes*. These characterizations, often associated with good designers, may include the following [2]:

- View design as an inquiry and/or iterative loop of *divergent-convergent thinking*,
- Focus on the “big picture” in all stages by including *systems thinking* and *systems design*,
- Handle *uncertainties* that are likely to arise,
- Arrive at decisions,
- Think and act as a member of a team,
- Think and communicate using known languages of design,
- Be familiar with relevant background and technical knowledge that lead to successful design

The starting point of any design project, irrespective of the object or nature of the project, is the **problem definition phase** characterized by asking relevant questions and attempting to find plausible/realistic answers. No sooner has a client or professor defined a series of objectives for a design project than the designer- whether in a consulting office or in a classroom- want to find out what the customer really wants. Questions such as: what is an economic project? How do you define the best design? What is a safe design? What are the factor(s) that will affect the design the most? Phrasing it differently, knowledge resides in the questions that can be

asked and the answers that can be provided [2, 3]. A sequence of inquiry characterized by a hierarchy: certain questions need to be asked and answered before other questions can be asked. There is a set procedure which constitutes the inquiry process in an epistemological context. Taxonomies of such a procedure or inquiry process have been extended to computational models [4], to the intricacy between asking and learning [5], and would also apply to the questions students ask during a class and/or tutoring session [6].

There are two classes of questions within a design context; the first is the category of questions that do have a specific answer, or a specific set of answers. Such questions are characteristic of **convergent thinking**, where the questions attempt to converge on and reveal “facts”. As such, answers to converging-type questions are expected to be truthful and verifiable. The second category of questions is diametrically opposite to the first, and is characteristic of **divergent thinking**, where multiple alternative known answers exit, regardless of being true or false. The key distinction between the two types is that **convergent** questions operate in the knowledge domain; whereas **divergent** questions operate in the concept domain [1]. This has strong implications for teaching conceptual design thinking, since concepts need not be truthful or have true value, whereas knowledge does. **Design thinking** therefore is seen as a series of transformations from the *concept domain* to the *knowledge domain*. Such questioning and thinking is the “backbone” of any design process, and the major tool by which designers add to the pool of engineering knowledge [7]. The significance of the transformations between the *concept* and *knowledge* domains is further supported by the finding that the combined incidence of deep reasoning questions and generative design has been shown to correlate positively with performance, in arriving at design solutions [8]. Therefore, any properly produced design is preceded by effective inquiry that includes both a *convergent* component (lower level and deep thinking questions) and a *divergent* component (generative design questions intended to create the concepts upon which the design is based).

The forgoing discussion raises questions relevant to teaching design in all engineering disciplines. Clearly, the *divergent* inquiry in *design thinking* is neither recognized nor included in most engineering curricula. I think the time is right to introduce the iterative *divergent-convergent* process(s) in order to develop better pedagogical approaches to engineering design.

Focusing on Design-related Education: Recently, designers, throughout the world, have helped develop an increasingly complex “built” environment that includes some major large-scale engineering projects. Simultaneously, designers have been pushing the envelope at relatively fast rate making products, systems and engineering projects increasingly more complicated as they strive to improve reliability and increase service-life by increasing number of components and their

interdependencies. Further, designers have to expand the design boundaries to include environmental factors, social impacts, and public safety issues in their designed systems and projects. The author believes that engineering designers are in need of skills and experience to help them cope with the complexity and facilitate the arrival at optimum design. Invariably, this type of: knowledge, skills, and related experience need to find its way to the classroom through curricula updating, proper counseling, mentoring, and insuring a conducive classroom environment.

There are *four* aspects of design education believed to be of relevance to acquiring and/or enabling young designers, and students in particular, to embark on the mission. The *four* are highlighted in the *subsections* to follow.

1) Thinking about a system's approach: A good designer is some one who can anticipate and deal with intended and unintended consequences resulting from interactions among the multiple factors of the system. Exposure to system analysis and system dynamics – preferably through a rigorous course(s) - would assist the designer in sorting variables, prioritizing, and managing the design process. Unfortunately, these skills are not common, do require prerequisites, and regarded by most as difficult to learn. Many different teaching methods have been proposed to improve people's abilities to grasp and retain knowledge under this category. Recognizing that there are difficulties in proper delivery of *systems analysis* and *systems dynamics* to engineering students; the fact remains that these tools are extremely useful for someone who plans to become a designer. Therefore, ways have to be found to enhance the understanding of systems' thinking, and at the same time, to develop educational experiences that could efficiently improve learning outcomes.

2) Looking at risk management and uncertainty: Engineering design is carried out relying on incomplete data, imperfect models, often with unclear objectives, and other potential problems and constraints. The effects of such uncertainties on the design of a project may have serious consequences unless proper safeguards have been undertaken based on probabilistic and statistical approaches to design and factors affecting design. Some have argued that current undergraduate curricula greatly underemphasize the theory and application of probability and statistics in engineering [9]. Research has revealed that people are generally prone to serious errors in probabilistic and statistical thinking, including neglect of prior probabilities, insensitivity to sample size, and misconceptions of regression[10]. The formal course work in probability and statistics falls terribly short of exposing engineering students to various encountered errors, e.g., systematic underestimation of uncertainty. Engineering educators are concerned, and some have been working to alleviate the difficulties by stressing conceptual understanding, emphasizing active teaching methods, and using more graphics & simulations [11]. There is a long way to go with regard to *uncertainty* and the way it ought to be handled in the classroom. Suggested improvements and changes have included the following [12]:

- offer probability and statistics courses early on in the program,
- include "*uncertainty*" and its implications in engineering analysis courses,
- consider offering technical electives, in this domain, and let "*uncertainty*" be a central theme,
- make use of modern computational tools to support probabilistic thinking.

Such curriculum changes may fall short of meeting set goals without adequate research aimed at continued improvements in probabilistic and statistical thinking for engineering in general and design component in particular.

3) Estimation: A main challenge of a project design is the number of variables and their interactions during the design process. Often, the system stretches beyond designers' capability to grasp all of the details simultaneously [1]. One strategy for coping with the many variables is to bring the system back within the limits of human mental capacity by focusing selectively on a limited number of factors, preferably the most significant ones. Designers are usually good at estimation. They are able to size up parameters, sort them out in terms of their relative importance, and neglect the ones that have less impact on the project. Today's graduates are not good at estimation [1]. This poor performance by the new graduates appears to be related to a weak conceptual understanding of basic engineering science, limited ability to form appropriate analogies, weakness in visual perception, short-term memory, and insufficient interaction with their physical surroundings. Additionally, current engineering education emphasizes sophisticated methods for precise calculation and thus may underemphasize approximation skills [13]. Attempts to rectify the situation would require research and development and eventually instigating potential changes in curricula and teaching methods

4) Physical modeling and experimentation: Unfortunately, the advent of the computer and its impact on teaching engineering has made it easy to produce computer-based models at the expense of physical models. This fact is behind a general trend of teaching applied engineering subjects with minimal students' involvement with physical set-ups including laboratory experiments. Carrying out laboratory experiments and generating experimental data, visiting a project site, and using pencil and paper to produce a schematic, are gradually fading away. These traditional tools were instrumental in developing an engineering common sense. It is argued here that generating data from physical models is potentially a great learning tool, particularly when the model is built by the students. Building a model, testing a model, generating physical data from the model, and analyzing said data, help students alternate between *inductive* and *conductive* processes, thus broadening their design vision and their understanding of the experimental approach to engineering design. There is potentially a real need to research the ways to teach engineering students how to make proper use of physical models and experiments.

The four aspects (discussed above): thinking about a systems approach, looking at risk management and uncertainty, estimation, and physical modeling and experimentation – are intended to pin point some shortcomings in design-related education that need to be addressed, using a principled approach to dealing with these issues.

DEVELOPMENT AND GROWTH OF DESIGN THINKING IN A TEAM ENVIRONMENT

All aspects of design is being recognized and taught today in most institutions as a team process with socio-technological dimensions [13]. One practical reason is that ABET general engineering criteria target the social aspects of engineering education at several levels. In addition to criterion 3(c), “an ability to design a system, component, or process to meet desired needs,” criterion 3(d) addresses the need to function on multidisciplinary teams, criterion 3(f) social and ethical responsibilities, criterion 3(g) communication skills, and criterion (h) addresses global and social impact. Constructivist theories of learning, irrespective of the subject matter, recognize that learning is a social activity, and design-based courses, including project-based courses, are regarded by most as opportunities to improve students’ ability to work in teams, as well as their communication skills. As a result, universities now incorporate many of these aspects in their design classes, ranging from first-year design courses to capstone design. In fact, many of the early researchers have emphasized that the design process requires the designer to continually raise questions, and exchange views with others over the advantages and disadvantages of alternative solutions [14]. Also, design has been defined by some as “a social process” in which teams define and negotiate decisions and each team member possesses an “ingrained” set of technical capabilities that could act as a filter during design team interactions and , consequently, the end result is an intersection—not a simple summation of participants inputs. This view of design has received the attention of many researchers, and was used by some to develop relevant pedagogies, to promote multidisciplinary discourse and constraint negotiations [15].

Several researchers investigated the role that gender plays in design education and in forming design teams [16]. The results have shown that background and technical knowledge are far more important than gender and/or ethnicity. There is also a wide body of research in design practice and design learning on the use of psychometric measurement of personality type, such as MBTI, to analyze and predict the behavior and likelihood of success of teams in general [17,18]. Such techniques have been successfully applied to forming design teams in engineering classes, particularly the use of MBTI that has shown that better outcomes are achieved with teams consisting of members with complimentary roles, a plurality of viewpoints, and a neutral team leader [19]. Much effort has been devoted to furthering the understanding of individual influences on team behavior. More insight may be gained by exploring the relationship between personality and

learning style preferences [20]. Lent et al [21] have described the effect of *collective efficacy*, a team’s beliefs about its capabilities to work together, on the cohesion and satisfaction of the team. They found that negative feelings of *collective efficacy* may limit outcome expectations, requiring remedial steps to promote effective teamwork. Clearly, more research appears needed on applying set measures to analyze team behavior and to form teams, and on furthering the understanding of the impact of individual diversity factors on team performance.

PROJECT-BASED LEARNING

Project-based learning (PBL) begins with an assignment, to one or more students, to carry out specific tasks that would eventually lead to the arrival of a final product- a design, a model, a device and/or a computer simulation. The end result is normally a written and/or an oral report highlighting the main steps undertaken to produce the product and the outcome. (Note: the acronym PBL is also used to denote problem-based learning. But it is used here to refer to project-based learning). At the initial stage, there are two approaches: either the instructor chooses the project, which helps maintain a focus on course and curriculum objectives. The second is to allow students the autonomy to choose their own project: its general objective, its formulation and strategies and their approach to it, which, most likely, tend to increase students’ motivation and self reliance. Which is best? The answer is to be decided taking into consideration students’ prior experience, their skills, and students’ abilities to use available resources. De Graaf and Kolmos [22] define three types of projects that differ in the degree of student autonomy:

- **Task project:** Student teams work on projects that have been defined by the instructor, using primarily instructor-prescribed methods. This type of project is part of traditional instruction in most curricula, and results in minimal student motivation and skill development. It falls under traditional instruction as per most engineering curricula.
- **Discipline project:** the instructor selects and defines the subject area of the projects and specifies in general terms the methods to be used (involves common methods usually deployed in the subject area and usually known to students), but the students identify the specific project and select the method/approach they decide to follow to complete the project.
- **Problem project:** In this type of project students have complete autonomy to choose their project and their approach to it from beginning to end.

The common difficulty faced by students in a PBL environment is the ability to transfer methods and skills acquired in one project to another project in a different setting or discipline. Instructors should include such transference in their course objectives and should guide students to see connections between their current project and what they have learned previously, and gradually withdrawing this support as

the students gain knowledge and become more capable of seeing the connections by themselves. The instructors should also prepare students to fill in gaps in content knowledge when the need arises, taking into account the fact that such gaps are likely to arise in PBL than in conventional lecture-based instruction [22]. In essence, PBL addresses one of the key issues in the cognitive sciences, *transfer*, which can be defined as the ability to extend what has been learned in one context to other new contexts [23]. This is an important component of engineering competency development. While the design studio has long been a centerpiece of design thinking and pedagogy outside engineering, it took the medical community to lead engineers back to thinking formally about PBL and related pedagogies. Project-based learning at the individual course level is known in engineering education, having been used almost universally in capstone design and in first-year engineering courses and in courses that engage students in consulting projects. A few European schools, including the Universities of Aalborg and Roskilde in Denmark, and others in Europe and Australia, have made PBL the focus of most of their engineering courses [24].

The use of PBL in medical schools demonstrated that the first-year students were significantly better diagnosticians, i.e., practitioners, than those taught by lecturing [25]. Today, the professions are converging; engineering, medicine, law, and business are moving toward similar project-and problem-based pedagogic frameworks. The evidence is clear: that PBL encourages & supports collaborative work, and that it improves retention and enhances design thinking. However, there remains the need to extend the results already obtained and to demonstrate as well PBL's values in increasingly authentic design scenarios that typically include participation across disciplines, as well as across geographical boundaries [1].

Introducing PBL in the First Year: The first year design-oriented courses are similar to many capstone design courses, but differ markedly in their tendency to focus more heavily on conceptual design methods and less on discipline-specific artifacts (e.g., cars in mechanical eng., chips in electrical eng.), primarily because there are now many accessible sources of information, including textbooks, and also, because most first year students can do reasonable conceptual design without the detailed technical knowledge they acquire only later in their programs. In fact, there is a strong belief that first year design-oriented courses:

- Enhance students' interest in engineering as well increase students' retention in engineering programs;
- Motivate learning in upper division engineering science courses; and
- Enhance performance in design courses in general and in capstone design courses in particular

While there are different views of the proper metric for assessing retention, there seem to be enough data to support the thesis that a design course or a course that contains design elements- including projects, teams and written and oral

communication- can produce very positive changes in engineering student retention rate [25]. In terms of other measures of potential benefits of design courses, much data is available from various institutions. Purdue's EPICS program reports that students regarded team work, communication, and time management and/or organization as "the three most valuable things learned" from the EPICS course [26].

There is strong evidence that supports the statement noted above [27] including assessment data on the impact of PBL and design courses on student' benefits, general outcome, & future career [28]. Mills and Treagust [29] reviewed published evaluations of PBL programs in engineering and concluded that students who participate in PBL early on, are more motivated, demonstrate better communication and teamwork skills, and have better understanding of professional practice and how to apply their learning to real problems; however, some may have less complete mastery of engineering fundamentals, and some may have "second thoughts" about the time and effort required by projects and the interpersonal conflicts they experienced in team work, particularly with teammates who fail to devote the time and effort required to get the job done properly. In addition, if the project work is done entirely in groups, some of the students may be less equipped to work independently.

Intertwining PBL with Problem-Based(The Hybrid Approach): Curricula with high concentration of Project Based Learning intertwined with Problem Based Learning were assessed at the University of Louvain[30]. The assessment measures included pretests and posttests of students' basic knowledge, understanding of concepts and the ability to apply them. Also, students' self-efficacy, satisfaction with the curriculum, attitudes towards team work, instructors teaching practices, and the impact of the "*hybrid*" curriculum(*project/problem-based*) on the instructional environment. The results of the Louvain assessment are extremely supportive of the "*hybrid*" (*project/problem-based*) curriculum. Students in the "hybrid" curriculum expressed their satisfaction with the new curriculum, because: they received a lot of support from the instructors, saw more connections between theory and practice became more willing to use autonomous learning strategies, and were less reliant on rote memorization relative to students in the traditional curriculum[30] The positive outcomes for the "hybrid" curriculum-taught students is attributed to two main factors: factor one, is the great support received from their instructors; factor two, students' perceptions that they should work harder than students taught traditionally. Teachers in this study saw a positive impact of the "hybrid" curriculum on student competencies in team work, transfer of knowledge, and learning; the quality of student -teacher interactions and teacher-teacher interactions; and teachers' pleasure in teaching and their willingness to change their teaching practices to make it compatible with the new system they have adopted[24, 30]. The last two outcomes were particularly strong among teachers who perceived their administration to be supportive of teaching, in general, and

valuing teaching improvement in particular. This outcome has important implications for the critical role of college administrators in attempts to reform education.

GETTING STARTED WITH DESIGN COURSES, INCLUDING: PROJECT-BASED LEARNING

Once instructors are persuaded that design and design – related pedagogies are worth attempting, they face the question of which method to use, and when is the appropriate time to embark on the selected method(s). The answer, like the answer to any real question, begins with “it depends” ; it depends specifically on the instructor’s learning objectives, his or her prior experience with learning-centered teaching methods, instructor’s teaching skills and his/her willingness to acquire new skills when the need arises, and the availability of local expertise and support for each of the selected methods. Before teaching a topic or series of lessons using design-related pedagogy, the instructor should focus on *learning objectives* that define what the students should be able to do (search, calculate, derive, analyze, design, model, critique,...) after the course and/or instruction has been concluded. The learning objectives should guide the choice of focal points, learning activities, potential changes, and assessment methods. Once *learning objectives* have been defined, a suitable instructional method(s) may be identified. When the decision regarding the adoption of a method or methods, is made, the instructor should refer to relevant texts, articles, and Web-based resources on the chosen method(s) and take full advantage of experienced colleagues and teaching center consultants who can offer advice on implementing selected method(s) and dealing with problems that may arise with its use.

There is a clear need to expand the number of faculty members interested in and capable of teaching design including *project –based design* courses. The most important recommendation is that engineers in academe, both faculty members and administrators, make enhanced design pedagogy one of their highest priorities in future resource allocation decisions. In addition, there are ways of approaching design education that can offer systematic payoffs and help in setting up a framework for continuous quality enhancement [1, 2, 13]. These include the following:

- Encourage experienced design faculty to help manage the contextualization of engineering design theory and practice. This would not only bring invaluable experience into the classrooms, but would also alleviate the shortage of faculty who want to teach design.
- Adopt the idea that engineering design courses, and related courses, should be taught across geographically dispersed, culturally diverse, international networks [1].
- Challenge all engineering faculty to incorporate the tools of *design thinking* into relevant parts of the engineering curriculum.

- Alert the administration to the cost of lost human design potential resulting from the lack of investment in design pedagogy.
- Provide forums where design practitioners, design teachers, design researchers, and experts from industry to come together to discuss and collaborate on all aspects of design teaching.

Finally, design education represents both serious challenges and great opportunities for faculty, college administrators and stakeholders. On the other hand, it is clear that incorporating the elements discussed above will raise the cost of education (smaller sections, involvement of experts, etc.), but, on a macro, or global scale, these costs are small compared to the cost of lost human talent in the engineering pipeline. Design is what engineers do, and if proper steps are taken to improve design education, both students and the instructor should soon start seeing positive outcomes.

CONCLUDING REMARKS

On the whole, the intended move towards encouraging instructors to adopt *project-based learning (PBL)* seems farfetched and difficult to accomplish, especially in the initial stage. This is because time is needed for those undertaking the task to be trained to implement and gain the experience necessary to move the process forward. Time is also needed for other stakeholders to be convinced and provide the support needed to prescribe the change. Most importantly, those promoting the change must be able to show evidence that PBL is effective for engineering education.

It is highly recommended that an “Active Learning Taskforce” be formed of experienced faculty, to initiate, infuse, and oversee the progress made. Their determination, patience, and resilience are required to successfully promote college-wide implementation of PBL. Nevertheless, with clear intention, goals and plans of action, coupled with support from the highest level of the University’s key personnel, the Taskforce and other core groups, should be able to move the process forward. Success would almost be guaranteed, when a well-coordinated College-wide implementation of PBL is underway in other departments and colleges of the University.

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Advancing Research on Engineering Design using e-Journal

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Abstract—The potential of typical, handwritten engineering design journals to advance knowledge in engineering education is diminished by technical issues (e.g., readability and interpretability), writing lens (i.e., focus on the result not the process), and the ‘freshness’ of the events recorded. The authors argue that utilization of a novel online electronic-Journal (e-Journal) can overcome these challenges and open a new avenue to learn about students’ self-regulation within the context of engineering design. Work is underway to develop a system fulfilling this need. The resulting e-Journal is designed concordant with the engineering design phases: Problem Definition, Conceptual Design, Preliminary Design, Detailed Design, and Design Communication. The e-Journal enables the act of going back and forth between phases to support the iterative nature of engineering design. The online nature of this e-Journal ensures data currency because students can report their activities concurrently with design activities or at their convenience. Analyzing rich recorded data will enable researchers to learn about student’s activities in areas such as task interpretation, project planning and execution, monitoring efforts and design goals, and management of resources, time and teamwork as individuals and teams. Additional work will focus on the way the e-Journal is utilized within a two-part mechanical engineering capstone course and will analyze the obtained results after both parts conclude.

Keywords—engineering design, electronic journal; self-regulation

I. INTRODUCTION

Engineering education researchers are able to reap benefits from the analysis of engineering design journals (or notebooks) to learn about students’ self-regulation during their design process. Studies find that students with good self-regulation skills are inclined to be successful academically [1]. In engineering areas, higher awareness of thinking processes lead to better engineering design [2]. Consciousness of the cognitive process is not innate but rather a trainable expertise which is attained by those who seeking it. Meticulous investigation of students’ design process will lead to means for teaching self-regulation skills to all engineering students, which, in the long run, can improve the quality of graduating engineers.

One major obstacle for engineering education researchers in collecting meaningful design journal data is the incongruity between the researchers’ and students’ priorities. As designers,

students are interested in various design concerns and issues, e.g., experimental results, data sets, calculations, drawings, measurements, ideas, and thoughts. On the other hand, researchers are interested in students’ process of thinking through and solving the design problem, e.g., students’ interpretation of the tasks, planning, and how they monitor progress. Providing prompts to guide students’ in writing the journal entries could resolve these differences in expectations. However, some journal entries can be hard to read due to students’ handwriting. Additionally, student’s entries are highly contextualized to their project and tasks, which yield them harder to interpret. We argue that providing an alternative journaling system in a digital form could solve these problems.

An electronic-Journal (e-Journal) is conceptually similar to a physical design journal which serves to record students’ design notes, sketches, and drawings in digital form as students engage in these tasks. With the ubiquitous presence of mobile devices connected to the Internet, this journaling method provides a high level of access to the participants of the study along with 5 additional benefits: 1) prompts to guide entries can be provided; 2) minimization of handwritten data; 3) ability to collect various types of data (e.g., pictures, drawing packages, videos, and voice notes); 4) enabling concurrent access by team members, instructors, and researchers; and 5) improving communication among them. Having multiple data points (e.g., design artifacts and planning scenarios) will ease the interpretation process of contextualized reports. These features not only will improve the quality of research, but also enhance students’ dynamics within the group.

Our work utilized an open source project management system called Redmine [3]. This system was ranked first out of 21 other potential software platforms according to our criteria for a good e-Journal: being accessible online, having secured data connection and storage options, an ability to support multiple users and projects, a file management system, milestone arrangement, task tracking, custom form, and plugin system. Redmine is a cross-platform and cross-database web-based system, coded using Ruby programming language [3], [4] with a Rails framework [3], [5] which enables us to modify or add additional functions in a fairly uncomplicated way. We customized this software by installing additional plugins (e.g., Custom Field, Finance, and Contacts) and modified the core codes to create desired functionalities. We also developed

additional plugins to enable uploading digital documents and writing design journal entries. The web-based program was then used to collect data from the first segment of a two-part capstone engineering design course at a state university in the Intermountain West of America. A capstone course encompasses the practical application of students' prior coursework [6]. Capstone courses aim to teach professionalism [7] by providing experience of working on a real design project (e.g., assessing client's needs and create design requirements).

This paper discusses our e-Journal's features, user roles, workspace, student-system interactions, system's logging characteristics, collected qualitative data, method of analysis, and future work. The work presented here puts forward a framework for a system capable of obtaining a richer level of detail from engineering design journals than is currently available. Validating the use of online journaling resources can bring about a deeper understanding of the dynamic changes occurring within the design process and provide tools to help researchers explore the self-regulated learning of students and teams as they employ these tools to address design challenges.

II. CAPSTONE ELECTRONIC-JOURNAL

The e-Journal is being developed as a project management system and data collection tool for engineering students, design instructors, and educational researchers. This section illuminates important characteristics of our e-Journal in terms of features, roles, users' workspace, and student-system interaction. From here forward, for the sake of simplicity, the term e-Journal will be used to refer to our Capstone e-Journal.

A. Features, Roles and Security

In terms of functionality, the e-Journal consists of three modules, which are Design, Communication, and Finance modules. All are crafted to help students to finish their design project in a structured manner. Each module consists of several services. Access to these services is regulated by user roles, which will be explained further at the end of this subsection, after the discussion of each module.

First, the Design module is fashioned to provide services related to design activities: planning, monitoring, and reporting. Collecting design activity reports (or design journal entries) is its main service. Users are able to submit their design progress through a form, along with additional digital documents (e.g., drawings, text documents, or images). The module stores journal entries systematically based on submitted date, design phase, category of reported activity, and work breakdown item. The e-Journal accommodates five design phases, which are Problem Definition, Conceptual Design, Preliminary Design, Detailed Design, and Design Communication; these phases are adopted from [8]. Each phase has a different overarching goal, for example the goal in Problem Definition is to "clarify client's objective and gather the information needed to develop an unambiguous statement of the client's wishes, need, and limits" (p.24), while Conceptual Design's goal is to "generate concepts or schemes of design alternative or possible acceptable designs" (p.26). Hence users' activities for each phase are also different, e.g., activities in Problem Definition are clarifying design objectives

and constraints, while activities under Conceptual Design are establishing functions and design alternatives.

A part of the planning process is to populate design tasks based on their characteristics in a hierarchical structure that makes the tasks easy to be completed and managed independently [9]; work breakdown structure is suggested for such a purpose [10]. In the e-Journal, task breakdown is merged with task assignment and both are tied to a Gantt chart. In essence, for each breakdown item, there is an identical Gantt chart item. Having these items correlated facilitates in assigning team members to each item, setting start and end dates, and monitoring their team's progress whenever they want.

Second, the Communication module is fashioned to enable rapid exchange of relevant data among team members, by means of Forum, Wiki, News, and Activity History tabs with email notifications from each. This module takes advantage of the online nature of the e-Journal: it is accessible from anywhere, at any time and multiple users may access information concurrently. Team members are able to utilize forums to discuss design issues among themselves. Every user is able to start and reply to discussions. Unlike Forum, News is designed as one-way communication. A member of the team can use News to inform the rest of the group about a major breakthrough or issue within the project. A Wiki function is designed similar to Wikipedia; which can be used as a digital notepad or manual. A Forum, News, or Wiki post is capable of containing documents, images, or videos. The e-Journal is configured to send email notifications for every new post, which enables users to monitor their project via email, without having to log into the e-Journal. Journal entries are likewise configured, enabling users to get email notification for new design reports. The last service is Activity History, which displays reported activities in sequential order.

Third, the Finance module is designed to help users in tracking their income and expenses, but does not have transaction processing features. To set up access this tool, similar in function to a bank account or check register for their project, users have to fill in an account name. It is possible to set up more than one account for each project which could help users to keep track of and plan for transactions and varying sources of funding. This module is independent from the previous two modules discussed; hence automatic cross reference checking is unsupported. This module also comes with a service for listing contact information, e.g., their own, and that of suppliers, product vendors, document editors, researchers, and clients.

Accessibility of each module by different users is not equal, but determined by role. Excluding the Administrator, there are three distinct levels of access: Researcher, Supervisor, and Student. Student level access has full use of all three modules. Supervisor and Researcher have full access to the Communication module and read access for the Design and Finance modules. In addition, the Supervisor role is able to write comments for every financial transaction and had full access to the Contact service.

With security in mind, the e-Journal is configured to back up its data (i.e., uploaded files, self-reported texts, and system

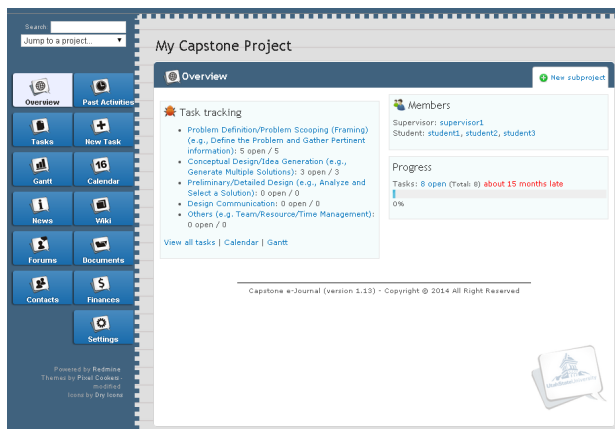


Fig. 2. The e-Journal workspace.

logs) automatically every Tuesday and Friday at 11:59 PM. Days and times were arbitrary selected. Updating is done rapidly, taking less than five minutes to export, compress, and back up e-Journal data to Cloud storage. Additionally, secure data transfer is available to those who wish to use it. Although the unlikely chance of machine and software failure exists, there were no losses of data and access to the most recent data was possible for a substantial portion of the project time frame.

B. Project Workspace

The e-Journal groups its users by project. The e-Journal system is able to host any number of projects and users. It is also possible to establish relationships within projects by partitioning it into several subprojects. A project may have more than one user working on it and a user can be assigned to more than one project or subproject. Within a project, it is possible for a user to have more than one role, but cannot be added without one. Therefore a relationship between a user and a project is a requirement of the e-Journal, otherwise user privileges cannot be assigned.

It is important to note that the e-Journal is not designed to replace the design process or help students to shortcut engineering work on their capstone project. Rather, it is designed to help them manage their project communication, document progress, finances, and collect artifacts, coordinate schedules, and manage finances, thus becoming a window through which to view traditionally internal processes. In order to use the e-Journal, students have to know their project (e.g., design statement, requirements, teammates, supervisors, and clients) prior to using it. They are able to apply for e-Journal accounts once they acquire that information. Applicants' registration will be executed as a group. They provide personal information, i.e. names, students' ID numbers, and primary email addresses. Summarily, after the administrative process of creating the associated project workspace, each applicant will receive an automatic email from the e-Journal which contains the applicant's username, password, project workspace name, and a direct link to the e-Journal.

The project workspace (Fig.1) is accessible subsequent to the login page. Users are able to access Design, Communication, and Finance modules from a panel on the left side of the interface. The number of blocks on the panel is

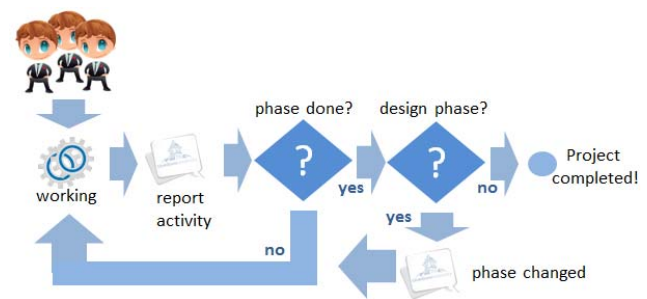


Fig. 1. Student-system's interaction flowchart.

generated based on the user's role. On the right, users can see identifying descriptions for his/her teammates, supervisors, and researchers. The process to register supervisors and researchers remains similar to students; they provide names, instructors' ID numbers, and institutional email addresses.

Although there is no specific client role, it is possible to include a client in the e-Journal. A client could be a person, a company, or even one of the faculty. A Supervisor role may also be given to him/her. However, if necessary, any new role can be added into the e-Journal. By including them, supervisors and clients are able to monitor students' progress, design and management issues, and interact with students in real time.

C. Student-System's Interaction

In this section we elaborate on routine interactions between students and the e-Journal in terms of design activities, which is illustrated in Fig. 2. Students' primary goal is to finish their project in a timely manner by working on their design tasks, either as a group, with a partner, or individually. The design tasks may be varied, including meetings, brainstorming, drawing, looking up information, calculating factors of safety, planning, or assigning group specific tasks and due dates.

Once the activity is finished, students write a journal entry about that particular activity. A reporting form with prompts is accessible by clicking the "report an activity" link on the Design module's main page. These prompts serve as guidance to write the journal entries. Six out of eight prompts are required an answer, e.g., "what did you do?", "what was the result of this activity?", and "how do you feel about the result?" Two operations are executed after the journal entry is submitted. First, the student will be returned to the Design module's main page. Second, notification emails about the new entry will be sent to all team members.

Having returned to the Design module's main page, students have a decision to make, whether they are done with their current phase (e.g., Problem Definition), or not. Suppose they choose no, their next option is to continue the working-reporting loop. However, if they decide to close their current phase (e.g., Problem Definition), they then have to complete three tasks before starting the subsequent phase (e.g., Conceptual Design). The first task is to set up carry-over access to prior documents needed for the next phase. Students are allowed to select attachments that they wish to retain access to. The second task is to confirm whether their latest results are valid. The third task is to fill out an Engineering Design Metacognitive Questionnaire (EDMQ) for that particular

phase. Lawanto, Butler, Cartier, Santoso, and Goodridge [2], [11] developed EDMQ to assess students' metacognitive strategies (e.g., task interpretation, planning strategies, and monitoring & fix up) on each phase and on overall team performance (i.e., teamwork, resources management, and time management).

Design processes are iterative in nature. In the e-Journal, iteration was accounted for by allowing students to return to any previous stage needed, e.g., a return to the Problem Definition phase, even when students have progressed to the Detailed Design phase. Reverting to an earlier phase is a regulation strategy, indubitably we required students to explain their reasoning for conducting this action. There is no instantaneous forward phase transition in the e-Journal, which means if we continue using the previous example, it is then necessary to at least pass through the Conceptual and Preliminary Design phases in order to return to the Detailed Design phase; but this is not a lengthy process.

Detailed design is not the terminal phase in the e-Journal. The final segment, rather, is the Implementation phase, which represents construction-heavy activities when the project's product is built. The activities that fall under this phase are building, testing, and improving design prototypes. Completion of this phase means that students have finished their capstone design course and are ready to deliver a finished product.

III. DATA TYPES AND METHOD OF ANALYSIS

There are three types of data collected: self-reported, system logged, and design artifact data. Each represents different aspects of students' engagement in their project and offers diverse insights into students' self-regulation. In this section, we elaborate on each data type and associated method of analysis.

A. Self-Reported Data

Self-reported data are defined as information which was consciously given by users on various e-Journal forms. There are at least nineteen self-report forms to be filled out within the e-Journal, e.g., to edit project descriptions, revert to a previous phase, and a financial transaction forms. In this subsection, we focus on two of those: the design activity report and Gantt chart forms. Both belong to the Design module (subsection II.C on page 3) and are described in subsection C on page 3.

The design activity report form is used to assess students' design activities, design results, feelings toward the results, teamwork, and an estimation of their task completion. Through data tied to specific design activities and results, researchers are able to learn about students' regulation strategies during every stage of the design process. This is important because it is plausible that students employed different strategies for each particular phase. By analyzing teamwork data, researchers are able to identify a person (or other instances) that triggered students' regulation, either their supervisors, clients, one of the team members, or a complete stranger. Conscientious analysis of a task's completion estimation will enable researchers to learn about students' ability to monitor their own progress. On a larger scale, meticulous study of design activity reports in

parallel with Gantt charts can explicate students' planning and follow up skills.

B. System Logged Data

This type of data is defined as that stemming from users interacting with the e-Journal and logged automatically. There are seven types of logged interactions, with each providing insight into different parts of students' regulation. In this subsection, we elaborate on methods of analyzing students' planning skills through system logged data.

Students' planning strategies are closely related to their Gantt chart, therefore each change made to the Gantt chart is recorded, e.g. adding tasks, deleting tasks, and revision of any other aspect of the plan. All internal system addresses that are accessed by users within the e-Journal are logged so that each user's time spent in the system is recorded. Analyzing this logged data enables researchers to describe the evolution of student planning in every stage, which illuminates students' strengths (e.g., planning or teamwork) or weaknesses (e.g., overconfidence, vague descriptions, and task breakdown that lacks in detail). By triangulating the Gantt chart log, design activity reports, and access log, researchers are better able to learn about students' planning, execution, and monitoring.

C. Design Artifacts

Design artifacts represent the design in a tangible way, either as CAD drawings, sketches, mathematical models, or tables and charts [12]. Artifacts are used as triangulation data; confirming that students are doing, or not doing, what they claim they did in the e-Journal, validating self-reported data and the research itself. In the e-Journal, students can upload their design artifacts in digital formats, either as word documents, presentations, 3D drawings, images, or calculations. Preliminary observations from the first portion of the class indicate that student use of the e-Journal yields unique data reflecting team involvement, distribution of effort and iterative actions within the design process.

IV. FUTURE WORK

Future efforts will focus on fine-tuning the way the e-Journal is utilized within a two-part Mechanical and Aerospace Engineering Capstone course and will analyze the obtained results after both parts conclude. Our goal is to improve e-Journal congruity with the class structure, dynamic and needs, which means to take user input into account, believing from a research point of view, that addressing these needs will increase data quality. We aim to make the e-Journal an integrated course tool available for validation by other users, while determining the extent to which student behavior reveals self-regulation in comparison to other methods in use.

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Using Robust Design as a Conceptual Framework to Understand Expertise

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Abstract—This exploratory study investigates design expertise through the lens of Robust Design. Robust Design is typically applied to manufacturing processes. Robust Design has the objective of minimizing the effects of uncontrollable noise factors on the output of the process or product. Designers achieve robustness through the control of design variables.

A coding scheme was developed from the conceptual framework of Robust Design, particularly investigating designers' awareness of noise factors and design variables. The dataset includes video and transcripts of working engineers in two conceptual design meetings. Protocol Analysis was employed on the transcripts of both meetings.

The Dreyfus model of expertise was applied to the observed behaviors. The designers displayed "competent designer" behavior in these meetings by identifying noise factors first and complementary design variables; this may be due to the moderator's problem framing to focus on a noise factor.

The result of problem framing and subsequent design activity can inform the development of undergraduate classroom interventions. Educational implications include 1) that instructors can advance students' design expertise by enhancing awareness of noise factors' and design variables' effects on the output and 2) that Robust Design can also be applied to cognitive design processes.

Keywords—robust design; expertise; protocol analysis

I. INTRODUCTION

Aerospace engineering as a culture seeks to reduce risk through the quantifying and reducing of uncertainty [1]. To that end, multiple design processes have been proposed in order to seek out sources of uncertainty earlier in the product's life cycle, one of which is Robust Design. Robust Design itemizes sources of variation and provides at least three methods for guaranteeing that the variations, though not eliminated, will not have disastrous impact on the product's performance, through the controlling and testing of design variables.

During the product design process, a set of the critical variables are the conditions in which the product is produced and implemented. The variation in these conditions will impact the product's performance. The essence of Robust Design is

that the product's consistency in performance will be improved by reduction of variations. Statistical quality control and optimization have formalized the concept into mathematical models. In this realm, Robust Design is defined as

"an efficient and systematic methodology that applies statistical experimental design for improving product and manufacturing process design. By making product and process performance insensitive to (robust against) hard-to-control disturbances (called noise factors), robust design improves product quality, manufacturability, and reliability at low cost" [2].

During the coevolution of the problem and solution spaces, designers are trying to meet the evolving requirements [3]. In this process, some designers may neglect variation of conditions. In other words, designers assume an ideal environment for product or process they are designing. The main reason for this negligence is lack of experience. Naïve designers fail in recognition of the variation in environment [4] since they are not familiar with the whole procedure. In contrast, competent designers' systematic outlook allows them to see the differences between the real world and the ideal one. They discern need for controlling conditions' variations. This perception of need and projected response should be assessed using a framework. Robust Design provides the framework that indicates the level of effort that designers put in defining the variation, their impact, and the control mechanisms.

What do designers recognize as sources of uncertainty? How do designers mitigate the impact of the identified sources of uncertainty? It is conjectured that as designers gain experience, they spontaneously identify and mitigate risk and uncertainty in design rather than ignoring uncertainty until externally prompted.

In this paper, we employ the concepts in Robust Design in order to understand designers' behaviors in a brainstorming meeting of working professionals. The data includes transcripts of two meetings. The Protocol Analysis includes an *a priori* coding scheme developed from Robust Design, along with a preliminary diagnosis of the entire team's level of expertise exhibited. The implications for aerospace engineering design education will be discussed.

II. CONCEPTUAL FRAMEWORKS: ROBUST DESIGN AND DREYFUS MODELS OF EXPERTISE

Two models from the literature provide lenses for understanding design and designers. First, in the aerospace engineering design context, Robust Design intends to reduce risk of failure by accounting for variations in the process or product, introduced through noise sources, through control of design variables, or items that the designer can control [5]. Second, [6] summarizes and adds to the Dreyfus model of expertise, also outlined in other work [4]. This model of design expertise identifies 7 or 8 levels of expertise along with ways of “perceiving, interpreting, structuring, and solving problems” [4]. An assumption is that a good designer would have an implicit goal to reduce risk of failure; therefore, the designer’s observable behavior would include identification of sources of noise and design variables as they affect the response of the process or product being designed.

The primary conceptual framework for this paper is Robust Design, presented as an overview and then expounded as three methods of design and experimentation [5]. The design process is presented with vocabulary oriented toward the machine, with only small reference to the user, but acknowledgement of the influence of the user is at least present. For the purposes of this work, the general understanding of Robust Design is sufficient because the data set involves only conceptual design but not experimentation or detailed mathematical modeling.

A general view of Robust Design is shown in Figure 1 below. The process or product at the center of the flowchart is the thing being designed. The response (right side) of the process should be equal to the target value (left side). The response is influenced by the design variables that the designers have control over, and influenced by the noise factors which the designers cannot control. The principle, then, is to mitigate the influence of the noise factors by adjusting the design variables and the process. Several categories of noise and examples are listed in the top left of the figure, with emphasis in this project on External Noise, such as Human Error.

A second representation of Robust Design’s concept of variation (noises) and its impact on the outputs (system performance), which the designers should control, is shown in Figure 2. This interaction (coevolution) should be controlled by the designers. With the consideration of the noises and control parameters, it is possible to create a designed product with less chance of failure and more consistent performance.

The secondary framework for this paper is Dorst’s interpretation of the Dreyfus model of expertise, as described in two different papers [4], [6]. Summarized are the two papers with 8 levels identified, though the later Dorst paper eliminates Proficient and adds Master and Visionary. Perhaps the titles of the levels are not as significant in this work as the column of Approach to Design Practice Description in Table 1 below. Key elements in this table that align with Robust Design are “makes plan” and “assesses risk” approach of the competent designer because of Robust Design’s intent to reduce risk.

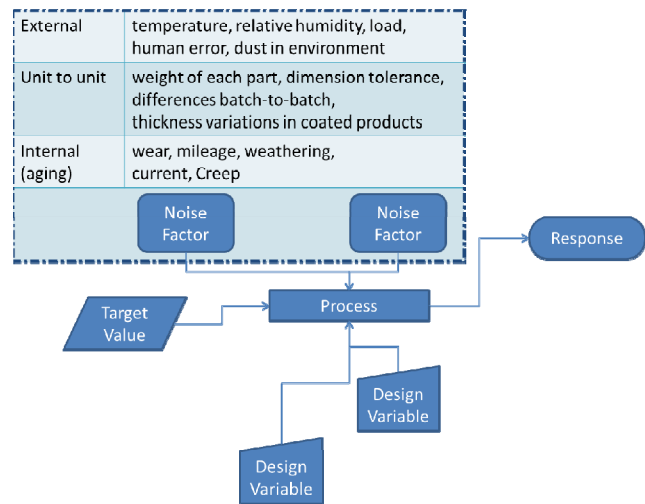


Figure 1. Overview of Robust Design, adapted from [5].

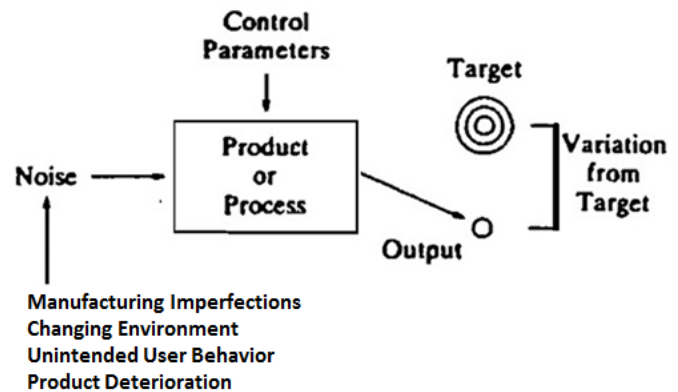


Figure 2. Objective of Robust Design, adopted from [2].

TABLE 1. ADAPTATION OF DREYFUS MODEL OF EXPERTISE [4, 6].

Level of Expertise	Approach to Design Practice	Approach to Design Practice Description
Naïve	Choice based	
Novice	Convention based	Consider objective features of situation, follow strict rules
Advanced Beginner	Situation based	Situational aspects important, sensitivity to exceptions to ‘hard rules’
Competent	Strategy based	Emotional attachment, trial-and-error, learning and reflecting, selects relevant elements, makes plan, assesses risk
(Proficient)		Immediately see most important issues, appropriate plan, reasons what to do
Expert	Experience based	Respond intuitively, perform appropriate action straightaway
Master	Create new schemata	
Visionary	Redefine field	

III. DATA

Working professionals in a company agreed to participate in a study as part of Design Thinking and Research Symposium 7. The data corpus includes 4-camera video, transcripts, and photographs of artifacts created in engineering and architecture meetings. The data set for this work includes

video, transcript, and artifacts of Engineering Meeting 1 and 2 where the design task is a thermal printing pen either as a toy or as a serious product [7]. This product is an internal TTP company project called Project Penny. The meetings take place in a conference room, with a projector as the central focus of the room, and a paper flipchart, about one fourth the size of the projection screen, to the right of the projection screen. The meetings were recorded using four cameras and they had access to flipchart, pens, and pencils.

Engineering Meeting 1 was prompted with a “homework assignment” as generated by a participant named Tony. The instructions included guiding topics: keeping print head level, protecting print head, print head activation, and print head angle. The participants were instructed to bring a product or picture of a product that glides smoothly over contours, which it appears that the participants completed. The data item here is the first 43 minutes of the 1.5 hour transcript. Early in the meeting, the focus of the meeting (as indicated by the gaze of the participants) moves from the projection screen to the flipchart, presumably because the intent of the meeting is brainstorming.

In the second meeting, a group of six engineers and one intern discussed product features, control and selection of user features, electronic architecture, and other applications. This conceptual design meeting duration was 100 minutes. The team members were discussing design of a thermal pen and its media. The pen has a small processor and memory, which can store pre-programmed patterns. At this stage, designers expressed more concern about the different applications of this product, its technical features, and possible extensions and developments.

Figure 3 shows the teammembers’ titles and their seating arrangement. Robert is doing his internship in the company and he is the project manager of the thermal pen development. He prepared some prototypes, which are not shown in the videos. The rest of the members are TTP employees. Data extracts relevant to Robust Design will be shown in the Results section of this paper.

IV. PROTOCOL ANALYSIS

Protocol Analysis is a well-established empirical research tool in studying the design process [8] [9]. A protocol is a piece of record of the time path of behaviors [10], which capture the content of the statements rather than the rationale of their occurrence [11]. Design protocols are usually in the form of recordings of designer’s behaviors, like sketches and audio-

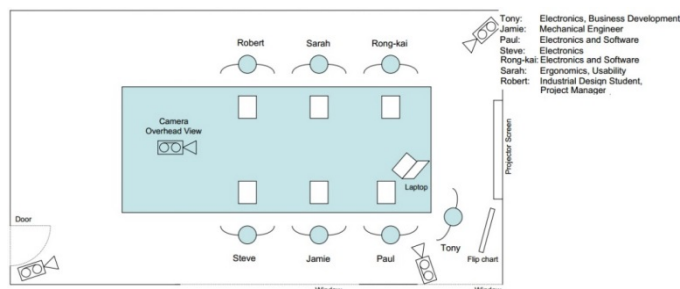


Figure 3. Engineering Meeting Two seating.

visual recordings captured by camera [12]. This study follows the steps:

- (1) Develop the Protocol Analysis framework
- (2) Observe the design session
- (3) Code the video using the framework
- (4) Analyze the coding results to find the design trend.

The first iteration of coding the video and transcripts was inductive to “chunk” by topic of conversation. For subsequent iterations, the Robust Design codes were utilized in each chunk. The coder for Meeting 2 trained the coder for Meeting 1 and they coded independently.

The first iteration of chunking according to topic of discussion was completed using either the words of the participants or the coder’s summation of the topic. For example, Meeting 2’s lines 1 through 50 were coded as “introduction and ground rules”, whereas lines 89 through 106 were coded as “arm movement”, specifically from line 97 of the transcript. Key phrases that indicate a new topic include, such as in line 89, “the focus...at the moment... is...”, and line 158 “any other things that that sort of generated?” or line 271 “any other pictures?” These chunks are very much situated in the discussion at the moment, with concrete artifacts being examined as part of the group discussion.

The second iteration of coding included the items from Figure 1: Target Value, Noise, Response, Design Variable, and Process/Product. It is assumed that Response specifically and only refers to the resulting printed pattern of the thermal pen. The Process here is mainly the interaction of the user with the thermal pen in making a printed pattern. The Product here is mainly the thermal pen and its many analogies of existing products. These delineations and definitions of what fits into those codes only leaves Target Value, Noise, and Design Variable as the available codes for most of the transcript. A considerable amount of the transcript remains uncoded if it does not easily fit these codes, such as clarifying questions, jokes, repeats and one word interjections. The coded sections were analyzed and the exemplar findings are presented in the next section.

V. RESULTS

In Meeting 1 lines 1190 to 1268, the first topic is “controlling the printed pattern by using barcodes.” Here, designers try to evaluate the concept after they have reached a conclusion that using a barcode scanner can be helpful. They then try to expand the idea to make the tool capable of generating the entire image after scanning its barcode. It takes approximately 3 minutes for the design team to understand that the concept is not very useful. Table 2 shows the coded quotes for this topic.

The second topic is safety, a concern which was present in earlier conversations but was not discussed. It is in line 1130 that Rong-kai (approximately 1:04:30) asks about it and shows concern. From here to line 1189 (1:07), the design team discusses safety issues. It takes less than 3 minutes for them to consider what is needed to prevent the head from becoming very hot. The result of the analysis for this topic is shown in Table 3.

The third topic concerns the battery. Like safety, batteries and charging the device were concerns from the beginning of the meeting, as the terms appear in conversations in the first 30 minutes. The designers revisited this issue and started analyzing it in more depth in line 1428. However, the discussion deviated from the topic in line 1464. They again came back to the issue in line 1552 (1:23:30), with the discussion about energy ending in line 1716 (1:32:30), when Rong-kai showed concern about the device's noise. In total, these two topics are discussed for 10 minutes. The results of the analysis of this topic are shown in Table 4.

TABLE 2. EXAMPLE OF CODED TRANSCRIPT FOR THE TOPIC "CONTROLLING THE PRINTED PATTERN BY USING BARCODES".

Code	Description	Example
Target Value	Requirements that the product must satisfy like: Allows children to print a picture by scanning its barcode (Easier the better) Allows children to make their own patterns (Easier the better)	Kids would like that Course they will
Noise	Variation from the original problem space	...kids do not worry about the barcode.
Response	Performance of the product/process such as: How easy kids can use the device or How much kids love it	..for kids you can imagine designing really simple sort of click click click on the dots almost draw a picture and then generate the barcode for that
Control Variables	Reducing the variation and the variations' impact like: Using the barcode instead of complicated user interface	..put this barcode underneath the image so you know if they want it they scan it.
Product/ Process	The way the pen functions normally	..scan it with the side of the pen or something... or ...got a link to the PC but it's actually an electronic link...

TABLE 3. EXAMPLE OF CODED TRANSCRIPT FOR THE TOPIC "BURNING RISK".

Code	Description	Example
Target Value	Requirements that the product must satisfy like: Do not burn skin or papers (colder the better)	It wouldn't hurt you at all actually
Noise	Variation from the original problem space like: unexpected user behavior	Going into natural selection Or Wouldn't be any more harmful than eating a tin of whole crayons
Response	Performance of the product/process such as:	You might be able to do it erm just from the temperature of the carrier
Control Variables	Responses to the possible variation in the system., like: Having sensors or locks for turning down the device	Could you erm put some sensors... Or So some safety locks that sense when the time is wrong
Product/ Process	The way the pen functions normally	Press down to make the head-...-come out so head will come out retract and not

TABLE 4. EXAMPLE OF CODED TRANSCRIPT FOR THE TOPIC "BATTERY AND POWER SUPPLY".

Code	Description	Example
Target Value	Requirements that the product must satisfy like: Heat up the media (faster the better)	...you wanted a hundred and eighty dpi quickly
Noise	Variation from the original problem space like: Speed of the pen	...either quickly or slowly its going to heat it up
Response	Performance of the product/process such as: Cost of the pen including battery	...it will be a bit on the faint side
Control Variables	Responses to the possible variation in the system., like: Limiting the voltage in specific range so variation cannot impact the system	...because rechargeables are the worst because they're low voltage aren't they?... Or ..but if you're driving into a two amp resistor-
Product/ Process	The way the pen functions normally	() is constant it doesn't matter as you increase speed or increase (size)

In Meeting 2, the design team identified target values straight away, but without assigning numeric values: angle, grip, heat, feedback to the user, and force or pressure. The conversation in the 43 minutes of coded transcript circulates around these target values. It is no surprise that the conversation focuses on these items, especially since the moderator identifies the problem of "the wobbly arm movement of the users... five to eleven years olds" in line 97 and 98. The moderator further defines the problem as two problems "the printout needs to stay in contact with the thermal print paper to actual print" in line 101 and "printout needs to stay in the right angle to print" in line 103.

Throughout the 43 minutes coded, the design team identified a large number of design variables, or items that they could control in order to achieve the target values or account for the noise factors. For the angle of the print head, they identify the shape of the base (line 141, line 160), a universal joint or a gimbal. For the grip, they identify the relative size of the pen (line 171), a grip that feels right, or even a joystick. For the heat source, they consider a battery source, switches, and detection of heat. For feedback to the user, they identify a projected image (line 652) and a grip that feels right (line 777). For force or pressure, they identify pressure sensors and springs. For following a contour, they identify tracking capability, ball bearings, rails, and suspension. Of course, these items are not solely linked to the target value listed, but can have interacting impact.

The team identified noise factors beyond the problem of wobbly arms. They identified a difference between hand grip and using a joystick. They identified left and right handed influences (line 783). They identified intentional jerking movements. They identified overheating or going cold (line 247). They identified the desire for the user to lift up the pen to check the results (lines 672, 674). They identified holding the pen the wrong way, which may result in the pen leaning. They identified non-standard pencil-holding form of the hand (lines 719, 270).

Several things the team identified do not seem to fit well with the Robust Design coding scheme: the user giving up, the user feeling patronized by the feedback (line 697), or the user not recognizing feedback as a comforting sound or feel (line 700). However, these effects could be considered as a failure if these effects cause the potential users not to buy or use the product. Alternatively, the design team identifies the product as potentially teaching a skill, such that the user might have a sense of achievement (line 373).

VI. DISCUSSION

The items identified by the design team in the Results section shed light on their design expertise. The design team in a short time identified noise factors and then immediately identified design variables to mitigate the impact of the noise factors on the product's response. Of course, the problem framing by the moderator as a problem that needs control certainly helps the design team get into the mindset of designing in robustness. Then the team's quantity of design variables in qualitative terms is considerable. They demonstrate an awareness and mitigation of risk without excessive prompts from their moderator. They also identified not their own emotional attachment to the product, but the likely impact of the product on the user's emotions. These behaviors align with a competent designer in Table 1.

The design team basically stayed within the bounds of an electrical solution rather than a mechanical product. The design variables identified included heat source, sensors, light, noise, and feedback in the electrical domain. Mechanical elements as design variables included shaping such as finger holes for a proper grip. The constraint away from a mechanical solution, such as the rubber stamp wheel and inking pad proposed in lines 391 to 428, perhaps constrain the team from proposing something radically different, which might limit the ability to see Master and Visionary design expertise levels.

There are a few items that the team does not appear to do. First, the design team did not spend much time defining the response of the product, which is the printed pattern it should make. There is slight reference to varying a pattern, to color density, and to thickness of lines. Perhaps the team assumes that controlling the inputs is more difficult than defining and modeling outputs. Second, the team did not mathematically quantify or mathematically model much of what they discussed. There were few attempts to assign numerical values or units to heat, speed of movement of the product across the medium, battery life, or temperatures. Perhaps these behaviors are more explicitly demonstrated later in the design process.

VII. CONCLUSIONS AND IMPLICATIONS

The Robust Design framework showed significant potential for communicating uncertainty, coding the risks and mitigation process as well as for technical reasoning and iteration. In Meeting 1, three topics have been coded using the framework. The first two topics were about the operation process in which users play a significant role. Since the users' behaviors are not completely predictable, the system should be robust in order to continue performing, even under extreme conditions. The

designers' responses to this need were captured using the Robust Design framework. The third topic focused mainly on "control variables", "Product and Process", and "Response" spaces. In that portion of the meeting, designers evaluated several options by looking at the way that system would perform and what the control factors would be. Therefore, we have shown that this framework is able to code the designers' communications about variations and risks and makes the protocol capable of evaluating and then differentiating among designers based on the time and effort they spend at different spaces (noise, control, target value, response, and product/process).

We also have shown that this framework will be beneficial in coding the detailed design process because in detailed design, dimensions are clearer. In detailed design, when designers are discussing the target values, they use boundaries and when they are talking about control variables, they mention the limits using numbers or other technical language. In conceptual design, sometimes it is difficult to distinguish transitions between control and target, and between control and response. This is because they are talking about several options with different limitations and different performance levels, so they have to go back and revise the target value and change the applications of the device.

There are educational implications from this exploratory study of working professionals that can be applied in the classroom. First, ahead of the second meeting, the moderator set up a homework assignment and some ground rules for the brainstorming session, which provided the atmosphere and artifacts to elicit robust design thinking. By introducing a noise factor as the problem to solve, the design team set to thinking about items that they could and could not control, with special attention on mitigating the uncontrollable elements. Second, a team of designers instead of an individual designer brought multiple perspectives for noises and for design variables. Third, the layout of the room with the flipchart or common drawing surface being far removed from the participants probably had an effect on the mode of communicating ideas from sketching to verbal, which may be beneficial for transcription but perhaps not beneficial for collaboration.

For researchers, further studies of design meetings, using the lens of Robust Design, can enhance our understanding of Robust Design thinking as a cognitive process in addition to manufacturing processes. Researchers can continue the work of discovering cognitive processes in order to inform curriculum. This may help bridge the gap of students' transition from the classroom to industry, especially in the manufacturing processes [13].

For educators, a lesson from these meetings is to train students to collaborate respectfully by setting ground rules, to welcome multiple perspectives, even those perspectives that challenge theirs, to think ahead for planning activities of design meetings, to consider different scenarios creatively, and to communicate verbally and visually. Overall, 1) a more robust product may be developed and 2) students' design expertise can be advanced through an intentional focus on Robust Design.

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Establishing Functional Concepts Vital for Design by Analogy

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Abstract— Student designers and professionals alike have difficulty accessing appropriate analogies for design problems. Recognizing the advantages of Design-by-Analogy (DbA), the Design-Analogy Performance Parameter System (D-APPS) tool was developed to include a library of analogy entries and a matching algorithm. These components are combined into the Design Repository & Analogy Computation via Unit-Language Analysis (DRACULA) software package that maps functions across domains in order to present analogies to designers as initiated through engineering performance metrics and critical functions. Most tools developed for DbA emphasize the searching by function feature. Since analogies are based on more than function, DRACULA incorporates both performance and function for the user to identify relevant analogous solutions. Prior to exposing engineering students to this tool, we investigated their ability to use analogies when crossing domains. During this process, we identified three function concepts to be vital for students to effectively use analogies across domains: reoccurring functions, critical functions, and mapping functions. The results establish a better understanding of the information that students utilize in order to formulate appropriate and creative analogous design solutions.

Keywords— *design-by-analogy, engineering education, functional modelling, mapping functions*

I. INTRODUCTION

Through academic efforts, engineering curriculum aims to prepare students with a developed and extensive skillset in order to provide them with the means to successfully implement their knowledge in innovative and real-world applications. However, the challenge arises for the need to equip these engineers-in-training with the ability to understand both concept and application. Analogical reasoning or Design-by-Analogy (DbA) presents this opportunity for growth within the engineering domain. Amidst the complexity among the engineering domains, Design-by-Analogy offers the prospect of alleviating the barriers and potential design fixations associated with crossing domains.

In designers' attempts to tackle engineering problems, plausible solutions can be discarded or remain untouched

early in the design process. During these early stages, designers can access multiple tools that can aid in concept development and idea generation. Of the many tools that are available for designers to use, functional modelling is one that allows designers to decompose a design problem into specific functionality as per a generalized taxonomy, the functional basis [1]. This generalizable decomposition introduces and pinpoints areas of innovation. It is in these areas of functional innovation that the Design-Analogy Performance Parameter System (D-APPS) tool can offer potential analogies. Integrating the D-APPS tool with the Design Repository & Analogy Computation via Unit-Language Analysis (DRACULA) software package seeks to provide analogies of similar functionality to design engineers and to employ the use of engineering performance metrics in a quantified manner. DRACULA consists of a repository, a matching algorithm, and an interface that returns alternative solutions.

Through the initial research in developing DRACULA, three function concepts were identified: reoccurring functions, critical functions, and mapping functions. For the purposes of the paper, functions are active verbs denoting an operation in a design process. The reoccurring functions are the functions that are commonly utilized throughout the various domains. Critical functions are the functions that are crucial for solving a specified design problem and defining the functionality of the product. Mapping functions are the functions that are favorable for determining appropriate analogies when crossing domains. Prior studies sought to validate the existence of reoccurring and critical functions [2-4]. During these studies, the concept of mapping functions surfaced. The process and initial findings regarding mapping functions are presented in this paper. It is important to note that these three function concepts are not mutually exclusive. There is overlap between them. This overlap introduces opportunities in building up the DRACULA repository in such a way that magnifies the potential for students to employ analogies across domains while reducing the potential for design fixation.

II. BACKGROUND

A. Design by Analogy (DbA)

To alleviate the effects of design fixation for students, analogies can offer alternative solutions to a design problem. When solving design problems, analogies provide engineers with latent analogical solutions based on a linguistic or visual portrayal of the design problem and description. Visual analogies are also useful in increasing the innovation of the design solution for both novice and expert engineers [5]. However, experimental results show that experts employ more analogies than novices [6].

Further experimentation has focused on using analogies as a means of improving design innovations [7-9]. In seeking innovative design solutions, human reasoning utilizes analogies through adhering to the design process, where the student polls their memory for source analogues. The student designer searches his or her memory and finds analogies that are comparable to the original problem. The connection between the design problem and the analogue can be established based upon experiences and memories. The final step is to develop the final design solutions using all of the analogical inputs.

To use analogical inputs in the design process, a repository of knowledge is required. Unfortunately, student and novice engineers do not have as robust of a repository as experienced engineers have due to an expert's wealth of experience that comes through practice. However, novice engineers are more willing to utilize previously employed technologies or solutions in their designs [5]. Because novice engineers do not always realize analogies to their fullest extent, they only partially reap the benefits proffered by abstraction.

B. Functional Modeling

Innovation can be engendered by functional modelling where a product is broken down into sets of functions that comprise the final tangible solution. When approached from a systems (top-level hierarchical) methodology, the sequential grouping of requirements for certain functions or subsystems (lower-level hierarchical) can lead to the same final functionality simply encased in a different form. In particular, function structures allow for the functional representation of a product using the system concept, as demonstrated through individual function boxes and flows. Function structures allow for a level of abstraction to be incorporated into the product design. Pictorially, the function and flow combinations allow for a form-independent solution that meets the design requirements. While the design progresses, the form becomes more function-dependent, and student designers can establish the specific nuances of the product in greater detail [10].

The function structure methodology requires breaking the functionality of the product into individual purposes or sub-functions. Graphically, the individual purposes are functional boxes with flows as both input and output arrows. Each flow is a material, energy, or signal that becomes pertinent to the operation of the box as derivative-notation, in a mathematical sense.

1) Functional Basis

Otto and Wood [11] proposed a defined taxonomy that can be used across multiple engineering disciplines and applications. This taxonomy was developed and refined in an attempt to aid functional modelling methods by utilizing a generic level of specificity and synonyms, also known as functional basis [1]. In this functional basis, the verb-object combination correlates to the function-flow relationship of the individual purposes. This vocabulary can be used in conjunction with the function box diagram aforementioned.

Within functional basis, functions are verbs that necessitate a specified action at a certain point in the requirement sequence. Consequently, the functions are formulated and generalized into a hierarchy of eight classes: channel, support, connect, branch, provision, control magnitude, convert, and signal. More specific functions result from the further decomposition of these eight classes. On the other hand, flows are the noun or form that coincides with this verb. Flow taxonomies can be broken down into three levels of general abstraction: material, energy, and signal as mentioned previously. As with the functions, greater levels of specific abstraction are the result of the decomposition of these three flows.

C. Functional Classification

Through the contributions of several universities, a design repository has been initiated as the basis for this work. The synthesis of the function structures in the repository led to the concept of various function classifications external to the class structure devised by Hirtz et al. [1]. This research broke down the functional modelling utilizing functions and flow based upon functionality. This functionality was derived from specific design problems possessing the potential to provide analogies for the same functions and not just linguistic similarity. The critical functions, reoccurring functions, and mapping functions are all subsets of the functions. As such, the relationship between these three function concepts is demonstrated in Figure I. The repository for providing analogies will be populated from the intersection of the critical and reoccurring functions.

1) Reoccurring Functions

Reoccurring functions are those functions that are most commonly used to model design problems in and among multiple domains. The reoccurring functions are domain specific and do not traverse boundaries as per analogical mapping. These functions are the most frequently represented functions and do not hold any specificity to the design problem. When solving design problems, student designers will more frequently use these functions to decompose the given problem, regardless of the domain for which the students are solving the problem in. For example, a student might decompose the design of a pulley system to include the function and flow combination of "import energy". This same combination of "import energy" can be utilized in efforts to decompose the design of a lamp. The pulley is in the mechanical domain whereas the lamp is in the electrical domain. Although the pulley and lamp are in different domains, the function "import" can be commonly

incorporated into the functional decomposition of each product.

2) Critical Functions

Although reoccurring functions are commonly used in functional decomposition, this general subset of functions is not necessarily vital to the product's performance. Critical functions are those functions whose performance directly relates to a Key Performance Parameter (KPP) or over-arching purpose of the product or system as a whole. These functions are crucial in decomposing the product into appropriate subsystems that still successfully represent the overall system. The premise behind this concept is that not all functions hold the same level of importance in satisfying the KPPs. The KPPs are problem specific and are akin to the over-arching system-level black box model in functional modelling. Though critical functions can be made from reoccurring functions or mapping functions, critical functions are not explicitly defined by either reoccurring or mapping functions. Instead, the critical functions are problem specific and are the corner stone for this research.

III. MAPPING FUNCTIONS

Design-by-Analogy promotes design creativity and innovation [12, 13]. Innovations are either implicitly or explicitly considered when recognizing analogies. A formal definition of mapping functions is proffered as:

Mapping functions are the general subset of functions that are most conducive for successfully mapping analogies across domains in a specific design problem as laid out by functional modeling.

The differences and similarities between critical functions and mapping functions must carefully be addressed. Mapping functions behave differently in their use and purpose. Regarding domains, mapping functions act across domains in order to provide analogies which thereby indicates their lack of domain specificity. These functions illustrate the similarity between the original inspiring analogue and the analogous solution. On the contrary, critical functions are essential to the development and use of a product. Despite this difference, a mapping function can be a critical function for solving the design problem, as demonstrated in the overlapping region in Figure I. Therefore, for a given design problem, a mapping function may or may not be a critical function, and a critical function may or may not be a mapping function. The advent of mapping functions originates from the results of the following empirical pilot study and product study.

A. Empirical Product Study

This research corresponds with the study run by Ngo et al. [2] who conducted a pilot study to investigate patterns that designers use when mapping out functions for design analogies. Because of the coalescence between mapping functions and the study run by Ngo et al. [2], it is important to evaluate wherein lies the extraction of mapping functions through process that Ngo et al. follows. The process for the pilot study investigation follows that of an empirical product study, as shown in Figure II. By utilizing an empirical study, the research sought to investigate the claim that inventors

will focus on certain critical function to the design problem when developing analogies. Investigating this, the study aimed to compare the critical functions of a product to the critical function of the product's respective source analogy, as pertaining to the black-box functional models. Results from the pilot study instigated further experimentation in a full-scale product study, which will be addressed later in this paper. When viewing the outcomes of both studies, the analysis suggested the presence of mapping functions in design.

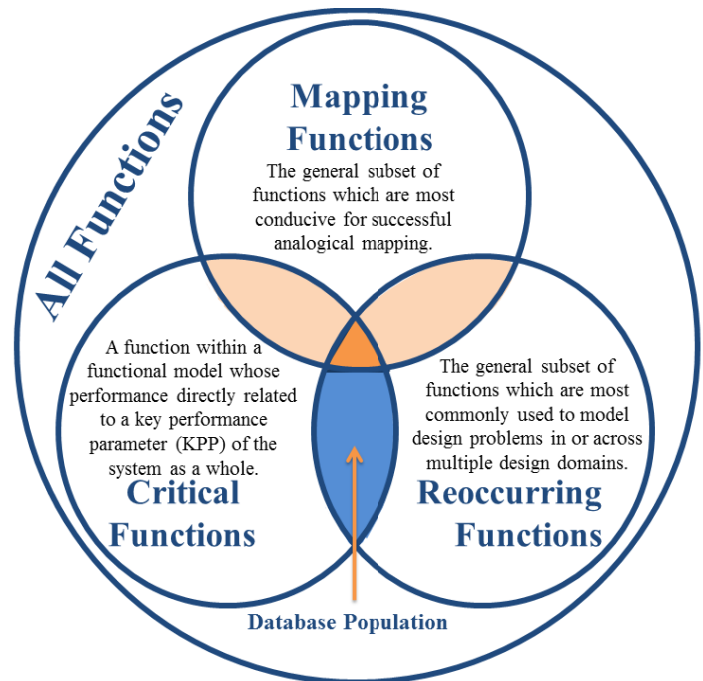


FIGURE I DESIGN SPACE FOR FUNCTIONS THAT STEM FROM FUNCTIONAL MODELING.

1) Example Collection and Screening

Prior to the pilot study commencing, the researchers searched for already existing products that were inspired by analogy. After searching through a wide range of sources, a commercial product collection was compiled to include 77 product examples. These examples were screened to ensure they were in fact inspired by analogy; as such, this resulted in removing 20 examples from the collection in order to give a total of 57 product examples that would be presented to the participants of this study. A more descriptive account on the specifics of the screening process can be found in Ngo et al.'s work [2].

2) Classification

While the pilot study primarily sought to investigate the claim that inventors focus on particular critical functions, 5 classification variables were applied to the design processes that are utilized when creating the analogy-inspired products [2]. A classification variable is a variable that depends on features of the given product, the inspiring analogy, or the design process to characterize the examples provided. The 5 classification variables used are as follows:

1. Critical Functionality and Performance:

Recalling that a critical function corresponds to the purpose of the system, the method for identifying the critical function originates from the method demonstrated by Otto et al. [11] with the Functional Basis. However, the detection of critical functions was discerned by Lucero et al. [3] as being both problem and domain specific. For each critical function, we needed to identify the system's complementary solution and performance effects. In other words, the critical function is the need, the system's solution is how the system solves that need, and the system's performance effect is the how the system's performance changes (i.e. durability, simplicity, maneuverability).

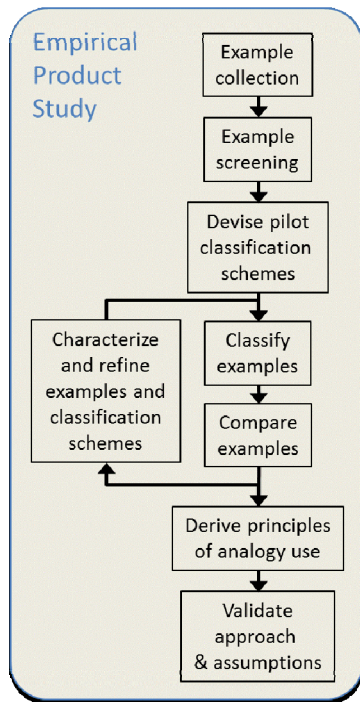


FIGURE II THE EMPIRICAL PRODUCT STUDY METHOD USED FOR PRODUCT EXAMPLES INSPIRED BY ANALOGY AS PRESENTED BY [2].

2. Main Benefit of Analogy Usage:

In design-by-analogy, the analogs inspire innovation. The main benefit of analogy usage establishes the primary contribution that an analogy inspires in an innovative product. There remain three benefits for design-by-analogy:

- **Function-benefit:** The analog inspires a new way of accomplishing a task.
- **Performance-benefit:** The analog inspires a better way of accomplishing a task.
- **User Interaction-benefit:** The analog inspires a new way of user interaction for accomplishing a task.

3. Analogy Difference Level:

Although the analogy inspires changes in the product's design, recognizable differences exist between the analogy and the product. Based on a low, medium, and high relation, these differences occur in the following areas:

- **Critical Function:** The product or analog's main purpose or function.
- **Construction:** The product or analog's physical configuration: material and geometry.
- **Operating Environment:** The product or analog's surrounding environment and conditions.

The low, medium, and high scale derives from counting the number of areas that the analogy and the product are different. When the difference is in 1 area, we assign the variable to have low-difference. With difference in 2 areas or significant difference in 1 area, we designate a medium-difference to the variable. As such, a high-difference occurs when there is difference between the product and analogy in 3 areas or significant difference in 2 areas.

4. Inventor's Primary Field of Work:

Recording the inventor's main area of work aimed to determine if their primary field of work impacted their analogy usage causing cross work domain differences to occur. The primary work fields were given as:

- **Academic:** This includes professors and students.
- **Commercial:** This includes companies and entrepreneurs.
- **Military:** This includes government affiliated laboratory researchers.

5. Analogy Origin and Driving Approach

During the design process, the context for how and why the analogy is used pertains to the driving approach. Analogies are not arbitrary used when mapping functions, but rather can be applied in two potential manners.

- **Solution-driven approach:** The designer understands a system or phenomena that can be used as an analogy, recognizes a design problem, and identifies the analogy to be the solution to the design problem.
- **Problem-driven approach:** The designer recognizes a design problem, identifies a system or phenomena to be used as an analogy the solution to the design problem,

and fully understands the analogy being used.

3) Mapping Functions in the Pilot Study's Results

In order to analyze the analogy and product features, Ngo et al. [2] counted the number of examples regarding the criteria for each categorical variable, summarized this information into a contingency table as found in Table I, and recognized existing patterns in the data. Of the patterns found through the analysis, two patterns insinuate and validate the existence of mapping functions.

1. Critical Functions: Typically, inventors duplicate one or two of the analogue system's critical functions into their products.
2. Driving Approaches: The identifiable driving approach used for analogy mapping impacts how the analogy is incorporated into the design process.

TABLE I CLASSIFICATION SUMMARY OF THE PILOT STUDY [2].

Classification variables and labels	# of examples
Critical Function Matching	
Identical - One critical function	17
Identical - Two critical functions	4
Different - Inverted	1
Different - Other	2
Total	24
Analogy Benefit	
Function	30
Performance	24
Interaction	3
Total	57
Analogy Difference Level	
Level 1 – Low-difference	47
Level 2 – Medium-difference	9
Level 3 – High-difference	1
Total	57
Inventors' Field of Work	
Academic	32
Commercial	24
Military Research	1
Total	57
Driving Approach to Analogy Mapping	
Solution-driven	9
Problem-driven	4
Total	13

4) Critical Functions

Of the 24 varying analogy examples, results demonstrated 28 identifiable product and analogue critical functions pairs. For the 25 identical critical function matching pairs, we realized that there are not only critical functions, but also functions that allow for analogue mapping to occur. Since critical functions cannot be mapped across domains, these limitations on critical functions imply that certain functions exist that surpass such limitations. As such, the presence of functions capable of being mapped between domains signifies that mapping functions are a valid conjecture.

Since the results suggest that inventors directly transfer critical functions from analogies to products, further speculation insists upon the existence of mapping functions.

To address these phenomena, we reviewed the latter portion of the content of the pilot study and designed a study to include human participation for data analysis

5) Driving Approach

From the pilot study, we re-examined the design process associated with the 13 products that had originally been investigated in efforts to determine the approach that inventors took for analogy mapping. The results of this effort can be found in Table II. As demonstrated, the solution-driven approach outnumbers that of the problem-driven approach by 9 products to 4 products. Additional results from this study indicate that: academic inventors gravitate towards solution-driven approaches whereas commercial inventors remain balanced in their approaches; problem-driven approaches tend to produce less performance beneficial analogies than function beneficial analogies whereas solution-driven approaches maintain a balance for analogy benefits; the analogy difference level does not depend on the driving approach that the inventor takes [2]. In the follow-up study performed by Ngo et al. [14], the inventor's occupation presented no correlation to the approach taken.

This analysis indicates the difference in the driving approaches influences the design process and the success of the design. In design-by-analogy, inventors travel down different avenues in their pursuit for innovation and design fabrication. In one path, the inventor already has inherent knowledge of a system or phenomena and applies their knowledge by means of an analogy in order to formulate a solution to a design problem; otherwise, this is known as a solution-driven approach. For the alternative pathway, the inventor knows of a design problem and seeks the solution through researching and applying potential analogies. This correlates to the problem-driven approach. Both approaches require mapping between domains.

TABLE II DRIVING APPROACHES VS. OTHER CHARACTERISTICS [2, 14].

Driving Approach	Field of Work		
	Academic	Commercial	Military
Solution-driven	5	4	
Problem-driven	1	3	
Driving Approach	Analogy Benefit		
	Function	Performance	User Interaction
Solution-driven	5	4	
Problem-driven	3	1	
Driving Approach	Analogy Difference Level		
	1- Low	2- Medium	3- High
Solution-driven	6	3	
Problem-driven	3	1	

In each approach, mapping functions initiate the response of the inventor. For the solution-driven approach, the inventor recognizes how certain functions within a system can be applied as functions in solving a design problem. These specific functions (aka mapping functions) allow the designer to acknowledge the similar functionalities between the product and analogue domains. As with the problem-driven approach, the inventor pursues a solution to a design problem. In their pursuit, they search to match functions of

the desired product to that of an applicable analogy. Once again, the inventor heavily relies on the ability to map functions between domains. Evidently, mapping functions are essential for the inventor's ability to successfully implement analogical mapping. The mapping functions lead the designer to recognize inherent similarities between a product and an analogy.

6) Follow-up Study

In a follow-up study, Ngo et al. [14] compiled a collection of 70 products inspired by analogies for a larger cross-sectional empirical product study and analysis. In this study, two additional classification variables were incorporated for measuring the benefits in using analogies in design: additional function and improved performance. Additional function refers to a supplementary capability that arises in the participant's analogous product and not in the original functions associated with other existing products [15]. Moreover, improved performance signifies the analogy-inspired product's ability to exceed the initial functions of similar contemporary products. Integrating these variables into the analysis, subsequent results revealed that 90% of the analogy inspired products demonstrated improved performance in shared functions and 21% utilized additional functions when compared to similar products that did not utilize design-by-analogy.

We hypothesize that a majority of student designers who use analogies in analogous mapping will produce products with improved performance. However, designers will likely refrain from instituting additional functions to their innovative product. Nevertheless, during this process of mapping across domains, these results suggest that the student designer seeks to identify certain mapping functions which will not only allow them to develop an analogy-inspired design but also a product with enhanced-performance. In utilizing mapping functions, inventors have the ability to match functions across domains while producing more successful products.

IV. STUDY

A classroom study was performed to investigate the use and identification of mapping functions by engineering students. Mechanical engineering undergraduate students in a design course at Clemson University participated in the study. In this one semester course, students were trained in the engineering design process outlined by Otto and Wood, and also taught the functional basis for functional modeling [11].

A. Method

A specific in-class assignment was employed for use in understanding how students use mapping functions in the design process. Students were each provided with a function

structure for a fruit/vegetable peeler as seen in Figure III for problem contextualization. The customer needs for the peeler product included a portable device that shields the operator from potential harm during use. Students were given different functions and a single flow type for their assignment. They were asked to provide analogies for the same action of the function on the flow. The assignment asked for any action that performed the same function to the listed flow. Directions for the assignment were given to the students as: *"You have been given three functions and a single flow type. You are to provide analogies for the same action of the function and flow. Provide any action that can do the same function to listed flow. For example, the 'Guide energy' function can be analogous to trees sucking up water through capillary action. You may use analogies from any other domain and can use your phones or other devices to look up analogies."*

The students were each provided with a table template of paired "function + flows", an "analogy" column and a "rationale" column. Students were verbally instructed that this was to be an individual assignment to be completed without the use of external sources such as mobile devices or books. The instructor emphasized the desire to have as much creativity in the responses as possible by encouraging open-ended responses. Students were told there were no "correct" answers and their assignment would be graded as a participation credit.

B. Results

Provided with the given design problem, students' responses were categorized by function and analogy in order to determine their ability to produce analogies when provided with a function. Looking at the four potential functions that the students were asked to identify analogies for, convert, dissipate, position, and regulate, demonstrate relative equality in initiating analogies within the students' responses. As shown in Table III, the students who were able to create an analogy for convert was 76%, for dissipate was 64%, for position was 61%, and for regulate was 72%. This demonstrates that 24-39% of the students were not able to successfully generate analogies using the provided functions. Students and novices clearly require more support for generating analogies. Through additional analysis, the number of ideas generated was compared with the number of analogies produced, as demonstrated in Table IV. This shows that of the ideas generated for the convert, dissipate, position, and regulate functions 69%, 55%, 51%, and 64%, respectively, were analogies. Once again, the ideas generated that were not analogies ranged from 31-49% for the provided functions. This demonstrates the students' ability to utilize mapping functions when using analogies to cross domains.

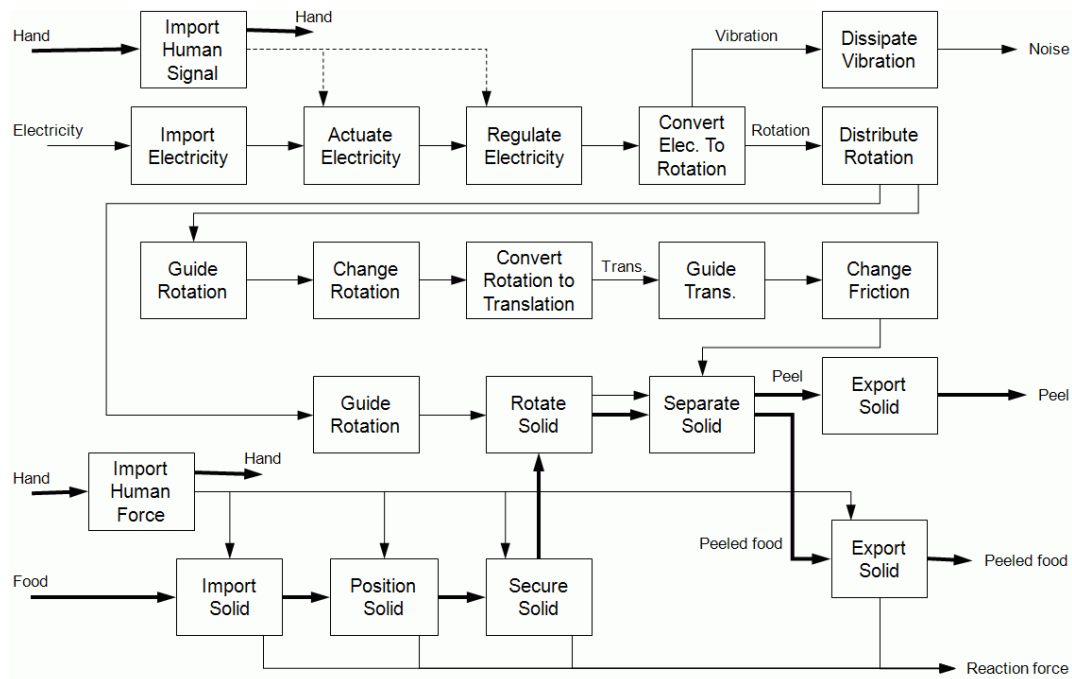


FIGURE III FUNCTION STRUCTURE FOR FRUIT/VEGETABLE PEELER FOR STUDENT ASSIGNMENT [11].

TABLE III NUMBER OF STUDENTS WHO WERE ABLE TO CREATE ANALOGIES.

Function	# of Students Who Created an Analogy	Total # of Students	% of Students Who Created an Analogy
Convert Energy	34	45	76%
Dissipate Energy	30	47	64%
Position Solid	27	44	61%
Regulate Energy	34	47	72%

TABLE IV NUMBER OF ANALOGIES FROM IDEAS GENERATED.

Function	# of Ideas Generated	# of Analogies	% of Analogies to Idea Generated
Convert Energy	80	56	70%
Dissipate Energy	77	42	55%
Position Solid	84	43	51%
Regulate Energy	84	54	64%

V. CONCLUSION

This research seeks to abate the effects of design fixations on engineering design problems when plausible solutions have been discarded too early in the design process or have yet to be found. By using functional modelling to decompose a design problem into specific functionality with a generalized taxonomy, certain areas of innovation can be pinpointed. These areas demonstrate the potential for student designers to more successfully utilize analogies across domains in order to create innovative and plausible designs.

When it comes to utilizing analogies across domains, mapping functions are the general subset of functions which are most conducive for successful analogical mapping. The mapping functions are an area of continued investigation at this time. Identified during the critical function study of Lucero et al. [3] and Ngo et al. [14], these specific sets of functions have the potential to provide more analogous

solutions than those of just the critical functions or the reoccurring functions.

The research herein identified the mapping functions as retaining function, performance or user-interaction benefits between the analogue and product. The benefits of these functions then are based upon the product critical functions, the construction, and the operating environment. The approach of the mapping functions to generate analogies is based upon either a solution or a problem approach, similar to a forward or reverse methodology. To further validate the findings, additional studies are currently in the works and will be published.

ACKNOWLEDGMENT

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Is the Engineer of 2035 a Maker?

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Index Terms – Making; tinkering; engineering pathways; engineering education

SESSION GOALS

Participants in this special session will:

1. Learn about the knowledge, skills, and attitudes possessed by Makers
2. Discuss the similarities and differences between Makers and Engineers
3. Discuss how Makers fit ABET's model for engineering graduates
4. Discuss how Makers fit the Engineer of 2020 model for engineering graduates
5. Leave enlightened and informed on how the worlds of Making and Engineering could collide

SESSION DESCRIPTION

In the last 5 years, there has been increasing interest within the engineering education research community about the growing community of Makers who engage in informal engineering education and tinkering activities to create technical artifacts. A Maker is an emerging colloquial term we use to describe a group of do-it-yourself-minded individuals participating in informal communities (doing-it-with-others) that support building and prototyping technical proof-of-concept exploration and ad-hoc product development.

Novices and experts alike share an enthusiasm and appreciation for building and creation. Individuals and groups embark on projects of all sorts, led primarily by their interests and curiosities, informed by their skills or the skills they want to learn. They make creative efforts like fire-breathing robots as performance art, combining contributions from community members with electrical, mechanical and embedded systems know-how or construct intricate, wooden geometric puzzles CNC'd from exotic woods commissioned by patrons.

Makers also embolden the *Engineer of 2020* characteristics of *practical ingenuity*, *creativity*, and propensity toward *lifelong learning*, which are indispensable to future workplace innovation.

Some Makers have followed life pathways that include formal engineering education; some have not. Other Makers are professional engineers by day, others are not. Some participate in group-based informal engineering education organizations (e.g., robotics teams), while others Make alone in the privacy of their garages, supported by the growing Making ecosystem on the Internet. Makers come in all ages, demographics, professions, and interests – but are they engineers?

In this special session, we will explore the similarities and differences between Making and Engineering, guided by archetypes of Makers from our ongoing NSF-funded research on the Maker community [1,2]. These archetypes will provide a foundation for discussion in groups of questions such as, (1) *Can a Maker be considered an engineer, and vice-versa?* and (2) *Is the Engineer of 2035 a Maker?*

SESSION AGENDA

1. Introduction to Makers (5 min presentation)
2. What are Makers? What are Engineers? (15 min small group post-it brainstorming)
3. Report out (10 min)
4. Makers and Engineers: Similarities and Differences (10 min large group discussion)
5. Introduction of Panel of Archetypes (10 min presentation with handouts)
6. ABET and E2020 Ranking of Archetypes (15 min small group analysis)
7. Report out (10 min)
8. Is the Engineer of 2035 a Maker? (10 min large group discussion)
9. Resources for Lifelong Learning on Makers (5 min presentation)

PAPERS

The results of this Special Session will be submitted as a Full Paper to FIE 2016.

ANTICIPATED AUDIENCE

At our paper presentations at ASEE in 2013 and 2014 and at FIE in 2014, the rooms were packed with engineering faculty and NSF program officers on the forefront of the field. At FIE, we similarly expect a lively participatory

audience of faculty and NSF program officers interested in learning more and debating the boundaries between Making and engineering. We believe the smaller discussion-based atmosphere of FIE will make the Special Session lively and engaging for participants.

REPORTING OUTCOMES

One week after the Special Session, participants will be asked to complete a follow-up survey to identify characteristics of a Maker and an Engineer, given the discussion and time to reflect after the Special Session. Post-its generated and worksheets completed by each team will be collected and analyzed by Dr. Jordan and Dr. Lande's research group as part of ongoing NSF-funded research studies on Makers. Summary results will be electronically distributed to participants shortly after the Special Session. A full qualitative analysis will be conducted, and the results compared with results from other Maker research. The final comparison will be submitted as a full paper to FIE 2016, and will support future research by the engineering education community on Makers.

SESSION JUSTIFICATION

There is a significant interest among members of the engineering education community in the Maker movement. During our recent presentation on the background of our NSF-funded study entitled, *Should Makers be Engineers of the Future?*, we were greeted by a packed room of people with many questions about Makers and the Maker community. We ran out of time to answer the numerous questions and engage in the deeper discussions on who Makers are and what we could learn from them in the Engineering Education community. This response, paired with Alan Cheville's DiSRuPTioN special session at FIE 2013, inspired us to propose a special session on the hot topic of Makers.

Additionally, Drs. Lande and Jordan are emerging leaders in studying the Maker community. They have two NSF-funded Research in Engineering Education grants to study the knowledge, skills, attitudes, and life pathways of both Adult and Young Makers. They attend and present regularly at Maker Faires around the country, and are liaisons to build bridges between the Engineering Education and Maker communities.

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Special Session: Agents for Change in Engineering & Computer Science Education

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Abstract— Engineering and Computer Science (E&CS) Education is an emerging discipline and is a subset of the larger field of STEM (science, technology, engineering and math) education. E&CS Education has a relatively brief history, and many individuals who are not directly involved in the discipline are often confused about its purpose. In this special session, we will use up to two background stories to frame the larger questions around E&CS Education goals and help draw the conversation from practice to philosophy while creating a safe space for open conversation addressing issues of change in our discipline.

Keywords—special session; organizational change; case study; goals of engineering and computer science education

I. INTRODUCTION

We attend FIE partly because we want to make positive change in STEM education, especially Engineering and Computer Science (E&CS) Education and, through that, in our world at large. E&CS Education is an emerging discipline with a brief history and its purpose is not always clear to individuals outside the discipline. As a consequence, the goals for the E&CS Education disciplinary community have largely been surface layer objectives provided by reports and outside groups, e.g. increase the number of students studying E&CS fields. While we need the surface layer objectives in our portfolio, we also need to have the deeper conversations within our community regarding what we want and why we exist. Without the deeper discussion, we have a limited understanding of the real impacts of the proposed objectives, intended and otherwise. This special session will create a safe space for this deeper discussion among a cross-section of the FIE community. The deeper goals of our discipline not only help us answer the larger questions of how we serve society and empower people, but they also help us evaluate the meaning, efficacy, and desirability of objectives provided to us.

In the context of working towards identifying goals of E&CS Education based on historical context and discussion, the goals of this session are:

- To open the conversation on the future goals of E&CS Education to a broader audience while providing a tool for supporting change in a local context.
- To provide structured time for contemplating academic change dilemmas and role playing potential paths towards solutions.

II. CASE STUDY APPROACH FOR THE SESSION

In this special session, we will use a case study approach to frame these larger questions and help draw the conversation from practice to philosophy while creating a safe space for open conversation. A set of background stories is a product of the Engineering Education Research NetWorkshop (NSF grant numbers 1314725 and 1314868). The NetWorkshop was a series of workshops held for engineering education researchers in conjunction with the ASEE Annual Meeting to focus on mid-career leadership, development, and community building. The NetWorkshop used the "Influencer" framework [1] to give participants tools to navigate confrontational issues. Our approach to working with the stories is based on elements of this framework. The background stories are aggregated experiences that feature issues recognizable to most individuals in our community. These experiences come from the viewpoints of individuals in roles common to E&CS faculty members and administrators. We will present tools to help participants prepare for "crucial conversations" that often arise from these background stories [2], and participants will practice the tools while role playing at least one background story. This and other similarly constructed case studies can be adapted for future use by participants.

A. Background Story 1: Managing Up to Affect Change

A discipline-based education research (DBER) faculty member is thrust into an administrative role when changes at her university result in her being the most senior faculty in her DBER department. To protect and advance DBER as a discipline, she undertakes a crash course in managing up – trying to communicate the mission of her department with the administration, and developing a strategy for survival and

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growth. It seems that there are two separate conversations underway (internal and external to the department) about the actual goals of DBER, and what role DBER could/should play in shaping undergraduate and graduate education at the institutional level. The struggle to reconcile these two conversations results in simultaneously advocating for more resources and asserting, with evidence, that the DBER department has successfully fulfilled its role in leading innovation in E&CS Education. This background story includes navigating the change process, the roles played by faculty, students and administrators, and the ongoing adjustment of how the mission and strategic plan for a DBER program are articulated to all involved.

B. Background Story 2: Change Among Peers and Students

Here, the chair of an engineering department finds himself having to navigate course and curricular changes that had been proposed by his predecessor. The proposed changes were developed during a faculty meeting in which all members of the department suggested ideas which were then ranked by popularity. As the chair seeks to rally support in moving from ideas to actions, he finds that underlying seemingly simple course changes are layers of unstated assumptions and beliefs which are deeply held but poorly articulated. As frustrations build faculty discover that while they all are speaking the same words—"design", "problem solving", "hands-on experiences"—their conceptions of these differ greatly from those of their colleagues.

This background story, drawn from work on curriculum theory [3], explores how differing beliefs of faculty along with the inability to clearly articulate wants and needs can paralyze a change process even when on the surface there is a clear consensus for change. During the role play, participants will discuss past experiences and potential approaches to moving forward. The case study created through role play will also discuss common mistakes in managing departmental changes including shutting down opposing views, assuming everyone draws upon the same information, and not carefully considering both potential gains and losses. The background story contrasts lived academic experiences with published change models [4], pointing out areas where these align and examples where best practices can fall short. Participants will experience applying a change model that identifies and leverages influencing factors to achieve a desirable outcome.

III. OUTCOMES AND FUTURE MOVES

The expected outcome is a broader basis for the facilitators and other interested individuals to continue discussions and

implementation of change actions in STEM education broadly and E&CS Education in particular. Ultimately, we hope to articulate how the discipline of Engineering and Computer Science Education serves society and empowers individuals and toward a better understanding of the issues facing our community as we act as change agents to achieve these goals. This workshop focuses on tools to support development as change agents.

This is the second FIE special session in the overall dialogue [5], and it builds on the participant feedback regarding the direction of the conversation that is reflected in the background stories and associated analysis. As the deeper conversation moves forward, the facilitators anticipate further discussion-based sessions/workshops summarizing the conversation so far and engaging additional members of the community, papers on the deeper goals of our DBER discipline and what the goals mean for the community, and increasing the confidence and effectiveness of our community members as change agents.

The only way to build sufficiently deep and broad goals for the E&CS research community is to involve a cross-section of community members. As a special session, this emerging discussion can move forward as a conversation that is framed by real experiences and representative stakeholders while not constrained by narrow participation.

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An Investigation of the Relationship between K-8 Robotics Teams' Collaborative Behaviors and Their Performance in a Robotics Tournament

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Abstract— This study investigated the relationship between robotics team members' collaborative behaviors, communication and coordination in particular, during hypothetical challenges and their teams' actual performance during physical robotics challenges. Dataset included robot performance, robot design, research project, core values, and collaboration quality scores for 61 K-8 Robotics teams (N = 366) that participated in a FIRST LEGO League (FLL) Championship in 2015. Our analysis primarily focused on how well the collaboration quality scores predict team performance across different categories. Results indicated that the level of collaboration quality among team members is significantly associated with the team performance in the robotics tournament.

Keywords—Robotics, Teamwork, Collaboration, Programming, Informal Learning.

I. INTRODUCTION

In recent years, robotics programs for young people have become highly popular interactive and innovative educational activities. Literature shows robotics in K-12 settings having been typically used as a learning tool to develop student's academic skills and to stimulate their curiosity and interest towards Science, Technology, Engineering, Mathematics (STEM), and computing [1]. Benitti's review study [2] showed that being a part of a robotics team has the potential to significantly influence a student's academic and social skills, by allowing learners to actively engage in critical thinking and problem solving in team settings through designing, assembling, coding, operating, and modifying robots for specific goals. In addition, its interdisciplinary nature makes robotics a valuable pedagogical resource for both formal and informal learning environments.

Robotics teams allow students to collaboratively engage in tackling problems by designing and building robots and then programming them for autonomous tasks. Successful

collaboration requires effective communication, coordination, trust, and respect among team members, as well as individual and team level responsibility and accountability to achieve certain tasks. However, some studies in learning sciences and educational psychology have shown that achieving successful collaboration is challenging, and working in small groups is not always beneficial in terms of group performance and individual learning [3, 4]. Lou and colleagues' [5] meta-analysis study showed almost 25% of the published experimental studies in collaborative learning indicated null or even unpredicted effects when compared to individual learning conditions. Dillenbourg and Hong [6] argued that the lack of the elaborated explanations, mismatch in mutual regulations of cognitive processes between group members, low quality of arguments and the nonexistence of negotiation of meanings reduces the effectiveness of collaborative learning.

Working effectively in teams is one of the most critical 21st century skills [7], and robotics team settings provide a good venue to study the effective factors on team performance for young people. However, very few studies have investigated how being a part of a robotics team influences students' collaborative skills and how the quality of collaboration effects team performance in informal robotics education. In this study, we explored the role of the collaborative behaviors on teams' performance in a robotics competition by investigating the level and quality of students' engagement during teamwork. In addition, we specifically investigated the relation between team collaboration quality and programming performance to understand how well the programming quality and efficiency predict teams' collaborative behaviors. Lastly, we examined the relation between the experience of teams and their collaborative behaviors.

The structure of the paper is as follows: Section II briefly reviews the robotics competitions, section III presents the data sources and team scores used in this study, section IV describes the conducted analyses and results. And section V

summarizes the findings and concludes this study by discussing some of the limitations and future work.

II. ROBOTICS COMPETITIONS

Robotics competitions provide unique opportunities for students and teams to engage in teamwork for a shared goal in a certain timeframe. The common goals for many competitions include the development of skills, interest, and awareness toward STEM and computing, a focus on the ability to effectively work in teams, and the development of cooperation and respect towards the other teams participating in the competitions. Robotics competitions have immensely contributed to the recognition of the educational robotics, especially in United States and other developed countries [8]. There are two main types of robotics completions, FIRST and VEX robotics. Within FIRST, there are several types of events, beginning with JFLL (Junior FIRST LEGO League), FLL (FIRST LEGO League), FTC (First Tech Challenge) and FRC (FIRST Robotic Competition), whereas VEX is comprised of VEX, VEX IQ Challenge, Botball Educational Robotics Competition, and RoboCupJunior (RCJ). The data in this study comes from an FLL Championship held in Pittsburgh, Pennsylvania, in January of 2015.

The FIRST competitions, founded in 1989 by Dean Kamen, are currently one of the most popular competitions worldwide. FIRST LEGO League (FLL) began in 1998 as a collaboration between the FIRST organization and the LEGO group to introduce robotics to students ranging in age from 9-14 years-old. According to the FLL website, there are more than 25,000 FLL teams in approximately 80 countries. To compete in FLL, teams are required to use LEGO kits (MINDSTORMS robot sets) and work on a real-world scientific topic themed challenge, with past themes including climate change, senior solutions, food safety and medicine. The challenges are announced by FLL organizers at the same time each year, after which competing teams have several months to prepare for the final Grand Championship competition, during which their performances are evaluated, based on their scores during the robot game, and their success on a research project, robot design/programming, and FLL core values.

III. METHODS

A. Data

Dataset in this study includes the 61 K-8 Robotics teams (N=366) that participated in the FIRST LEGO League Western PA Championship, with participants ranging in age from 9 to 14 years-old. Dataset included scores for actual performance (i.e., table scores), core values, project, and robot design. All 61 teams were being judged on these categories, with different groups of judges evaluated each team and their performance. Each team received three scores for core values, project, and robot design categories, with the

scores for these three categories ranging from 1 (beginning) to 4 (exemplary). Additionally, each team was assessed in terms of collaboration quality while working on a hypothetical challenge. The minimum score for collaboration quality was 1 (minimal) to 3 (substantial). All these categories are discussed in detail in the following section. Table 1 shows the means and standard deviations for all scores.

TABLE I. AVERAGE MEANS AND STANDARD DEVIATIONS OF EACH SCORE FOR ALL TEAMS.

Team Scores	Mean	Standard Deviation
Average Table Scores	99.87	63.22
Core Values	3.00	.64
Project	2.50	.98
Robot Design	2.49	.84
Collaboration Quality	2.16	.60

B. Measures

1) Table Scores:

Table scores indicated the actual robot performance on the specific challenges. Each team's robot performed for three rounds, with the best round score being used for the tournament ranking. In this study, we used the average score of the three rounds instead of the best scores for our analysis.

2) Core Values:

Core values included three sub-categories, being: inspiration, teamwork, and gracious professionalism. The inspiration was evaluated based on teams' ability to integrate the FLL values to their daily lives, their enthusiasm for team spirit, and balanced emphasis on all aspects of FLL. The teamwork score was based on teams' efficiency and effectiveness for problem solving, time management, distribution of roles and responsibilities, and team independence with minimal involvement of team coach. For gracious professionalism, teams were judged by their attitudes and respect towards their own team members and their recognition of friendly competition.

3) Project:

In addition to designing, building, and programming robots, each FLL team was also responsible for a research project, creating an innovative solution for a problem that they identified, correlating to the theme of the competition. The project scores were

evaluated based on the value and clarity of the research question, innovation and creativity of the solution, and the quality of the presentation.

4) *Robot Design:*

Robot design scores involved mechanical design, programming, and strategy & innovation subcategories. The mechanical design was evaluated based on the durability, efficiency and mechanization of robots, while the programming sub-score was assessed based on quality, efficiency, and autonomy of robots with minimal to no driver intervention. The strategy & innovation sub-score indicated the characteristic of design process, the team's game strategy, and innovative nature of the robotic features that teams developed and integrated.

5) *Collaboration Quality Scores:*

We developed a collaboration quality rubric to evaluate the collaborative behaviors of all teams (see Table 2 for more details). This rubric was used to explore joint versus individual behaviors of team members while they worked on a hypothetical challenge. The challenge had teams generate a computer program to allot for a reliable path in order for a robot to move from the start to the finish, successfully avoiding any and all obstacles (Figure 1). This challenge was novel to all teams, therefore, they did not have a chance to practice or prepare for the task beforehand. The spectrum of the collaboration quality scores ranged from minimal (score 1) to moderate (score 2), and to a substantial level of discussion (score 3). For example, teams received a score of 1 when none or only one student generated detailed statements, or when none of the team members asked why/how type questions, or discussed each other's claims. On the other hand, teams received a score of 3 when students clarified or completed their partners' statements through expanding, elaborating, or rebuttal.

TABLE II. RUBRIC FOR THE COLLABORATION QUALITY SCORE

Score 1	Score 2	Score 3
A <i>minimal</i> level of discussion.	A <i>moderate</i> level of discussion.	A <i>substantial</i> level of discussion.
None or only one student generates detailed statements.	One student's statements are mostly substantive and the other varies between detailed and shallow.	Substantive statements of each student build upon those of the other, indicating a shared line of reasoning.
Students do not	Statements are	Students clarify or

clarify or complete their partners' statements, instead voicing generic responses of agreement.	discontinuous as each student makes assertions independent from those of the other.	complete their partners' statements through expanding, elaborating, restatement or rebuttal.
One student decides what to write while the other agrees but contributes very little.	One student contributes most to what will be written while the others take a smaller, though substantive, roles.	Conclusions are jointly constructed with two or more students involved fairly equally in determining what to write.
None of the students ask why/how type questions, discuss each other's claims, or elaborate in response to questions.	Some students effectively engage in the collaboration process. A few why/how type questions are asked and discussed.	Most students effectively engage in the collaboration process. More than one why/how type questions are asked and discussed.

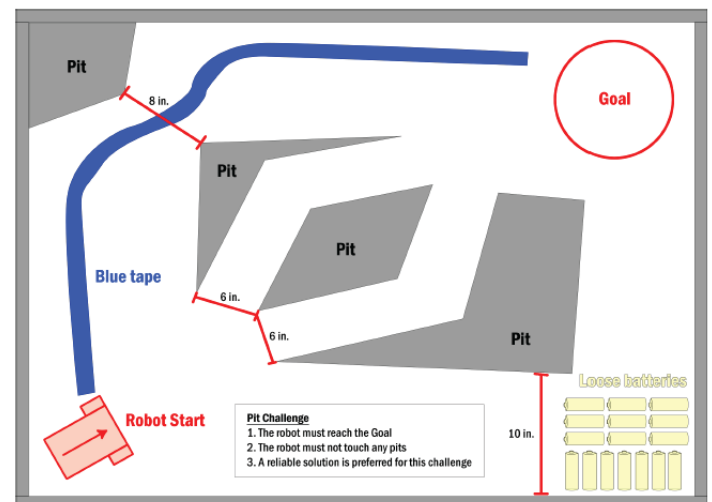


Figure 1. A sample hypothetical challenge for students to work collaboratively in order to describe the computer program for the robot to reach the goal.

IV. ANALYSIS AND RESULTS

A. *Collaboration Quality and Overall Team Performance*

Since the main goal of this study was to explore the role of the collaborative behaviors on teams' performance, our first set of analysis focused on understanding the relation between teams' collaboration quality scores and other

variables. First, we computed a set of correlation coefficients by using the Bonferroni approach to control for Type I error across four correlations, a p value of less than .0125 (.05/4 = .0125) was required for significance. The results of the correlational analyses presented in Table 3 show that all four correlations were statistically significant. The results indicate that the collaboration quality score is significantly associated with the teams' performance across different categories in the FLL robotics tournament.

TABLE III. CORRELATIONS BETWEEN THE COLLABORATION QUALITY SCORE AND OTHER MEASURES

	Average Table Score	Core Values	Project	Robot Design
Collaboration Quality	.39*	.49*	.55*	.46*

* indicates $p < .0125$

Next, we conducted a multiple linear regression analysis to evaluate how well the collaboration quality, core values, project, and robot design scores predict the average table performance of teams. The linear combination was significantly related to the average table performance, $F(4, 56) = 13.91$, $p < .01$. The sample multiple correlation coefficient was .71, indicating that 50% of the variance of the average table scores can be accounted for by the linear combination of predictors. All the bivariate correlations between the average table score and other predictors were statistically significant. However, the only significant partial correlation was between the robot design score and the average table score, indicating that the robot design score for each team is the best predictor for the average table score. Table 4 presents the bivariate and partial correlations.

TABLE IV. THE BIVARIATE AND PARTIAL CORRELATIONS OF THE PREDICTORS WITH THE AVERAGE TABLE SCORES

Predictors	Bivariate Correlation	Partial Correlation
Collaboration Quality	.39*	.14
Core Values	.30*	.01
Project	.24*	-.12
Robot Design	.70*	.63*

* indicates $p < .05$

B. Collaboration Quality and Team's Programming Performance

We were also interested in understanding the relation between the collaboration quality and teams' programming

performance. The programming score was one of the subcategories of the robot design score, and involved three components: programming efficiency, programming quality, and automatic features of robot's movement. We were interested to conduct a multiple linear regression analysis to evaluate the strength of relationship between the programming sub-scores and the collaboration quality score. However, the programming sub-scores were highly correlated to each other (all correlations were equal or greater than .70), which increase the possibility of multicollinearity. Due to this multicollinearity problem, we conducted stepwise regression and the best-fit model excluded the "programming efficiency" and the "automatic/navigation" variables. So, the final model was a bivariate linear regression with the "programming quality" variable as the sole predictor, $F(1, 54) = 11.37$, $p < .01$, with $r^2 = .17$. The regression equation for predicting the collaboration quality score was

$$\text{Predicted Collaboration Quality Score} = .50 \\ \text{Programming Quality} + 3.17$$

Please note that there were five teams with missing data for the programming sub-scores and therefore our analysis for the programming performance did not include these five teams.

C. Collaboration Quality and Team Experience

The dataset used in this study also included information for the relative experience of the attending robotics teams. The team identification number in the FLL competitions indicates that the teams with smaller numbers are more experienced robotics teams than the teams with greater numbers. In our dataset, team identification numbers ranged from two digit numbers (e.g., 30) to five digit numbers (e.g., 13000), and based on these identification numbers we divided the 61 participated teams into three categories as most experienced, experienced, and least experienced teams. Our goal was to understand to what degree the team experience was associated with the collaboration quality of teams. Table 5 indicates the means and standard deviations of collaboration quality scores for three groups.

TABLE V. THE MEANS AND STANDARD DEVIATIONS OF COLLABORATION QUALITY SCORES ACROSS THREE GROUPS BASED ON TEAM EXPERIENCE

Level of Experience	N	Mean	Standard Deviation
Most Experienced	16	2.32	.44
Experienced	26	2.30	.47
Least Experienced	19	1.84	.75

We conducted one-way analysis of variance (ANOVA) to evaluate the relationship between collaboration quality score and team experience. The ANOVA was significant, $F(2, 58) = 4.48$, $p = .01$. The strength of relationship between

team's experience and their collaboration quality score was moderate with the experience of teams accounting for 13% of the variance of the dependent variable.

Additionally, we conducted follow-up tests to evaluate the pairwise comparisons among the three groups by using Tukey HSD test. Two of three pairwise comparisons were significant; most experienced and least experienced, and experienced and least experienced. Table 6 shows the 95% confidence intervals for the pairwise comparisons.

TABLE VI. 95% CONFIDENCE INTERVALS OF PAIRWISE DIFFERENCES IN MEAN CHANGES

	<i>Experienced</i>	<i>Least Experienced</i>
<i>Most Experienced</i>	-.85 to .87	.02 to 1.86*
<i>Experienced</i>		.11 to 1.75*

* indicates that the difference in means is significant at the .05 significance.

D. Limitations of the Analysis

The results of this study are limited by a number of factors. First, since we mainly conducted correlation and linear regression analyses; these results do not imply causal relationship between collaboration quality and robotics team performance. Second, our sample size is relatively modest, since all of our analysis is at the team level. Therefore, we had a reduced chance of detecting true effect in some of our analyses. Third, there might be a validity problem with the judging scores, especially for core values and research project, due to a lack of detailed rubrics. In addition, since the judges were volunteers and a different group of judges evaluated different teams, the judging scores might be subject to reliability threat as well.

V. CONCLUSION

This study explored the relationship between collaboration quality among team members and their team's performance in a robotics competition. The results showed that collaboration quality is a good indicator for robotics teams' overall performance in a competition as well as for the core values, project, and robot design categories. We were also interested in investigating how collaboration quality is related to teams' programming performance. The stepwise regression analysis showed the programming

quality is highly associated with the collaboration quality. Moreover, the team experience was significantly related to the collaboration quality. In other words, the students in more experienced teams engaged in more substantial levels of discussion compared to the students in less experienced teams. That is interesting to note, since there were no differences in regard to attending students' age groups and their individual experience across different teams. However, the results indicated that being in a more experienced team lead to better overall performance in robotics competitions and higher level of collaboration quality.

As discussed in the section above, we are aware of the limitations in this study, but we believe that these factors do not invalidate our main conclusions. Taken as a whole, our analyses suggest that the effective collaboration skills among team members are significantly associated with robotics team performance in competitions, and further investigations, experimental studies, are needed to understand the causal links between these relationships.

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Effects of report-writing on a multi-stage-experience educational program using an autonomous mobile robot

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Abstract—System design and development are fundamental capabilities for an engineer. The Department of Control Engineering at the National Institute of Technology, Nara College, has been offering a course called “Practical System Design,” a unique opportunity for students to experience the entire process of developing an autonomous mobile robot, to fourth-year students for about 20 years. However, in recent years, robot design and construction have become a huge challenge for these students. To address this problem, we have worked on improving the engineering program. First, we have introduced a problem-based learning (PBL) education program in all experimental engineering classes in years 1–3. Also, we require students to submit a written report after each class session. This report is intended to help improve the students’ schedule management, role-sharing, and work-tracking skills. These reports are reviewed by the relevant course teachers and assessed for logic and quantitative representation. In this paper, we discuss the approach to, achievements of, and future subjects to be taken up by this multi-stage-experience educational program, especially the effect of report-writing.

Keywords—PBL; active learning; engineering experiment; working report; evaluation method; LEGO Mindstorms; PDCA cycle

I. INTRODUCTION

Problem-solving skills are important for engineers, and they are usually honed through practical experience. In the Department of Control Engineering at the National Institute of Technology, Nara College, the course “Practical System Design” has been offered to fourth-year student for the past 20

years [1]. In this class, students study system design and development through the design and construction of autonomous mobile robots. However, for some students, it is challenging to design and construct autonomous mobile robots owing to a lack of design and construction experience. Additionally, it is difficult for students to gain problem-solving skills because of insufficient practice in schedule management, role-sharing, report-writing, etc. To address this problem, we have worked on improving the curriculum for the course and the program as a whole. First, we have introduced a problem-based learning (PBL) education program in all experimental engineering class in years 1–3. By increasing the students’ exposure to robot design and construction, we allow them to substantially improve their system design and development capabilities. Second, we have introduced a written report requirement, to be submitted after each class session. The goal of the report is to help to improve the students’ schedule management, role-sharing, and work-tracking skills.

The aim of this research is to develop a new quantitative evaluation method for the report-writing assignments. In this paper, we discuss in detail the approach that was employed, the current state of evaluation, and expected future issues.

II. APPROACHES AND METHODS

First, we give a brief outline of the multistep experience-based problem-solving program. In this program, students construct an autonomous mobile robot using LEGO Mindstorms. Thus, students have many opportunities to experience the process of robot design and construction. Figs. 1

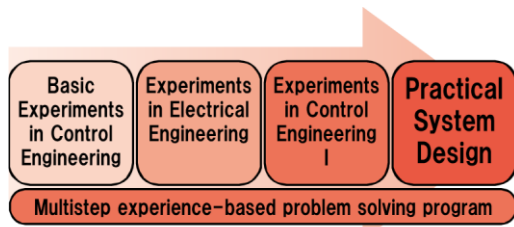


Fig. 1. Multistep experience-based problem-solving program





Grades	1 st grade	2 nd grade	3 rd grade	4 th grade
Subjects	Basic Experiments in Control Engineering	Experiments in Electrical Engineering	Experiments in Control Engineering I	Practical system design
Number of school hours	3H×10 weeks	3H×7 weeks	3H×6 weeks	2H×30 weeks
Bases	LEGO Mindstorms	LEGO Mindstorms	• LEGO Mindstorms • Original	Original
Learning contents	• System design method • Interest in robots	• Electronic circuit • C programming	• Part design and production	Design and create whole robot system
				
Aim to build construction experience of real system				

Fig. 2. Contents of the multistep experience-based problem-solving program in each grade

and 2 show a schema of this program and the content of the program for each academic year. By offering the opportunity to experience the process of robot design and construction from the first year onward, students can come to understand the need to learn about special subjects such as electric circuits, control engineering, material mechanics, and engineering drawing. Moreover, the content of this program evolves as the students advance to the next year. For example, in the first year, students do their program work using GUI-based programming and attached components. In the second grade, they work on the program using control circuits that they have developed themselves, and CUI-based programming.

Second, we explain the content of the program for first-year students, which began in 2012. In this paper, we focus on last year's class. Table 1 shows the class schedule. The class consists of 10 sessions, each of which lasts for 135 min. In the class, about 40 students are divided into 8 groups (5 or 6 students per group). Students in each group design and construct an autonomous mobile robot using LEGO Mindstorms. The challenges and rules of the competition change yearly. The outline of the competition content for the last year is as follows. Students are instructed to design and construct an autonomous mobile robot using LEGO Mindstorms EV3; in the competition, students try to collect one designated block specified as a reference block and carry it back to a goal area. Fig. 3 shows the competition field. Four blocks of different colors are placed in the target block area. Thus, the robot needs to have a function for sensing and tracing the lines and blocks, and a mechanism to collect the designated block. The maximum permissible size of robot is 500 mm * 500 mm. The time limit for completing this task is 3 min. Groups gain points depending on the time to goal. The overall

TABLE I. SCHEDULE OF THE MULTISTEP EXPERIENCE-BASED PROBLEM-SOLVING PROGRAM IN FIRST YEAR

Week	Course contents	
1	• Guidance regarding the schedule, competition rule, and report writing • Assembly of LEGO EV3 • Exercises in programming 1	working in groups
2	• Exercises in programming 2 • Disassembly of LEGO EV3	
3	• Lecture on machine elements	
4	• Explanation of PDCA cycle • Design and construction of robot	
5		
6	• First competition (line following, color recognition)	
7		
8		
9		
10	• Second competition • Poster presentation	

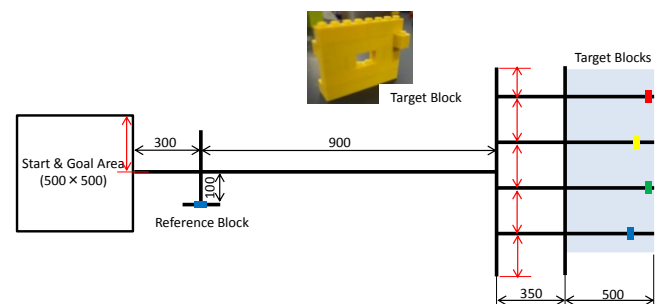


Fig. 3. Competition field

ranking is determined based on the total number of points gained.

Next, we describe the report-writing process. We require students to submit a written report after each class. The goal of the report is to help improve students' schedule management, role-sharing, and work-tracking skills. In addition, it helps to increase their awareness of the PDCA cycle. The work report must include five items: (1) Objective for the week, (2) Describe your work today using a figure, (3) Describe today's achievement status in quantitative form, (4) Find and describe some helpful points from other students' work and reports, (5) Describe your approach to your next problem based on your reflections and the helpful things described above.

The reports are reviewed by subject teachers and assessed for logic and quantitative representation. Fig. 4 shows an example of a reviewed working report. Teacher comments are shown at the right-hand side of the figure. Students then go through the results of the review and resubmit corrected reports. The number of marks allocated to the report indicates the degree of (need for) modification. Thus, in this study we focus on variation in marks awarded to the reports, in order to evaluate the effect of the report-writing.

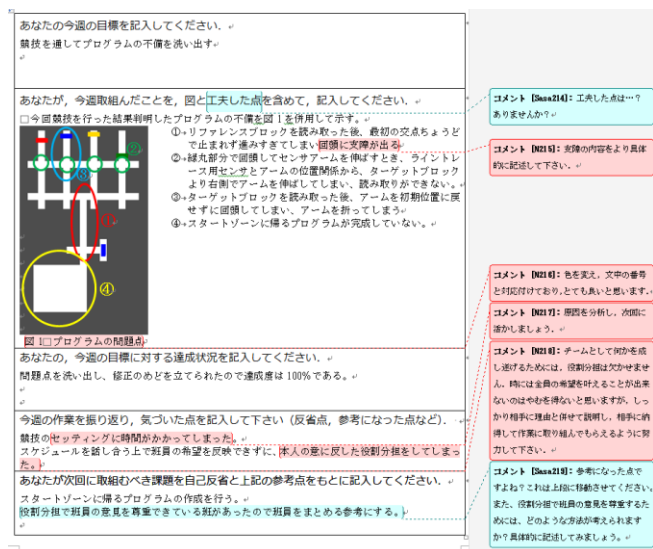


Fig. 4. Submitted and reviewed working report

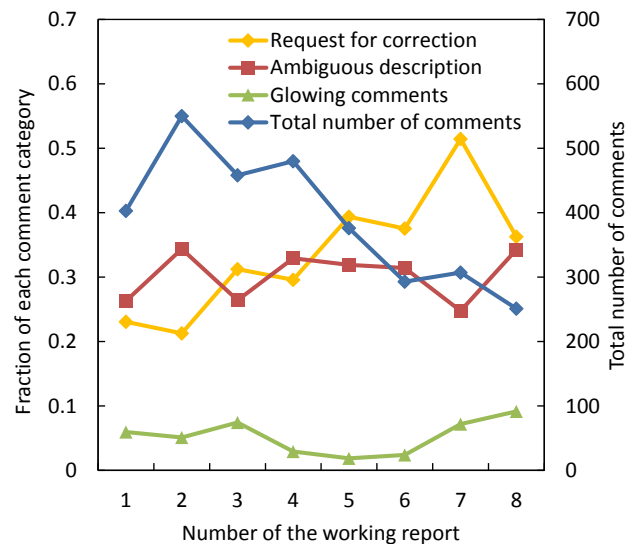


Fig. 6. Variation in the categorized comments

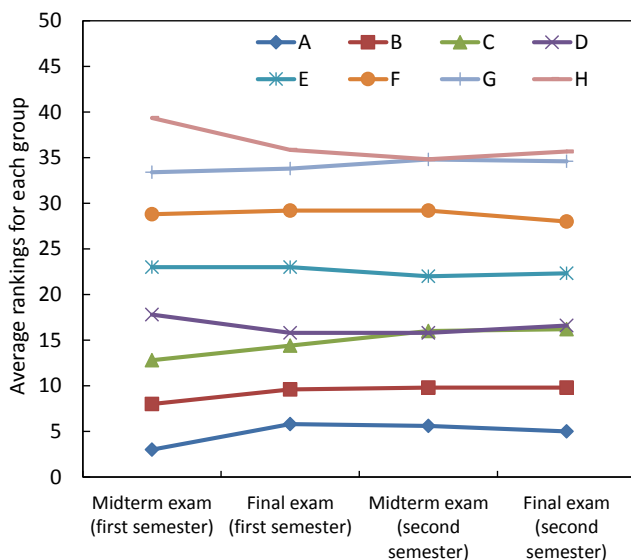


Fig. 5. Variation in the average rankings for each group

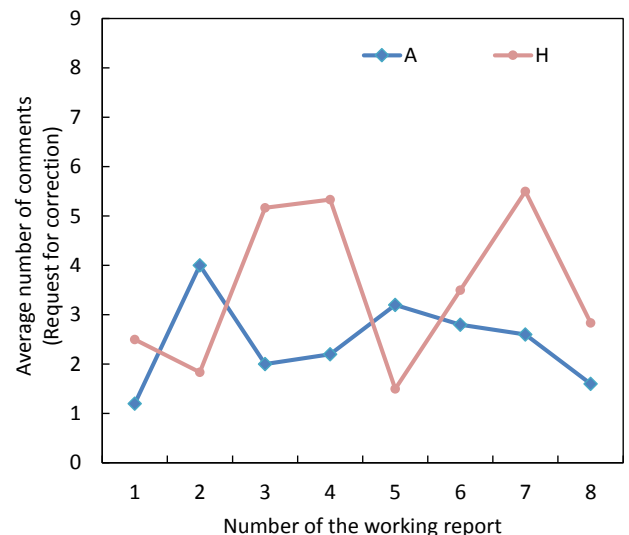


Fig. 7. Variation in the average number of negative comments (Requests for correction) for groups A and H

III. RESULTS AND DISCUSSION

In last year's program, students were grouped into eight groups (Groups A, B, C, D, E, F, G, and H) according to the results of their first-semester midterm exams in "Mathematics α ," "Mathematics β ," "Information mathematics," and "Physics." Fig. 5 shows the variation in average rankings for each group. The abscissa is each periodic exam and the ordinate is the average rankings for these subjects. Thus, the grades of students in group A are higher than those of students in group H. Also, since there is no inversion of ranking, we see that the effect caused by this program on classroom lectures is small.

To evaluate the effect of the report-writing, we classify the teachers' comments added to the work reports into three categories depending on content. Comments that contain the

words "unnecessary," "correction," "quantitative," or "specific" are categorized as "Request for correction." Comments that contain question marks are categorized as "Ambiguous description." And comments that contain the word "good" are categorized as "Glowing comments." Fig. 6 shows the variation in proportions of comments by category, and the variation in the total number of comments. The abscissa is the number of the working report, the left ordinate is the proportion of overall comments accounted for by each comment category, and the right ordinate is the total number of comments. As you can see in Fig. 6, the total number of comments decreases with repeated report-writing. On the other hand, the proportion of comments categorized "Request for correction" increases, and the fractions categorized "Ambiguous description" and "Glowing comments" are almost constant. Although the share of each comment category does not decrease, the total number of comments does decrease. Thus, we consider that report-writing in the multistep

experience-based problem-solving program helps improve students' writing capabilities, especially with regard to the logic and quantitative representation.

Next, we focus on variation in the number of comments within each group. Fig. 7 shows the variation of the average number of negative comments (Requests for correction) for Groups A and H. The abscissa corresponds to the number of the working report and the ordinate corresponds to the average number of comments categorized as "Request for correction." The average number of comments is obtained by dividing total "Requests for correction" by the number of students in Group A or Group H (respectively). From Fig. 7, we see that the variation for Group H is large compared to the variation for Group A, and that the total number of comments categorized "Request for correction" is 98 for Group A, consisting of high-achieving students, and 169 for Group H, consisting of low achievers. Therefore, we consider that the effects of report-writing and reviewing by the subject teachers correlate with the academic results of students.

IV. CONCLUSIONS

To improve the problem-solving skills of engineering students, we have introduced a multistep experience-based problem-solving program for first- to third-year students. This program promotes seamless transition to the "Practical System Design" class, which is offered in the fourth year. Further, we designed the content of this program such that it evolves as students advance from year to year. We also introduced a written report that we require students to submit after each class. As a new quantitative evaluation method for the reports, we focus on variation in the number of marks assigned to the reports. By categorizing the comments by content, we find that although the proportions of positive, neutral, and negative

comments do not change with repeating report-writing, the total number of comments does decrease. Additionally, we can see that the variation in the average number of comments categorized as "Requests for correction" depends on the academic results of students. Therefore, we take it as confirmed that report-writing by students and review of reports by subject teachers helped to improve the students' work-tracking skills, and that this effect correlates with the academic grades of students.

There are some further subjects that remain for future investigation, such as the optimal review framework and improvement of our method for evaluating the whole process. In particular, we consider that "Glowing comments" are important as well as comments requesting corrections, and deserve further attention. Also, to reduce the large variation in number of comments, structured rules for review are needed.

ACKNOWLEDGMENT

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Integration of Robotic Arm Manipulator with Computer Vision in a Project-Based Learning Environment

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Abstract—This work-in-progress paper describes our experience in introduction of a Project-Based Learning environment in teaching of undergraduate students in the field of electrical engineering at Sogn og Fjordane University College in Norway. In the scope of this work, a robot capable of playing the tic-tac-toe game with a human and an additional laboratory exercise in robotic manipulation with computer vision has been developed. In this lab, the students integrated the robotic manipulator with computer vision in order to prepare a fully autonomous robot navigation using a prepared library that provides the functions for robot control and image processing. The project can be an interesting tool for learning some advanced topics such as robot vision, robot mechanics and autonomous robot navigation. The results show that students with strong motivation start to carry out an advanced project without any theoretical background in robotics and image processing. Another advantage is that the students can test in practice the influence of all stages of image processing on final robot navigation and understand that we may control robotic manipulators by using the vision information.

I. INTRODUCTION

Robotics is one of the most important and exciting fields of technological advancements of our age. The first industrial robots have been introduced to the factories in early 1960s and we still observe the strong growth of new applications in recent years. The evolution of the technical needs of society and the technological advances achieved cause that robots are widely used in many areas such as agriculture, surgery assistance, rehabilitation, automatic refueling, automotive assembly line, etc. [1]–[3].

Robotic arms are one of the most important industrial robots, but they are typically designed to repeat tasks. Integration of the robot with the information coming from the camera can extend the functionality of their in automatic industrial process [4], [5]. However, in order to ensure the continued development and meet the future challenges in service robotics, it is important to train engineers, who will cover those necessities.

In recent years, an increased interest in robotics is also observed from the industry in the Sogn og Fjordane region in Norway. In order to respond to demands for skillful engineers Sogn og Fjordane University College (SFUC) cooperates with the regional industries in the realization of bachelor's projects. Within this cooperation almost all projects are conducted in such a way that the students receive the fragments of tasks

that should be implemented under supervision of teachers from SFUC and employers. The result of this work is a bachelor's thesis connected with real-world problem and an industrial deployment of a technology. This work is the only way to conduct the projects connected with robotics. However, due to the fact that there are no courses as introduction to the robotics and image processing in the undergraduate curriculum, the students avoid the topics related to computer vision and robotics.

During a three-month visit of one of the authors (KR) under Erasmus internship program to SFUC, there appeared an idea to design an advanced application that can be presented as a spectacular demo of the robot's capabilities for visitors of the university and encourage the students to choose the robot-related tasks. As the result of this internship, a robot capable of playing the tic-tac-toe game was developed.

The laboratory in SFUC is equipped with Universal Robots UR5 and KUKA KR3 robot manipulators, but in this work we will focus on the UR5 robot, as we received many positives opinions from Norwegian companies, which successfully deployed this robot in their business. This robot was also used in many research projects [3], [6]. The UR5 robot with the control panel is presented in Fig. 1.



Fig. 1. The UR5 robot from Universal Robots.

The second idea under this internship was to design and introduce an optional laboratory exercise that would give the students an opportunity to design, develop, evaluate, integrate and manage projects, in which they will use a robotic arm and computer vision algorithms in real-life applications. However, due to the fact that this internship took place during summer vacation, there was no possibility carrying this laboratory with the students and the laboratory stand was prepared to control it via Internet. To achieve this goal for all devices the public IP addresses were assigned, the web-camera was mounted near the robot and a free app TeamViewer for remote access to the system was used. The final workshops with the students were conducted by both authors, but one of the authors (KR) supervised the work of the students via Skype and TeamViewer applications.

This laboratory was designed in the form of Project-Based Learning (PBL) [7], because many researchers note the positive influence of PBL on education process [8]–[12]. The main idea of PBL approach is to engage students in learning and stimulate their thinking by solving a real-world problems instead of traditionally lecture-based learning [13].

The aim of this exercise was to illustrate how to localize a simple objects using computer vision methods for preparation of an autonomous robot navigation and check if further one-semester course in robotics can be conducted without lectures in robotics and image processing as PBL.

To accomplish it, we developed a basic application, in which the students need to change a small part of code to solve two proposed problems: removing all predefined objects from the table and adjusting the proper values of thresholds to recognize other types of the items on the table.

In this work-in-progress paper, we present the preliminary results of applying the PBL approach in teaching programming of robots and integrating it with computer vision and designed environments. The main idea was to introduce an additional laboratory project for the undergraduate students of electrical engineering at SFUC in Norway and show the students that they are able in an easy way to control the robotic arm using the ready-made algorithms. The next Section provides a brief description of the developed laboratory stand and prepared applications. In Section 3 we discuss the results and the impact of the deployed robot on the learning process and finally we conclude the paper.

II. LABORATORY STAND DESCRIPTION

The most challenging part of this work was to find an alternative way to motivate and capture the interest of students to obtain programming skills for solving robotic tasks. To realize it, we prepared two applications containing ready-made algorithms for robot motion planning using computer vision algorithms.

The first application is an implementation of a robot capable of playing tic-tac-toe (or Noughts and crosses) game that has been presented on student university open days, when the robot played with students and visitors to show the possibility of using robot. The tic-tac-toe is a simple and short game, in

which two players take turns marking the spaces in a 3×3 grid. The player who succeeds in placing three respective marks in a horizontal, vertical, or diagonal row wins the game. Typically, it is a paper-and-pencil game, but in our solution, we used basic geometric figures (red rectangles and blue circles) as pawns in the game.

In order to find the optimal move in the tic-tac-toe game for the robot a Minimax algorithm has been applied [14]. The Minimax algorithm is simple recursive algorithm that performs a deep search strategy checking the possible game states and allows to select the best move for the robot. A similar robot capable of playing the tic-tac-toe game was developed by a group of engineering students at São Paulo State University in Brazil [15].

A robot is able to play with a human by analyzing the position of the pawns on the table and the free fields of the game board using the visual information gathered by the Basler Ace GigE camera mounted at the end-effector of the robot. The scheme of the laboratory stand has been presented in Fig. 2. To communicate with the camera, we used SDK of Basler camera, to control the UR5 robot, we used a Python urx library developed by Olivier Roulet-Dubonnet [16], OpenCV library [17] for image processing purposes and GUI has been developed in using Qt library [18]. The communications between the camera, the robotic arm and the PC was performed via TCP/IP protocol.

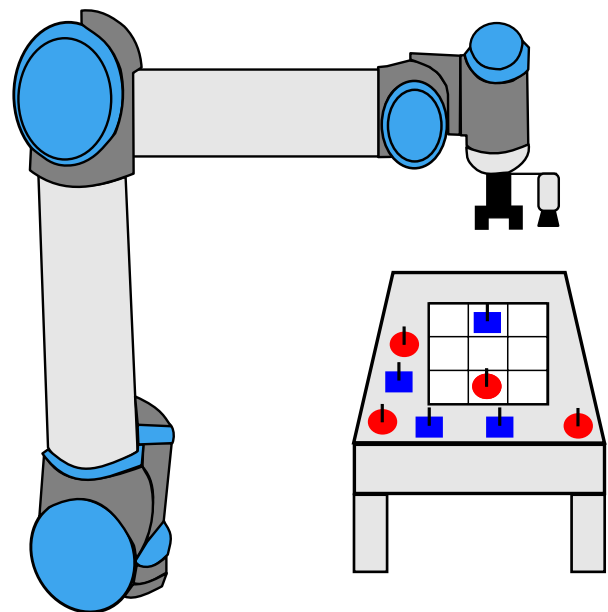


Fig. 2. A scheme of developed Tic-tac-toe playing UR5 robot manipulator.

The second application illustrates how to localize simple objects (blue circles and red squares) on the table and move them to other locations. This application was used in an additional laboratory course, in which students needed to change some part of code and modify a basic image processing algorithm in order to teach a robot to recognize new items.

Similarly to the work [19], our software was divided into separate classes:

- class *Robot* for communication between the robot and the PC,
- class *FrameCapture* for images acquisition,
- class *ObjectDetection* for objects detection within the captured images,
- class *TableInterpreter* for transformation of visual information to appropriate robot's movements.
- class *MainWindow*, in which a user GUI was developed.

Within class *TableInterpreter* the functions were developed for automatic calibration of the distance between the robot's gripper and the table, the angle between camera and the robot coordinate system. Two different coordinate systems for the robot and the camera sensor are presented in Fig. 3.

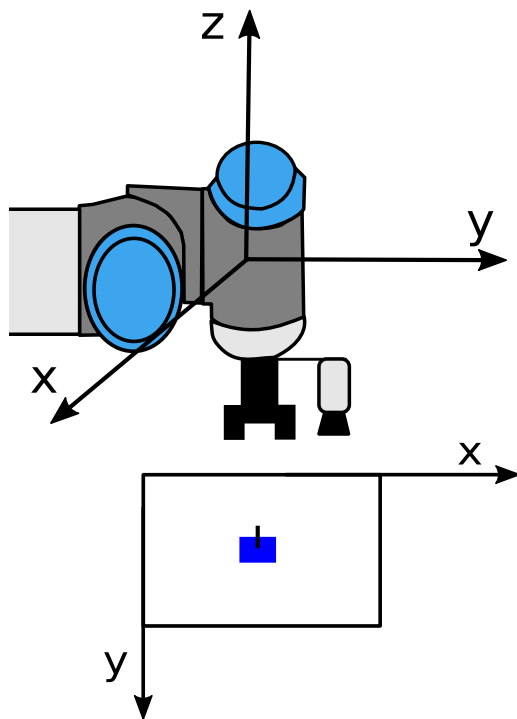


Fig. 3. A scheme of coordinate system of the camera and the robots.

In the proposed course there are not any advanced computer vision algorithms what allows for easy understanding of the whole objects detection process for the student with limited previous knowledge in image processing. In the applied algorithms all objects are detected based on the color properties of the objects using HSV color space by setting the proper thresholds. Then, morphological post-processing was applied to remove artifacts, which may have appear in the previous step and connected-component labeling was used to detect connected regions in obtained binary image. Finally, for each detected object the mass center has been calculated in order to move the robot arm through the desired position. The flow chart of the developed object localization method is presented in Fig. 4.

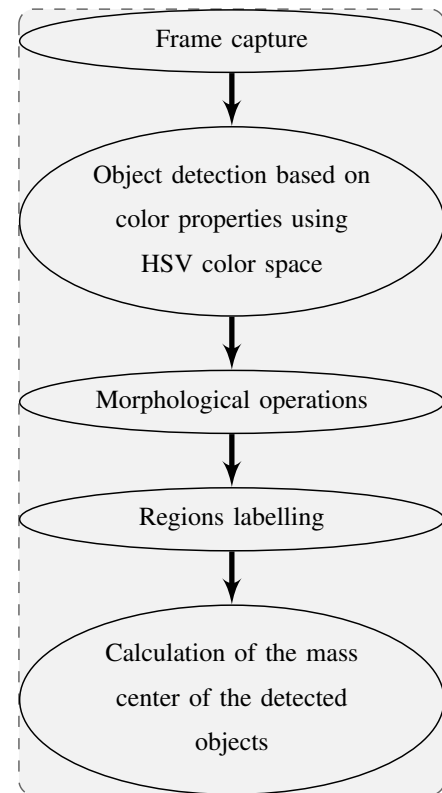


Fig. 4. Flow chart of the vision module used for object detection.

III. EVALUATION OF THE EDUCATIONAL EFFECT

The primary objective of this study was to evaluate if an obligatory course in robotics with computer vision planned in the future can be conducted in the form of PBL without traditional lectures in this field. This is due to the fact that there is limited possibility to add novel courses in image processing and robotics to the current undergraduate curriculum in electrical engineering at SFUC.

For this laboratory we prepared two simple tasks, the first connected with planning the movement of the robot arm and the second focused on image processing problem. The first task required from students a modification of the function **PickCircleObject()** that picks up a single blue circle from the table and places all the circles detected by the function **DetectCircles()** on the line. The second task was to write a function to detect the black nails based on the HSV color space using the code of the function **DetectCircles()**. In this task a short introduction to the HSV color space was conducted and an additional function with the trackbar sliders that visualize the results of image thresholding in HSV color space.

In order to evaluate educational effects and determine the degree of interest, we observed students' attitude and reactions during the laboratory. In addition, in order to avoid subjective bias, we also prepared an anonymous questionnaire before and after exercise with questions about students' motivation, interests and expectations. 60% of students of the third year participated in this optional laboratory. We divided them in

three groups.

Generally, all students in the survey reported that their knowledge about robotics and computer vision is minimal. Most students before the exercise expected to see the robot in action and acquire knowledge about the robotic arm programming and programming environment. Three persons were especially interested in the topic of workshop, because they would like to use this knowledge in their bachelor's project.

Due to the lack of earlier experience, most of the students considered computer vision and robotics as difficult and they thought that they would not even be able to start the project related to robotics. Almost half of the students noticed that they did not know that the camera sensor systems can extend the functionality of a robotic arm.

The answers from the questionnaire after exercise showed that 30% of the students were interested in both robotic arm programming and integration of the robot with camera sensors and application of image processing methods for autonomous robotic manipulation. On the other hand 40% of students were interested only in robotics without using computer vision.

The questionnaires also showed that the biggest problem for the students was the use of HSV color space, because they never heard about the Hue-Saturation-Value (HSV) color model. They were only familiar with RGB and CMYK color model and they were able to work with this novel color space only after a detailed explanation of the necessities of applying different color spaces. Another difficulty was caused by the different coordinate system for the robot and the camera and the fact that the robot axes were not directed perpendicular to the table with the items. Therefore, most students would like to receive learning materials and an instruction before the laboratory in order to prepare better for the upcoming exercise. These difficulties show that even in realization of PBL a detailed instruction is always required and it is not possible to treat the robot movement functions as "black boxes".

Contrary to our expectations, the students did not see any difficulties in conducting the laboratory exercise remotely using English by one of the lecturer. However, some concepts had to be explained by local lecturer in Norwegian language. Furthermore, all students have completed the tasks and they were satisfied with the exercise. This exercise was planned for 2-3 hours, but the students wanted an opportunity to learn for a longer period of time. Half of them outlined also the necessities of learning of some novel programming languages as they had only programming course in Java. All students will also recommend the participation in this laboratory to the other students.

IV. CONCLUSIONS AND FUTURE WORK

In this work-in-progress paper, we provide a detailed description of prepared applications, especially our robot capable of playing the tic-tac-toe game and show preliminary results and experience in conduct of a small PBL workshop related to programming robotic arm and integrating it with computer vision for autonomous robotic manipulation. The students participation in this optional exercise gave us positive feedback

on this activity and confirmed that they would like to take part in an obligatory course realized in this form.

Based on this experience, we are planning to introduce in the future an obligatory course of robotics with elements of computer vision for the students of electrical engineering at SFUC in the form of PBL.

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Programming Design Process: Providing K-12 Students with a Structure to Attain Programming Goals

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Abstract—The Cyber Innovation Center’s Cyber Science curriculum is an interdisciplinary approach to educate high school students to become better cyber-citizens. Through Cyber Science, students learn applicable fundamental concepts from political sciences, history, and law as well as science, technology, engineering, and mathematics (STEM) disciplines as they relate to cyber. In particular, the curriculum includes basic programming and structures; advanced computer science topics; and the concepts of security and privacy in relation to cyberspace. The project-driven nature of the curriculum enables students to refine their computational problem-solving abilities through challenging and engaging programming problems. Mirroring the engineering design process, the Cyber Science curriculum introduces an iterative software development process to give students a structured procedure to approach and solve programming problems. This work in progress will address the purpose for developing the Programming Design Process (PDP), define the model used to create the process, and provide an example of a programming problem guided by the PDP.

Keywords—Cyber, Design, Programming, Robotics

I. INTRODUCTION

Careers in STEM and cyber are growing exponentially. However, the number of available positions is greater than the number of qualified professionals able to fill those jobs. One career website stated, “in 2013 there were 209,749 postings for cybersecurity-related jobs nationally.” Additionally, they pointed out that these jobs are difficult to fill due to lack of qualified talent [1]. A report by the Bureau of Labor Statistics projects there will be a 22% increase in computer and mathematics occupations by 2020 [2].

To help build a workforce for these fields, it is evident that an emphasis needs to be placed on these disciplines at the K-12 level. The students of today will be the workforce of tomorrow; if they are introduced to the possibilities of careers in STEM and cyber, then they are more likely to pursue the fields in college [3]. A deficit of U.S. STEM professionals is a major motivating factor for the development of engaging K-12 curricula that fosters excitement in STEM. The introduction of programming through simple and easy-to-use applications and platforms has become an increasingly popular method for

getting K-12 students excited about STEM and cyber. One such curriculum is Cyber Science [4], an interdisciplinary course designed by the National Integrated Cyber Education Research Center (NICERC), the education division of the Cyber Innovation Center (CIC). The CIC is a 501-3c not-for-profit organization set up as an economic development engine in Northern Louisiana (LA). Through NICERC, the CIC is able to bring engaging curricula to not only LA, but the nation as well. The CIC defines cyber as the integration of STEM and liberal arts disciplines, wrapped in a societal context with a technology underpinning. With this definition at the forefront, Cyber Science was developed to teach high school students applicable and fundamental concepts from political science, history, law, computer science, and STEM disciplines as they relate to cyber. Students are presented with various cyber-related programming activities that are both challenging and engaging.

Although curricula and programs that use programming have shown positive results toward engaging students in STEM fields [5-7], the process of programming can be difficult for some students to understand [8, 9]. The algorithmic thinking and analytical problem solving that is required to solve programming problems can be challenging for many students. To enhance step-by-step logical thinking by allowing students to organize their thoughts as they develop programs, a subject matter expert (SME) in computer science developed a process to guide students through programming problems from start to finish. The Programming Design Process (PDP) is a five-step iterative software development process that requires students to: 1) identify the goal, 2) design a solution, 3) implement the solution, 4) run and evaluate the program, and 5) customize the program.

In the rest of this paper, we provide an overview of the Cyber Science curriculum and the incorporation of the PDP, present and discuss each step of the PDP, and illustrate the implementation of the PDP with an example of a programming problem featured in the Cyber Science curriculum.

II. CYBER SCIENCE

The CIC quickly understood that in order to grow the cyber workforce, cyber education should be introduced in K-12

schools. NICERC was established and partnerships were formed with universities and K-12 school systems to grow and build opportunities to engage and challenge students in the field of cyber. For instance, the Cyber Discovery program [10] is a project that was developed at Louisiana Tech University (LA TECH) by faculty from diverse disciplines including engineering, mathematics, computer science, history, political science, architecture, and others. Cyber Discovery provides both professional development for K-12 teachers and an engaging summer experience for students. After the teachers attend two professional development workshops designed to give them the knowledge and pedagogical techniques to teach cyber concepts, the teachers mentor their students in the residential summer program. The summer program challenges students to compete with other schools in robotics competitions, solve a cryptographic treasure hunt, write thought-provoking essays, and build architectural structures; all activities and challenges are inter-related and are centered around cyber. The overwhelmingly positive student and teacher feedback from Cyber Discovery prompted the CIC with the following question: *How can the CIC keep students engaged throughout the school year?*

The CIC collaborated with SMEs and LA TECH faculty to create a year-long curriculum for high schools such that all students can experience, learn, and be challenged by cyber. Paralleling the Cyber Discovery curriculum, the Cyber Science curriculum was created with the intent of integrating liberal arts, computer science, and engineering. The course is composed of five major cyber-themes to provide a holistic view of cyber: programming basics, foundations of computer science, networking and security, artificial intelligence, and ethics and societal issues. Specifically, the curriculum includes basic programming structures (variables, algorithms, searching, sorting, etc.); advanced computer science topics (networking, security, cryptography, problem complexity); basic electrical engineering (parallel and series circuits, sensors); and the concepts of security and privacy in relation to cyberspace.

Cyber Science is taught at the high school level as an elective course. It was first piloted with a small group of regional schools in 2011 and has grown nationally with 100 high school teachers and administrators having access and having been trained to teach the curriculum; training is provided through a week-long immersive professional development workshop conducted by CIC SMEs.

III. THE PROGRAMMING DESIGN PROCESS

The engineering design process is a well-defined guide used as a problem-solving mechanism [11]. The process provides structure for students to methodically work through design ideas and challenges while also encouraging creativity [3]. Although at their core, programming problems are engineering problems that can be solved with the engineering design process, the algorithmic (step-by-step) nature of programming is not explicitly present in the process. Thus, mirroring the engineering design process, the Cyber Science curriculum introduces a simple iterative development process to give students a structured procedure to approach and solve programming problems. Figure 1 depicts the overall structure



Fig. 1. Programming Design Process

of the PDP; the following sections will discuss each step of the process.

A. Step 1: Identify the goal

The PDP begins when a student is given a prompt, problem statement, or project overview for a programming task; typically, programming problems are presented in an abstract manner. Thus, one of the most important skills a student should possess is the ability to analyze a problem statement and deduce the requirements of the program. The ultimate question that a student should answer in this step is: "What is the goal of the program?" A concise statement that details the desired functionality of the program should be written before proceeding on to the next step of the project.

B. Step 2: Design a solution

Again, only after an end goal has been established should a student attempt this step. This step requires a student to create a plan to solve the problem. As the Cyber Science course progresses and students gain more experience using the PDP, it will become clear that the best designs are those that are in the form of a sequence of steps. Using step-by-step designs make the programming implementation easier, because they model the sequential behavior of a program; however, no programming should be done during this step. The questions to address in this step include:

- 1) What steps are needed to reach the goal?
- 2) Which variables and types, if any are necessary to reach the goal?
- 3) Will any decisions need to be made to reach the goal?
- 4) Should or can any of the steps be repeated?

In particular, the solution should be designed on paper (or a computer) using English prose, pseudocode, or a flowchart. As

soon as the student is satisfied with their design, they can continue to step 3.

C. Step 3: Implement the solution

Depending on the solution design in step 2, the completion of this step should be relatively easy. If the design included a step-by-step plan to achieve the goal, the hardest part is determining what are the instructions used to convert each step into code. For example, if a step in the solution is to make a robot move forward, the students need to figure out exactly how to tell it to move forward in a language the robot can understand (lines of code). A good thing to keep in mind is the exact coding commands to implement a solution vary by programming language, and within a programming language there may be multiple ways to reach the same result.

D. Step 4: Run and evaluate the program

As the programmer, the student has the power to run, or execute, their programs. When a program is run it is checked for syntax errors. If the code is error-free, each line of code is executed. When the program execution is complete, the student should decide if the desired functionality was achieved. Essentially, did the program accomplish the goal? If so, they can move on to step 5. If the goal was not met, the students must backtrack to step 2.

E. Step 5: Customize the program

This is an optional step, but if the student has time, they can customize their program as desired as long as they have already produced the correct functionality.

IV. IMPLEMENTATION: PDP

All of the programming problems in the Cyber Science curriculum require students to program a Parallax Boe-Bot robot [13], where implementation is written with the PBASIC programming language. The advantages for teaching students to program through PBASIC include: PBASIC contains special commands for monitoring and controlling circuits; program execution is one single process to make it easy to understand and follow; the syntax of the language is simple and is not case-sensitive.

This section will present an example of a programming problem and the guided use of the PDP to program a Boe-Bot to make a left turn.

A. Left Turn: Identify the goal

The prompt for this program is simple so determining the goal of the program is straight-forward. After reading the prompt, the student is required to write a concise statement:

Goal – Move forward and then make a sharp left turn.

B. Left Turn: Design a solution

Again, in this step the student should design a general procedure that satisfies the goal; to do so, the student may choose from English prose, pseudocode, or a flowchart. In this example, we will choose pseudocode:

- Move forward
- the left tire should spin counterclockwise

```

counter  VAR Word

' Full Speed Forward
FOR counter = 1 TO 122
  PULSOUT 13, 850
  PULSOUT 12, 650
  PAUSE 20
NEXT

' Sharp Left Turn
FOR counter = 1 TO 122
  PULSOUT 13, 650
  PULSOUT 12, 650
  PAUSE 20
NEXT

```

Fig. 2. Left Turn: PBASIC Implementation. The PULSOUT command sends a pulse signal to a servo with a specified duration. In this example the servos are connected to pins 12 and 13 of the Boe-Bot, and the durations of 650 and 850 represent the spinning in clockwise and counterclockwise directions, respectively. The PBASIC syntax does not require curly braces or semicolons; the green text represent comments.

→ the right tire should spin clockwise

→ pause between pulses

→ Sharply turn left

→ the left tire should spin clockwise

→ the left tire should spin clockwise

→ pause between pulses

The goal is the driving factor for the pseudocode design, and hints that there are two phases of the program: moving forward and turning left. However, the student should reflect about the engineering and behaviors that cause the Boe-Bot to move forward and turn left. In particular, the Boe-Bot is designed in such a way that the servos controlling the tires are mounted opposite each other; in order for them to collaboratively produce a forward motion, both servos need to spin in different directions. Thus, in order to turn left, the servos should spin in the same direction.

C. Left Turn: Implement the solution

Once the pseudocode has been designed, the conversion from pseudocode into the PBASIC language is relatively simple. Figure 2 shows the implementation of the design in PBASIC code. The hardest part of this step is determining the equivalent PBASIC commands for each line of pseudocode, and understanding the PBASIC syntax.

D. Left Turn: Run and evaluate the program

After writing the program, the student should test the code to make sure that behavior of the Boe-Bot corresponds to the goal. If the Boe-Bot successfully moved forward and then turned left, the student may continue to the next step. Else, they should revisit their design in step 2 and revise their pseudocode if necessary. If the design is correct, then there may have been an implementation error that should be fixed in step 3. This iterative process should continue until the Boe-Bot is programmed to follow the correct functionality specified by the goal.

E. Left Turn: Customization

At this point, the student has the opportunity to customize the program. Specific to this problem, the student can experiment and make changes to the speed of the robot, the sharpness of the left turn, add code to move in other directions etc.

V. CONCLUSION AND FUTURE WORK

Establishing the PDP was the first step in creating the foundation for future research on the effectiveness of a methodical structure to help guide students to better understand programming and achieve goals. The PDP was developed in summer 2014, and was first introduced into the Cyber Science curriculum during the fall 2014 school year with a small set of teachers to pilot the process. During the professional development training over the summer 2015, an emphasis will be placed on the PDP to educate K-12 teachers on the effective implementation of the process within the Cyber Science curriculum. At the workshop, surveys will be provided to teachers to collect their feedback about the PDP. Similar surveys will be given to the students during the school year. At the end of the year, the feedback from teachers and students will be collected and analyzed to determine the value that the PDP brings to the curricula, as well as the process' ability to help students attain programming goals.

To help familiarize teachers with the PDP at the summer workshops, a fill-in-the-blank style template sheet was provided to simplify the learning and completion of each step in the process. These PDP template sheets help to build the teachers' confidence in programming as well as provide a useful supplemental resource to the PDP that help the teachers implement it in their classrooms. Thus far, in workshops where the PDP and PDP template page have been used, the teachers have shown greater confidence in programming and teaching programming than when they have not been used. Preliminary data taken from surveys at the workshops show a positive response to the PDP. However, more data will be collected over the course of the summer and upcoming school year. Current data has not been formally analyzed as this paper is a work in progress. Future plans are to use the data collected to assess the effectiveness of the PDP in both teaching and building confidence in programming for K-12 teachers and students.

NICERC has also added the PDP to other curricula that feature programming components. Specifically, at the high school level, Cyber Physics and Cyber Literacy are two NICERC courses that utilize the structure provided by the PDP to help students solve programming problems relevant to the course; both courses also use the Parallax Boe-Bot platform. Additionally, NICERC's middle school curriculum, STEM

Explore, Discover, Apply, contains coding modules where the PDP is used to guide the students through programming a Lego EV3 [14] and creating a game using the Scratch programming language [15]. These additional implementations of the PDP show the flexibility and applicability of the process to programming problems in different domains and will provide a larger test bed for assessing its effectiveness.

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Micromouse: An Autonomous Robot Vehicle Interdisciplinary Attraction to Education and Research

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Abstract— The objective of this paper is to instill in students motivation and interest for what they are studying a little bit further of the theory they learn in classroom. Sometimes students prefer more interactive classes and want to know why the material given in class is helpful in their career. Do we have a solution for this? Autonomous Robotic Vehicle (ARV) projects can be the solution to this problem. This type of project are interdisciplinary and offer students varieties of challenges, while involving different areas of interest like programming, design, assembling and testing. One of the best ARV project is the Micromouse. The Micromouse is a small robot that solves mazes. The basic idea is that the student makes his own Micromouse from scratch using knowledge acquired from different classes and the research done. This project also helps the student to develop teamwork skills and creativity to complete the different challenges and objectives that appear when building a Micromouse. The student learns the importance of working with students from other engineering concentrations, which allows him to experience how a career in engineer will be.

Keywords— Undergraduate Research, Education, STEM, Micromouse, Autonomous Robot Vehicle

I. INTRODUCTION

In this century the courses should be appealing to students. Why is this important? Because when the professors have the student's attention the lesson imparted is better received and the student is able to recall more of the knowledge acquired in the classroom [1]. Some studies reveal that 60% of students feel bored in half of their classes, while other 30% said they feel bored in all classes. Even in this recent research some "hands-on practical sessions achieved the highest boredom ratings". The author of this research attributes the results of these hand-on session to the fact that experiments were controlled exercises were the students already knew the results [2]. The difference between those hands-on experiences and the Micromouse project is that they lack diversity of results, outcomes and challenges, while the Micromouse does not. When the student finds an obstacle there is no instructor or manual to tell him what to do next, the student doesn't know beforehand what the outcome will be.

In today's world efficient and effective communication is essential in any career. This is especially true for engineers, since many of the projects that they are involved in include people from different areas and problems in communication

could end up in fatalities like the Space Shuttle Challenger Accident [3]. While the student learns the theory in the classroom and practices it in the laboratory, there is lack of a place where to integrate the knowledge acquired from different classes and where to interact with people from other majors. The Autonomous Robotic System (ARV) Micromouse Project is ideal to give the students the opportunity to expand their knowledge to these different areas. To achieve this objective, the integration of three different major was considered: Mechanical, Computer and Electrical Engineering.

The integration of these three majors adds diversity and variety to the project giving the students the opportunity to have the experience of working with people from different majors, to learn by social interaction and to develop social and communications skills. Through this Project students design and build a land robot able to travel across a maze. In others words, students get the opportunity to improve their skills by

II. WHY A MICROMOUSE?

This year a team was created for the research project: *The Quadcopter and the Micromouse: A Cooperative Robotic System* presented to Industrial Affiliates Program (IAP) at the University of Puerto Rico, Mayagüez (UPRM). The objective of this project was to engage two autonomous vehicles: an aerial vehicle (quadcopter) and a land vehicle (Micromouse), to work simultaneously to complete the mission of solving an unknown maze. This paper focuses on the Micromouse related part of the project. The Micromouse group consists of 4 students, 1 of 4th year and 3 in 5th year. One of the students is from Computer Engineering, 2 from Electrical Engineering and 1 from Mechanical Engineering.

III. APPROACH OF DESIGN

The students from the three majors worked together to design a working Micromouse prototype as seen in Fig. 1. Since the micromouse is a relatively complex robot there are mechanical, electrical and programing aspects that should be considered before building the robot.

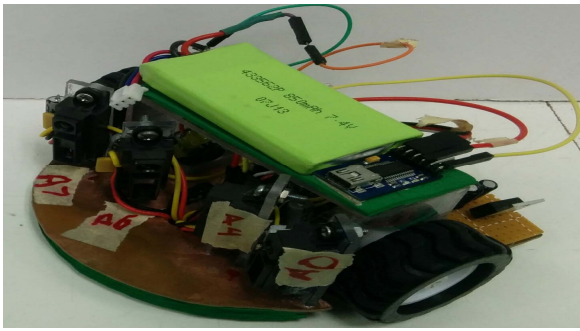


Fig. 1. UPRM's M_{inds}^2 CREATE Micromouse Prototype

A. Mechanical Engineering Approach

A mechanical engineering student learns to work, not only with mechanical systems, but also to design thinking about where and how the other students will place the various circuits and sensors. The student must take into account the needs of his peers to make an effective design. The student also has to communicate the mechanical constraints to the others so that these are taken into account. When the students learn to communicate effectively with each other the result is a design that integrates all the mechanical and electronic system in the best possible way.

Besides improving technical communication tools of the students, the Micromouse project allows the integration of knowledge acquired in different classes, and furthermore, it allows the student to go from theory to practice. It is true that laboratories can implement the concepts learned in class, but there are many classes that don't have laboratories, and the practices and laboratory experiments are limited to issues of the class to which they belong.

In this project the mechanical engineering student puts into practice knowledge acquired in design, static and dynamic classes. When designing the vehicle it is necessary to take into account the weight of the various static elements and where those components will be placed because if the weight distribution on the robot is not the desired, the movement of the vehicle will be affected for worse. The knowledge acquired in design classes is extremely important for the student of mechanical engineering that belongs to the Micromouse project. In Fig. 2 can be seen the design consideration for positioning the infrared sensors and in Fig. 3 a possible design of a modular version of the Micromouse [4].

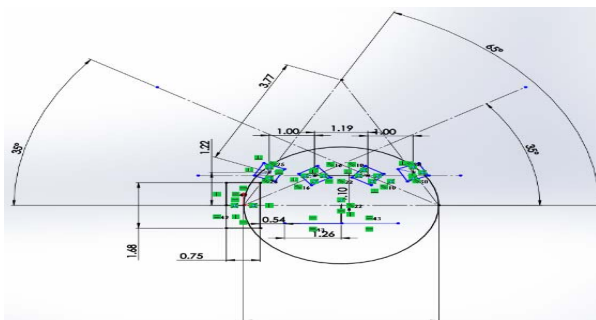


Fig. 2. Top view of sensors with angles



Fig. 3. Next Generation Prototype

The main difference between the design process used for the Micromouse and designs done in class is that for the Micromouse, apart from considering other systems, the student must take into account the availability of tools and the skills the students have to build the robot and the time available to do it. Now the student has to take into account factors that were previously irrelevant. Finally the Micromouse project provides mechanical engineer students a close experience to what could be found in the workplace, closer than classes and laboratories ever will.

B. Electrical Engineering Approach

Electrical Engineer students did a research of which components were needed to design and build a Micromouse considering the limitations and constraints of the maze. Student's research parted from the different components that were be available at the laboratory with the intention of making this Micromouse a modular and economic attraction [5].

1) DC Motors and H-Bridge

There are several types of motors (stepper, servo and DC) which could be used for this project; DC motors were the chosen ones because they have higher revolutions per minute. Because we are using a microcontroller we needed a way to control the motors. An H-Bridge, which allows to control the DC motors with the microcontroller, was used. Thanks to the H-Bridge the rpms of the motors can be controlled with the PWM (Pulse with modulation) pins of the microcontroller, which means that now the DC motors can go at different speeds, as desired.

2) Encoder

An encoder is a sensor of mechanical motion that generates digital signals in response to mechanical motion. There are available magnetic and optical encoders [6]. The two types are linear which responds to motion along a path and rotary that responds to rotational motion. The encoder is able to provide information concerning position, velocity and direction.

In this design rotary magnetic encoders were used, due to their efficiency and they avoid three major vulnerabilities that optical encoders have, which are: seal failures, bearing failures and shattering due to vibrations. There are many methods of detecting magnetic field changes, but the two primary types used in magnetic encoders are the Hall Effect

and magneto resistive. The Hall Effect detects a change in voltage by magnetic deflection of electrons and magneto resistive detects a change in resistance caused by a magnetic field.

Rotary magnetic encoders use two main components to provide position feedback shown in Fig. 4. The first component is the rotor which is magnetized with north and south poles that are lined around the perimeter of the disk. The second component is the sensor. The CPR stands for counts per revolution of the motor shaft.

3) IR-Sensors And Microcontroller

Students found a variety of sensors for the Micromouse. The sensor chosen was the IR-LED distance Sensor (SHARP), because it could provide distance measures and students were already familiar with this sensor. As it was mentioned before one of the future works interest is making a modular Micromouse, so it was decided by the students to use of an Arduino Pro mini. Arduino Pro mini offers a plug and play option with small dimensions, ideal for our design.

4) Printed Circuit Board Design

One of the jobs in this research project was working with Printed Circuit Board (PCB) design. This design is achieved based on a computer program (software) together with a special machine to make these designs called PCB Controlled Numerical Control (CNC) router. The program used to design the PCB was Eagle 6.1.1 and the program that the CNC works is called Mach 3, this is the program that gets the g-code generated by Eagle and converts in to coordinates for the CNC machine to draw the PCB. This part of the project is interesting because there is no electrical engineering class that teaches how to do a PCB design and how to use a CNC machine. In Fig. 5 you can see our design using Eagle.

C. Computer Engineering Approach

The students of computer engineering have the responsibility to understand the different components of the Micromouse. It is important that students doing both mechanical and electrical design provide the students programming how the components work and their limitations. Also computer engineering students should know is the task that the Micromouse should do. In our project we were building a land robot able to travel through a maze. The computer students, knowing this, programmed the Micromouse to be able to travel in straight line and to take turns. To move in straight line the Micromouse was programed to measure the distance between the IR sensors and the walls, if the distances are constant the robot is moving straight if the distances change then the Micromouse has to correct its course. With this information the microcontroller sends more voltage through the H-Bridge to the motor that is moving less to correct the trajectory. When the Micromouse is going to take a corner it uses the encoders to determine how much the wheels are rotating and the IR-sensors to give distance to the walls, as feedback, to know how much it has turned.

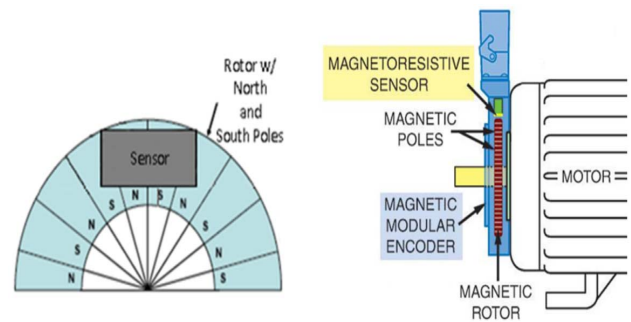


Fig. 4. Rotary Magnetic Encoder [8]

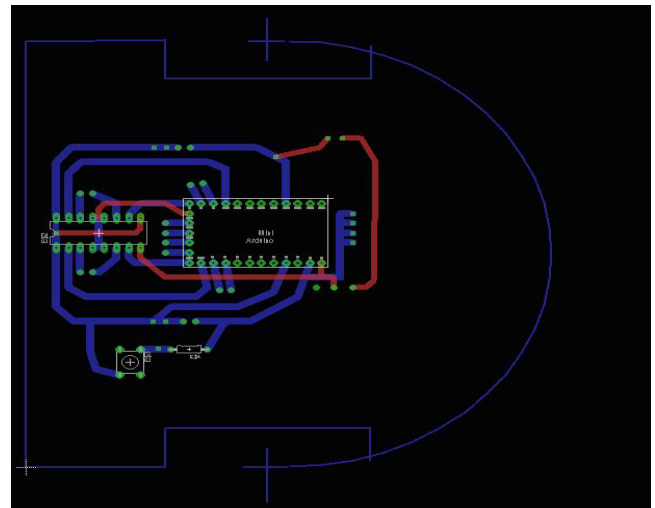


Fig. 5 Eagle Design of the Micromouse

IV. EDUCATIONAL THEORIES FOUND IN THE MICROMOUSE PROJECT

In the field of education there can be found a lot of theories describing what should be the correct method and approach to teach and give the lessons to students. One of the most used in our times is learn by doing. The most influent person in this kind of approach to student education was John Dewey. Learn by doing consist in students using the theory learned in classes to do hands-on activities [7]. An example is that the student is assigned to achieve an objective (build a Micromouse capable of navigating through a maze) and doing it with all the information learned in class and research (Micromouse navigating through maze). This hands-on activity gives the opportunity to the student to apply the lesson received in class to a real life problem with different levels of difficulty and types challenges. Learn by doing provides the student interactions with materials and equipment used for the construction of the Micromouse, often not known from previous university courses.

This project also provides the students the opportunity to interact and work with students from others majors such as Mechanical Electrical and Computer Engineering. Here is another of the theories found; learning by social interaction. When in the group there is a more skillful peer the others students learn in a faster way. Also by this social interaction students are able to share their knowledge acquired in their respective areas of studies and they learn how to simplify it for others to understand their work [8]. By doing this, students develop social and communication skills which are very important in STEM careers. Students here get the closest experience to a career job in engineering and begin to understand the importance of diversity in a project.

V. SKILLS DEVELOPED

The students were able to develop a variety of skills during this research. The skills that students developed can be easily demonstrated with *Criterion 3. Students Outcome* used by Accreditation Board for Engineering and Technology (ABET) [9]. During the academic year the students made progress reports where they mentioned the research done and the objectives achieved.

- Ability to apply knowledge of mathematics, science, and engineering – This can be seen through all the process of the construction of the Micromouse.
- Ability to design and conduct experiments, as well as to analyze and interpret data - Students conducted various experiments with encoders and sensors. Also they interpreted the data received by encoders and sensors and programmed based on that data.
- Ability to design a system, or process to meet desired needs within realistic constraints such as economic and manufacturability.
- Ability to function on multidisciplinary teams - The group was composed of three different mayor Electrical, Mechanical and Computer engineering.
- Ability to identify, formulate, and solve engineering problems
- Understanding of professional and ethical responsibility
- Ability to communicate effectively - To achieve the project's objective students needed to communicate efficiently to get the work done.
- Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

VI. SUGGESTED COURSES

For this research is expected that students have taken several courses before working on the Micromouse project. In Table I, there are some courses that the student should take, or is expected to have some knowledge before taking part in the design and development of the Micromouse project. Since this project is multidisciplinary, the table will have courses from the three majors involved in the project. Some of this courses have been suggested to other undergraduate research experiences at UPRM [10], [11].

TABLE I. Suggested Courses [12].

Course	Course Description
INEL 3105 Basic Circuit Analysis	Analysis of direct current and alternating current linear electric circuits; laws and concepts that characterize their behavior
INEL 4102 Intermediate Circuit Analysis	Networks functions; Circuit analysis by Laplace Transforms and Fourier series; Two-port Networks; Butterworth and Chebyshev Filters; Computer aided Analysis of these System.
INGE 3016 Algorithms and Computer Programming	Development of algorithms and their implementation in a structured high level language. Programming techniques applied to the solution of engineering and mathematical problems.
INEL 4505 Introduction to Control Systems	Analysis of Control Systems and their mathematical models; analysis and design of Control Systems for single input plants; Computer solution of problems will be emphasized.
INEL 4201 Basic Electronics Circuits Analysis	Semiconductor device characteristics: Semiconductor, Diodes, Bipolar Junction Transistors and Field Effect Transistors; analysis of basic digital circuits; analysis and design considerations of Transistor Amplifier Introduction to Integrated Circuits.
INEL 4206 Microprocessors	Architecture, organization and operation of microprocessors and their supporting devices; design of Microprocessor based systems.
INEL 4416 Introduction to Power Electronics	Introduction to basic power electronic topologies including but not limited to rectifiers (AC-DC), buck, boost, buck-boost converters (DC-DC), inverters (DC-AC), cycloconverters (AC-AC).
INGE 3809 Creative Design I	Introduction to the underlying principles and methodologies of engineering graphics communications. Fundamentals of graphic visualization, sketching, PC-based Computer-Aided-Design (CAD), and technical presentations.
INME 3810 Creative Design II	Product dissection, hands-on dissection exercises to develop in students the ability to understand a machine in not only its functionality but also in terms of its history, social impact and the design methodology. Use of proper technical vocabulary to describe mechanical and electrical components.
INGE 3031 Eng. Mechanics Statics	Analysis of Force Systems; The Laws of Equilibrium; Analysis of Simplestructures; Distributed Loads; Friction; Centroids and Moments of Intertia.
INME 4011 Design of Machine Elements	Application of strength of materials and material science in machine element design. Introduction and use of static and dynamic failure theories in the design of machine elements.
ICOM 4015 Advanced Programming	Advanced programming techniques applied to the solution of engineering problems; extensive use of subprograms, logical and specification statements. Principles of multiprogramming, multiprocessing, and real-time systems.
ICOM 4035 Data Structures	Data structures in programming languages, representation of information as data. List in linear, orthogonal, strings and array distribution, collection, and sorting data. Tree structures. Techniques for storage allocation, distribution, collection, and sorting data.

VII. FUTURE WORK

During the process of research and design it was known to the students that using the IR Sensors would require a bigger Micromouse. For further works it is planned to use smaller IR Sensors so the design would be smaller. Also it is planned the implementation of a maze's solving algorithm to this new version of the Micromouse so it can solve the maze autonomously. The research group noticed that it was needed a modular Micromouse for this kind of activities that is way the robot presented in this paper have some parts and components considered for our next design.

VIII. CONCLUSION

The students in this research were able to design and build a Micromouse capable of navigating through a maze. They were able to identify problems in design and overcome them with different approaches. At the end the Micromouse responded to the commands send via Bluetooth. This kind of research takes the students to a whole new level of experience and challenge. They can acquire knowledge with the interaction of students from different majors. While they interact they develop team work and oral skills. The experience working in the lab with the different programs and design tools gives the student a close approach of what a STEM career will be.

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Finding Competence Characteristics among First Semester Students in Computer Science

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Abstract—First-year students are often not well equipped with the base competencies that are a necessary precondition for effectively acquiring complex new knowledge. Among others, these base competencies comprise self-organization, analytical thinking, or communication skills. Shortcomings in these competencies often lead to problems in the study process. To solve these problems, we need to investigate the students' initial competencies, in order to become aware of possible deficits, find ways to deal with them, and thus to enable students to reach their goals. Therefore, we developed a self-assessment on base competencies, an accompanying knowledge test and a questionnaire on personal information. The data collected by these tools was analyzed, searching for competence characteristics which influence whether our students persevere and participate in the final exam, or drop out early. The results of our data analysis support the assumption that both non-technical and technical competencies are crucial to study successfully. Correlation analysis has identified several characteristics which distinguish the students that participate in the exam from those who do not. Based on these results, we suggest ways to optimize university courses, teaching methods, and the support of first-year students to meet their needs.

I. INTRODUCTION

Over the last years, computer science industry has been growing. This trend is likely to continue, as computer science becomes more and more important for both everyday life and business. As a consequence, industry requires a growing work force of well educated software engineers. Correspondingly, universities denote an increasing number of students that enroll in computer science and related topics. Nevertheless, computer industry still faces a shortage in well educated engineers [1, p. 7], [2, p. 37] and [3, p. 58]. In Germany, one reason for this situation is a high drop out rate of over 30% in STEM (Science, Technology, Engineering, and Mathematics) subjects [1, p. 8], [4, Tab.2.5.78c] and [5, p. 60].

Our observations identified two main factors for this high drop out rate. The first one is the diversity of our first-year students' academic skills, caused by Germany's heterogeneous system of secondary schools, which lead to a variety of different entrance qualifications for higher education. Thus,

lecturers have difficulties in identifying the ideal knowledge baseline from which they start their class, trying to challenge their students neither too little nor too much. As a second factor, many of our first-year students experience their first term at university as a tough challenge, having to adapt to a new way of learning and teaching. In computer science, especially, they must deal with a highly abstract manner of thinking, which differs from what most of them are used to from school or everyday life.

A. Problem Statement

The CS department of Munich University of Applied Sciences offers three different bachelor programs. In all of them, the mandatory course on software development is the major hurdle that freshmen have to face. More than five years of statistical observations indicate that each year, a total of approximately 70 percent of our freshmen students pass the final exam of this class with a rather poor grade (3.3 or worse, on a scale from 1.0—excellent to 5—fail, with 4.0 being the last passing grade), fail the exam (grade 5), or postpone taking the exam to some later semester. As software development skills are the fundamental basis for many of the more advanced courses in later semesters, students who were unable to cope with study requirements right from the beginning only have a very small chance to study successfully later on.

From past teaching experience, lecturers strongly suspect that in many cases, the observed difficulties in acquiring new CS knowledge are caused by significant deficiencies in certain base competencies (i.e. self, practical/cognitive and social competencies). Moreover, past teaching experience shows that whenever lecturers identified gaping holes in the base competencies of individual students, and were able to close these gaps by specific coaching and tutoring, these students were enabled to study successfully. So far, this detection and mending of base competency deficiencies has mainly been guided by the lecturers' gut feeling, and focused only on a small subset of students. To increase the impact of this approach, it has been evolved into a more systematic set of tools consisting of a

self-assessment of base competencies and a knowledge test [6]. These two tests have been taken by all of the first-year students at Munich University of Applied Sciences at the Faculty of Computer Science in winter semesters 2013/14 and 2014/15.

B. Current state of our project

To measure the initial competencies of freshmen students, two tests were developed. A self-assessment [6] focuses on base competencies that are crucial to study computer science or related topics successfully. An accompanying knowledge test addresses fundamental academic skills, such as German and English reading comprehension, fundamental maths, basic computer skills and abstract thinking. A supplementary questionnaire provides personal information, such as the students' migrational background and type of their university entrance qualification.

To gain insight into our students' biography at university, we developed a third questionnaire focusing motivation and current attitude towards their studies, which we assessed in November 2013 and 2014. Finally, we identified via aliases which students participated in the final exam of the mandatory course on software development.

C. Research Objective

Lecturers cannot influence the base competencies and knowledge that students acquired before enrolling at university. However, lecturers need to be aware of the first-year students' competencies to pick them up where they are. Therefore, as a first step we identified competencies that are success factors for studying computer science or related topics [7].

Based on the data we gained by several test-instruments, which are described in detail later on, we want to identify attributes of our first-year students that enable us to detect early on those students who might be in danger of not taking their first semester exam in software development, and thus are at risk of falling behind and never catching up. Identifying the group of students which is insufficiently prepared provides the basis for a portfolio of interventions that help these students to improve their insufficient base competencies. Thus, we want to reduce drop-out rates in our first-year programs of computer science and related topics.

To achieve this, we analyze the data gathered by our tools (tests and questionnaires), using a combination of visualization as well as statistical and data mining methods. Furthermore, lecturers want to gain insight into their cohorts' competencies and deficits, to be able to guide them effectively through their student entry phase. Lecturers will coach students in their attempts to close their gaps, to enable them to complete their studies successfully. Thus, known teaching methods need to be investigated and maybe adapted, if necessary, or even new methods need to be developed.

II. RELATED WORK

High drop-out rates in engineering and computer science are an internationally observed phenomenon [1, p. 8], [4, Tab.2.5.78c] and [5, p. 60].

French et al. [8] find high school ranks and SAT scores to be the most reliable predictors of engineering students'

retention and academic performance. The study acknowledges, though, that the results may not be representative of academic achievement and persistence of minority and/or international students. Furthermore, much variance remains to be accounted for.

Carnegie et al. [9] confirm that high school grades in specific subjects may, with some restrictions, be used to predict academic success of students in "digital" engineering programs including computer science.

A number of studies points to other factors that influence students' retention and academic success in computer science and engineering [10], [11], [12], [13]. They show that students are not attracted to or leave the fields because of perceived culture, perceived inadequate teaching and lack of opportunities to engage.

In [7], we considered many studies on competencies and success factors while identifying competencies that are relevant for studying computer science and related topics successfully. Based on this research, we developed a set of tools to assess the students' initial competences and knowledge [6].

Sharabiani [14] described an approach to use data mining methods to build a model for predicting students' academic performance. When using several data mining methods with different parameters, an enhanced bayesian network provided the highest accuracy. Thus, we adopt this approach for our data analysis. In addition, we employ statistical methods to identify characteristics among our students.

III. INSTRUMENT DESIGN

Every year, an extremely heterogeneous group of students enrolls at Munich University of Applied Sciences, Faculty of Computer Science and Mathematics. Students differ regarding their cultural, educational and professional background. As not all incoming students are well equipped with base competencies or knowledge to study successfully, paper-based questionnaires have been developed to gain insights into students' initial level of competencies, knowledge and personal background.

In total, there are six data sources: Self-assessment, knowledge test, personal information (e.g. work experience and migration background), presence in a lecture in November, participation in the final exam (yes/no) and additional information (e.g. degree program, study group). Students fill out these tests during their first year of studies. The data sources can be correlated by means of an individual anonymous alias.

A. Self-Assessment

The self-assessment used to assess competencies has already been published in [6] and presented at EDUCON2014. We will give a short overview of this instrument in this section.

Our self-assessment focuses on base competencies necessary for the study process in general, and on base competencies that are specifically needed for acquiring knowledge in computer science [7]. Examples are self organization, thinking in an abstract way, or thinking logically. All in all, the self-assessment consists of 36 competencies. Two positive

competencies were matched into complementary pairs of competencies and are depicted on a bipolar scale. In order to avoid misunderstandings, each competence is explained in a short sentence. Normally, it is very difficult to decide for only one of two positive competencies on the bipolar scale as competencies are not always located at exactly one position. Usually a combination of the competencies is necessary to achieve a perfect result. To reflect this, students were asked to consider each pair of competencies in two different modes: *normally* and *easily adoptable*. In *normal* mode, students have to decide which competence fits their normal behavior. The range in which students can easily move between two complementary competencies, is the mode *easily adoptable*. In this mode, students have to tick several check-boxes in a row, which represents the range [6]. An example of two complementary competencies from the self-assessment and how the question has to be filled in correctly is depicted in figure 1.

To evaluate the self-assessment tests the research team designed a *Model Student* based on the results of interviews with lecturers [6]. From these results a level for each base competence has been calculated. These levels can be seen in the radar chart in figure 2.

In order to validate the feasibility of our self-assessment, we did a pilot study. We successively tested the instrument on small groups of students. Based on their feedback and first results, we improved the assessment design and introductory usage instructions again and again [6].

Furthermore, we met the following current standards [15] that are well-known for assessment execution, while carrying out our self-assessment.

B. Knowledge Test

The knowledge test contains questions on: German and English reading comprehension, fundamental maths, basic computer skills and methodical competencies, like logical and analytical thinking. Amongst others, the math section contained questions about reducing a fraction, solving equations or probability theory and statistics. To test methodical competencies, we used tasks, like finding the odd graphic out of five, doing some modeling in order to find a solution, understanding an issue shown in a given graphic, or extracting a rule set based on given examples and transferring it to another situation. This test evaluates students' current knowledge at school level, not at university level.

Some tasks were deliberately designed in a way that they assess selected competencies in the self-assessment. For example, in the self-assessment we ask students about their reading skills, the ability to understand graphics or how distinctive their ability to think logically is. Adjusted to the crucial competencies, we included questions focussing these competencies [6].

A concrete example would be finding a rule set based on given examples of combinations of X and O that can be transferred to code consisting of a, b, c, i, x and o. Afterwards, students need to transfer this rules to another combination of X and O to find the correct code (cf. figure 3) [16]. Thereby, we gain insight into how adequately students are able to assess their own skills [6].

X	X	O	O	O	X	X	bxcobx
X	O	O	O	O	O	X	axeoaax
O	O	I	I	I	I	O	???
X	O	X	I	X	O	X	axaoaxiaxaoax
X	X	O	O	O	X	X	bxcobx

Fig. 3. Example question from the 'Informatik Biber' [16]

C. Personal Information

To complete our data, we developed a questionnaire focusing on personal information, like university entrance qualifications, migration background, family environment, work experience and current employment, as well as, details of the school background.

The questionnaire used in winter semester 2013/14 often contained questions with free text answers. In the second run in winter semester 2014/15 we changed all answer possibilities to multiple choice, in order to allow an automatic import to a computer system. Based on the answers given in 2013/14, the multiple choice answer possibilities were chosen.

D. Limitations

In the first run, data was transferred manually from paper-based questionnaires to a computer program. This can imply mistakes and can lead to wrong data if not done with the necessary attention and accuracy. Thus, this process should be automated. This approach has been implemented in winter semester 2014/15. All questionnaires are created and scanned with EvaSys©, which is a survey automation suite.

IV. EXECUTION

Data collection started in winter semester 2013/14. During an introductory day we successively assessed the students to not overcharge or bore them. The day started with a game where students get to know each other. Subsequently, we started with the self-assessment, followed by some team-building exercises. After the knowledge test, which also contained the questionnaire on personal information, the day ended with another action to promote team-building.

In the winter semester 2014/15 we also had such an introductory day containing all activities and tests with minor changes.

A. Population

At the beginning of the winter semester 2013/14 we asked all first-year students of computer science, scientific computing, information systems and management as well as geotelematics and navigation at Munich University of Applied Science, Faculty of Computer Science and Mathematics to complete three questionnaires. All in all we assessed about 320 first-year students. In the following winter semester 2014/15 we again assessed about 315 first-year students.

B. Test Execution

All first-year students in winter semester 2013/14 and 2014/15 completed the same paper-based self-assessment and



	obstinate	self-contained				team-oriented				over dependent
		I like to decide and act myself, based on my own knowledge and/or my beliefs.				I like to work in a team, share my own results and accept results from others. I am attentive and responsive to others and share my success.				
	exclusively	very	quite	slightly	little	little	slightly	quite	very	exclusively
normally	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
easily adoptable	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I don't know	<input type="checkbox"/>									

Fig. 1. Filled example of a pair of complementary competencies [6].

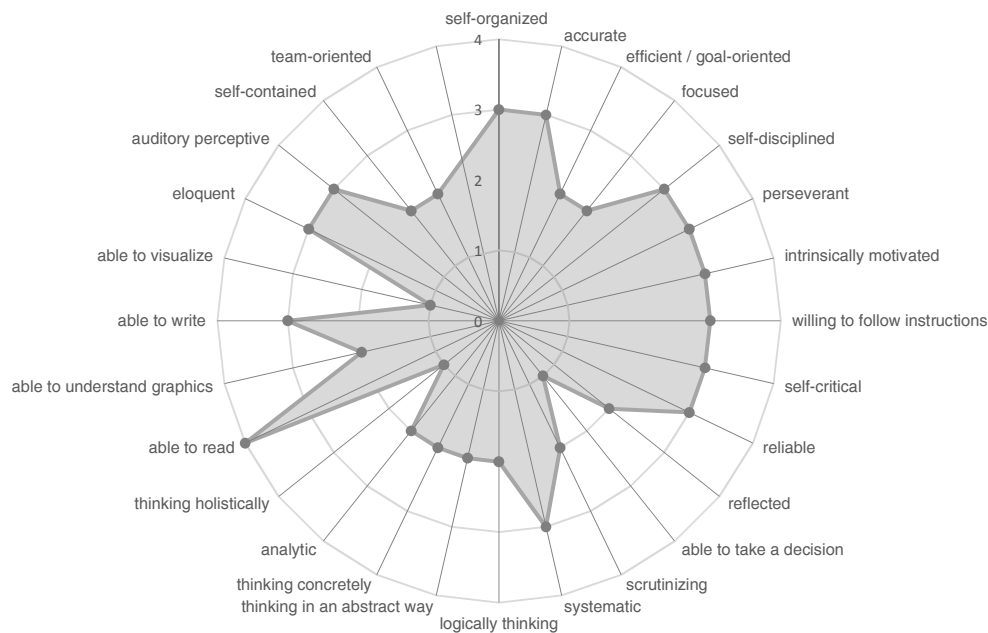


Fig. 2. Expectations towards students at the beginning of the first semester (Model Student). Defined with help of lecturers of different Universities of Applied Sciences.

knowledge test at the same time and place within one hour each. We shortly introduced our project and the benefits of the self-assessment, in order to motivate students to fill in the questionnaires. Additionally, we handed out a manual summing up the usage instructions for the self-assessment. Furthermore, we insured that all assessment results will be processed anonymously and privacy issues will be observed at all time. Students were requested to fill out the instruments on their own. They were able to ask questions that might occur, while working on the questionnaires [6].

C. Tracking During the Semester

In November 2013 and 2014, thus after 2.5 months of studying, students were asked to fill a short questionnaire about their motivation and current attitude towards their studies. We think this is a good point in time to evaluate this, as most of the students are still attending classes and they already obtained some experience about the study contents as well as the study process. Hence, they are able provide a first

assessment. This questionnaire also asked for the alias, to track students presence in the lecture.

Additionally, just before the beginning of the final exam on Software Development, students were asked to provide their alias on an anonymous sheet, so we can keep track of the individual attendance.

V. ANALYSIS OF THE DATA

Based on the test results, we analyze if there are competence characteristics among our first semester students that distinguish the students that attend lectures regularly or participate in the final exam of Software Development from those who do not. Furthermore, we provide lecturers with an idea of the initial skills of their particular cohorts and an overview of all first semester students. As well, we gain information on the heterogeneity of our students. During the analysis, we focus on technical as well as non-technical competencies. For analysis we used both data mining methods and classical statistical methods.

A. Analytic Process

In order to develop a predictive model from the given data, it is necessary to prepare and select attributes as well as to train and validate the model in the end [17].

After data has been collected, new attributes can be generated based on existing ones in the *preparation* step. Furthermore, values are normalized and transformed if they have variable ranges in this step. Subsequently, data is selected (*selection*), both relevant instances and attributes. In the *analysis* step, data can be visualized, for example, which is often very effective. Correlation can be used to find relationships between attributes. When classifying instances, classifiers are used. We use supervised learning methods to create classifiers that are based on labeled instances. This enables us to predict the classes of new instances, i.e. whether a new student is likely to pass or drop out. Finally, in *evaluation*, results of the analysis must be interpreted, documented and evaluated whether they are significant or not [17].

B. Data Preparation

In the first step all information from the different data sources are merged. We ended up with about 180 attributes per instance.

Furthermore, attributes are transformed and combined to create new ones as well as discretized. This is common practice in data mining to try to improve the success of the methods [18, p. 305]. The goal is to automatically or at least semi-automatically discover meaningful pattern in electronic data [18, p. 4–5]. An example is that buying patterns are different on weekdays and weekends. This can only be seen, if an attribute weekend (yes / no) is present in the data. Otherwise, it can be created based on the invoice date.

SELF-ASSESSMENT

Filling out the self-assessment [6] is not simple. Some students did not understand the concept of modes or did not fill in all check-boxes of the questionnaire consequently. Most of the time this happened in the mode *easily adoptable*. Students just ticked the most left and right check-box to indicate their range (cf. figure 1). In this section, we give several examples for the data preparation we did.

Missing check-boxes in a row, especially in *easily adoptable* mode, were filled automatically. In more detail, all check-boxes between the most left and right check-boxes were ticked if not done by the students themselves. Whether students understood how to fill the questionnaire or not, was investigated manually by the research team. Questionnaires where students obviously did not understand the process, were deleted from the data set.

The data set is enriched by the maximum value of all competencies in normal and easy mode. Furthermore, the minimum value of all competencies in easy mode has been added. As students in normal mode have to position themselves on one side of a bipolar scale, the minimum value is always zero. In addition, the overall media and average for normal as well as easy mode is calculated.

KNOWLEDGE TEST

Answers of the knowledge test can be easily corrected, whether

they are right or wrong. To reduce the number of attributes, results of topics are grouped. For example the knowledge test contains German and English reading comprehension as two separate topics. The number of correct answers of each topic is summarized to form a new attribute. Moreover, an attribute is introduced that states whether students exceed the predefined threshold of this topic or not. The same approach is applied to subtopics in mathematics like: fractions, functions, statistics, stochastics and problems formulated in text form.

Thresholds for each topic or subtopic are defined in consultation with lecturers. They represent the expectations towards first-year students on their first day.

Furthermore, we had questions focusing different competences on three different levels (easy, medium, difficult). Based on the number of correct answers given per level, we calculated a number that can be compared with the self-assessment of this competence. Subsequently, we can compute, whether a student overestimated, underestimated him or her self, or if the self-assessment was correct.

PERSONAL INFORMATION

Most of the questions in this questionnaire contain free text answers. This creates many different response formats. One example is the last math grade. In Germany there are usually grades from 1 (best) to 6 (worst) with a step size of 1 at school. In more advanced years there are grades from 15 points (best) to 0 points (worst). It is possible to transfer grades from one system into the other. However, some students did not clearly specify which system they use. Hence, there occurs the problem that it is not clear, if they had 1 to 5 points or grade 1 to 5. Points were transferred to the benefit of the students into grades, though.

Furthermore, students noted how long their last math class dates back. These data is clustered into three classes: less than 6 month, between 6 month and one year, more than a year.

Some of the students completed a vocational training before starting their studies. This is also asked in the questionnaire. Students also state, which job they were trained on. With help of these two information snippets a new attribute “type of apprenticeship” has been generated. It has the following characteristics: IT apprenticeship, non-IT apprenticeship, no apprenticeship.

C. Data Selection

After all data has been revised, transformed and new attributes have been generated the impact of each attribute towards building the prediction model can be identified. This can improve the performance of the data mining methods [18, p. 305]. Thereby, a reduced set of attributes is generated. Additionally, only complete instances (data per student) are considered for further analysis.

INSTANCE SELECTION

For some students at the Faculty of Computer Science and Mathematics their studies started with an introductory day. They had to fill in one questionnaire, two tests and socializing games took place between the tests. All other students just filled in the questionnaire as well as the two tests during a lesson.

As some students were late or left earlier, there is not always an accompanying knowledge test for each self-assessment or vice versa. For analysis, only a complete instance of a student is considered. An instance consists at least of: self-assessment, knowledge test and personal information. Consequently, incomplete instances are deleted from the data set. After this process, 228 instances were left ($n=228$).

Subsequently, the data set was partitioned into two sets:

- Computer Science, Scientific Computing and Geotelematics and Navigation
- Information Systems and Management

This was done, as these two groups had a different amount of lecturers on software development per week as well as a different curriculum. All ongoing steps, like attribute selection, are executed on both data sets in parallel.

ATTRIBUTE SELECTION

Attribute selection is an important part of the data mining process, as irrelevant attributes can confuse the algorithms.

As a first step all possible *linear correlations* between two attributes are calculated. In case the correlation is high, one attribute can predict the other. Hence, one is irrelevant for data analysis and can be deleted. However, no linear correlations exist in the data. Hence, we additionally use standard attribute selection methods from Weka© to extract attributes that are influence the prediction. These methods to find relevant attributes are successful for our data.

D. Data Analysis

After the attribute selection data can be analyzed. The aim is to create a classifier that predicts, whether a student participates in the exam or not. Furthermore, the competencies or their combinations which are different among this two classes of students should be discovered. Thereby, competencies that are relevant for successful studies can be identified. Moreover, lecturers can help students to close their individual gaping holes, so they can study successfully.

As we do not know what patterns exist in the data and we do not want to assume one, we use methods from the field of data mining, rather than classical statistics [19]. We chose Decision Trees as the result is easily understandable for people and it can be visualized. Hence, a profile of students participating in the exam or not can be simply constructed from the visualized tree. k-Nearest Neighbor is a promising method, because different distance measures can be used. Other distance measures than euclidean distance might fit the data much better. All methods were used several times with different settings to find the classification model that is as accurate as possible. To evaluate the models, a 10-fold cross validation is applied.

E. Validation

In order to validate the classifier, *10-fold cross-validation* is used. This method partitions the data into 10 approximately equal-sized subsets. One of the subsets is used for testing the model, the remaining $k - 1$ subsets are used for training the classifier. The process of training and testing is repeated ten times. Mean- while, each of the subsets is used once to validate

the model. Afterwards, the results are averaged or combined to come up with a single classifier. One advantage of this method is, that all instances are used for training as well as testing [18].

F. Correlations

Another tool for analyzing data that is often very effective, is visualization. Standard methods for visualization are plots [17]. A possibility to basically analyze data are pivot tables combined with pivot diagrams. They can be easily generated and interpreted. In order to find interesting attributes that influence the exam participation (attribute with occurrence yes or no) we use pivot tables and diagrams in Microsoft Excel 2013© to quickly generate contingency tables and diagrams. This helps to get an overview of the data and to identify interesting correlations. Furthermore, we calculated frequencies of different attribute combinations. For highly interesting correlations, we additionally compute the p-value with help of Fisher's exact test [20].

VI. FIRST RESULTS

In the following, we show first results from the tool set conducted at Munich University of Applied Sciences, Faculty of Computer Science in winter-semester 2013/14 and 2014/15. Students filled in these tests as part of an introductory day. The most interesting attributes and their possible values can be found in table I.

TABLE I. OVERVIEW OF THE MOST INTERESTING ATTRIBUTES AND ATTRIBUTES WITH A HIGH IMPACT ON THE PREDICTIVE MODEL.

Attribute	Values
exam participation	yes, no
lecture attendance (lecture in November)	yes, no
specialization at school	social, technology, economy, no answer
abstract thinking (self-assessment, knowledge test)	0 – 5
comparison (self-assessment and knowledge test)	correct, over, under (estimated)
apprenticeship	no, IT, non-IT, no answer

All other practical and cognitive competencies, like thinking concretely or logical thinking have no impact on the exam participation or lecture attendance.

A. Details about the Study Population

In winter semester 2014/15, 262 of 312 students stated their gender. About 75% were male and 25% were female. This is a distribution we usually have among our students at the Faculty of Computer Science and Mathematics. Furthermore, 33% of our first-year students participated in the final exam of Software Development, after the first semester.

About 34% of the first semester students in 2013/14 made an apprenticeship before starting their studies. Approximately 14% of the apprenticeships were related to computer science. The other 20% accomplished a vocational training in other fields, like media, welfare, science, technology, engineering, and mathematics (STEM), business administration or finance.

In 2014/15 we had a similar distribution of: 22% non-IT apprenticeships and 15% IT apprenticeships. Figure 4 shows the corresponding diagram for the distribution.

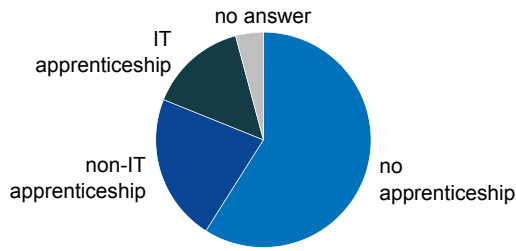


Fig. 4. Distribution of students (2014/15) according to whether they made an apprenticeship before starting their studies or not. (n=148)

B. Data Mining Results

It is important to test different data mining methods and divers parameter values to see which works best [18, p. 305]. This empirical testing of various attribute selection methods combined with different classifiers has shown that the data set of 2013/14 has a certain relevance. It is possible to predict the exam participation for more than 70% of the students correctly using k-nearest neighbor. A value of correctly classified instances greater than 70% using 10-fold cross validation is a good result for both data sets. Hence, the questionnaires have a relevance for predicting the exam participation.

A restriction to relevant competencies is possible. Weka's GainRatioAttributeEval [21] reduced the number of attributes to four respectively nine relevant attributes, namely:

- 1) Information systems and management students
 - Self confident
 - Abstract thinking
 - Logical thinking above/below our predefined threshold
 - Specialization at school
- 2) Computer science, Scientific computing and Geotelematics students
 - Serenity
 - Analytical thinking
 - PC theory
 - PC practice
 - Knowledge test overall above/below our predefined threshold
 - 3 concrete specialized questions

These results support the assumption that the tests and the questionnaire ask the right questions to get information that are necessary to forecast students' exam participation. Furthermore, the classifier refers to non-technical as well as professional base competencies. This indicates that there are base competencies and technical competencies that are crucial to study successfully. Results are promising, so more time should be spent on manually choosing attributes and applying more advanced data mining methods.

C. Correlations

Correlation analysis has shown that there exist several attributes that distinguish students who participate in the exam or attend lectures regularly, from those who do not.

If students of Computer Science, Scientific Computing and Geotelematics and Navigation exceed the defined threshold for the number of correct answers in the knowledge test, there is probably no influence on the exam participation. However, if

students failed to exceed the threshold, they supposedly do not participate in the exam on Software Development I. Table II shows the corresponding calculation.

TABLE II. FREQUENCY OF THE STUDENTS' PARTICIPATION IN THE FINAL EXAM COMBINED WITH THE THRESHOLD OF THE KNOWLEDGE TEST FOR STUDENTS OF COMPUTER SCIENCE, SCIENTIFIC COMPUTING AND GEOTELEMATICS AND NAVIGATION (DATA OF 2013/14).

Exam participation	Threshold passed	Threshold failed	Overall
yes	44.44%	18.46%	34.15%
no	55.56%	81.54%	65.85%

Applying classical test theory (Fisher's exact test [20]) we get significant results in the sense that the null hypothesis *The participation in the end of term exam in Software Development is independent from passing the knowledge test* can be refused with error probability less than 10^{-3} .

Experiences at our institution show, that students with an apprenticeship often manage the study process better than students without. This assumption is confirmed by the data of 2013/14 (cf. table III). Students with relevant work experience additionally benefit from there already existing professional knowledge in some subjects, especially in introductory courses like Software Development I or Introduction to Databases. Thus, they can focus on dealing with the study process itself. Again high significance for the correlation between the exam participation and whether students did an apprenticeship before their studies or not.

TABLE III. OVERVIEW OF THE STUDENTS' PARTICIPATION IN THE FINAL EXAM REGARDING THEIR PREVIOUS VOCATIONAL TRAINING.

Exam participation	IT	non-IT	no apprenticeship
yes	60.47%	42.37%	32.66%
no	39.53%	57.63%	67.34%

Furthermore, it is very interesting that in all degree programs, students that specialized on social topics at school, did not participate in the exam. Table IV shows, that the frequency of students who participate in the exam for the group 'Social' is 0%. Whereas the frequency for 'Economics' is 20.59% and for 'Technology' is 40.63%. Among all students participating in the exam of winter semester 2013/14 the frequency was 29.46%.

TABLE IV. FREQUENCY OF THE STUDENTS' PARTICIPATION IN THE FINAL EXAM REGARDING THEIR SPECIALIZATION AT SCHOOL (DATA OF 2013/14).

Exam participation	Social	Technology	Economics	Overall
yes	0.00%	40.63%	20.59%	29.46%
no	100.00%	59.38%	79.41%	70.54%

Beside the exam participation, we also want to examine the attendance at lectures. Therefore, we tracked students in November, after two month of studying. Thereby, we want to find characteristics of students who skip lectures at an early point.

For example, students who attended the lecture in November, where we tracked their attendance, tend to underestimate their competence of abstract thinking at the beginning of their studies (cf. table V). If we additionally look at the students

who underestimated themselves, we see in table VI that these students achieved a high level in the knowledge test compared to other students. That good students underestimate themselves also applies to logical and analytical thinking. However, when looking at this two competencies, the impact on the attendance is not that high.

TABLE V. FREQUENCY OF THE COMPARISON OF SELF-ASSESSMENT AND KNOWLEDGE TEST REGARDING ABSTRACT THINKING COMBINED WITH THE LEVEL STUDENTS ACHIEVED IN THE KNOWLEDGE TEST (DATA OF 2014/15).

Attendance	Comparison self-assessment and knowledge test			Overall
	Correct	Over	Under	
present	53.45%	56.38%	65.98%	59.44%
not present	46.55%	43.62%	34.02%	40.56%

TABLE VI. FREQUENCY OF THE COMPARISON OF SELF-ASSESSMENT AND KNOWLEDGE TEST REGARDING ABSTRACT THINKING COMBINED WITH THE LEVEL STUDENTS ACHIEVED IN THE KNOWLEDGE TEST (DATA OF 2014/15).

Self-assessment	Level of abstract thinking (knowledge test)				Overall
	0	1	2	3	
correct	9.38%	24.62%	30.43%	24.81%	23.29%
overestimated	90.63%	66.15%	43.15%	9.30%	37.75%
underestimated	0.00%	9.23%	26.09%	65.89%	38.96%

This indicates, that abstract thinking is an important competence in computer science and related topics and can not be easily learned beside the studies. Whereas, it seems that logical and analytical thinking can be trained with help of the usual assignments.

Moreover, it shows that good students tend to underestimate themselves. From past teaching experiences, we suspect that self-critical and reflected students perform better than other. Good students still see room for improvement and actively call for feedback during the practical sessions. This assumption is supported by this data.

VII. CONCLUSION AND FUTURE WORK

Experience shows that students in computer science or related topics often encounter problems at the beginning of their studies, due to deficits in those base competencies that are required for dealing with the study process itself, as well as for acquiring complex new knowledge. To pick students up where they are, lecturers need to be aware of their competencies and deficits.

Our first goal was to gain an overview of the students. Thus, each lecturer received a short report containing statistics on personal information, results of the knowledge test and a summary of the cohort's non-technical competencies, compared to the *Model Student*. These cohort-specific reports comprised details similar to those shown in this paper for all the first-year students at Munich University of Applied Sciences in 2013/14 and 2014/15.

Secondly, we wanted to identify similarities and differences among the students with respect to their attendance at one specific lecture as well as the participation in the final exam on Software Development. Correlation analysis using plots, contingency tables and frequencies show that there exist several

attributes that distinguish students who participate in the exam from those who do not. Some of these results were surprising, while others were expected. For instance, it was quite obvious that students who completed a vocational training in the field of computer science prior to their studies would perform better than others that are new in the field. However, an alarming result was that none of the students who specialized on social topics at school participates in the final exam. This evidence suggests that there are certain crucial qualifications which are neither taught to students who focus on social topics at school, nor recapitulated during the first term at university.

After we gained these new insights into our cohorts, we started to include reflection phases into the practical lab sessions. Here, students correct each other's assignments and give hints to improve solutions. Afterwards, each student has to give a short feedback whether he or she accepts the suggestion or not, and why. This enhances the abilities of being self-critical or reflected as well as the ability to scrutinize.

In a next step, we want to analyze the differences of the specializations at school as students who focused on social topics apparently come along with some deficits and knowledge gaps. Subsequently, we can for example design a bridging course or directly address the students' deficits and knowledge gaps in the lectures. Furthermore, we will focus on abstract thinking during our practical sessions, as this skill (or its lack) seems to have a strong impact on the lecture attendance and maybe on the exam participation, too.

The third goal was to build a classifier to forecast the participation in the final exam on Software Development. The data allows us to correctly predict the participation of more than 70% of the students (2013/14). Thus, the tests and questionnaires developed by the research team have a significance for predicting the exam participation. The process of assessing students and analyzing their results indicates which students are at risk not to participate in the final exam.

Furthermore, an alternative to the automatic attribute selection methods of data mining is to select the relevant attributes manually. In this process, decisions are based on a deep understanding of the data. This might increase the accuracy of the prediction model.

All in all we want to continue collecting and analyzing data in the next semesters in order to enrich our data set, to confirm our findings and to reveal new relationships. Concurrently, a portfolio of appropriate interventions can be developed to support students who are at risk of falling behind and never catching up. These interventions should help students to overcome their deficits and to reduce drop-outs. A first evidence is to fortify students' identities and professional skills as engineers [22], [23]. Subsequently, we want to develop an integrated approach to increase retention in our first-year programs, as students are well equipped with those base competencies they need to study successfully.

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What is the Effect of Establishing Programs that Address Sense of Belonging on Undergraduate Engineering Retention?

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Abstract - Research ascribes that a variety of factors (e.g. course load, poor instruction, financial restraints) contribute to students' decisions to change majors and to drop out of college. Less well understood, however, is the influence of a sense of belonging on student persistence, particularly within engineering. Several studies have connected sense of belonging with retention, but few have focused on the relationship between specific programs and longitudinal retention among engineering students. In this study, researchers examined the long-term effects of a suite of strategies designed to enhance a sense of belonging of engineering students.

To evaluate these reforms, an interrupted time series approach was utilized. Fourteen annual cohorts were examined from 1998 through 2013. Trends were first evaluated among the engineering students as a whole, and then by gender and ethnicity. Overall, the rate of retention increased at an average rate of 1.1% per year. Prior to reforms, retention was on the upswing but only at a rate of 0.9% per year. Following the new strategies, this rate nearly doubled to 1.6% per year. Finally, it is noted that the increase in retention occurred alongside an increase in the overall size of the engineering student body.

Keywords – retention, persistence, sense of belonging, co-curricular, student support programs

BACKGROUND/RATIONALE

Recent research has shown that engineering students tend to leave their majors at a rate comparable to other students enrolled in the

humanities, business, and education. Students who are changing majors, however, are then far less likely to select engineering as their next career choice [1]. This relative outflow without a balanced influx has created a high degree of attrition within engineering schools across the country. Possibly, administrators keep this imbalance in mind as universities enroll far more students in their freshman engineering courses than will ever graduate from these programs.

Despite this, nearly all future projections call for an increase in the number of students trained in the STEM (Science, Technology, Engineering, and Mathematics) fields, particularly engineering. Even with this growing spotlight, however, some studies have still shown how the number of students entering college as STEM majors has actually declined in recent years [2]. This issue of low matriculation combined with growing national attention highlights a need to place a higher priority on the retention of enrolled engineering students.

Attrition issues are often ascribed to a variety of factors, including problems with course load, poor instruction in introductory courses, and a student's sense of belonging within the discipline [3,4]. The theoretical works of Spady and Tinto are particularly useful for integrating the idea of a "sense of belonging" and its impact on retention for college-level students [5]. Tinto's model indicates that there are multiple points at which students may "depart," and deselect themselves from a major. This framework highlights that

student retention is related not only to academic integration (e.g., identification as a student, enjoying the subject) but also to social integration (e.g., personal contact with faculty, friends in the major). In this framework, the depth of integration is related to both goal commitment (motivation to earn a selected degree) and institutional commitment (motivation to graduate from a particular institution) [6,7].

Tinto's work further points out how institutional adaptations can promote retention by directly addressing students' academic and social integration. Several studies have connected sense of belonging with retention, but few have focused on the connection between a deliberate development of programs and longitudinal retention among engineering students. And while there exists some prior research into these ideas, most current literature addresses only general retention and fails to be specific enough to examine issues particular to engineering. Relying upon these general trends thus fails to explain why engineering as a discipline experiences this greater level of attrition when compared to other fields. To fill this gap in knowledge the following study focused on the concept of a student's sense of belonging within engineering, as that has been shown to often be one of the best indicators for future success [8,9]. More specifically, it examines whether certain programs designed to promote students' belonging has an effect upon retention within the Ira A. Fulton Schools of Engineering at Arizona State University.

Starting in the late 1990s, the Fulton Schools instituted a variety of strategies with the goal of better addressing the attrition of its engineering students. Examples of these changes included formalizing tutoring opportunities, elucidating programs of study, and adjusting advising procedures. In 2003, the college implemented a significant change by revising the graduation requirements for its programs from 128 credit hours to 120 credit hours. This helped afford students a reduced workload and greater flexibility in their scheduling, making it more feasible for students to graduate within the four-, five-, or six-year tracks. This can be seen in that

(while both figures have risen over time), since 2003 the percentage of students graduating in four years has risen far more dramatically than the percentage of students graduating in six years (Table 1). These reforms were not always implemented simultaneously across the different disciplines, but the college still experienced a substantial growth in its retention rates.

Beginning in 2007, however, a much more concerted effort was made toward advancing retention rates. Prior to this most reforms implemented were programmatic, and were not designed to target a student's sense of belonging. To rectify this, the college instituted a large series of systemic changes to address students' feelings of displacement as first- and second-year engineering students. This new suite of strategies can be further broken down as *Co-Curricular Experiences*, *Course Curricular Experiences*, and *Student Support Programs*.

- *Co-Curricular Experiences* include undergraduate research opportunities, engineering summer camps for freshmen, and professional student societies (often specific to a student's major). The goal of these programs is to have students bond with one another and with faculty outside of the classroom, all the while honing their research and professional skills.
- *Course Curricular Experiences* refer to two mandatory courses all engineering students in the college must take. The first is a student success course taken by all entering university students focused on time-management and study skills. The second is a revised introduction to engineering course designed for first-year students, geared toward problem-solving and team-building tasks.
- *Student Support Programs* are many-fold and include upper-division engineering students serving as peer mentors and undergraduate teaching assistants (UGTAs), supplemental instruction made available through an engineering-specific tutoring center, and a student residential

community wherein all freshmen engineers live together in a centralized, on-campus complex. Together these policies provide physical support and role models for students who may be struggling while also promoting the development of close-knit, supportive cohorts within the greater engineering community.

These different strategies and programs were made available to all Fulton engineering students, across the different degree programs. As was described above, however, many of the strategies specifically targeted underclassmen engineers. This was done in the hopes of reinforcing these students' early sense of belonging within the engineering community, thereby encouraging their retention.

METHODS

An interrupted time series approach was utilized to evaluate the effects of this suite of strategies implemented during the 2007-08 academic year. Both enrollment status and retention data for the entire engineering college were available from 1998 through 2013. A quasi-experimental design was then employed comparing the retention of incoming freshmen engineers from their first semester through to the beginning of their junior year. As a result, in this study being 'retained' was operationally defined as a student who entered into an engineering program and then remained in that program at the two-year mark.

This cutoff was chosen because, at this particular institution history shows that a student who remains in their engineering program for the first two years is then likely to graduate from the college within six years (Table 1). For example, only 50% of the freshmen from the 2007 cohort were retained (still enrolled) in their engineering majors by the fall of 2009. Within this subset that stayed, however, 83.6% (41.8% of the original

class) went on to graduate from the college within six years. The largest drop off in student retention thus occurs early on, making the two-year mark a good testing point for a student's likelihood to persist through to graduation.

This cutoff thus yielded a set of nine pre-intervention two-year cohorts (the 1998 – 2006 freshman classes) that were then compared to five post-intervention cohorts (the 2007 – 2011 freshman classes). Retention trends were first examined for the entire engineering student body. Following this first look, the results were then disaggregated and analyzed by both gender and ethnicity to determine whether these reforms had additional effects on any particular sub-groups.

In order to efficiently address ethnicity, two aggregate ethnic categories were created. The first was comprised of students identifying themselves as either White or Asian/Asian-American. The other category was then comprised of traditionally underrepresented minorities (URMs) within the field of engineering, namely American Indian, Black, and Hispanic students [10]. These categories thus encompass the five groups historically addressed within American higher education research (i.e., Asian, American Indian, Black, Hispanic, and White). While we acknowledge that the experiences of each of these lumped minority groups would be distinct, their small sizes prevent them from being analyzed individually. This classification also filtered out students who did not provide ethnic identification, identified as multiracial, or were listed as international students.

In all cases, retention rate was the relevant measurement. Finally, mean retention rates (i.e., slope) of the different groups were compared and evaluated to determine if change, such as abrupt change or delayed change, had occurred [11].

Table 1: Percent of Student Retained Compared with Percent Graduating in Four and Six Years

Entry Year as Freshmen	Percent of Students Retained at Two Years	Percent of Students Graduating within Four Years	Percent of Students Graduating within Six Years
1998	44.9%	11.0%	34.4%
1999	46.2	9.5	33.6
2000	46.8	11.0	32.7
2001	47.5	9.9	31.6
2002	42.2	12.4	29.8
2003	46.3	11.8	33.8
2004	50.7	18.2	37.9
2005	50.7	15.9	37.6
2006	53.9	24.6	42.5
2007	50.0	26.3	41.8
2008	55.2	31.0	N/A
2009	57.4	32.4	N/A

Table 2: Percent of Students Retained in Engineering Freshmen through Junior Year

Cohort	Overall	Gender		Ethnicity	
		Women	Men	URM	Asian & White
1998-2000	44.9%	39.5%	46.5%	38.5%	46.1%
1999-2001	46.2	48.0	45.6	46.8	45.4
2000-2002	46.8	52.2	45.3	30.2	50.2
2001-2003	47.5	52.8	46.1	42.9	47.2
2002-2004	42.2	40.1	42.6	36.6	42.3
2003-2005	46.3	49.3	45.7	41.8	46.3
2004-2006	50.7	53.7	50.0	45.1	50.4
2005-2007	50.7	46.5	51.7	43.6	51.4
2006-2008	53.9	49.6	54.9	48.5	55.4
2007-2009	50.0	54.2	49.0	37.8	52.7
2008-2010	55.2	53.5	55.6	49.8	56.0
2009-2011	57.4	55.9	57.8	48.0	59.8
2010-2012	57.5	58.9	57.2	53.1	57.1
2011-2013	56.9	54.5	57.5	42.7	58.9

RESULTS

There was a clear, overall 14-year upward trend in the proportion of freshmen engineering students who persisted in their program through to the start of their junior year (Table 2). Interestingly, this growth is found both before and after the introduction of the new strategies in 2007.

Over the 14 year period, retention rate (as modeled by linear regression) increased at an average rate of 1.1% per year (Figure 1). Breaking apart of the timeline, however, produces some more interesting results. Prior to the new wave of reforms, for example, this increase in freshmen persisting until their junior year was only 0.9% per year (Figure 2). With the addition of the new programs, however, the average retention increase then jumps to 1.6% per year (Figure 3). This jump occurred while the incoming freshman class simultaneously increased from an average of 774 to 957 students. Part of this observed increase, however, can also be attributed to a drop in the retention of the 2007 cohort (50.0%), allowing the trend line to slope higher for the subsequent years as it jumped back up. Overall though, these new strategies appear to be successful in helping to retain a growing percentage of a growing number of students.

Figure 1: Overall Percent of Engineering Freshman Retained

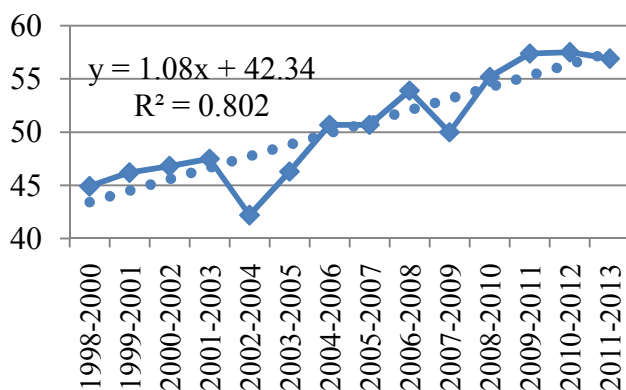


Figure 2: Percent Retained Pre-2007

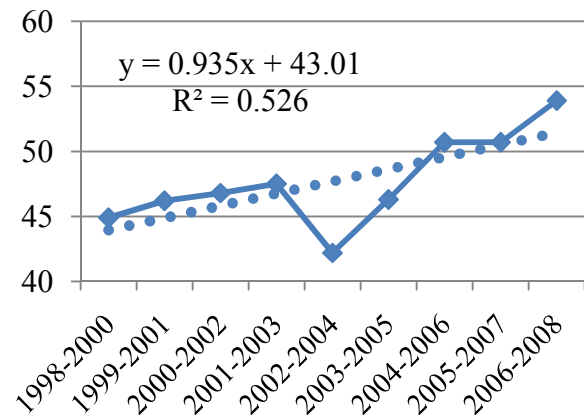
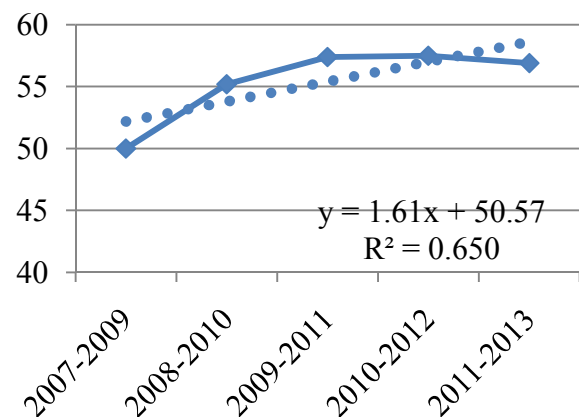


Figure 3: Percent Retained Post-2007



Examination of data based on gender indicates that overall retention rates similarly rose over time for both male and female students (Figures 4 & 5). Examining before and after, however, reveals that these strategies seem to have affected the two groups differently. There is a noticeable jump in the rate of retention of male students following the introduction of these new programs – 1.0% to 1.9% per year. The strategies, however, seem to have had minimal effect on furthering a retention rate increase for female students, as that trend remained level at 0.6% per year.

Figure 4: Percent of Men and Women Retained Pre-2007

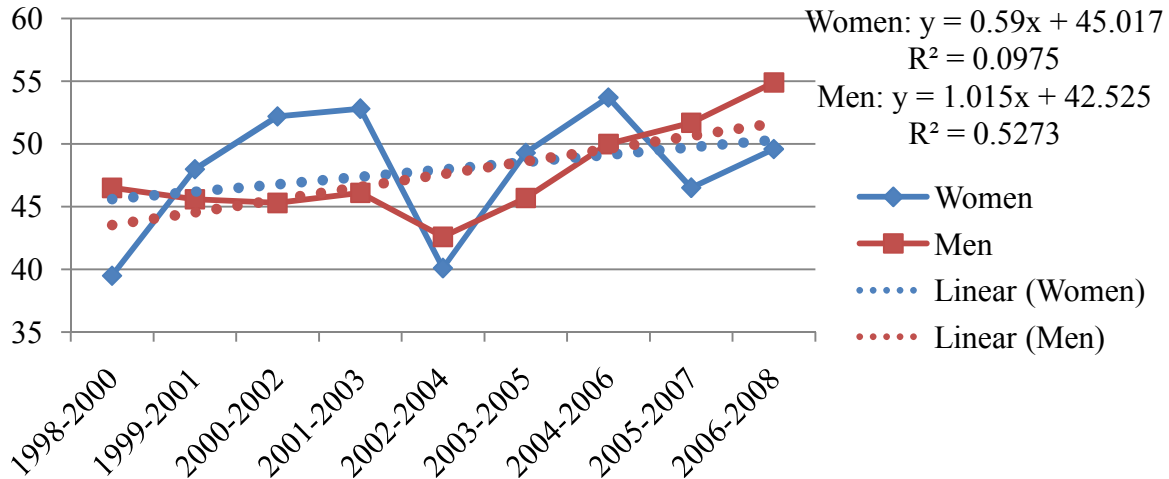
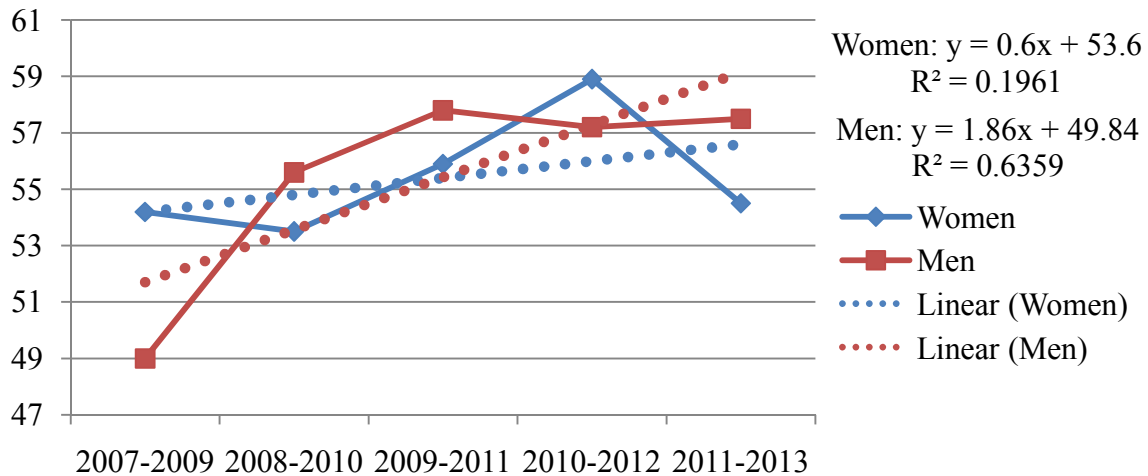


Figure 5: Percent of Men and Women Retained Post-2007



Similarly, the retention rates for URMs (underrepresented minorities) along with Asian and White students continued to exhibit an overall upward trend (Figures 6 & 7). Both of these categories saw incremental jumps in their retention rates following 2007 – from 1.0% to 1.3% for URMs and from 0.9% to 1.4% for Asian and White students. Despite this, it is also worth

noting that the retention rate for Asian and White students was almost universally higher than that of URM students (the 1999 cohort presents the only exception). This consistent gap (not found in the gender breakdown) highlights the need to develop further programs that will target the retention of specific groups of students, in order to better balance retention of the different groups.

Figure 6. Percent of Ethnic Groups Retained Pre-2007

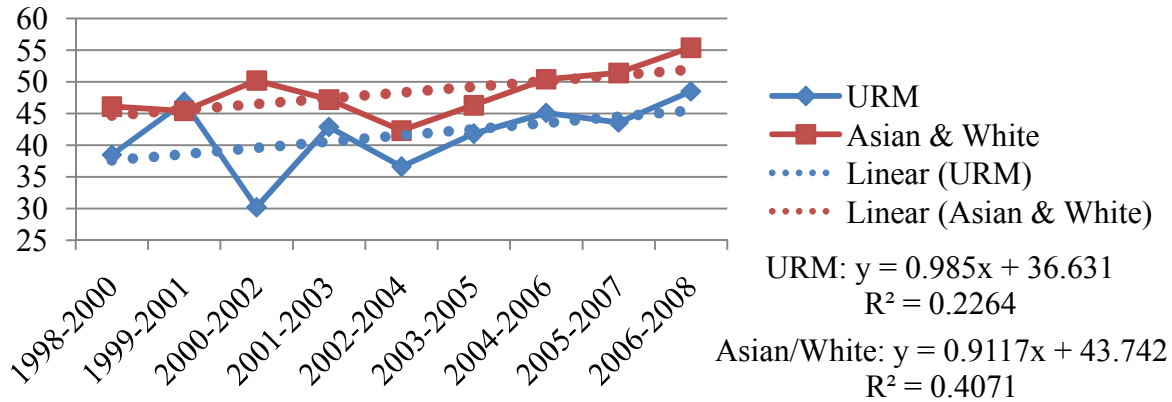
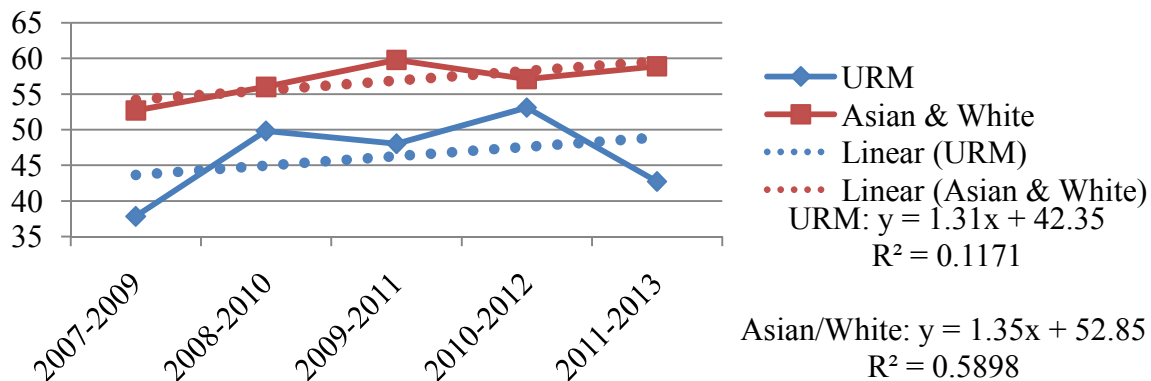


Figure 7. Percent of Ethnic Groups Retained Post-2007



CONCLUSIONS

In reviewing the results of the program, it's important to bear in mind that these new strategies were not created to address a lagging retention rate. On the contrary, these reforms targeting students' belonging were launched while retention rates had already been experiencing an overall steady increase for nearly a decade. Instead, the concern expressed from the Fulton schools was centered on the fear that retention would soon reach a ceiling, if not decline. Keeping this idea in mind then, a linear progression toward 100% retention was not the goal of these new strategies. Instead, the objective was to maintain momentum in retention by

promoting and supporting students' belonging as engineering students.

As a result, analysis of these data is somewhat inconclusive. While we can say that the retention rates did experience substantial change overall, the initiation year of the interventions (i.e., 2007) did not result in a clear spline, knot, or polynomial transition for all of the various subgroups. Instead, results are mixed across the different populations, notably seeming to have had a larger positive impact on the retention of males than it did for females. These new strategies also failed to bridge the retention gap observed between White and Asian students and URM students, though it's important to note that doing so

was not the purpose of these reforms. Overall then, this study highlights the overall success of the integration of these new strategies. At the same time, however, it also opens the door into possible future research topics further investigating the differentiated effects among subgroups.

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Grit for Engineering Students

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Abstract— Studies suggest that students' attitudes toward engineering courses may determine whether they persist in engineering, rather than academic performance alone. We take a mixed-methods approach to explore gritty attitudes and to confirm whether previous research on grit can be applied to undergraduate engineering students. We address two main research questions: (1) Does the grit scale predict retention among first-year undergraduate engineering students? (2) What does grit specifically look like for engineering students? To answer the first question, we invited all first-year engineering students at one university to complete the grit scale during Fall 2014. We will check whether the scores on the grit scale correlate positively with retention in engineering. To answer the second question, we invited all students who were persisting in engineering after having earned a D or an F grade in a required technical course to participate in a semi-structured interview. We hope to capture how these engineering students respond to academic setbacks and what they believe about effort, perseverance, and academic success.

Keywords—grit; retention; mindsets; academic motivation

I. INTRODUCTION

In the United States, engineering programs suffer high rates of attrition. Among students who start as freshmen in engineering, only 57% complete baccalaureate degrees in engineering [1]. Numerous studies (for example, see [2]) have identified reasons for attrition from engineering. These studies suggest that students' attitudes toward engineering courses may determine whether they persist, rather than academic performance alone. In this study, we explore how gritty attitudes play a role in the retention of engineering students. Grit is defined as the perseverance and passion for long-term goals [3]. To measure grit, Duckworth et al. [3] devised a grit scale, which was revised by Duckworth and Quinn [4]. Each item is scored on a 5-point Likert scale, then all items are summed and divided by the number of items to produce the grit score. Therefore, a grit score of 5 would describe a very gritty person while a grit score of 1 would describe a person as not gritty at all. The grit scale predicted the retention of freshmen cadets at the U.S. Military Academy (West Point) better than a combination of admission scores, including GPA [3][4].

We address two main research questions: (1) Does the grit scale predict retention among first-year undergraduate engineering students? (2) What does grit specifically look like for engineering students? The results of this study will determine whether previous findings about the grit concept and the grit scale can be applied to engineering students in college,

who differ significantly from previous populations with which the scale has been tested. The results may also help identify engineering students who may be more likely to drop out and inform the ways in which educators can advise at-risk students.

II. ADMINISTERING THE GRIT SCALE

A. Participants

In the middle of the Fall 2014 semester, all engineering freshmen at a public university in the Midwest were invited to complete the grit scale [3] through an online survey, including demographic information. The invitation email was sent through the engineering orientation course that all first-year engineering students were required to take. No form of compensation was offered for completing the grit survey.

B. Preliminary Results

Out of roughly 1600 first-year engineering students, 310 students completed the survey, a response rate of about 19%. Table I compares the demographic characteristics of the survey respondents with the demographics of the undergraduate engineering population. Female and domestic students were slightly overrepresented among survey respondents.

The results of the grit scores are shown in Table II. Students were given the option not to disclose their ethnicity. Non-Hispanic Whites seemed to have the highest average grit score at 3.49, while Asians or Asian Americans had the lowest

TABLE I. DEMOGRAPHIC COMPARISON

<i>Demographic Category</i>	<i>Survey Results</i>	<i>Undergraduates in Engineering</i>
Male	69%	83%
Female	30%	17%
Domestic	83%	76%
International	17%	24%
Non-Hispanic White	60%	58%
Asian or Asian American	24%	28%
Black or African American	1%	2%
Hispanic or Latino American	5%	7%
Other or Mixed	5%	4%
Undisclosed Ethnicity	5%	1%

TABLE II. GRIT SCORE RESULTS

<i>Demographic Category</i>	<i>Sample Size</i>	<i>Mean</i>	<i>Standard Deviation</i>
Total	310	3.42	0.52
Male	214	3.40	0.52
Female	93	3.47	0.50
Domestic	257	3.43	0.53
International	53	3.39	0.44
Non-Hispanic White	155	3.49	0.50
Asian or Asian American	61	3.31	0.55
Black or African American	3	3.44	0.27
Hispanic or Latino American	12	3.41	0.65
Other or Mixed	14	3.48	0.54
Undisclosed Ethnicity	12	3.10	0.64

average grit score at 3.31. Our total average grit score of 3.42 was a bit lower than the engineering freshmen cohort at Northeastern University [5], whose average grit score was 3.55. However, the student population at Northeastern was very different from our study's population. At the end of the academic year, we will collect retention data and correlate grit scores with retention, using binary logistic regression. We expect to see a positive correlation similar to the results for the freshmen cadets at West Point [3].

C. Preliminary Statistical Analysis

Using the statistical software package R, we determined that the following categories did not pass the Shapiro-Wilks test for normality: Total, Male, Domestic, and Non-Hispanic White. As a result, we used non-parametric tests to compare grit scores. We chose the standard 0.05 threshold for statistical significance. According to the Mann-Whitney-Wilcoxon test, there was no significant difference between Male and Female populations ($p = 0.49$) nor between Domestic and International populations ($p = 0.44$), but amongst the ethnicities, there was a significant difference between Non-Hispanic Whites and Asian or Asian Americans ($U = 3750$, $p = 0.018$, rank-biserial correlation = 0.21). The Kruskal-Wallis test showed that there was no significance difference between ethnicities as a whole ($\chi^2(4) = 5.479$, $p = 0.24$). No tests were conducted using the Undisclosed Ethnicity category.

III. CONDUCTING SEMI-STRUCTURED INTERVIEWS

A. Purpose

Duckworth [3] describes gritty behavior as “working strenuously toward challenges, maintaining effort and interest over years despite failure, adversity, and plateaus in progress.” As engineering is a challenging major, many students often find themselves having difficulty in college even when they had performed well in high school. Some students respond better to poor academic performance than others. We used semi-structured interviews to explore this gritty phenomenon and focused on engineering students persisting in their major.

B. Participants and Procedure

In the Spring 2015 semester, all undergraduate engineering students at a public Midwestern university were invited to participate in a one-hour, semi-structured interview. The recruitment email specifically invited students who were persisting in engineering after having earned a D or an F grade in a required physics, math, computer science, or engineering course. We thought that this particular population would be information rich in helping us understand the variety of ways students dealt with poor performance in a required course.

The interview questions asked students how they responded to poor exam grades or failing a class, what strategies they would take to succeed in challenging classes, and how they defined success and failure. The questions were designed to understand failure from the student's point of view and see how their interpretations of failure helped them persist.

There were 26 interview participants total, from freshmen to seniors, ranging in years and majors. The interview data are still being analyzed. Our analysis of the interview data will use Dweck's theory of growth and fixed mindsets because interventions designed to change students' mindsets seem to promote gritty behavior [6]. Through our analysis, we want to see how these mindsets align with gritty students. We will use phenomenography to describe the variety of ways engineering students respond to failure. We chose phenomenography because the ways in which students respond to academic setbacks vary and we were interested in how students' perception of their failures influence their realities [7]. We will follow the standard thematic analysis methodology to construct categories of students' responses to failure based on mindsets, attitudes, and success strategies. We will use the results to inform interventions aimed at improving retention by motivating undergraduate engineering students to succeed even after experiencing academic failures.

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Measuring Student Integration and Institutional Support

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Abstract—Engineering is a demanding discipline and otherwise qualified students often take their talents elsewhere—either before earning a Bachelor’s degree or shortly thereafter. As a result, engineering educators must provide students with adequate support to increase the chances of students successfully integrating into the field of engineering. However, little is known about the relationship between *Institutional Support* and *Student Integration* or how each construct influences the retention or early-career decision-making of engineering students. Drawing on the Model of Co-curricular Support, the purpose of this paper is to describe current efforts to develop survey instruments that can be used to investigate how undergraduate engineering students rate themselves on *Institutional Support* and *Student Integration*, paying close attention to gender and race/ethnicity. Survey instruments that are valid and reliable within this context would be useful for assessing the impact of student interventions.

Keywords—retention; student support; diversity; integration

I. INTRODUCTION

Engineering is a demanding discipline and otherwise qualified students often take their talents elsewhere—either before earning a Bachelor’s degree or shortly thereafter. As a result, engineering educators must provide undergraduate students with adequate institutional support to increase the chances of students successfully integrating into the field of engineering. Towards this effort, considerable resources have been allocated to institutional practices intended to support undergraduate engineering students, particularly those from underrepresented population. However, little is known about the relationship between *Institutional Support* and *Student Integration* or how each construct influences the retention or early-career decision-making of engineering students. Grounded in the recently developed Model of Co-curricular Support (MCCS) [1], this research posits that students who receive sufficient *Institutional Support* and achieve *Student Integration* may be more readily retained and more likely to pursue engineering-related careers. We selected these constructs because they represent the outputs—or student experiences—associated with co-curricular interventions from the perspective of student-support practitioners (*Institutional Support*) and the medium-term outcomes associated with students who receive said support (*Student Integration*). While developed on the foundation of Tinto’s Model of Institutional Departure [2], the predictive/explanatory power of the MCCS has not yet been explored and, thus, the development

of survey instruments that can be administered to undergraduate engineering students are necessary. The specific changes made to Tinto’s Model are detailed elsewhere [1]. At a high level overview, changes included expanding the model to incorporate the broader intentions of student-support practitioners, subtracting constructs from Tinto’s Model that were not appropriate for this particular application, and aligning the longitudinal sequence of Tinto’s Model with the naming convention of logic models.

The purpose of this work-in-progress is to describe our current efforts to develop survey instruments to be administered to undergraduate engineering students that can be used to investigate the level of *Institutional Support* and *Student Integration* received and achieved by undergraduate engineering students, paying close attention to gender and race/ethnicity. While *Institutional Support* and *Student Integration* are easily understood in abstraction, little, if any, consistency exists in the current literature with regard to operationalizing these constructs in the context of undergraduate engineering education. Understanding the influence that these constructs have on student retention and early-career decision-making will assist the engineering education community with ensuring that all undergraduate students are sufficiently supported and increasing the likelihood of them selecting engineering-related careers after successful matriculation. To address this purpose, our work is guided by the following research question: What aspects of the undergraduate experience should be included in instruments to measure *Institutional Support* and *Student Integration* in the context of undergraduate engineering? Answering this question will enable us to develop instruments that are valid and reliable within the context of engineering to measure *Institutional Support* and *Student Integration*. Such instruments will be useful in assessing current and developing future support interventions aimed at promoting integration.

Through this research, we will develop measurable definitions of four integration constructs: (1) *Academic Integration*, (2) *Social Integration*, (3) *Professional Integration*, and (4) *University Integration*. We will also provide definitions of six support constructs: (1) *Academic Performance*, (2) *Faculty/Staff Interactions*, (3) *Extracurricular Involvement*, (4) *Peer-group Interactions*, (5) *Professional Development*, and (6) *Additional Circumstances*. Clearly defining each construct is an

important first step in evaluating current efforts geared towards supporting students. Since there has been minimal research in engineering education regarding the measurement of these constructs, this research fills a notable gap by examining the impact support provided by engineering colleges can have on students, particularly those from underrepresented populations. This work is a part of the lead author's long-term research plans, and it is directly geared towards student-support practitioners, administrators, and engineering education researchers interested in inclusion, retention, and diversity in engineering.

II. OVERALL RESEARCH PROJECT

This work-in-progress is a part of a larger study exploring the appropriateness of Tinto's Model of Institutional Departure [2] with regard to co-curricular support in engineering. By examining six Engineering Student Support Centers (ESSCs) of varying classifications, the larger study investigated whether or not each construct outlined in Tinto's Model encompasses the components of integration considered in undergraduate engineering education and the areas of institutional support commonly provided alongside undergraduate engineering programs. So far this larger project has yielded the Model of Co-curricular Support [1], which is a repurposed version of Tinto's Longitudinal Model of Institutional Departure [2] that was developed throughout the phases of the overall research project. The Model of Co-curricular Support posits that students who receive more comprehensive institutional support will more thoroughly integrate and subsequently are more likely to be successful undergraduate engineering students.

We are currently using a subset of the data from the larger study to develop survey instruments that can be used to measure levels of *Institutional Support* and *Student Integration*. The development of the survey instruments will be carried out in seven steps, following best practices as defined by Gall et al [3]:

1. *Clearly define the construct of interest.*
2. *Define the target population.*
3. *Review related surveys to generate ideas regarding format and validity.*
4. *Develop the prototype of the survey instrument.*
5. *Evaluate the prototype.*
6. *Revise test based on suggestions.*
7. *Collect data to determine test validity and reliability.*

The developed survey instruments will be grounded in the Model of Co-curricular Support [1].

III. METHODOLOGY

The methods described in this work-in-progress were completed to clearly define *Institutional Support* and *Student Integration* and to collect data to generate items that could be used to develop the prototype of the survey instruments to measure these constructs. This involved analyzing interviews conducted with student-support

practitioners tasked with serving these populations and open-ended surveys completed by undergraduate engineering students.

During the overall research project, we interviewed 17 student-support practitioners across six student support centers housed at four institutions to identify and categorize existing institutional practices for providing undergraduate students (particularly those from groups traditionally underrepresented in engineering) with co-curricular support. We used semi-structured interviews [4] to ask these practitioners about the programs, activities, and services provided by their respective support system. We reviewed the particulars of each intervention in search of underlying themes that would provide insight with regard to *Institutional Support* and *Student Integration*. To analyze the interviews, we used a priori codes [4] grounded in Tinto's Model to categorize the outputs of the institutional efforts in distinct areas (e.g., *Academic Performance*) and open codes [4] to identify emergent themes (i.e., categories) within each of the areas (e.g., the *Academic Performance* areas contains *Academic Information*, *Academic Resources*, *Academic Monitoring*, *Transferrable Student Skills*, and *Course Preparation*). We completed this process to modify Tinto's Model in a way that encompasses the retention-related institutional practices used in undergraduate engineering education and to operationalize the subsequent constructs. Tinto's Model provided four areas in which we anticipated finding outputs geared towards: (1) *Academic Performance*, (2) *Faculty/Staff Interactions*, (3) *Extracurricular Involvement*, and (4) *Peer-group Interaction*. In developing the MCCS, we confirmed the inclusion of these areas and expanded the model to also include (5) *Professional Development* and (6) *Additional Circumstances*. Open coding was used to identify emergent themes within each of these six areas.

We also distributed open-ended surveys to students to solicit feedback with regard to the isolated experiences of students served by each support system. We asked students to indicate whether the support system at their institution had positively, negatively, or not influenced them with regard to each of the following: (1) interactions with engineering faculty and staff; (2) interactions with other students; (3) academic performance; (4) participation in extracurricular activities; and (5) professional development. To analyze the open-ended responses, we reduced the data through the process of unitizing; this involved dividing data chunks into single concept coding units that could be further analyzed and compared [5]. The process of unitizing included dividing multi-concept original responses into multiple unitized statements and combining single-concept original responses that included the same concept into a single representative unitized statement. In instances where a single-concept original statement was unique, the response was reduced to a single unitized statement as well. In total, this process resulted in a list of unitized statements that represented the original responses provided by students across ESSCs. Some examples are shown in Table 1. We

completed this process to triangulate the data collected from practitioners with the student perspective and to develop single-concept statements that could potentially be used to develop prototypes of the survey instruments to measure the constructs of interest. Specifically, triangulation included using the emergent themes within five of the six a priori categories to map each unitized statement to emergent themes previously identified. We did not use *Additional Circumstances* because this output area/theme was emergent and students were not asked specifically about this area in the open-ended survey.

Table 1 - Unitizing Example

Original Response	Unitized Statements
“[ESSC] helps me study because I have study partners. It helps me understand concepts because of the wealth of upperclassman knowledge.”	I had an easier time forming study groups and finding people to work with academically.
	I had access to students whom I could ask for academic assistance.
“The [learning community] academic events definitely had a positive influence on my grades last semester.”	“I received academic assistance at the help sessions I attended.”
“The exam reviews are helpful.”	

IV. CURRENT STATUS/PRELIMINARY FINDINGS

The results from clearly defining the constructs of interest are below. In total, we divided *Student Integration* into four constructs, each with a specific definition that is listed in Table 2. We divided *Institutional Support* into six constructs, each with a specific definition that is listed in Table 3. In addition to the constructs outlined in Table 2 and Table 3, we developed a list of unitized statements for each of the constructs except *university integration* and *additional circumstances*, which emerged following the open-ended survey being deployed and as a result were not included during the initial phases of the larger study. Examples of these statements are listed in Tables 4-5.

Table 2 - Student Integration Constructs

Construct	Definition
Academic Integration	Student having a positive perception with regard to intellectual fit (i.e., access and support) and sufficient interactions within the formal and informal academic systems of an engineering college and is most directly impacted by their academic performance and faculty/staff interactions.
Social Integration	Student having a positive perception with regard to social fit (i.e., access and support) and sufficient interactions within the formal and informal social systems of an engineering college and is most directly impacted by their extracurricular involvement and peer-group interactions.
Professional Integration	Student having a positive perception with regard to professional fit (i.e., access, support, and characteristics) and sufficient interactions within the formal and informal professional systems of an engineering college and is most directly impacted by their professional development.
University Integration	Student having a positive perception with regard to institutional fit (i.e., access, support) and sufficient interactions within the formal and informal university systems surrounding an engineering college and is most directly impacted by their personal and financial experiences at the university level.

Table 3 - Institutional Support Constructs

Construct	Definition
Academic Performance	Institutional support geared towards disseminating information related to improving academic performance or circumstances, providing access to resources that support academic performance, monitoring academic performance or development, or contributing to the development of content-independent and content-dependent skills that contribute to academic performance.
Faculty/Staff Interactions	Institutional support geared towards disseminating information related to interacting with faculty or staff, increasing the quantity of interactions students have with faculty or staff, and helping student establish informal or formal relationships with faculty or staff.
Extracurricular Involvement	Institutional support geared towards disseminating information related to improving or increasing extracurricular involvement and providing students with extracurricular opportunities.
Peer-group Interactions	Institutional support geared towards disseminating information related to students interacting with other students, increasing the quantity of interactions that students have with other students outside of the classroom, or grouping students based on some part of their identity or academic circumstances.
Professional Development	Institutional support geared towards developing industry-independent skills that contribute to obtaining employment or admittance; disseminating information related to career opportunities via an undergraduate degree in engineering; providing work experience that contributes to the professional development of students via employment; providing access to role models along different career trajectories; or developing industry-independent skills that contribute to successful professional performance.
Additional Circumstances	Institutional support geared towards acclimating students into the university environment; facilitating access to financial assistance; publically acknowledging the successes of students; or discussing life as an underrepresented engineering student.

Table 4 - Student Integration Statement Examples

Construct	Unitized Statements
Academic Integration	I can effectively approach engineering problems.
	I can manage the academic workload.
	I can effectively prepare for engineering exams.
Social Integration	I can actively participate in a student organization.
	I can positively interact with other engineering students.
	I understand the importance of extracurricular activities.
Professional Integration	I can communicate in a professional manner.
	I can network professionally.
	I have leadership skills that will be useful as an engineer.

Table 5 - Institutional Support Statement Examples

Construct	Unitized Statements
Academic Performance	I received academic assistance from tutors/mentors.
	I had access to a positive learning environment.
	I received advice on how to manage my time better.
Faculty/Staff Interactions	I was encouraged to interact with engineering faculty.
	I had the opportunity to network with engr. faculty.
	I have become more familiar with engr. professors.
Extracurricular Involvement	I was encouraged to become involved in the community.
	I had the opportunity to be involved in many activities.
	I was more aware of the opportunities at the university.
Peer-group Interactions	I had the opportunity to develop social skills.
	I met engineering students that shared my interest.
	I met upper-class engineering students in my major.
Professional Development	I received assistance with developing a resume.
	I talked to engineers about their career paths.
	I receive professional guidance/advice.

V. FUTURE WORK

Our preliminary findings provide clear definitions for the constructs of interest, define the target population, and lay the foundation for developing prototypes of the survey instruments. In the next phase of this process, we are developing surveys to be evaluated and revised. The surveys will include questions geared towards each of the constructs previously discussed. Once the survey is revised, we will collect data to determine validity and reliability.

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Recruiting, retaining and transitioning computing undergraduates the STAIRSTEP way

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Abstract— Lamar University's Students Advancing through Involvement in Research Student Talent Expansion Program is designed to recruit, retain and transition undergraduates in five Science, Technology, Engineering and Mathematics disciplines. The program was supported by a five-year grant from the National Science Foundation that started in 2009 and is currently supported by the university. This paper focuses on the computer science arm of the program. During the five years of National Science Foundation support, 100 percent of participants in STAIRSTEP Computer Science were retained as majors. Their grades in major courses were consistently higher and drop rates consistently lower than cohorts of students from the five-year period prior to inception of the program. Incoming enrollments in the Computer Science Department grew dramatically, as did undergraduate majors and degrees awarded. This paper briefly describes the strategies used in the STAIRSTEP model and describes in detail how activities supporting the strategies were implemented in the Computer Science Department. A formal assessment documents the positive impact that the program has had on the department and its students. The paper includes suggestions for others who may want to adopt these methods and discusses successes and challenges in sustaining the program in the absence of external support.

Keywords—broadening participation, retention, undergraduate research

I. INTRODUCTION

Lamar University's Students Advancing through Involvement in Research Student Talent Expansion Program (STAIRSTEP) is designed to recruit, retain and transition undergraduates in computer science and four other Science, Technology, Engineering and Mathematics (STEM) disciplines. The program was supported by a five-year grant from the National Science Foundation that started in 2009 and is currently supported by the university. Over its five-year span, the STAIRSTEP disciplines as a whole experienced a dramatic increase in the number of undergraduate majors and incoming students, and the program has been very successful in helping students to make the transition to the STEM workforce or graduate study. It received a 2013 Star Award from the Texas Higher Education Coordinating Board for exceptional contributions to closing the gaps in higher education in Texas.

An earlier paper described the STAIRSTEP model and the accomplishments of the program as a whole. [1]. This paper focuses on the computer science arm of the project, which has exceeded all of the program goals. Section II describes the need for this type of program in computer science. Section III briefly describes the model, its goals and strategies. Section IV describes how activities supporting the strategies were implemented in the Computer Science Department. Section V presents the results of a formal assessment that documents the positive impact that the program has had on the department and its students. Section VI presents suggestions for others who may want to adopt these methods in their institution. Section VII discusses successes and challenges in sustaining the program in the absence of external support.

II. MOTIVATION

The United States President's Council of Advisors on Science and Technology 2012 Report [2] indicates a need to produce a million more college graduates in STEM fields in general by 2022 and notes that fewer than 40% of students who enter as majors in STEM fields complete a degree in STEM. There is also a shortage in STEM professionals in other countries, including the UK, Germany, Austria, Belgium and Poland [3].

It is especially important to produce more Computer Science graduates because computing careers are predicted to be among the fastest growing in the next decade, while current degree production is much lower than it was a decade ago. Between 2012 and 2022, U.S. jobs for software developers are predicted to grow by 22%; computer systems analyst positions by 25%; and positions in information security will increase by 37% [4]. The 2014 National Science Board's Science and Engineering Indicators [5] shows that the number of bachelor's degrees granted in computer sciences dropped dramatically from 2004 to 2009, rose in 2010 and 2011 but still has not reached its 2004 level.

III. THE STAIRSTEP MODEL, GOALS, STRATEGIES

STAIRSTEP implements best practices for increasing participation in STEM in an innovative way. The program engages undergraduates in an enriched team research experience that includes faculty and peer mentoring, tutoring and other support. Small teams of undergraduates are paid a competitive stipend to participate in team research, outreach

and transitioning activities for an average of 10 hours a week under the direction of a faculty mentor in their discipline. Teams can include students from all levels, freshmen through seniors. Graduate students can help lead the teams. The more advanced students mentor, tutor and train the less experienced students.

STAIRSTEP targets talented ‘at risk’ students, including low income, first generation, and/or underrepresented students who face social and economic challenges that can make it difficult for them to progress to graduation. Students apply to participate and are selected based on their grades, income, first generation status, race, ethnicity, letter of interest, and letters of reference. Students can participate for multiple years, as long as they participate fully and maintain at least a B average in their major courses and a 2.5/4.0 overall grade point average (GPA). Faculty mentors receive one course release time for each long semester of participation.

STAIRSTEP’s innovation lies in the scope of students served (freshmen through senior), the breadth of activities (research, outreach and transitioning) and the multidisciplinary approach (computer science and four other STEM disciplines targeted). More details can be found in [1].

The program’s goals are as follows:

1. Retaining students: at least 70% of program participants will be retained in their STEM major.
2. Transitioning students: at least 80% of graduating student participants will be transitioned to careers or advanced study in STEM within 6 months of graduation.
3. Recruiting students: incoming freshmen will increase by 5% a year starting in year 2; and incoming community college transfers will increase by 20% starting in year 2.

The program uses the following strategies for retaining and transitioning students.

- Engage students in team research with tutoring, mentoring, and peer support.
- Dispel misconceptions that discourage participation in STEM.
- Use institutional relationships to help students bridge to the next level.

The program’s strategy for increasing incoming students is as follows:

- Engage STAIRSTEP undergraduates in team outreach to high school, community college and university students

This paper focuses on how activities supporting these strategies were implemented and results achieved in the Computer Science arm of STAIRSTEP. STAIRSTEP CS activities are similar to the Students & Technology in Academics, Research and Service (STARS) program at the University of North Carolina at Charlotte, a broadening participation in computing project that offers a wide range of student support, engaging students in selected research outreach or service activities [6]. STAIRSTEP students are

engaged in both outreach and research activities, as well as peer tutoring and mentoring and transitioning activities. This range of services is broader than that offered by STARS and helps students develop a wider range of professional and interpersonal skills that are needed throughout the continuum from entry to career transition.

IV. IMPLEMENTATION OF STAIRSTEP STRATEGIES IN COMPUTER SCIENCE

A. *Engage students in team research with tutoring, mentoring, and peer support*

STAIRSTEP engages undergraduates in research that is beneficial, engaging, and accessible while building upon the expertise of the faculty mentor. The first author is the faculty mentor for the Computer Science team. The team engages in research in computer science education, robotics, and machine learning. Students who enter the program as freshmen typically start in computer science education research and can progress to research in either robotics or machine learning.

Computer science education research involves developing engaging instructional materials that can be used to increase high school students’ computing knowledge and interest. Even first semester freshmen can engage in this research. Participation in this research strengthens the understanding and skills of the undergraduate researchers, who must learn to articulate their knowledge correctly and clearly. The materials are used in hands-on workshops with students from local schools, and formal assessments document the effectiveness of the approach. The undergraduates are instructors in the hands-on workshops, which increases their communication and teaching skills. These events also improve the students’ organizational and teamwork skills. The undergraduates present their research at local and regional conferences. Two teams have won awards for their research presentations [7, 8].

The robotics research centers on developing autonomous robots. Robots are attractive to students, and research in robotics reinforces concepts in software engineering, artificial intelligence, computer networks, architecture, operating systems, and other areas. Past work includes designing and implementing a system that allows a resource limited robot to use the services of a remotely located planner. This work won third place in an international student research competition [9]. Current work centers on using machine learning techniques to enable a robot to learn its tasks [10].

The machine learning research centers on improving the performance of various learning algorithms. Machine learning is a very popular research area because students know that it is being used by big firms like Google, Microsoft, IBM, Disney, and others and is being applied in search engines, recommender systems, games, and many areas that affect our everyday lives. Typically, participating juniors and seniors who have taken coursework in machine learning can select to engage in this research. Because the machine learning course was introduced in 2013, relatively little has been done thus far [11]. The undergraduates work with graduate students who are performing theses in this area under the direction of the faculty

mentor. Current work focuses on improving the performance of a neural network learning algorithm [12].

Teamwork and peer instruction are critical to this research. In many cases, students are exposed to concepts in the lab that they have not yet encountered in the classroom. The more experienced students help train and lead the less experienced. This reduces the burden on the faculty mentor, who would otherwise have to teach each member individually. Over time the students progress from team member to team leader as they grow in experience and confidence. This also gives all the students valuable experience in communication and teamwork, critical skills that are highly valued by computing employers. Working in teams toward common goals also helps develop a sense of community and belonging among the members.

The faculty mentor not only leads the team in STAIRSTEP research but also encourages eligible members to participate in other research programs both on and off campus. Several of our undergraduates have participated in the McNair Scholars program, which is designed to encourage underrepresented low income students to progress to graduate school; and the ASCENT program, which provides support for juniors and seniors to enable them to complete their degrees in a timely fashion. One team member participated in a Research Experience for Undergraduates (REU) in robotics at Texas A&M.

Team members tutor each other in computing and other courses, and the students often form study groups. Team members also tutor other Computer Science majors in computing courses, and typically one or two STAIRSTEP undergraduates help students in the hands-on programming labs in the first two introductory programming classes. Their involvement in these freshman labs has helped to increase the program's visibility and recruit new students into the program.

The Computer Science STAIRSTEP teams have ranged in size from 3 to 8 students. During the five years and eight months of NSF support, eighteen percent of CS STAIRSTEP participants had overall GPAs 3.5 or above (on a scale of 4.0). Fifty-eight percent had a GPA between 3.0 and 3.49. Twenty-four percent had GPAs between 2.5 and 2.9. Most started as freshmen or sophomores. This sets STAIRSTEP research apart from other undergraduate research programs, which typically target juniors and seniors with high grade point averages [13].

Computer Science STAIRSTEP participants include freshmen through seniors and graduate students. This facilitates the peer instruction model and provides peer mentoring, tutoring and community building to undergraduates at each level. This model provides a way to include undergraduates in research during their freshman and sophomore years, when retention is most at risk; and to broaden the base of undergraduate researchers to include students whose grades are not the highest.

B. Dispel misconceptions that discourage participation

Females and underrepresented minorities are in general underrepresented in STEM. Computer science degrees awarded to women has seen a decline in recent years, with only 11.7% of degrees awarded to women in 2010-2011 [14]. Of the

2012 entering freshman population, only 1.4% of females, 3.2% of African Americans, 2.9% of Hispanics/Latinos, and 0.8% of American Indians or Alaska Natives indicated an intention to major in computer science [15]. The lack of role models and the stereotype of the computer scientist with no social skills who works alone with his machine create the misconception that computing is a non-inclusive and socially isolating field, which makes it unappealing to women and minorities.

To help dispel these misconceptions, STAIRSTEP hosts Research Seminars and Career Forums. Research Seminars bring renowned researchers to campus and expose students to current STEM research and successful STEM researchers. Career Forums host successful practicing professionals and expose students to career opportunities in STEM. Wherever possible we include as our guest speakers females and underrepresented minorities and give our students face time with these successful role models. During its first three years, STAIRSTEP CS partnered with Lamar University's Increasing Student Participation in Research Development (INSPIRED) Program in co-hosting its Research Seminars and Career Forums. INSPIRED was a National Science Foundation Broadening Participation in Computing project that was directed by the first author [16].

The Computer Science arm of STAIRSTEP has hosted or co-hosted one or more Research Seminars each year. Some of our more notable speakers include the following, some of whom are pictured in Fig. 1:

- Professor Juan Gilbert, Clemson University, who was named one of the nation's top African-American Scholars by Diverse Issues in Higher Education and a national role model by Minority Access Inc.;
- Professor Nancy Amato, Texas A&M, who is a member of the Computing Research Association's Committee on the Status of Women in Computing Research (CRA-W) and the Coalition to Diversity Computing (CDC) and codirects the CRA-W/CDC Distributed Research Experiences for Undergraduates Program and the CRA-W/CDC Distinguished Lecture Series;
- Professor Valerie Taylor, Texas A&M, who has received numerous awards for distinguished research and leadership, including the Tapia Achievement Award for Scientific Scholarship, Civic Science, and Diversifying Computing; and
- Professor Robin Murphy, Texas A&M, who was awarded the Al Aube Outstanding Contributor award by the AUVSI Foundation for founding the field of rescue robotics and was named one of the Most Influential Women in Technology by Fast Company and an Alpha Geek by WIRED Magazine.

STAIRSTEP CS has hosted one or more Career Forums each year. Forums have ranged from one guest speaker to a dozen. Panelists include alumni, representatives from local companies who hire our students, members of the department's Industrial Advisory Board, and members and associates of the Association for Women in Computing Houston organization.



Fig. 1. Research Seminar Speakers Gilbert, Taylor, and Amato (left to right)

The panelists have spanned a broad spectrum of industries and organizations, including IBM, DuPont, JP Morgan Chase, SYSCO Foods, Accudata Systems, Southwest Research Institute, Rice University, Schlumberger Information Solutions, and Giddings Independent School District. These forums expose students to a wide array of careers and give them advice on job search and on what types of knowledge, skills and experience are in demand.

C. *Use institutional relationships to help students bridge to the next level*

STAIRSTEP CS partners with several organizations across campus to help students bridge to either advanced study or careers in STEM. This includes the university's McNair Scholars Program and ASCENT program, described below, the university's Career Center, and the Computer Science student professional societies.

The Lamar University McNair Scholars Program encourages juniors and seniors who are first generation and low-income students, or who are from a group underrepresented at the doctoral level, to pursue graduate studies by providing opportunities to define goals and to engage in research. STAIRSTEP partners with the Lamar University McNair Scholars Program to help increase the rate of graduate school progression among STAIRSTEP students. STAIRSTEP encourages its eligible students to participate in this program. Thus far three of the Computer Science STAIRSTEP undergraduates have participated as McNair Scholars.

ASCENT provides scholarships for eligible juniors and seniors majoring in computer science or mathematics to help students progress to graduation within two years. STAIRSTEP Computer Science partners with the ASCENT program to help our juniors and seniors progress to a timely graduation. Thus far five STAIRSTEP CS students have participated in ASCENT.

STAIRSTEP partners with the university's Career Center by encouraging students to participate in a wide variety of center-sponsored events, including job fairs, speed interviewing events, networking events, seminars on interviewing techniques, and workshops on LinkedIn. The faculty mentor makes students aware of the center's database of jobs and internships and encourages them to post their resumes in the center's online database. Several Computer Science STAIRSTEP students have received internships and jobs as a result of this participation.

STAIRSTEP CS students must be active members of the student Association for Computing Machinery (ACM) professional society. This has breathed new life into the society, whose membership had dwindled. We also partner with the student ACM to bring to campus guest speakers for the ACM's spring banquet and the CS STAIRSTEP Research Seminars. Since the program started, most of the officers of the student ACM society have been STAIRSTEP members. Many STAIRSTEP students have also served as officers in the Computer Science student honor society. These societies have initiated free tutoring and mentoring programs for students.

D. *Engage STAIRSTEP undergraduates in team outreach to high school, community college and university students*

A key STAIRSTEP strategy is to transform undergraduates into a powerful source for attracting others to STEM. Through their participation in the program, the undergraduates become strong and enthusiastic advocates and role models who demonstrate that computer science is not just for white males.

STAIRSTEP Computer Science students participate in a wide variety of outreach events to students in K-14. This is a much more extensive program than the 'road shows' pioneered by Carnegie Mellon University [17]. Examples of selected activities are included here.

1) *Computing academies for middle and high school students*

Computing academies embody our most formal, intensive and impactful outreach activity. Computer Science undergraduates participate in the design, implementation, testing and assessment of these academies.

STAIRSTEP students participated in eight Computing Academies for middle school students and three Computing Academies for high school students in 2009, 2010, and 2011. The academies were hosted by Lamar University's INSPIRED Program, described in Section IV B. The 2009 and 2010 academies taught programming concepts to high school students in a week-long series of hands-on labs in robot programming and web page creation. The 2011 academy used game programming instead of robotics. The middle school academies exposed kids to programming concepts in one-day programs with hands-on labs in programming Lego robots, creating animations with Scratch and webpage creation. A total of 193 middle school and 59 high school students participated in these academies. Formal assessments showed that the participants experienced a significant increase in interest and knowledge of computing [18, 19]. During these years, STAIRSTEP partnered with INSPIRED. INSPIRED students taught the academies, and STAIRSTEP students gave hands-on help to the middle and high school participants during the labs and helped with other organizational tasks.

In 2012, STAIRSTEP Computer Science hosted a computing academy as part of the Lamar Achievement in Mathematics Program (LAMP), a two-week residential program. The STAIRSTEP undergraduates taught computing concepts to 24 high school participants in a series of hands-on labs using the game programming materials. Formal assessment found that the participants experienced a significant increase in knowledge; 71% of participants reported an

increase in interest in computing, and 62% said they were more likely to take computing courses in the future.

2) *On-campus visits by local high school students*

STAIRSTEP hosts day-long visits by students from local high schools. The typical visit includes a campus orientation and tour, an on-campus lunch, and visits to each of the STAIRSTEP disciplines. During the visits with Computer Science, the CS STAIRSTEP team makes presentations on careers in computing and engages the students in fun hands-on activities that expose them to computing. The team is currently developing one-hour hands-on labs that expose students to basic programming concepts using Snap! [7]. Materials have been designed, created and pilot tested by current STAIRSTEP CS team members during an on campus visit by 52 local high school students in spring of 2015. These materials will be used and formally assessed during a series of on-campus high school visits that STAIRSTEP plans to host in fall of 2015.

3) *Road shows to local high schools*

The CS team routinely participates in visits to several local high schools. During the visits, the undergraduates talk to the high school students about the field of computer science, careers in computing, computer science programs at Lamar University, life on campus, the STAIRSTEP program, their research, and other topics of interest. Some of the road shows include more formal presentations and demonstrations.

4) *Road shows, on campus visits with community colleges*

For several years, STAIRSTEP CS students have made visits to computing classrooms of local community colleges. These visits are typically informal talks about the benefits of going on to pursue a 4-year degree after the associate's degree is completed, degree programs, research, scholarships and other opportunities at Lamar University. STAIRSTEP CS hosts similar visits for prospective community college transfer students who are escorted to our campus by an alumnus who teaches computing courses at a local community college.

5) *Formal presentations*

The Computer Science students made a formal presentation on their research to about 50 students and teachers at a spring 2015 talk sponsored by the Lamar University Office of Undergraduate Research.

6) *Computing workshops for K-12 teachers*

For the past four years, STAIRSTEP CS students have participated each summer in Lamar University's National Science Foundation sponsored Computing Institute for K-12 Teachers [20], providing hands-on help to local K-12 teachers in a week-long workshop designed to teach them computer science fundamentals and programming for classroom use.

7) *Manning booths at New Student Orientation and Open House*

STAIRSTEP undergraduates participate in these and other similar events on campus, talking one-on-one with prospective students about computing as a discipline, a major, and a career.

V. ASSESSMENT

The second author is Director of STAIRSTEP Assessment. The assessment plan includes both formative and summative

elements. The STAIRSTEP Program has three major goals: (1) retain and develop at risk students majoring in STAIRSTEP disciplines through an enriched research experience that includes mentoring, tutoring, and other support, and activities that are designed to dispel some of the misconceptions that make these fields unattractive; (2) help transition these students to graduate study or careers in science; and (3) attract more students to the fields through targeted recruiting functions. The goals/expected outcomes and evaluation methods are summarized in Table 1.

The Computer Science faculty mentor worked with the STAIRSTEP Director of Assessment to develop and fine-tune two instruments for assessing the program. Studies were conducted to establish the validity and reliability of the instruments.

The Learning Outcomes Questionnaire (LOQ) attempts to measure students' progress towards attaining the learning objectives of their discipline that prepare them for the transition to graduate school or careers in STEM; and the degree to which STAIRSTEP has contributed to this progress. Each STAIRSTEP discipline has its own LOQ because the learning objectives of each are different. During the program's first year, a high number of advanced students participated in STAIRSTEP. These students started the program at an advanced level of preparedness, so growth was limited. This appeared to have functioned as a confounding variable in the measurement of program effectiveness. For this reason, revisions to the LOQ instruments were made in Spring 2010. The revised questionnaires ask students to rate their progress towards each of the learning objectives of the discipline's undergraduate program on a scale of 1 (lowest) to 10 (highest) and to similarly rate the impact that participation in STAIRSTEP has had on their attainment of each learning objective.

The Self-Assessment Questionnaire (SAQ) asks students to rate their own interests and abilities in seven different areas: (1) ability to work in a team; (2) ability to write technical reports/papers; (3) ability to make a technical presentation; (4) interest in their STAIRSTEP discipline as a field of study; (5) interest in obtaining an advanced degree in their STAIRSTEP discipline or a related field; (6) knowledge of job search/interviewing techniques; (7) interest in pursuing a career in their STAIRSTEP discipline; (8) organizational skills; and (9) leadership ability. Students rate their abilities with the use of a rubric on a scale of 1 to 5 and the impact of the STAIRSTEP program on their abilities on a scale of 1 to 10. All STAIRSTEP disciplines use a common SAQ instrument.

Assessment is performed at the end of the spring semester of each academic year of participation. In addition to analysis of the student responses on the two assessment instruments, the assessment compares retention rates, grades, and drop rates of STAIRSTEP participants with those of cohorts of students from five years prior to start of the program. It also measures enrollments, majors and degrees granted in the discipline.

A. Assessment Results

This section reports the cumulative findings from the inception of the program on 1/1/2009 through the end of NSF

TABLE I. EVALUATION METHODS

Goals/Expected Outcomes	Evaluation Methods
At least 70% of STAIRSTEP participants will complete their degrees in STEM	<ul style="list-style-type: none"> Retention rate comparison Grade and drop rate comparison Self-Assessment Questionnaire
The STAIRSTEP experience will help students attain their department's targeted learning outcomes, preparing them for advanced study or careers in science.	<ul style="list-style-type: none"> Learning Outcome Questionnaire
At least 80% of STAIRSTEP students who complete the program will make the transition to advanced study or careers in science within six months of graduation.	<ul style="list-style-type: none"> Structured Exit Interview
FTIC enrollments in STAIRSTEP disciplines will increase by 5% or more starting in Year 2, Community College transfers to STAIRSTEP departments will increase by 20% starting in Year 2.	<ul style="list-style-type: none"> Student enrollments

support on 8/31/2014. A total of 21 undergraduates participated in the Computer Science arm of STAIRSTEP during this period.

1) Retention

The goal of retaining 70% of STAIRSTEP participants in their Computer Science major was exceeded, with 100% retained as CS majors. Cumulative statistics show that since inception STAIRSTEP CS participants have consistently made higher grades (3.45 GPA vs. 2.62) and lower drop rates (1.99% vs. 12.5%) in their major courses than cohorts of students from prior years. The cumulative STAIRSTEP student responses (all disciplines) on the Self-Assessment Questionnaire suggest significant perceptions of growth ($t=6.66$, $p<0.000$). A p score of 0.05 or less is considered significant. Students perceive STAIRSTEP as having a significant impact on their growth ($t=14.25$, $p<0.000$).

2) Graduation/field Placement (Transitioning)

The goal that at least 80% of STAIRSTEP students will transition into advanced studies or careers in STEM within six months of graduation was exceeded, with 90% of STAIRSTEP CS graduates that had been graduated for six months having transitioned into either graduate school or STEM employment. Ten STAIRSTEP CS students had graduated by 8/31/2014. All but one (10%) successfully transitioned into either graduate studies programs or STEM related employment.

An analysis of the students' responses on the Learning Outcomes Questionnaire is summarized in Table II. The results of the LOQ reported by the CS students cumulatively since the improved form was implemented in Spring 2010 suggest significant growth towards readiness within the Learning Outcomes necessary for their discipline. Students also report that this perceived growth within their discipline was attributed to participation in the STAIRSTEP program to a significant level. The results for the last year indicate that the perceived growth and impact were continuing to improve.

TABLE II. LEARNING OUTCOMES QUESTIONNAIRE RESULTS

Period	Learning Outcome Progress		STAIRSTEP Impact on Growth	
	<i>t score</i>	<i>p value</i>	<i>t score</i>	<i>p value</i>
Cumulative Spring 2010 – Spring 2014	6.08	0.000 ^a	7.54	0.000 ^a
Fall 2013 and Spring 2014	7.5	0.000 ^a	10.97	0.000 ^a

^a A p score < 0.05 is considered significant.

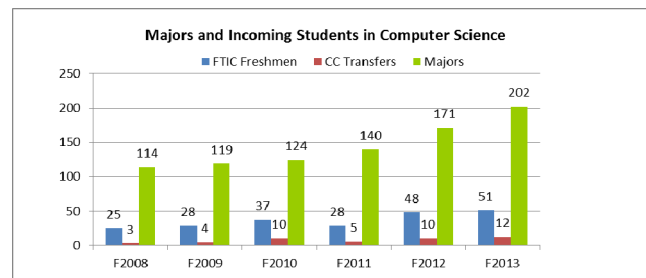


Fig. 2. Incoming First Time in College freshmen, community college transfers, and majors in Computer Science grew dramatically during the five years of NSF support.

3) Attracting Students

The goal of increasing enrollment of First Time in College (FTIC) freshmen by 5% starting in Year 2 was exceeded. Since STAIRSTEP started, CS enrollments and majors have increased dramatically, as shown in Fig. 2. The number of FTIC freshmen enrolling in CS increased from 25 in the fall of 2008 before STAIRSTEP started to 51 in the fall of 2013, an increase of 104%, despite two increases in entrance requirements (Fall, 2009 and Fall 2011). This compares to a 21% decrease seen in the university's non-STEM disciplines during the same period. Undergraduate majors in CS grew from 114 to 202, an increase of 77%. This compares to a decrease of 1 % in the university's non-STEM disciplines during the same period.

The goal of increasing community college transfers into CS was likewise exceeded. As of Fall 2013, the number of community college transfer students in CS was the highest it has been in the past 6 years, and is four times as high as the Fall 2008 pre-STAIRSTEP number.

B. Comments from Students

Included here are selected comments from CS STAIRSTEP participants with respect to various components of the program:

- Research: “<STAIRSTEP> gives the students valuable research experience which places the student at a higher level when applying for a Masters or Doctorate program or when applying for internships and REU programs at other universities.”
- Research Seminars: “We got to hear Dr. Murphy talk about the challenges that robots experience when trying to rescue people who've been involved in disasters. I really

appreciated the view into that world. She also told us things that we'd need to know if we planned to pursue graduate studies, some I already knew, but other things I did not."

- Career Forums: *"She made me think that I could make it in a computer science career."*
- A computing workshop for high school students: *"It felt wonderful to teach the students useful skills and concepts in my field of study and doubly so after I saw their faces light up while they began to create and experiment."*
- A visit to a local community college: *"I think one of my favorite parts of this program is the outreach. Our talks <with students in a community college class> were seemingly enjoyed by the class and several students said they would see us here at Lamar in the fall."*
- A visit to a local high school: *"These visits to ... local high schools help to provide information about the program to students at critical points in their lives, and help them to consider a degree in Computer Science."*

The following are excerpts from selected student testimonials:

- an African American male who participated in STAIRSTEP for 3 years, starting while taking freshman level CS courses, completing the BSCS/MBA program in December, 2014: *"As a typical student before STAIRSTEP, I would attend class, go home and have no involvement in the Computer Science Department. After joining STAIRSTEP my GPA increased, I became more involved with the department, and was able to fine tune my personal and career goals....The relationships and the experience gained from working as a team ... allowed for me to create and grow in a manner that is not possible while working alone....All of the extra-curricular activities have developed and honed skills that would not be there otherwise. These are not only resume material, but they are character building."*
- a Caucasian female who joined STAIRSTEP while taking freshman level courses and has participated for 1.5 years: *"When I started my first Computer Programming class ... I had no programming knowledge... After I was assigned any homework I knew that someone would always be in the <STAIRSTEP>lab to help me <with free tutoring>. I decided that I really wanted to be a part of STAIRSTEP so I could help others the way the older students helped me. Being able to participate in STAIRSTEP has been an amazing opportunity. The STAIRSTEP team has kept me motivated to make good grades. The research aspect of STAIRSTEP has helped further my knowledge about the Computer Science world and opportunities... I have learned to work in a team and collaborate my work with others. With the outreach programs we have I think we can really affect others, making an impact on student's lives and future career paths."*

VI. SUGGESTIONS

The following advice is offered to those who wish to adopt these practices in their programs.

The importance of a formal assessment plan directed by an independent evaluator cannot be stressed enough. The independent assessment provides evidence that the program is succeeding and can help identify problem areas. The former is a requirement for publication and recognition of the program. The latter is essential for program improvement.

Wherever possible partner with others who have similar goals. Partnerships can help broaden the program's base of support and increase its impact. The partnership with the Career Center has helped achieve the common goal of preparing students for the workforce. The partnership with the student professional organizations has helped develop students' professional and social networks and helped bring distinguished researchers to camps. The partnerships with other research and outreach programs on campus have helped extend and strengthen the impact of each.

Make use of professional organizations. The ACM's Distinguished Speakers Program is a good source for guest research speakers. Organizations like the local Association for Women in Computing can help provide speakers for career forums and help develop the students' professional network. The department's Industrial Advisory Board can likewise be a good source for career forum speakers.

Wherever possible include graduate students in the team. They can help lead the undergraduates in research, serve as role models for the undergraduates, and provide advice to them on applying for and succeeding in graduate school.

Promote the program ceaselessly. Publish in professional settings, give informal talks on and off campus. Work with the university's public relations department to help publicize the program. Work with the marketing department to develop promotional brochures. This will increase visibility of the program and help promote its success.

VII. SUSTAINING THE PROGRAM IN THE ABSENCE OF EXTERNAL SUPPORT

Some components of our program have been sustained without external support, while some remain a challenge.

The Research Seminars are now institutionalized in the Computer Science Department. The speakers often are provided by the ACM Distinguished Speakers program. The department pays for local travel expenses. Likewise, the Career Forums have been adopted by the department. Speakers are representatives from local firms that hire our students, members of the department's Industrial Advisory Board, and members and associates of the Association for Women in Computing, Houston. These speakers have generously given of their time and do not request reimbursement for travel.

Participation of undergraduates in on-campus and off-campus recruiting events has been adopted by the department. Students now routinely volunteer to participate in Open House and other on-campus events, and have also accompanied the department chair on visits to local high schools.

Partnerships with the McNair Program, ASCENT program, and Career Center continue and need no external support. Partnerships with local K-14 schools are continuing and

growing. Some of our past STAIRSTEP participants who are now teaching STEM classes in local high schools and community colleges are facilitating these partnerships.

The CS STAIRSTEP program has fostered a sense of community among our students, who have learned to help each other rather than to remain isolated or compete with each other. It has also helped to develop a culture of undergraduate research that will continue, with support from the university's recently established Office of Undergraduate Research (OUR).

Going forward, the proposed plan is that a number of STAIRSTEP teams will be supported each year, depending on available funding. The teams can come from the five original STAIRSTEP disciplines (Chemistry, Computer Science, Earth and Space Sciences, Mathematics, and Physics) and from other STEM disciplines. Interested faculty can apply to participate each academic year. From the pool of applicants, participating faculty mentors will be selected by a steering committee. The proposed budget includes faculty release time/stipends, student stipends, and support for supplies and research related travel.

Lamar University has agreed to provide limited support for STAIRSTEP teams in Computer Science, Mathematics and Physics for two years, during which time the faculty mentors in those three disciplines must secure external support to sustain the program. STAIRSTEP and its budget have been placed under the umbrella of the OUR, with additional duties in support of the OUR entailed. The faculty mentors are working with University Advancement, the Career Center, the Sponsored Programs Office, the local Workforce Development Board, and others to find sources of external support. The Beaumont area industry is largely petrochemical. There is currently no critical mass of employers of computer scientists in this area. That makes it difficult to secure adequate funding from local industry. The search is ongoing.

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A Course in Innovative Product Design: A Collaboration Between Architecture, Business, and Engineering

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Abstract— The importance of innovation and entrepreneurship has grown significantly over the past decade. Institutions of higher education have recognized the increasing level of importance being placed globally on producing college graduates with the skills to innovate new products and services, and many are rising to the occasion. Recently, Texas A&M University has established a small business accelerator available to all students. In addition, the University has supported the development of a new course where junior and senior students across the University can interact and learn about ideation, innovative product development, and entrepreneurship. Looking across the literature, most institutions are moving in a direction of fostering entrepreneurship through interdisciplinary courses either within engineering, business or through partnerships between both. This new course is novel in that, in addition to integrating product development with entrepreneurship, it also incorporates the ideation and innovation processes through involvement of the College of Architecture. By embedding architecture students into the teams of engineering and business students, expertise in these areas is added to the teams. Finally, the course exposes all students to new tools such as the lean startup method and Launchpad Central.

Keywords—*entrepreneurship; innovation; interdisciplinary; product development; lean startup*

I. INTRODUCTION

It is widely recognized that it is not enough for today's engineer to be technically competent, they also need an innovative and entrepreneurial mindset. Not only does education in the area of entrepreneurship give students the engineering and business sense to create new products that are marketable and have the potential for profit, it is also one of the fastest growing subjects in undergraduate education over the past thirty years [1]. In fact, according to the US Department of Commerce, as of 2013 there were over 450 institutions of

higher learning with programs in entrepreneurship [2]. From the standpoint of engineering education, these programs take on many forms. A study performed by the National Collegiate Inventors and Innovators Alliance (now known as VentureWell) determined that technology entrepreneurship programs are typically driven by engineering (53%), business (26%) or as a partnership between the two (13%) [3]. One example of these partnerships is an interdisciplinary course developed at Villanova as a joint engineering-business venture in the area of pharmaceuticals [4].

While partnerships between business and engineering make sense because of the need for both technical and business expertise when creating a technology-based startup, Texas A&M University has been looking at a key component that is often insufficiently addressed: ideation and innovation thought processes. Through the College of Architecture, Texas A&M has been offering courses in this area for many years to students across all disciplines. Now, by creating a new three-way partnership, the university seeks to create entrepreneurial teams that have a technology background, business acumen, and formal processes for innovation. This paper describes a new University-level course in Innovative Product Design that formalizes this teaming approach.

II. BACKGROUND

Although entrepreneurship, business startup and product development have been topics of interest across the Texas A&M campus for many years, there has been no integrated effort available to support all of these areas for undergraduates. However, pockets of experiential learning exists in a number of the colleges together with a growing interest in pursuing such an interdisciplinary educational initiative.

For example, the College of Architecture offers coursework to a wide range of students in innovation and ideation. These

courses focus on creativity and outside the box thinking as it pertains to new product and services. The School of Business provides a number of business-oriented courses focused on small venture startups and operation. In addition, the School has established the Center for New Ventures and Entrepreneurship (CNVE) that promotes and supports activities and competitions geared to recognizing intra- and entrepreneurial efforts and successes within the “Aggie family.” Both Architecture and Business had significant interests in expanding their undergraduate educational activities to include product-based models. Within the Look College of Engineering, some departments have created courses to include innovation and entrepreneurship. For example, the Electronic Systems Engineering Technology program recently refocused its curriculum on the design, development, documentation, and delivery of working prototypes that meet private and public sector sponsors’ problems or ideas [5]. The ESET program also established its Product Innovation Cellar as an electronic, embedded software and mechanical maker space to support multidisciplinary teams undertaking projects that created prototypes with commercialization potential [6].

A new initiative fostered by the University’s VP of Research provided an opportunity for representatives from all three colleges to interact. Known as Startup Aggieland [7], the facility had the tasking and ability to unify undergraduate entrepreneurial activities across the university. Because Startup Aggieland was open to everyone at Texas A&M and was not affiliated with any one college, department, or program, all students and faculty felt welcome to participate in its activities. An outcome of this type of interaction and engagement was the creation of a new interdisciplinary undergraduate course and laboratory for innovative product and systems development. Unlike other courses developed and offered by one department or college and taken by students in other departments or colleges, two faculty members from each of the three colleges planned and delivered the Innovative Product Design course for the first time in Spring 2014.

III. COURSE OVERVIEW

The new Innovative Product Design course has been taught for three semesters; Spring 2014, Fall 2014, and Spring 2015. The enrollment for each offering was limited to twenty-four junior/senior students (six teams of four) with approximately eight from each college. The format of the course includes:

- faculty and guest presentations on innovation/ideation, engineering aspects of product development, and business concepts related to new business startups,
- a flipped classroom approach to teaching lean startup methodologies and the business model canvas,
- a course project where interdisciplinary teams create a startup and experience ideation, customer interviews and pivots.

Table I lists the topics covered in both the presentations and in the flipped course videos. The presentations are provided by core faculty and entrepreneurs associated with either Engineering (ENGR), Architecture (ARCH) or Business

TABLE I. INNOVATIVE PRODUCT DESIGN COURSE OUTLINE

Week	Presentations		Flipped Videos
	Topics	College	
1	Team Formation Creativity and Global Trends	ARCH	Startups
2	Divergent and Convergent Thinking Ideation and Elevator Pitches	ARCH	Business Models/ Customers
3	Introduction to Launch Pad Videos Customer Meetings, Team Ideas	ARCH	
4	Intellectual Property (Law School)	BUSI	Value Proposition
5	Quality Function Deployment	ENGR	Customer Segments
6	House of Quality	ENGR	Channels
7	Reverse Engineering	ENGR	Customer Relations
8	New Product Development Process, Support and Sustainability	ENGR	Revenue Models
9	Startups in Regulated Industries	ENGR	
10	Intellectual Property II Patent Searches	BUSI	Partners
11	Financials for Startups	BUSI	Resources Activities Costs
12	Financing New Ventures	BUSI	
13	Developing High Performance Organizations, Managing Creativity, IDEO	ARCH	
14	Presentation skills, Being memorable	BUSI	
15	Final Presentations	ALL	

(BUSI) while the videos are taken from the Udacity course, “How to Build a Startup,” by Steve Blank [8]. Over the past three semesters, the course has evolved from a three-hour lecture/laboratory course to a three-hour lecture-only course. Currently, the course meets twice a week for seventy-five minutes each (a 50 minute lecture equals one credit hour) where one meeting time is reserved for presentations and interactive experiences by the participating colleges and the other meeting time is used in a flipped format where students and instructors discuss the lean startup videos and the individual team projects.

IV. ENGINEERING

In addition to the ideation and lean startup approach to new business startup, the course was designed to have a third of its content clearly focused on the engineering aspects of new product design and development. Each three-person team of students participate in a series of creativity exercises to identify potential products and services they can develop as a startup company. With an idea in mind, the teams will use the lean startup process taught by the business faculty using the videos available on the LaunchPad website [9]. Once these elements are in place, the teams begin to collect customer interview information and pivot on their new product/service idea based on feedback and observations they make. At this point, the engineering faculty members bring a number of technical aspects to the course. The five weeks of engineering product development concepts include: 1) Entrepreneur vs Intra-

preneur roles, 2) Understanding new product development processes and how product innovation happens within companies, 3) The House of Quality (HoQ) approach, 4) Reverse engineering process, and 5) Special needs of regulated industries. Two of these five concepts will be further defined as examples of the engineering content of the course.

Using the HoQ, teams are able to analyze the information collected from the interviews they conduct as part of the lean startup process. These narratives (or verbatims) are first assessed using a Verbatim Analysis and Sorting Table or Affinity Diagram to ferret out the customer root wants. The root wants are then used as inputs to the HoQ. Following this engineering process, the teams will produce a single diagram that translates the root wants of the customer to requirements and specifications that engineering will use to guide the prototype and product develop efforts. Each team is required to create, present and discuss the HoQ for their product.

Another important concept is reverse engineering. Engineering faculty presentations include principles of both white box and black box reverse engineering processes and how reverse engineering has been used as part of the new product development process. As part of the lab assignment on this topic, the teams select inexpensive electro-mechanical devices and perform both a white box and a black box reverse engineering analysis of the product to determine how it works and their recommendations for improvement. For this exercise, commercial products including toys, appliances, and quality of life devices are given to the student groups. Examples include remote control cars, toasters and bathroom scales. Fig. 1 shows interdisciplinary groups of students reverse engineering commercial products.

V. INNOVATION

The College of Architecture is the most unique aspect of this course. While many schools are developing partnerships between their business and engineering programs, it is Architecture at Texas A&M that brings a key ingredient necessary for the successful entrepreneur. Specifically, Architecture is responsible for developing the students' capabilities in creativity and innovation. To this end, they deliver presentations on team formation, ideation through convergent and divergent thinking, global innovation trends, creativity and flow, and innovation in high performance organizations.



Fig. 1. Reverse Engineering Experience

For example, in order to get the student teams into a mindset for developing their initial product concepts, architecture faculty deliver a lecture on global innovation trends as well as methodologies for creating new ideas. They then lead the student teams through multiple exercises that break down barriers to group innovation, encourage teams to rapidly develop multiple product concepts, and then converge on that single winning idea that seeds their startup experience.

VI. BUSINESS

Of the three colleges, the Mays Business School has the most experience in incorporating entrepreneurship into education. Through the CNVE, they have been fostering the entrepreneurial mindset through: idea and business plan competitions; a student organization focused on entrepreneurship; a graduate student-led consulting firm; and, most recently, the organization of the university-level Startup Aggieland incubator. Their interest in the Innovative Product Design course was as a creative outlet to involve their students in more product-based startups as opposed to the more typical service-based ideas that had been traditionally created by business-only teams.

In addition to leading the course project (discussed below), the business faculty offer approximately one third of the focused course presentations as well. The topics include intellectual property, finance principles for new startups, new venture funding, and new customer/investor presentation skills. For example, through their relationship with Texas A&M's new law school, the business faculty bring in guest speakers from the law school's Center for Law and Intellectual Property to introduce the concepts of patents, trade secrets, copyright, and trademarks. In addition, the business faculty host a workshop at the library on patent searching.

As a second example, each semester the business school brings in a successful former engineering student and entrepreneur who is CEO of his own company to discuss new startup financial concepts including how to understand cash flow, profit and loss, and balance sheets. To do this, the guest speaker has developed an interactive tool with an integrated cash flow statement, profit and loss statement and balance sheet. Through interactive scenarios, the class investigates how different real-world situations impact each of these statements and, ultimately, the bottom line of their company.

VII. COURSE PROJECT: MINIMUM VIABLE PRODUCT

A key aspect of the new Innovative Product Design course is experiential learning. This is accomplished through a semester-long project where students are broken into interdisciplinary groups, must develop the idea for a new product, and then use the lean startup method to create a Minimum Viable Product (MVP) and validate a new startup company in the form of a business model canvas as shown in Fig. 2. Project deliverables include:

- Document 100+ customer interviews as well as resulting pivots
- Create a full business model canvas to communicate their startup and business model

- Develop an MVP and build a physical, costed prototype or proof-of-concept

The project begins in the first week of the semester when students use speed dating to identify team members with similar interests. One constraint placed on the students is that they must form interdisciplinary teams, partnering with students from multiple colleges. The newly formed teams then use ideation concepts presented over the next two weeks to quickly define a product. In the interim, they have also started watching the lean startup video series by Steve Blank and so begin to develop their business model canvas. To assist in keeping track of their customer interviews and the development of their canvas, teams are required to use the Launchpad Central web environment.

Through multiple customer interviews each week, the teams learn to refine their idea through pivots, often changing their entire vision multiple times until they converge on that one winning idea around which to form their company. Through weekly team presentations, they receive feedback from other teams and from faculty to help them learn how to interpret customer feedback.

As each team's product becomes more well defined, they are encouraged to bring in other concepts from the in-class lectures such as using reverse engineering of competing products to refine their ideas, using the HoQ to translate customer verbatims into root wants and quantifiable product specifications, performing patent searches to make sure they have an original idea, and developing a financial model for their new startup.

Finally, in the last week of the semester, each team presents their customer discovery story to faculty and industry. Their presentation must include a history starting with their initial idea through the current concept including pivots as well as a complete discussion of their business model canvas. Finally, teams must make a go-nogo decision as to proceeding with their startup. As an incentive to help interested teams move their ideas forward, top teams are encouraged to apply for a space in Startup Aggeland. Of the first twelve teams in the course, three teams have been part of Startup Aggeland and one team went on to raise funding from Seed Sumo (a local private accelerator).

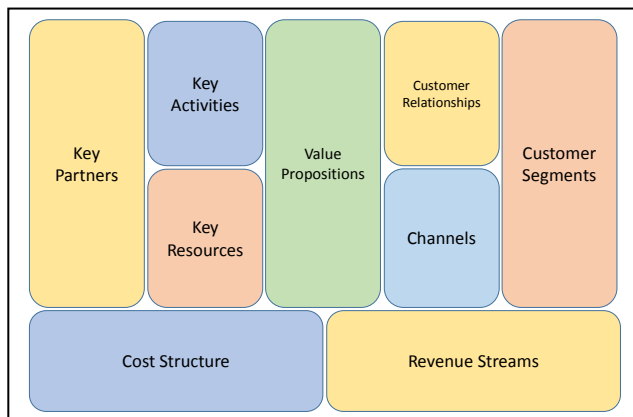


Fig. 2. Business Model Canvas

VIII. LESSONS LEARNED AND FUTURE WORK

So far, the new university-level product development course has been taught three times by faculty across three different colleges and has impacted approximately seventy-two architecture, engineering, liberal arts, and the business school students (while liberal arts does not participate in teaching the course, their students are welcome to enroll). From this experience, several lessons have been learned. First, the development of a single course by faculty with very different views on curriculum, teaching, and course development requires a team that has the patience and ability to work through contentious issues in a systemic way. To this end, it was agreed early on that "majority rules." This methodology allowed the group to avoid deadlock and move forward with the development of the course on multiple occasions.

Second, the group needs to focus on sustainable delivery strategies to ensure that the course could be offered on a permanent basis. For example, the initial offering had a three hour laboratory component. This created issues in terms of faculty availability and student schedules. Thus, the laboratory component was replaced with in-class interactive exercises and an increased expectation that student teams would meet and work outside of a regularly scheduled lab time. This flexibility has actually resulted in teams being more successful as evidenced by the increased number of customer interviews in the second and third course offerings. Other sustainability issues that are currently still being addressed include faculty loading, curriculum continuity as the faculty team loses and gains team members, and the recruiting of quality students for the course.

Third, the faculty need to develop strategies for helping student teams identify realistic product concepts. To date, anecdotal evidence indicates that about two-thirds of the teams are successful at developing creative and potentially viable products. The issue with the remaining third seems to stem from the beginning of the course where they have to quickly develop multiple products concepts and then down select. To help in the process, future offerings of the course will include a list of seed ideas from faculty and industry to help those teams who are having difficulty in getting started. It is anticipated that this will help those teams struggling to find initial ideas while not impacting teams that are self-starting.

As the Innovative Product Design course moves forward, there are multiple ideas for course improvement. For example, the faculty will perform a qualitative and quantitative assessment of student learning and team success. While anecdotal evidence shows that so far four of twelve teams have actually moved forward with their startup, the faculty need data in order to maximize the probability of teams actually creating a viable startup company. Second, the faculty team needs to find methodologies for scalability including the ability to accommodate more students per semester as the course becomes more popular and the ability to have teams interact with students from other institutions with similar interests in entrepreneurship. Finally, innovative methodologies for incentivizing students to take the idea of actually creating a new startup more seriously, perhaps through stipends and graduate degree programs.

ACKNOWLEDGMENT

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Assessing Idea Fluency through the Student Design Process

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Abstract—Engineering design is a complex activity for students to undertake and for instructors to assess. This research uses large learner data sets collected through automatic, unobtrusive logging of student actions in a CAD platform to address this difficulty in observing design behavior. We used a computer-aided design software that captured student design activities to investigate patterns of student design behaviors that are associated with idea fluency. We show how micro-level process data can be used to validate observations made from viewing the student design process through design replays. Students who engaged in high idea fluency showed evidence of fluency in both process data and design replays. Similar patterns were observed for low idea fluency students. There is great potential to investigate student design learning through system-collected data. Yet, how to justify the inferences made about students based on their process data is largely unexplored. Our results demonstrate how traditional forms of assessment data can be used to validate inferences made by process data. Implications of this work would be highly relevant to engineering educators as well as researchers who are interested in understanding the relationship between learner analytics and student learning.

Keywords—engineering design; idea fluency; creativity; assessment; clickstream data, process data

I. INTRODUCTION

Assessing student learning behaviors has garnered new options through advances in learning analytics [1]. In this article we discuss examples of using learning analytics to assess student idea fluency in the context of design.

II. LITERATURE REVIEW & THEORETICAL FRAMEWORK

A. Informed Design and the Iterative Designer

The Informed Design Teaching and Learning Matrix [2], herein referred to as “the Matrix,” provides a way to think about nine key design strategies employed by expert designers as compared to beginning student designers. The Matrix deconstructs the design process in order to better connect novice learning to expert literature in order to better support informed teaching with engineering design activities [2].

One design strategy discussed in the Matrix, idea fluency, is an important strategy as students work with multiple ideas in order to avoid fixation and to experience a range of design options. When generating ideas, expert designers work with a multitude of ideas by practicing design activities such as divergent thinking, and brainstorming. To become a more

informed or advanced designer, the Matrix encourages teaching strategies to focus on brainstorming and related techniques to achieve idea fluency. However, artificial attempts requiring student idea fluency have been shown to result in superficial efforts without the promise of transformation to informed design [2].

Although idea fluency is an important informed design behavior, it can be hard to identify in student design activities. Often educators do not see the realm of all design possibilities a student considers before landing on a few select options. Because idea fluency is linked to both creativity and reflective design [3], methods, illuminating a lack of student idea fluency early would allow these teachers to offer interventions that could encourage greater ideation and could lead to greater creativity.

B. Learning analytics & Process Data

Learning analytics is an emerging area of research [4][5] and “offers the possibility of implementing real-time assessment and feedback systems” to optimize learning environments [1]. Siemens [4] defined learning analytics as “the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs.” Some [1] posit that using such data analytics is imperative to improving teaching and learning by gleaning a better understanding of the student learning process from a large learner data perspective while at the same time improving individual student progress.

Next Generation Learning Challenges (NGLC) as well as the National Academy of Engineering (NAE) through partnership with the National Science Foundation (NSF) have funded efforts to scale learning analytics solutions through “Big Data.” The thought is that by understanding what students are doing, educators can offer better interventions.

Process data, sometimes known as clickstream data, is of particular interest in the application of learning analytics. Process data is essentially a log of user actions with the corresponding time stamp of each action. Analyzing this process data in an educational context can provide rich insight regarding student learning with hands-on technology. Using process data in conjunction with other more traditional methods of analyzing student design processes allows researchers to more fully understand student design behaviors.

While process data may not meet the “Big Data” criteria level for some, having learners’ clickstream data is certainly a more in-depth observation of learning that what is typical in educational assessment research. Machine generated data requires analytics beyond typical assessment methodologies and analysis.

III. BACKGROUND

This research was conducted with a free, open-source computer-aided design platform, Energy3D (<http://energy.concord.org/energy3d/>), to design and build energy efficient buildings. This software is very user-friendly and was developed with educational research purposes in mind. Energy3D collects large amounts of data in the background as students design. Among this data collected were process data and a logger of student actions allowing reconstruction of the entire student design process.

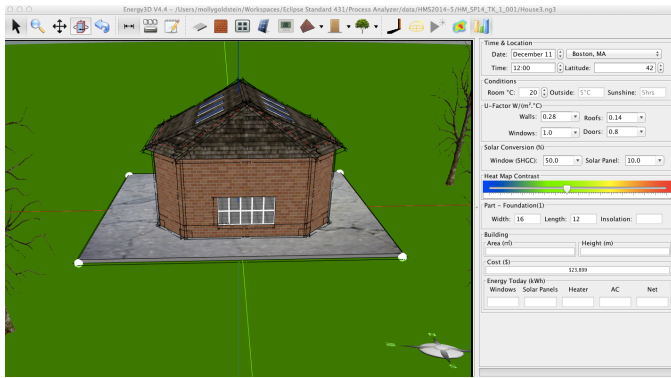


Fig. 1. Example student design in Energy3d

The design challenges that students undertake as they use Energy3D to design address the following engineering principles (i.e., design knowledge) outlined in the Next Generation Science Standards (NGSS) [8].

- HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
- HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
- HS-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

IV. RESEARCH DESIGN

This research sought to determine if idea fluency was evident from watching the student design process and if learning analytics corroborated the initial qualitative data analysis. Two student cases are presented in greater detail as they designed energy-efficient buildings using a computer-aided software system: (1) a student who exhibited a great degree of idea fluency; and (2) a student who exhibited a lesser degree of idea fluency.

A. Research Participants

This pilot study investigated eight (8) students in an AP Chemistry class at a large urban high school during the 2014 spring semester.

B. Design Challenge

The design problem presented to the students, named the Solar House Design Challenge, is set in 2020 where legislation dictates new homes must consume nearly zero energy. To that end, the challenge encourages students to consider solar energy in designing an energy efficient model house that maintains a comfortable interior temperature in both summer and winter. Design criteria are presented in Table 1.

TABLE I. SOLAR HOUSE DESIGN CHALLENGE CRITERIA

Criteria	Description
Energy	Minimize energy needed to keep the building comfortable on a sunny day or a cold night. Consume less than 8,000 kWh of energy per year.
Cost	Minimize total cost of the building. Cost cannot exceed \$50,000 in building materials.
Size	Comfortably fit a 4-person family (approximately 185.8 m ²). The house’s platform must not exceed the 28 x 36 m platform provided in the software.
Attractiveness	Has attractive exterior or “curb appeal”

C. Data sources – Design replays

The Energy3D software records every action of the students. In addition to having accessible process data, these logs of students’ actions such as sketching buildings, conducting experiments, collecting data using simulations, etc. can be used to reconstruct the entire student design process. This reconstructed process, a design replay, is similar to time-lapse photography in that the entire student design process can be sped up to provide a compressed view of the process in a shortened amount of time. In addition, if students took electronic notes while designing, these notes present were replayed synchronously to the students’ design actions.

D. Analysis

The design replays were viewed by two researchers looking for idea fluency. The researchers developed a codebook of idea fluency for student design actions, shown in Table II.

Two researchers then independently viewed all design replays coding for idea fluency. Differences in coding were noted and discussed before coming to a consensus on each student. An idea fluency score for each student was calculated by

summing the total idea fluency for each of these areas, where an individual student could have a total maximum score of 10. This scoring system allowed the researchers to identify a student who exhibited a high degree of idea fluency and a student who exhibited a lower level of idea fluency. Then, process data for these two students was analyzed to better understand if idea fluency that was visible through the design process was also evident from the process data.

TABLE II. IDEA FLUENCY CODING PROTOCOL

Strategy	Level of Idea fluency		
	Low (0)	Medium (1)	High (2)
Build/Modify Walls	Maintained same basic shape of house through all design iterations.	Experimented with 2 or fewer variations on the original house shape.	Made 3 or more variations on the house shape (height, overall shape, footprint, etc.)
Build/Modify Roof	Kept same roof throughout design.	Made one change in roof type (pyramid, hip, gable)	Made two or more changes in the roof type (pyramid, hip, gable)
Build/Modify Windows	Minimal change in window placement, size, or shape.	Evidence of changing 2 of the following: the size, shape and position of windows	Evidence of changing more than 2 of the following: the size, shape and position of windows
Add/Modify Solar Panels	No use of solar panels.	Explore either position of or quantity of solar panels.	Explore both position of and quantity of solar panels.
Add/Modify Trees	Added trees at the end of a design without modifying placement or type.	Explore either: position of type of, or quantity of trees.	Explore 2 -3: position of type of, or quantity of trees.

V. RESULTS

Table III presents the number of students within level of idea fluency for each of the design areas.

TABLE III. DISTRIBUTION OF STUDENT IDEA FLUENCY

Strategy	Level of Idea Fluency		
	0	1	2
Build/Modify Walls	1	7	0
Build/Modify Roof	4	4	0
Build/Modify Windows	0	6	2
Add/Modify Solar Panels	1	6	1
Add/Modify Trees	5	2	1

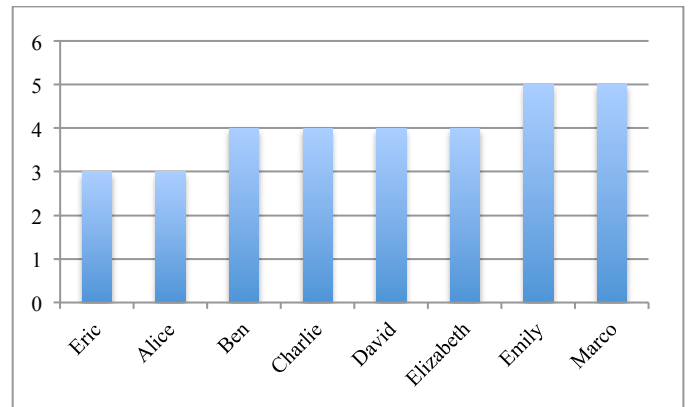


Fig. 2. Total idea fluency score per student

Design replays were reviewed and coded for all students in the class. Figure 2 shows the total idea fluency score for each of the students out of a possible 10. The cases of Emily and Eric are presented to illustrate difference in high idea fluency and low idea fluency.

The first student to be discussed, Emily, was among the most idea fluent students in the class. Through the design replays, researchers noted her use of idea fluency in particular in building and modifying the windows and solar panels in order to achieve better solar performance of the building. In the design replays, Emily changed the size, shape and position of windows in order to have a higher functioning home with lower energy usage requirements. Emily also explored many positions and quantities of solar panels as seen in the design replays. Her total idea fluency score of 5 reflects a level 1 in walls, 0 in roof, 2 in both windows and solar panels, and a 0 in trees (See Table IV).

TABLE IV. EMILY'S IDEA FLUENCY IN DESIGN

Strategy & Level	Detail of Idea fluency Level
Build/Modify Walls Medium Level	Experimented with 2 or fewer variations on the original house shape.
Build/Modify Roof Low Level	Kept same roof throughout design.
Build/Modify Windows High Level	Evidence of changing more than 2 of the following: the size, shape and position of windows
Add/Modify Solar Panels High Level	Explore both position of and quantity of solar panels.
Add/Modify Trees Low Level	Added trees at the end of a design without modifying placement or type.

The second student, Eric, practices a lower level of idea fluency. While he did modify the windows and solar panels in his design, he did not explore a wide range of options. His total idea fluency score of 3 reflects a level 1 in walls, 0 in

roof, 1 in both windows and solar panels, and a 0 in trees (See Table V).

TABLE V. ERICS’S IDEA FLUENCY IN DESIGN	
Strategy & Level	Detail of Idea fluency Level
Build/Modify Walls Medium Level	Experimented with 2 or fewer variations on the original house shape.
Build/Modify Roof Low Level	Kept same roof throughout design.
Build/Modify Windows Medium Level	Evidence of changing 2 of the following: the size, shape and position of windows
Add/Modify Solar Panels Medium Level	Explore either position of or quantity of solar panels.
Add/Modify Trees Low Level	Added trees at the end of a design without modifying placement or type.

Using process data we can also see similar trends. The following two sets of figures show more detail about the design actions for Emily and Eric. The top left graphic in both Figure 3 and Figure 4 is a combination of all design actions (build/modify walls, build/modify roof, build/modify windows, build/modify solar panels, build/modify trees).

Recall Emily’s high idea fluency in window and solar panel design. When comparing the window design actions it is clear that Emily practiced a higher degree of idea fluency in window modification. In the design replays, Emily’s idea fluency is seen comparative to Eric’s through the qualitative coding schema. This observation from the design replays is also apparent in the process data as shown in comparing Figure 3 to Figure 4. Through her total design, Emily practiced more design actions and was more fluent in her ideas as seen from the total height of the top figure. Her idea fluency with window design is very apparent when comparing to Eric. However, both students were showed low levels of idea fluency when designing with trees as evidenced from the design replays. The process data also corroborates this claim.

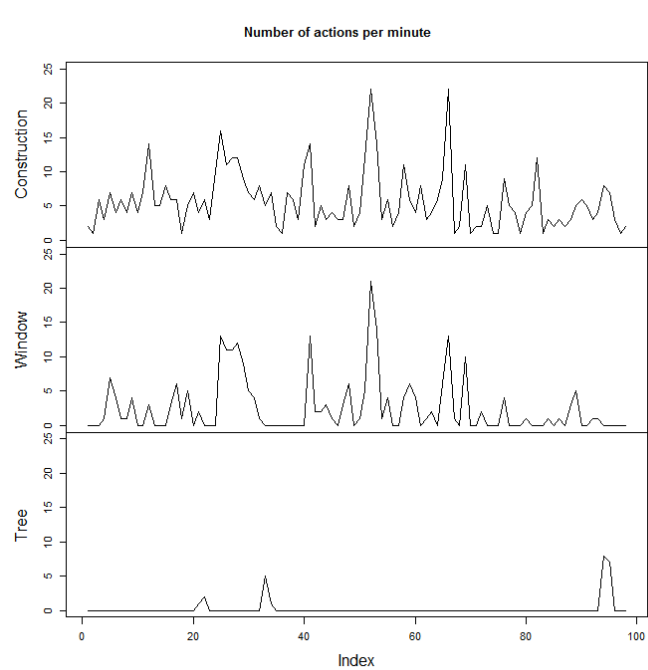


Fig. 3. Emily: Number of design actions from process data

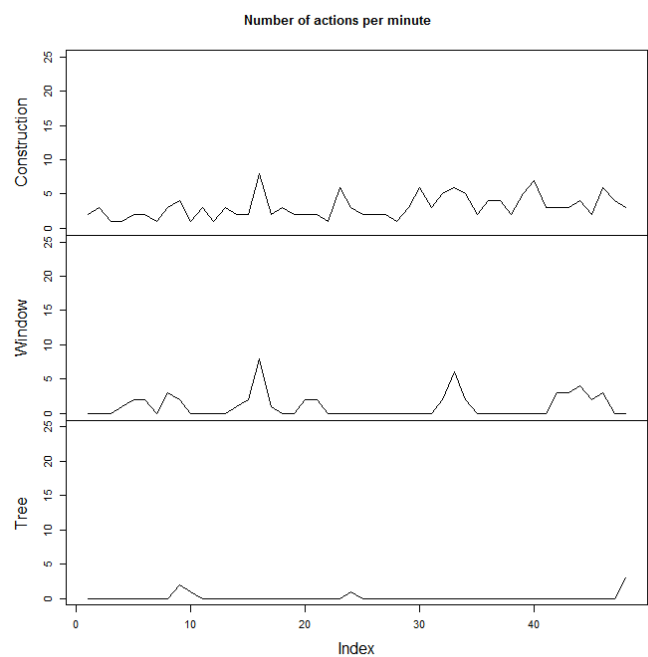


Fig. 4. Eric: Number of design actions from process data

VI. CONCLUSION & FUTURE WORK

Through the case of two students, we demonstrated how micro-level process data can be used to validate observations made from viewing the student design process through design replays. High idea fluency was evident in both design replays as well as in the process data. Similar patterns were observed for the low idea fluency student.

Our results demonstrate how traditional forms of assessment data can be used to validate inferences made by process data. Future work will compare students who are focused on idea fluency and students who practice a high degree of tradeoff analysis and will start to explore differences in developing creativity and science learning from design.

VII. LIMITATIONS

This study investigated eight (8) students in an AP Chemistry class at a large urban high school during the 2014 spring semester. While this sample size is in fact small, the AP Chemistry class represents a differentiated group of students who exhibit greater degrees of academic motivation and are of particular interest to explore design behaviors. Our goal for this pilot study was to sample few students from a very homogenous group. Although the data set may seem small, we believe that the validation process will have to start with small data as we move into large data.

VIII. ACKNOWLEDGMENT

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Engineering Design Journey and Project Management

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Abstract—This article discusses students' self- and co-regulation during their engagement in a senior design project. The specific focus of this study was to understand how participants monitor their design process and manage their projects with their teammates. Fourteen students working in four different teams participated in the study, each of which were in their senior year of Biological Engineering courses. The study attempts to answer two research questions: (1) How did students individually monitor the progress of their team-based design project?; and (2) How did their teamwork factor into the completion of the design project? Quantitative and qualitative data associated with student regulation on design process and teamwork were collected from our Engineering Design Metacognitive Questionnaire (EDMQ) survey instrument, an innovative e-journal, students' journey maps, design artifacts, and interviews. The preliminary findings suggest that (1) despite distinctive challenges in managing their team, each found ways to adapt to their team's unique dynamic; (2) teams that believed in a "fair share" task division seemed to utilize better team monitoring strategies; and (3) a design evaluation checklist to refine the number of possible design solutions was not widely used during the problem framing phase.

Keywords—*self-regulation; co-regulation; engineering design; teamwork*

I. INTRODUCTION

Design, a central part of engineering education, helps students develop problem-solving ability, critical thinking, and creativity. According to Jonassen [1], design problems range from well- to ill-structured. The latter are more difficult to solve because they require more cognitive operations than simpler, well-defined ones. Reitman [2] and Simon [3] classified design problems as ill-structured when they have ambiguous goals, no predetermined solution path, or require the integration of multiple knowledge domains. Design may have numerous solution pathways and be bound by constraints, which are not always presented with the problem. In engineering education practices, students are often required to work on their design projects with a team.

Although teamwork has been recognized as one of the major skills practiced in the workplace, in educational practices it is often perceived by many students as challenging and adding to the complexity of their design tasks [4]. In engineering programs, students are expected to be able to work in teams and this expectation is even prescribed in one of the student outcomes endorsed by Accreditation Board for

Engineering and Technology (ABET) [5]. Development of the skill of teamwork management is often only found in limited situations such as homework and lab activities, which differ from the ill-structured environment of design/build.

Working on a design project in a team requires effective self- and co-regulations. Research has found that self-regulation may be generalized to individuals in teams and teams as well [6] and in many situations, random assignment being one, social interactions may negatively impact individual and team self-regulation [7]. Conversely, it is well known that good quality teams have the ability to synergize, thus achieving a level of performance beyond which the individual team members could attain.

This article presents a study that is currently being conducted to understand student self- and co-regulation processes during a senior design project. The specific focus of this study was to understand how participants monitor their design process and manage their projects with their teammates. Some preliminary findings are included in this article.

II. RELEVANT LITERATURE

A. Engineering Design

The National Academy of Engineering suggested that engineering education was deficient if it did not include the global perspective in engineering design [8, 9], which views design from a systems level rather than from an isolated modular perspective. Not only do open-ended, system-type problems more accurately reflect industry practices, they also provide students more flexibility and choices [10].

Dym and Little [11] contended that the design process consists of five phases: problem definition, conceptual design, preliminary design, detailed design, and design communication. Similar models were proposed by Christiaans [12] and Cross [13]. These design phases are considered as high-level overall views of design processes. They involve a sequence of actions or strategies that are self-contained cognitive approaches and relate to the current state of the design process. For example, during the problem definition phase, students analyze the design problem. It may be divided into several functional subsets. Students frequently consider understanding of the problem to be the most important engineering design activity [14]. After clearly understanding the problem, they may be ready to propose a solution, analyze it, and decide whether to use it or find alternatives. Seniors

found identifying constraints and iterating more important than did first-year students.

Senior capstone design projects were selected to be the context of this research because they represent ubiquitous, complex, and ill-structured problems which prepare students for post-baccalaureate work by immersing them in industrially-based projects. This study will use Dym and Little's [11] five-stage prescriptive model to categorize and code cognitive engineering design strategies and evaluate students' metacognitive activities during the five design phases. This design model was selected for two reasons. First, it categorizes the design process into five 7 main phases (i.e., problem definition, conceptual design, preliminary design, detailed design, and design communication) with specific cognitive strategies in each phase. Second, the model offers clear coding categories for student cognitive strategies in engineering design.

B. Project Management

Kerzner (2013) [15] defines project management as an approach for finding internal solutions to resource control issues and requires, "methods of restructuring management and adapting special management techniques, with the purpose of obtaining better control and use of existing resources" (p. 2). Working in a team is not just about working together with peers sharing the same space and tasks to work on, but also balancing power and responsibility as they seek to control the path their team takes to meet its mission. Numerous studies have suggested that group learning offers a basis for social comparison and social learning [16] and teamwork quality and team diversity impact the effectiveness and quality of the task completion [17].

In the context of engineering senior design projects, the project mission is accomplished as students manage the demands of tasks and assignments from clients (someone who funds the design project), the instructor and each other. In academic environments, there may be a leader assigned to a particular group, yet members of the team are generally peers and the assignment of leadership may be arbitrary and loosely distributed as in social contexts the students may be more familiar with. Thus, the distribution of power and responsibility is subject to the unique dynamics of each group. Project management in this work is comprised of three components: Team Management, Resources Management and Time Management.

Team management includes the interpersonal dynamics of group planning, distribution of tasks, and utilization of each team member. Resource management is seen as the group allocation, tracking and use of funding. Time management is considered on an individual basis, as students prioritize work on their particular project tasks and coordinate with teammates to meet their pre-determined deadlines for delivering portions of the deliverables.

C. Self-Regulation and Co-Regulation

Research on self-regulated learning (SRL), which in this proposal is defined broadly as a complex repository of knowledge and skills for planning, implementing, monitoring, evaluating, and continually improving the learning process,

shows that enhancement of these abilities strengthens learning skills [18] and improves academic success [19-23]. Coutinho [24], along with Otero and Campanario [25], found that students with good SRL skills are more likely to achieve academic success and a high GPA. According to Zimmerman [26], self-regulated learners are "metacognitively, motivationally, and behaviorally active participants in their own learning process" (p. 329); therefore, self-regulated learners are skilled in goal-setting, self-monitoring, self-instruction, and self-reinforcement [27] and build "habits of mind" and commitment to the ideals of reflective thinking, assessment, and learning as an ongoing, lifelong process. When students are working in a team, team interaction may affect student's self-regulation with some interactions being especially difficult, such as when individuals are grouped together by assignment [7]. A student uses good SRL processes to oversee his or her learning process, plan and monitor ongoing cognitive activities, and compare cognitive outcomes with internal or external standards [28].

In this study, regulation in contexts of the model by Butler and Cartier [29, 30, 31] was used to assess the dynamic and iterative interplay between metacognitive and cognitive activity which characterizes SRL as a complex, dynamic, and situated learning process [28]. This model involves six central features that interact with each other: (1) layers of context; (2) what individuals bring; (3) mediating variables; (4) task interpretation and personal objectives; (5) self-regulating strategies; and (6) cognitive strategies.

Co-regulation, on the other hand, is a transitional process of interaction between two or more peers that acquire self-regulation in a common problem-solving plane [32, 33]. This co-regulation is a temporary support for each other's SRL and peers are required to be aware of one another's goals and progress and consider those in relation to the shared task [34]. In the co-regulation process, one of the peers is usually a more regulated peer that assumes responsibility for regulating a less regulated peer. Research suggests that students are benefited to succeed in learning as a result of participating in the co-regulation process [32].

In an engineering design educational context, the layers of contexts may include learning expectations in engineering as a field of study, the nature of engineering design tasks, and the expectations of particular instructors in different settings. The second feature of what individual brings include students' strengths, challenges, interests, and preferences. The mediating variables include students' knowledge, perceptions about competence and control over learning, and perceptions about design activities and tasks. Task interpretation is the heart of the SRL process. Students draw upon information available in the environment, and knowledge, concepts, and perceptions derived from prior learning experiences to interpret the demands of their design tasks. Students set personal objectives such as achieving task expectations in order to direct their engagement in learning. Fifth, students manage their engagement in academic work by using a variety of self-regulating strategies: planning, monitoring, evaluating, adjusting approaches to learning, and managing motivation and emotions. The sixth SRL feature is the cognitive actions or

strategies selected to realize their design and project management plans.

III. THE STUDY

The objective of this study was to learn about students' self-regulation during their engagement in a senior design project. The specific focus of this study was to understand how participants understand the tasks they are working on, make relevant planning strategies and monitor their design process and teamwork.

A. Research Questions

Two research questions were constructed to guide the study:

- 1) How did students individually monitor the progress of their team-based design project?
- 2) How did their teamwork factor into the completion of the design project?

B. Student Participants and Design Projects

Fourteen students working in four different teams participated in the study, each of which were in their senior year of Biological Engineering courses. Five among those 14 students were female. All had a GPA between 3.0 and 4.0 on a 4 point scale.

The first project was tasked with the development of a hernia mesh derived from synthetic spider silk with the ultimate objective to create an alternative hernia repair mesh using synthetic spider silk. The second project was to develop a drug delivery system using human serum albumin (HSA) as a carrier for anti-inflammatory, antibiotic, antiviral, and antioxidant drugs for kidney and/or liver failure patients. The third project was the production and purification of antimicrobial peptides in *Escherichia coli*. The objective of this project was to work towards optimizing a design to produce four different antimicrobial peptides by studying the effect that some different variables have on yield, activity, and purity and deciding which methods produce the best results. The fourth project was to design and optimize a process for the production of green fluorescent protein (GFP) secreted from recombinant strains of *Pichia pastoris* grown in bioreactors. Each group had to complete their project within two (spring and fall 2014) semesters.

C. Data Collection and Analyses

Students' self-regulation in the design process and project management were collected through Engineering Design Metacognitive Questionnaires (EDMQ) survey instrument, an innovative e-journal, students' journey maps and interviews.

1) *Quantitative Data*: Quantitative data were collected through EDMQ. The instrument development is grounded in Butler and Cartier's self-regulated learning (SRL) model which describes the interplay between motivation, cognition, and metacognition in a design activity. A rubric matrix combined Butler and Cartier's SRL features (i.e., task interpretation, planning strategies, cognitive strategies, monitoring/fixed-up, and criteria of success), as well as Dym and Little's design process and project management

components were used in the instrument development. Dym and Little contended that the design process consists of five phases: problem definition, conceptual design, preliminary design, detailed design, and design communication. The project management activities include students' teamwork, time and resource management. Individual performance on student self-regulation during the design process and how they managed their project were assessed using this survey instrument.

2) *Qualitative Data*: Qualitative data were collected through interview, Electronic Journal (eJ), design journey map and artifacts. Coding of interviews will follow the main categories in the Butler and Cartier model. Specific attention will focus on how students describe task demands in all phases of a project (to complement EDMQ data on task understanding), and interview probes will be used to ask for explanations of observed activities. Common themes are expected that may facilitate knowledge about students' understanding of design tasks, why they elect certain design strategies, how the strategies relate to task understanding, and how the strategies change during the course of a design project. The e-Journal was designed concordant with the engineering design phases: Problem Definition, Conceptual Design, Preliminary Design, Detailed Design, and Design Communication. The online characteristic of the eJ ensure the 'freshness' of the data because students can report their activities concurrently with design activities or at their convenience. The e-Journal enables the act of going back and forth between phases to support the iterative nature of engineering design. A form with prompts is available for the students to enter reports of their activities and upload related documents pertinent to each design phase. The reports also serve as a communication means among the team member in the group, or between the group with instructors, clients, supervisors or researchers. Students were required to attach files that comprised student's design deliverables. The design artifacts were evaluated to confirm what they said they would do and what they actually did. Approaching the end of the project time, participating students were asked to describe their cognitive (including metacognitive) actions and emotions as a journey map while working on their design project. These sort of pictorial descriptions tell a host of stories that cannot be captured by survey instruments.

3) *Analyses*: Students' design journal entries were coded to identify SRL features and engineering design strategies. Possible links between planning activities and engineering design strategies will be made in order to identify accomplishments, adjustments, or the abandonment of strategies. The accuracy of the information collected from the eJ will be judged through design artifacts. The measure of agreement between student reports from the eJ and other sources recording design progress will be validated and evaluated. An index score of EDMQ indicates the level of balance among domains of SRL activities. An Index Score was defined as the score associated with each of these

domains and helps shape this study's interpretation of student self-regulation effect. As such, the relationship was modeled using a magnitude from the EDMQ answers given, and a weighting factor that scales the applied SRL effect of each team member. As teams scores are found and normalized over the number of team participants, a corresponding efficiency of the team's SRL is obtained that corresponds very closely to the information being obtained about team dynamics from other sources. Thus it appears that team dynamics may have a powerful effect on SRL or vice versa. This effect is a prime area for more study.

IV. PRELIMINARY FINDINGS

The analyses are currently in progress and are not yet completed. In this work-in-progress paper, three preliminary findings are presented in this article:

1) Despite distinctive challenges in managing their team, each found ways to adapt to their team's unique dynamic. While adaptive methods may be generally viewed as positive, in these teams, it was apparent that there were various degrees and qualities of adaptation. Some adaptive behavior shown is highly self-regulated in nature, for example, taking over where someone leaves work undone, or in helping a struggling teammate. Conversely, examples have been shown where teams allowed roles to shift and stopped long range planning activities. What we are seeing is adaptive behavior over time that can either strengthen or weaken team efforts to continue SRL. Continued inquiry into this area of project based team behavior is needed.

2) Teams that believed in a "fair share" task division seemed to utilize better team monitoring strategies. They tended to stay on task, check each other's status more often and had more open communications with each other about the project. Teams with relatively higher composite TI/PS Effect scores showed an efficiency characterized by their members completing their design tasks or cooperative efforts to stay on track. In light of the other forms of data collected (eJ, interviews, journey maps) the self-reported characterizations of SRL effect correlate very strongly to the flavor of team dynamics encountered. For example, the team with the highest normalized TI/PS effect score over project management issues seemed to be composed of members more effectively implementing SRL, individuals were more team oriented than ego-centric, had better planning, strategies, more open communications, and a shared sense of responsibility and power. On the other hand, teams with lower normalized TI/PS scores on project management issue seemed to struggle with project management efforts regarding teamwork, time management, and resources management generally. Compelling evidence for these findings is qualitatively reflected from student interview and design journey map.

3) A design evaluation checklist to refine the number of possible design solutions was not widely used during the problem framing phase. This finding was indicated by the consistent lower self-regulation EDMQ scores on task-interpretation, planning and monitoring strategies associated with developing an evaluation checklist during problem-definition design phase.

V. NEXT STEPS

Further analyses are currently being conducted to understand our data and triangulate it from those multiple sources identified as providing input to answer the two research questions within this study. A novel approach to compare teams via composite index scores is currently being validated that may show relations across various SRL constructs. The results of this study are also being further analyzed in light of additional design artifacts. These have further information to provide that can inform studies of SRL among students design teams.

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Life-Based Design as an extension of problem-based learning - a tool for understanding people and technology

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Abstract—Global conditions are changing at such a rate that foreseeing trends in technological development, economic fluctuations and climatic conditions is ever more difficult. When developing technologies, there is one constant factor that practitioners and researchers should be aware of, and that is people. This is not to say that people, culture and social conditions remain stagnant, for these too evolve with the surrounding circumstances. Rather, appropriate tools and capabilities for investigating people, their lives and life situations, are integral to understanding what people need in terms of technology, how these technologies will be used, and more importantly how they will be valued in the scheme of a person's life. This paper describes the process and outcomes of a course in Cognitive Science focused on developing the tools needed for Life-Based Service Design (LBSD). The course is implemented via problem-based learning (PBL), and students are guided through the process by charting an explanatory method adhering to the Life-Based Design (LBD) ontology. This ontology comprises: 1) Form-of-life analysis; 2) service concept and requirements; 3) fit-for-life analysis; and 4) innovation design. Results show heightened awareness and sensitivity of life conditions, values and needs, revealing design concept strengths and weaknesses in the pre-development phase.

Keywords—*life-based design; problem-based learning; cognitive science; service design; interaction design*

I. INTRODUCTION

In the world of education there has been much discussion on the need to train students in 21st century skills [1] [2] [3]. Despite attempts to establish frameworks [2], the term 21st century skills often remains vague as a concept, especially in terms of substance. There is no prescribed set of skills that will prepare individuals for the 21st century [1]. However, Trilling and Fadel [2] identify that the century will require several skill sets. These include: 1) learning and innovation skills – critical thinking and problem solving, communication and collaboration, creativity and innovation; 2) digital literacy skills – information, media and ICT literacies; and 3) career and life skills – flexibility and adaptability, initiative and self-

direction, social and cross-cultural interaction, productivity and accountability, as well as leadership and responsibility.

While we are pointed to the direction of what types of skills need to be instilled and developed, the exact skills and tools needed remain vague. This vagueness lies in our inability to adequately predict the vast changes that are expected to occur over the next 20 to 30 years in relation to climate, technology, social, economic, cultural and other conditions that await. In fact, the dependence of our livelihood and wellbeing, physically, socially, psychologically and financially on radically developing technological conditions, means that we are quite often only able to rely on the state of things *today*, rather than count on what comes *tomorrow*.

For this reason, in the Cognitive Science education program, the university has introduced the Life-Based Service Design course. While we cannot fully imagine the possibilities of tomorrow on the basis of technology, we can direct students towards the source of these developments – people. People are diverse, not only amongst one another, but also within themselves. Due to continual physical and psychological life processes of cell generation and cell death, learning and experiencing, human beings are never the same entity from one moment to the next [4] [5]. This is why overlooking people and focusing on aspects such as technology, and other designed systems, leaves us prone to a lack of understanding regarding how these systems develop and operate.

In this paper we describe the Life-Based Design (LBD) methodology, and how it serves to gauge the nuances of human cognition from the perspective of life circumstances, or as termed in LBD, Forms of Life (FoLs) [6]. We then go on to describe problem-based learning (PBL) and how it is integrated into LBD as not only an approach to design practice, but also as a method for learning about human cognition, its relationship to physical reality, and how this impacts (or should impact) the way practitioners approach

service and system design. The paper moves on to describe how the LBSD course has been implemented over the past two years (2013 and 2014), what processes students undergo, how they choose topics, gain mentoring, and reflect these learning processes. The learning outcomes of the course are then described in terms of subsequent projects students have endeavored as well as resulting services. In the conclusion we discuss the effectiveness of the course, and directions for future LBSD problem-based learning.

II. LIFE-BASED DESIGN METHODOLOGY

The main tenet of LBD is that services and technology should exist for the benefit of life quality [6] [7] [8]. The four main phases of LBD methodology are: Form-of-life (FoL) analysis, concept design, fit-for-life design (FfL), as well as innovation design [8]. LBD differs from other human-technology interaction (HTI) design paradigms, which include human factors, usability engineering, and ergonomics in that these paradigms focus on the systems and services themselves. That is, according to Leikas et al. [8] they are devoted to establishing seamless and unproblematic interactions between people and systems, yet from a technological perspective [9] [10] [11] [12] [13] [14]. Thus, the study of people in these paradigms is focused on the HTI, and how well systems operate in light of the user.

LBD on the other hand, starts from human beings and their life conditions (i.e., family, career, age, gender, socio-economic, cultural, ethnic, religious, disabilities etc.) and identifies the areas which may be assisted and enhanced by particular technological solutions, in order to improve life quality. The components of LBD can be seen in Figure 1, which illustrates the relationship between FoLs, Rule-following actions (RFAs) and Technology-supported actions.

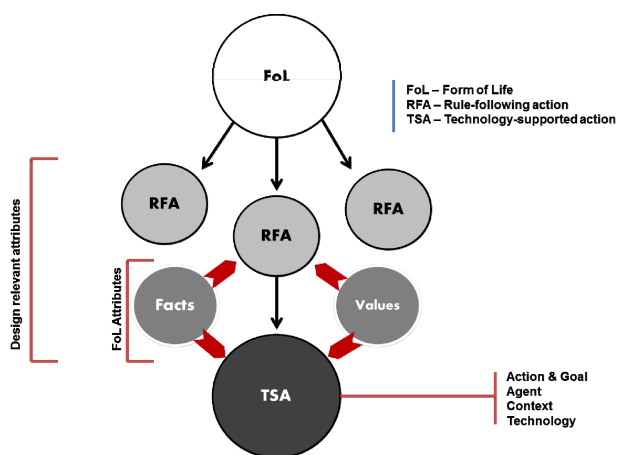


Fig. 1. Components of design leadership according to LBD, adapted from Leikas [6], p. 6.

As stated above, central to the service design process in LBD is the person and their FoL, or life circumstances (physiological, psychological, social, economic, information,

etc.). Everyone in their FoL engages in RFAs. That is, similar to routines, people fall into pattern of actions and behavior. These patterns may begin from a necessity, i.e., waking up early to go to work, and then continue even when the actions are no longer necessary (e.g. retirement or while on vacation). Thus, the *facts* are elements which are inherent to the FoL, such as the need to arrive at work on time, while the *values* (and norms) possess the meaning of action – why people behave the way they do. Then, the design relevant attributes inform the designer when making specific design decisions for people experiencing the FoL in question. This in turn affects the technology-supported action (TSA), which in itself is the dynamic interaction of action and goal, agent, context, and technology or service. [6]

III. PROBLEM-BASED LEARNING

Problem-based learning, or PBL, is a constructivist approach to learning that engages students through the presentation of problems, relevant to the desired learning outcomes in question [15]. It was originally developed by Howard Barrows and colleagues at the McMaster Medical School in 1969, not as a pedagogically or psychologically tried and proven method for learning, but instead as a way of making the learning of medicine fun [15]. While there are many forms and adaptations of PBL, some of the core principles behind the method are: 1) PBL is student-centered; 2) it generally takes place in small groups or teams; 3) learning is active, whereby learners actively seek answers themselves; 4) cases or problems are utilized as stimuli for learning; 5) and learning takes place during independent study time, which is usually significant [16] [17].

PBL has been defined in terms of learning objectives and goals, teaching philosophy, in addition to pedagogical attitudes and values [18]. PBL has even been identified as a 7-step process by authors such as Henk G Schmidt [19] who isolated the seven steps as being: 1) the clarification and agreement of ‘definitions in progress’ of terms and concepts which are as yet, still unclear; 2) identification of the problem(s) in question and agreement of issues and phenomena which need further explanation; 3) the analysis of effects of various components (via e.g. brainstorming) and explanations in order to form a rough hypothesis; 4) the discussion, arrangement and evaluation of likely reasoning facilitating the working hypothesis; 5) creating and ranking learning objectives; 6) undertaking independent research to develop a deeper understanding of these objectives between tutorials or seminars; and 7) the reporting of findings at tutorials and seminars, which thus aids in the establishment of plausible explanations and reapplication of these explanations to new information and problems.

PBL has been characterized in terms of its strengths and weaknesses. In terms of positive cognitive attributes, PBL is noted as promoting better memory retention of material learned during problem-based processes. The applied way in which knowledge is acquired means that this knowledge is more readily recalled and utilized in solving other similar

problems. Pattern recognition is enhanced and encouraged through knowledge acquisition that occurs over time via real life examples. Further, PBL promotes the activation of prior knowledge which enables efficient processing of new information. Knowledge, or pieces of information, are readily explained and contextualized during moments of learning. Then finally, the attachment of context to knowledge acquisition eases future recall. [15] [20]

The negative aspects of PBL have been characterized as mainly placing too much load on working memory. This is noted by Kirschner, Sweller and Clark [21] as being problematic in that the working memory is incapable of simultaneously problem-solving and learning. In other words, its capacity is said to only enable one of these actions per time. Additionally, Kirschner et al. [21] highlight that processes of learning how to practice in a field of knowledge such as medicine and the processes of actually practicing cognitively differ. We argue that by implementing PBL in the Life-based service design course we not only promote the learning of user-centered design (UCD) modalities in a fun way, but the processes of PBL and the LBD approach to UCD are complimentary, and can be used to reinforce one another.

This is due to the explicit stages of LBD ontology examination and definition which sit neatly with Schmidt's [19] outline of the 7-step approach to problem-based learning. Learners are encouraged to consciously reflect on the learning process, not simply in terms of the LBD methodology itself, but also of the designer's process in coming to understand other individuals (people in various FoLs) and in particular, their cognition. More will be explained about this mutually complimentary process in sections V and VII.

IV. PBL IN DESIGN AND ENGINEERING EDUCATION

In their article "Engineering education – is problem-based or project-based learning the answer?" Julie Mills and David Treagust [22] criticize the *then* dominance of "chalk and talk" (p. 2) education. Mills and Treagust highlight the importance of keeping pace with the rapidly changing technological conditions engineers in today's world face. They additionally emphasize the significance of developing skills such as flexibility, adaptability, and most importantly people skills. In particular, they stress research findings which suggest that engineers should possess effective teamwork and communication skills [23] [24]. On this note, Helen Beetham and Rhona Sharpe [25] see PBL as a means of gaining and strengthening 21st century skills precisely for its qualities in supporting collaborative learning and requiring that learners seek the answers themselves – without the guidance of a teacher or tutor. Their argument is that conditions the students find themselves in, such as their technological landscape, should guide the process. With this said, they emphasize that the technology should lead the learning process, rather than traditional teaching and learning methods, limiting the advantages of the technologies.

PBL is noted as being favored among students in that it prepares students for the eventuality that the worlds of engineering and design are problem-based environments [22] [26] [27]. Thus, allowing students to practice problem-solving in the safety of their learning contexts. This is critical when considering the design and engineering professions as solving everyday problems [28]. Furthermore, PBL is quite similar to project-based learning, in that they both require group work and collaboration as well as self-directed learning. Furthermore, both modes are noted for their interdisciplinary natures. However, the difference between the two is that project-based learning is focused on *applying* knowledge, while PBL is focused on *acquiring* it [29]. This is where LBD as a method differs from pure PBL in that it requires both acquiring and application during the research process, and in the reporting phase. With PBL as a methodological back drop, the following describes the application of LBD as an extension and practical application of this type of self-directed group approach to learning.

V. LIFE-BASED SERVICE DESIGN COURSE – IMPLEMENTATION AND LEARNING PROCESSES

The Life-based service design (LBSD) course has been offered as a course through cognitive science for the past two years. It is an advanced learning module, taught at a master's degree level with the possibilities to continue research cases from differing aspects in other courses held in the program. Due to the time and work demands of lecturers as the result of numerous supervision sessions (or tutorials) during the course, student numbers are kept to a minimum. The course is open to a maximum of 25 students per time, meaning that there are essentially five to ten groups, and thus, cases. While four group members are the maximum, ideally two to three member groups are the optimum size.

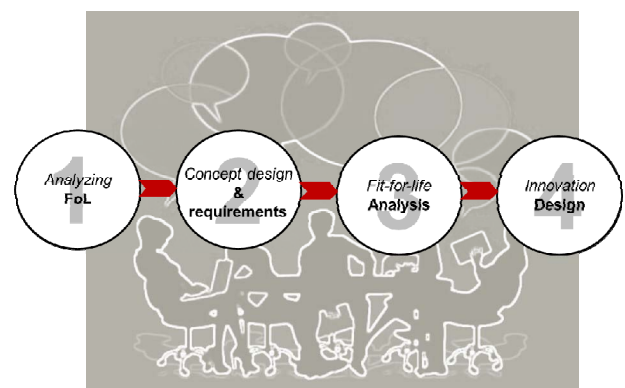


Fig. 2. Stages of the LBSD ontology (see [6])

At the beginning of the course students are provided with information about LBD in the form of two lectures. LBD is introduced firstly as a concept, and then as a design and engineering methodology. The concept is introduced in relation to research which has been undertaken relating to

technology generations, or gerontechnology [30] [31] [32]. It highlights the fact that in order to become genuinely engaged in UCD, and to essentially truly design for people and their diversity – differing requirements and desires for differing life circumstances – designers and engineers must become familiar with technology and service users on a *day-in-the-life* basis.

The methodology is explained at the same time as the assignment guidelines are distributed to the group. These guidelines are labeled ‘LBSD ontologies’, following the ontologies of LBD [8] and comprise four steps: 1) Analyzing forms-of-life; 2) the concept (design) and requirements; 3) Fit-for-life analysis; and 4) innovation design. These steps of the methodology are instrumentally used to break down the assignment task of the course. Each step is outlined as follows. Figure 2 illustrates the stages of the LBSD ontology.

A. LBSD ontologies and learning stages

1) Analysing forms of life (FoL)

For this step students, and ultimately designers/engineers, are guided to define the problem area and explore the nature of the FoL (life circumstances) of the service’s target users. Through contextualizing and identifying the problem area and human elements involved in the problem, the students are then able to establish a design problem, for example the lack of high speed internet connection for a particular digital learning application at an elementary school in some part of the world. Additionally, what is included in the ‘form-of-life analysis’ is the discovery of ‘Rule following actions’ (RFAs). These are typically known as habits which have formed through years of repeated actions, possibly for specific reasons. In an educational context this may be the practice of taking notes in lectures. Although these days students have access to lecture material via online learning platforms such as Moodle, Blackboard and other spaces, for more mature students, the practice of note-taking is upheld, and in many cases assists cognition through the kinetic processing of information [33]. These RFAs are particularly important when not only trying to understand users and potential users, but also when anticipating the use and potential use of the service in question.

Further, logically the actors, or users (teachers, administrators, learners and possibly parents), need to be identified even before commencing the journey of exploring life circumstances and RFAs. These actors need to be identified in terms of age, gender, skills, culture, social-economic circumstances, educational level, field, subject and other relevant information.

Then, the typical use contexts need to be established and explored. Information that is required of the context includes social, psychological, physical and technical factors. For instance, when designing digital learning services for mature aged students, designers must be aware of conditions such as technophobia, and possible social stigma surrounding technology such as computers, the internet and distance

learning that may be held by a particular group of learners. There are possibilities to overcome these issues via the technical design which may also be enhanced in the way the services are implemented – i.e. via a combination of face-to-face and online meetings.

Finally, as a tangible starting point for the service design, students are required to define the design theme and purpose of use. The purpose of use may have been the trigger for the service project, however, through FoL analysis other, previously unforeseen uses may arise, which could be critical to the success of the service.

2) The concept (design) and requirements

This step, which is quite similar to Schmidt’s step 2 in PBL, where the problem in question is determined, focuses on establishing what type of service design concept is to be developed in addition to the user requirements. Yet, rather than concentrating on the service itself, students are encouraged to explore the FoL in relation to RFAs in order to derive what types of technologies are appropriate and have the potential for enhancing quality of life. Thus, RFAs are examined for possible technology and service-supported actions. For example, telephone answering services have been developed with the idea in mind that in certain situations such as meetings, while driving and in other cases people cannot answer the phone. Yet, it is more convenient for the caller to leave a voice message than to independently type an SMS message. Similarly, online shopping – particularly grocery and even fast food ordering – have been developed for people who prefer to avoid crowds or do not have time to pick up goods in person.

At this stage students, and LBSD designers, investigate the possible alternative solution ideas. This is achieved by brainstorming – also prominent in PBL in steps 3 and 4 in particular. During these brainstorms attention is placed on elaborating various solution models – types of services or technologies, and what is required. The interaction between users and services is explored in terms of user-interface prototypes (fast or paper prototypes) and through further discussion.

Ideas and prototypes are tested with real users from the relevant FoLs (target groups). This is achieved both in terms of the conceptual model, and possibly even regarding more specific issues such as usability if the user interface prototype is at such a level of completion that usage can be simulated and/or evaluated. These investigations lead to a more precise definition of the technical solution concept. Thus, the design for development is known by now, and students can set their sights on gauging whether or not the service will suit the FoLs and RFAs in question.

3) Fit-for-life analysis

The *Fit-for-life analysis*, or FfL analysis, stage looks at how the FoL may be improved by the inclusion of the service

in development. This is somewhat of a departure from traditional product and service design in which a market is located through identification of possible uses [34]. Here, focus is placed specifically on how the innovation may potentially improve life quality of those who use it. Thus, emphasis is on the intangible value of the research and design work. This is quite similar to the hypothesis development occurring in PBL (Schmidt). Reflecting the design concept back onto real life situations and pairing the concept and its prototypes with target users' practical everyday life and values students (and designers/ engineers) can re-evaluate as to whether or not the concept is the best solution for the design problem in question.

During the FFL analysis meanings are explored, particularly in terms of what the service design concept means for the FoL under investigation. Meaning is especially pinned to the idea of improving life quality, whether this is in terms of making daily living (actions and chores) easier, or by encouraging *happiness* through social interactions with peers and loved ones. When considering life-long learning and its increasing popularity, digital and online learning solutions may be a key to improving life quality by enabling learners to become more actively involved in their learning. However, the learning solutions need to match the technologies and capabilities possessed by many mature-aged users.

Finally, during this stage special consideration needs to be given towards ethical questions regarding the user, usage, user context, and of course the service concept design being developed [35]. The service needs to be observed from an ecosystemic perspective which gauges the elements, not simply as separate elements, but as interacting actors, which change in meaning and therefore consequences depending on their combinations.

4) Innovation design

The final stage of the LBSD and learning process is the innovation design component. It is at this point that the actuality of the service design is considered. Here, matters such as infrastructure and use culture creation are examined. Distribution and sales are strategized in terms of marketing and implementation. Other problems or issues which need to be tackled by the students are for instance maintenance plans (particularly of online services) and the expected life-span.

B. How it works

The course is structured as to give students a brief introduction to the terms and concepts of the course. They are then initiated into the group assignment via the presentation of FoLs and their associated problems, in addition to already formed cases. For instance, one FoL may be young elderly people (55-75+) who have received an early diagnosis of memory impairment. Another may be mothers of young children seeking activities and play friends for their children. Groups are formed based on the students' interests, i.e.,

students choose a FoL and work with others who have also chosen the topic.

The instructions, in the form of the ontology, are made available for the students (both in their online learning platform and on paper) and students are given a week after the first meeting to begin structuring their research plan and approach to the FoL and subsequent LBSD process. The groups then present their ideas and preliminary plans to the group. During this research plan session questions are asked and feedback is given by both the students' peers as well as lecturers and tutors. After this presentation session all other meetings take place during supervision times arranged by the students with the teachers and tutors. In the two month course students are required to meet with teachers and tutors at least twice for guidance.

The supervision sessions are designed to provide the groups with advice regarding means of approach towards investigating the FoLs as well as in terms of theory. The theoretical direction of this supervision exists on three levels: 1) relating to the course subject – life-based service design – its philosophies and methodologies; 2) regarding the FoL in question, particularly in relation to issues of cognition and human-technology interaction (HTI); and 3) relating to design itself – students are required to investigate past and state-of-the-art services to discover possibilities and any present flaws in these services. There are no limits to how many times groups can arrange supervision, however the average amount of meetings is three. Generally, the amount of supervision sessions also rests on the level of challenge presented by the FoL and design problem in focus.

The groups present their projects at the final seminar of the course. Presentations take place according to the structure of ontology instructions, being with an introduction to the FoL stating simple facts about the group and then moving into previous scientific research regarding the FoL and specific everyday problems relating to this group of people. More previous research (if any) is presented regarding attempts to solve this problem. Then the students' own empirical component is explained. The empirical component consists of data collection from people experiencing this FoL via methods ranging from ethnography, to interviews and questionnaires, and even experiments in some cases. Based on the results of the empirical FoL material, the service design concept is either formulated or modified. The important aspect for students to remember in this process is that the research is not about discovering how to fit services into people's lives. Instead, it is about discovering how the services would naturally fit into their everyday lives.

The groups present their findings and following these they outline either the service design concept developed as a consequence of the research, or prototypes. In some cases groups have also managed to not only present prototypes, but also second or third iterations which have been influenced by

user or usability studies with people from the FoLs in question. Approximately one month after the completion of the course, students are required to submit reports of the project and design process. There are no set page requirements for this, however on average groups submit around 25 page reports, some even 50 pages – depending on the design challenge and level of motivation.

VI. OUTCOMES OF THE COURSE

Although LBSD is offered as a stand-alone course, its philosophies and the LBD methodology are present throughout the Cognitive Science Master's degree program. Therefore, continuation of projects initiated during the course is encouraged and supported. Since 2013, 49 students have taken part in the course. Of these, 24 were female and 25 were male. This equal representation of gender is already an achievement given that the course is held in the Faculty of Information Technology, which is dominated by male students. The age distribution of students is broad, the youngest being 23 years of age and the oldest being 58 - the average age being 31 years of age.

Besides the cognitive science students, students undertaking the course also come from disciplines such as information systems, computer science and software engineering. Students also come from diverse backgrounds, many already having vast professional experience either in the fields in question or in other fields. For this reason LBSD course and the LBD methodology, in light of the constructivist approach to learning that PBL affords, is highly advantageous for these types of student groups.

Since beginning the course 17 projects have been undertaken. The FoLs have included: young children (childcare and pre-school) learning about nature; families with children (young children and youth); foreign students seeking accommodation; people with memory impairment (institutionalized elderly and young elderly with early diagnosis); healthcare professionals providing services for elderly still living at home; tertiary students with Asperger's syndrome; tertiary students with vision impairment; foreign students with vision impairment; and organizational leaders seeking innovation management systems to name some.

The types of service concept designs which have derived from the studies have included: scheduling services; social media directly for the FoL in question; accommodation matchmaking; information systems enabling more fluent home healthcare options; affective toys; daily audio assistants; innovation management services; and augmented reality for educational application. Of these 17 projects, seven (41%) have continued after course completion. Some of these have been continued in other subjects offered by cognitive science such as User Research, Usability Analysis and Interaction Design. Four of the projects have been used as platforms for service business ideas, and two (an innovation management

service and an augmented reality educational application) have received national innovation funding to be developed further on a much larger scale. These funded projects in themselves are substantial achievements.

Numerous advantages have been noticed in adapting LBD as an educational approach and philosophy in the cognitive science program. Here is a list of the strengths of the method:

- It provides a fun and active introduction into human cognition placing real life situations at the foreground
- Theory is readily integrated into practical problems both relating to the FoLs as well as design issues
- Learning takes place on three levels: 1) LBD methodology and theory; 2) FoL familiarization; and 3) design theory, practice and state-of-the-art innovations
- Contextual, social, psychological and physical aspects affecting HTI are emphasized as central figures rather than the designs themselves
- Through consistency and support among staff (and faculty) LBSD course provides continuation to projects, supporting deeper learning
- Continuation and possibilities for greater achievements provide students with motivation for learning

During the course's history there has, however, been criticism towards this methodology, which can be seen as a side-effect of this independent, or self-guided (while in a group) constructivist approach. This relates to the minimal amount of lectures, an argument which contradicts the problems seen in the work of Mills and Treagust [22] who note the prominence of pen and paper engineering education, which sacrifices student motivation and engagement for the safety of traditional teaching implementation. Another problem rests in the group work itself and the distribution of responsibility between group members. Students have complained about final grades in light of some group members not producing as much as others.

Despite these short-comings, as the result of the consistency, adaptability and multiplicity of the course method, strengths rest not only in its effectiveness in relation to student learning, but its ability to construct firm collaborative relationships. These relationships occur within the student groups, between students, teachers and tutors, and between the teaching staff themselves. There is the atmosphere of constructing something larger in terms of understanding users, and possibly creating new innovations which will improve life quality. On this note, relationships between students and people in the FoLs themselves are also forged.

VII. LBSD COURSE APPROACH AS EXPLICIT PBL REINFORCEMENT

There are many overlaps between PBL and the LBSD course approach. However, as cited in relation to the comparison between PBL and project-based learning, LBSD is not only driven towards students acquiring information, it also requires them to apply it. Thus, through beginning with the empirical – FoLs – moving soon to the theoretical (both regarding the FoLs as well as design), and then back into practical application within the concept design (see Figure 3), LBSD can be seen as a combination of the two, plus more.

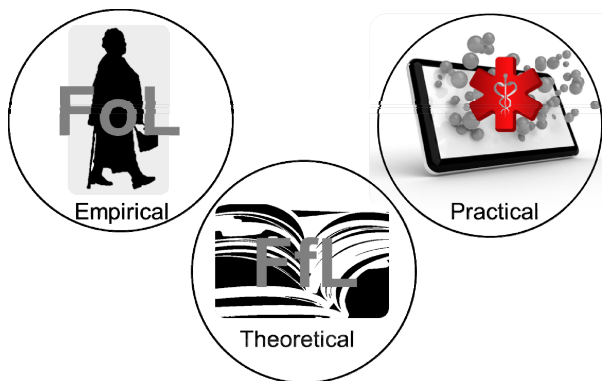


Fig. 3. LBSD methodological learning

The more comes into question when considering the holistic nature in which the LBSD course is delivered. That is, the projects that begin in the LBSD course do not simply stop there. If the students desire, they may continue their research and development projects throughout the cognitive science program, building on their knowledge and expertise of issues relating to cognition and HTI in relation to the FoL, and strengthening their skills as service designers. This may be continued into thesis work, and as seen in several of the projects so far, may even go on to develop into business ideas and/or attract national innovation project funding.

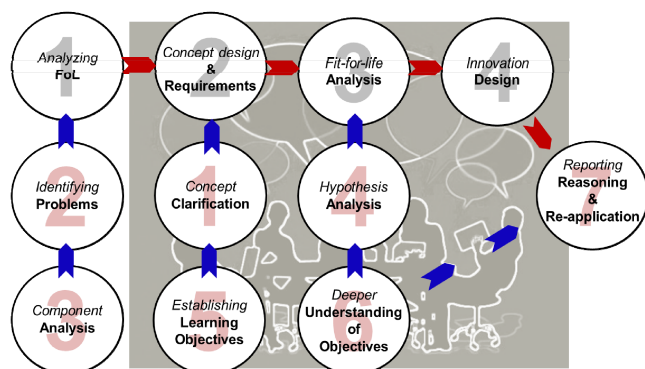


Fig. 4. Relationship between LBSD and PBL according to Schmidt's [20] 7-steps

There are four major stages in the LBD ontologies that students follow as a part of the LBSD course. While there are only four, they are intensive as three of the stages comprise at least six of the seven PBL steps Schmidt [20] outlines (see Figure 4). The LBD stages and the seven PBL steps are related in a non-linear way. As seen in the diagram, it may be noted that stage one, Analyzing FoL, entails the identification of problems and component analysis. Stage two, Concept design and requirements, includes the clarification of concepts and also the establishment of learning objectives (three fold – LBD, FoL and design possibilities). Stage three, FfL analysis, comprises hypothesis analysis – are the means of rationalizing the FoL and their needs and desires accurate? It additionally requires that students dig deeper and strengthen their understanding of the learning goals and objectives. Stage four, the innovation design component resembles part of the concretization phase of project-learning. Subsequently, at the end of the LBSD course, groups report their projects and reason their findings. Finally, there is the hope with this methodology that the learning does not end there, but continues with re-application and continual research – keeping abreast of the developments and changes which are occurring in our rapidly moving societies.

IX. CONCLUSION

This paper has focused on explaining the application of a design methodology, Life-based design, for the purposes of gaining a deeper understanding of people and their daily lives in the fields of service and technology development. As a point of departure, the paper has used PBL as an anchor in order to demonstrate the stages and components of the learning process when using a methodology such as this in a cognitive science program. This paper has highlighted criticism towards “chalk and talk” modes of teaching in engineering education, and emphasized the mode of learning in the LBSD course as that which is guided by real life. Design issues and problems are contextualized in social, physical, psychological, economic and even information (access to) factors. The contextualization forms motivation for delving into the theoretical, to find out how the FoL has been characterized, what the typical problems are, what has been done, and where the gaps lie for what can be done. This knowledge is then applied to the development of concept service designs, and even in some cases, prototypes and working prototypes.

The UCD process is iterative, and by following the LBD method, people from relevant FoLs not only inform the concept design but test the concepts and prototypes in terms of usability, usefulness and overall desirability of the products. Questions asked within the LBD methodological process do not purely pertain to whether or not the design would be useful or usable. Instead, the questions concern how the designs, technologies and services in general fit into the lives of these people, and whether or not, the services and technologies to be developed will improve their life quality.

Pressure is on educators to equip students with the much discussed “21st century skills”. While qualities such as self-

direction, communication and collaborative team skills have been emphasized, there is still something more that we as educators and (educational) designers may hope for. The term “designing for happiness” is not unfamiliar to developers of the LBD methodology [6] [7] [8]. And, given the versatile and uncertain conditions the students as future designers and engineers face, designing for happiness for people of all walks of life in diverse situations seems a noble goal strive for.

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A Spiral Curriculum in Design and Project Management

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Abstract—This paper documents the design and implementation of a four year, five-course sequence in design and project management within a general engineering program at a large public institution. The design of the curriculum was inspired by the “spiral curriculum” concept, and as a result, seeks to build knowledge and skills related to engineering design and project management during each of the four years. Course descriptions and examples of the ways that knowledge is spiraled through each are provided. The first cohort to progress through the entire spiral graduated in Spring 2015; next steps will continue to monitor the effectiveness of the spiral through continued program assessment.

Keywords—*design education; project management; curriculum development; spiral curriculum*

I. INTRODUCTION

At a large institution with a small engineering program, the engineering department was formally established in 2004 and has since offered a BS degree in engineering. The engineering program has a rigorous assessment plan that monitors fulfillment of ABET outcomes and provides a means for continuous improvement. In following this process, two program shortcomings related to design and project management were identified by the faculty.

The first shortcoming was observed at the outcome level when the outcome c (design) coordinator rated the satisfaction of that outcome a level 2 out of 5 for two consecutive assessment cycles during academic years 2008-2010. This prompted the formation of a committee charged with examining the current curriculum and identifying ways that design instruction may be improved. At the time, the sophomore year lacked a design-related course, and it was suggested that continuously building design knowledge throughout the curriculum might be a better approach. In fall 2010, the process of creating a revised curriculum, more strongly emphasizing engineering design and project management, began.

The second shortcoming was identified at the course level. During academic years 2010-2012, based on ongoing faculty assessment of design knowledge among students in ENGR 4010 (Senior Capstone Design Project I), it was concluded that there was a deficit in the readiness of seniors to begin capstone work. The deficit was characterized as a lack of competence

with some basic engineering design and project management knowledge. Although students were able to successfully complete capstone, too much time was being spent reviewing design and project management knowledge. It was believed that the existing three-credit hour project management course, ENGR 3500, was no longer successful in its attempts to provide junior-level students with adequate design and project management skills prior to entering capstone. Anecdotal data collected during exit interviews with students supported this finding.

A solution to simultaneously address both shortcomings was developed and implemented in the form of a four-year, five-course sequence.

II. CURRICULAR APPROACHES TO TEACHING ENGINEERING DESIGN

As Atman, et al. note in the *Cambridge Handbook of Engineering Education Research*, approaches to engineering design education typically align with one of three primary models: the capstone-only model, the cornerstone-capstone model, or the integrated model [1]. They also note a general shift among engineering programs toward more integrated approaches, in which design learning occurs throughout the curriculum, as the other models are being identified as insufficient.

Many examples of integrated approaches to teaching engineering design have been presented in recent years. Faculty at the University Park campus of The Pennsylvania State University developed a coordinated sequence of design courses, respectively featuring design tools and project management content in the second and third years, in preparation for a semester-long capstone during the senior year [2, 3]. At Queen’s University, the curriculum was redesigned to implement a four-year “spine” that sought to integrate technical and professional skills throughout as a solution for meeting newly required accreditation standards without a loss of traditional technical skills [4]. The general engineering program at James Madison University features a six-course, ten credit-hour design sequence in which students complete a year-long design project during their sophomore year and a two-year capstone project [5, 6].

While our approach to teaching design shares many of the characteristics of the integrated approaches mentioned here, we have attempted to structure our design and project management courses using the spiral curriculum model described by Bruner [7]. In the model, the “basic ideas” of a discipline are taught and continually revisited as instruction progresses throughout the student’s time in school. Bruner wrote of the spiral curriculum model in the context of K-12 education, arguing for the spiraling of topics as the developmental level of the child increases. Bruner’s view that students, regardless of age or discipline, could and should be taught in a realistic way that reinforces the principle ideas and structure of the discipline.

While not used specifically for design, the spiral approach has been used within engineering education previously in cases ranging from first-year curricula [8] to entire program curricula [9, 10]. Using this approach, we have attempted to integrate project management and design into all four undergraduate years of our curriculum, utilizing the principal ideas and structure of the engineering design process: problem framing, ideation, selection, implementation, and project management. We situate this within actual design practice using a series of small projects, each year increasing in duration, scope, and complexity.

III. IMPLEMENTATION

As mentioned previously, a solution to simultaneously address the identified design shortcomings was developed and implemented in the form of a four-year, five-course spiral. ENGR 3500, identified as no longer being effective, was eliminated and replaced with two new courses. The resulting course sequence is as follows:

- ENGR 1016, Introduction to Engineering Design, an existing two credit hour course.
- ENGR 2000, Engineering Design and Project Management I, a new one credit hour course.
- ENGR 3000, Engineering Design and Project Management II, a new two credit hour course.
- ENGR 4010, Engineering Capstone Design Project I, an existing two credit hour course.
- ENGR 4020, Engineering Capstone Design Project II, an existing two credit hour course.

This course sequence is mandatory for all graduates of the engineering department although transfer students may receive credit for some of these based on prior coursework. To better accommodate incoming transfer students who have not received credit elsewhere, a hybrid of ENGR 1016 and ENGR 2000 is taught as a separate three credit hour course. The following section will provide a general description of each of the primary courses listed above.

A. Course Descriptions

1) ENGR 1016 – Introduction to Engineering Design

ENGR 1016 is a two credit-hour course taken by most students during the second semester of their first year in the engineering program. The course provides a hands-on

introduction to conceptual engineering design through four team-based design projects, each culminating in a design product. The course follows a similar “practice-then-apply” scaffolding structure as that presented by Carberry, Johnson, and Henderson [11]. The first three projects are faculty-defined and each places a stronger emphasis on a different element of the design process (namely, problem framing, solution ideation, and solution selection). The final project is open-ended and allows teams to apply their accumulated design skills to a problem of their choice all the way from problem identification through solution selection and construction of a working prototype.

The course benefits from a relatively low student to faculty ratio. Each section is capped at 18 students and has a faculty member and undergraduate teaching assistant who facilitate the course. The course is also supported by two college lab supervisors.

2) ENGR 2000 – Engineering Design and Project Management I

ENGR 2000 is a one credit-hour course taken by virtually all students during the first semester of their second year in the engineering program. The course provides a more advanced experience with specific stages of engineering design through three team-based design projects: two culminating in a paper design and one in a physical realization. The first two projects are faculty-defined, with the first focusing on a project design and the second on a process design. The design foci vary each semester. The third design project is for students to select, design, and manufacture a prototype toy given cost constraints. All projects repetitively reinforce the key design processes of problem framing (problem statement), solution ideation, solution selection, and project completion. Both analytical and intuitive processes for ideation and selection are introduced. The selection processes include both a feasibility assessment (compliance with constraints and physical possibility) and selection processes for the remaining feasible processes. The feasibility assessment includes identifying the specific reasons for being infeasible (if it is) and then identifying modifications that may make it feasible. Both project framing and ideation topics begin with individual assignments before working as a team to limit production blocking commonly found in brainstorming. Project management skills from ENGR 1016 (problem framing, task identification, task scheduling, and project completion/implementation) are reviewed, but not expanded upon. The focus is on strengthening design skills. Both written reports and oral presentations by the teams are required. Cost assessment (materials and labor) are included in the analysis, but not the time-value of money.

This course does not use a TA and the course size is limited to 30 students with one faculty member.

3) ENGR 3000 – Engineering Design and Project Management II

ENGR 3000 is a two credit-hour course taken by most students during the second semester of their junior year. The course introduces more advanced project management knowledge and skills, specifically focusing on the integration of project management into the engineering design process. Students are given a semester-long design project, sometimes

recycled and de-scoped capstone or other example projects, to apply their design and project management skills toward solving through the conceptual phase. Engineering design knowledge from ENGR 2000 and 1016 is utilized and documented in project design reports but otherwise not expanded upon. Practical design fundamentals related to jointery, electrical and mechanical power transmission, pump theory, piping and tubing, manufacturing, and fabrication are also presented. Other topics to prepare students for capstone include literature searches and intellectual property considerations, engineering standards, Design for X, prototype testing, and written/oral presentation skill development.

The course size is approximately 30 students with one faculty member assigned to each section.

4) ENGR 4010/4020 – Engineering Capstone Design I and II

ENGR 4010/4020 is a two-semester capstone design course in which students are assigned to teams of 3-4 and tasked with designing a solution to an open-ended problem. The projects are typically sponsored by an industry partner. Ideally, ENGR 4010 culminates with a project proposal, which is then further designed, built, and tested during 4020. Designs are required to be detailed enough for implementation; some designs go through prototyping while others go through construction and testing. Skill extension from previous courses is required and new skill development is often expected.

While student teams largely work independently, they consult with an assigned faculty advisor and a liaison from their industry sponsor. The department's capstone coordinator also serves as an advisor.

B. Spiraling of Topics

The design and project management spiral curriculum seeks to revisit the areas of: problem framing, ideation, selection, implementation, and project management in each course. Examples to illustrate how some of these are spiraled throughout the course sequence are given below.

1) Problem Framing

With respect to problem framing, ENGR 1016 emphasizes the identification of a problem or need as a first step in the engineering design process. Differences between solution objectives and solution constraints are also highlighted, as is the construction of written problem statements. During the project specifically focused on problem framing, students practice interviewing a fictional client to assist in determining the objectives and constraints of a solution.

In ENGR 2000, students are asked to consider the problem from different perspectives. For example, a product design can be considered from the perspective of a purchaser, the company legal department, top management, etc. They then individually write a series of problem statements based on the perceived needs and desires of each of those groups. Based on that assessment, they work as a team to write a comprehensive problem statement for future use.

By ENGR 3000, students are expected to apply their problem framing skills to an open-ended project (sometimes a

recycled, de-scoped capstone project). In addition to identifying constraints and customer requirements, students must also use this information to determine a project scope. The requirements identified are based on interpretation of the information directly provided by the client(s) and other stakeholders, as well as substantive research conducted by the design team in the form of literature reviews and patent searches. Emphasis is placed on developing a clear chain of reasoning to support the inclusion of the chosen requirements.

During capstone, students in ENGR 4010 go through the problem framing phase for a new, open-ended design problem from their industry sponsor. In addition to the methods used in ENGR 3000, students must perform site visits, conduct interviews, investigate related codes and regulations, and perform more extensive research to define the problem. Students are expected to develop engineering design specifications that provide performance criteria for their design. Additionally, human factors and ergonomics are considered.

2) Solution Ideation

In ENGR 1016, students are encouraged to brainstorm individually and in groups as a means of expanding the design space. The basics of functional decomposition and research on existing designs are introduced and paired with brainstorming to generate novel solutions.

In ENGR 2000, students continue to generate ideas by looking at related solutions, modifying existing solutions, conducting internet searches, and brainstorming. They also use morph charts to identify key attributes of the problem and then mathematically combine all permutations of these attributes. They work individually through a round of ideation with the intent of generating a large number of potential solutions. Most teams generate hundreds of options and variations. The emphasis of ideation is to not judge: quantity is more important than quality. The quantity is judged both on the total number of ideas generated (ideational fluency) and on the total number of categories of ideas generated (ideational flexibility).

Solution ideation methods from the previous courses are practiced and applied to larger scope projects in ENGR 3000.

In ENGR 4010, student teams build on their previous ideation knowledge and skills by interacting with a broader range of creativity models such as: facilitated creativity, Phases of Creative Thought, value-focused thinking, biomimicry, painstorming, skit exercises, and others. The emphasis is on creativity and stretch.

3) Solution Selection

In ENGR 1016, students receive an introduction to using the decision matrix design tool and ensuring constraint satisfaction. Students are expected to demonstrate basic principles of creating and presenting a decision matrix, including qualitative and/or rudimentary quantitative justification of assigned ratings. During the project specifically focused on solution selection, students conduct an analysis of team-collected experimental data to argue for the preferred sensor option for use in their design.

The selection process becomes slightly more formalized and nuanced in ENGR 2000, as it is separated into two steps. The first step is a determination of each of the solution alternatives (or solution categories) for feasibility. A solution is feasible if it satisfies the constraints listed in the problem statement and if it is possible for the solution to be implemented. Each of the potential alternatives are assessed for feasibility. If an alternative (or category of alternatives) is deemed feasible, it is carried forward. If it is not, specific reasons for it not being feasible are identified and potential modifications that would make it feasible are developed. These modified alternatives, if they are feasible, are added to the list of alternatives to be considered further. The second step in the selection process is to develop both qualitative and quantitative metrics to compare the alternatives using a decision matrix. Students then use either or both types of metrics in the final selection of their alternative.

In ENGR 3000, the same design reduction methods from ENGR 2000 are employed and documented in project design reports. Students, however, are expected to utilize knowledge from relevant engineering analysis courses to create appropriate metrics – and assign scores using those metrics – in order to evaluate solution alternatives that have been considered feasible.

In ENGR 4010, students use their accumulated knowledge related to solution selection to present a proposal that they wish to develop during ENGR 4020. Students must identify and technically support engineering judgements that play a role in the selection process, particularly with regard to meeting their established performance requirements. Feasibility analysis is required from both technical and economic points of view. During detailed design, material selections and manufacturing process selections are discussed, along with Design for X considerations and robustness.

4) *Solution Implementation*

Projects in ENGR 1016 typically reach the initial prototype stage. Students have in-lab access to CAD software, desktop 3D printers, and simple construction materials such as foam board. Within the context of the second two projects, students are introduced to the basics of programming and learn how to incorporate sensors, actuators, and other mechanical, electrical, and pneumatic components into their designs. The final, open-ended projects typically incorporate many of these resources.

In ENGR 2000, the third project requires the creation of multiple copies of the toy prototype they design (one for each team member to keep and one to give to the instructor). A detailed cost analysis must also be made, including materials and labor, for the manufacture of a large number of the toys (typically 1000).

Since projects in ENGR 3000 are conceptual in nature, there is no direct implementation. However, other practical design fundamentals related to jointery, electrical and mechanical power transmission, pump theory, piping and tubing, manufacturing, and fabrication are presented.

In ENGR 4010/4020, the scope of the project is much larger than in previous courses. Designs are required to be detailed enough for implementation, and some designs go

through prototyping while others go through construction and testing.

5) *Project Management*

An introduction to constructing and utilizing work breakdown structures and Gantt charts is provided in ENGR 1016. Basic Gantt charts are constructed using spreadsheet software, and emphasis is placed on correct activity sequencing, determining slack time, and identifying the critical path of the project.

Work breakdown structures and Gantt charts are reviewed in ENGR 2000, and students are expected to provide these for their final project. In this case, little new material is presented, and the main course focus is on developing design skills.

Project management is once again revisited in more detail in ENGR 3000. In this course, students begin utilizing more specialized project management software programs like Microsoft Project® to construct Gantt charts, Network diagrams, and resource charts. They also discuss, in more detail, how to estimate project time and costs, precedent-successor relationships, and project oversight. Students are asked to apply these project management techniques to their semester project. Other relevant topics, like managing project risk, project leadership, and resource management, are also discussed.

In ENGR 4010/4020, students are evaluated on their ability to use project management tools in directing and executing project activities. Development of a full project management plan is required, including detailed documentation of the project schedule, resources, responsibilities. Students submit individual time sheets reporting project activity hours and weekly activity reports.

IV. SUMMARY AND CONCLUSION

Implementation of the design and project management course spiral to date has taken nearly four years. With the creation of the new courses, ENGR 2000 and ENGR 3000, we feel that our students are better prepared for capstone than in previous years. While each course currently contributes to students learning design knowledge and skills, there is still improvement needed on synthesizing the content of each course into a more cohesive spiral. Most of this is not a problem of content, so much as a problem of context. Currently, the different courses – and even different instructors teaching the same course – sometimes use different terminology to express the same phenomenon, or worse, the same terminology to express different phenomenon. Understandably, this inconsistency leads to confusion among students, who find it difficult to integrate new knowledge within their prior knowledge gained from earlier design courses. From a program assessment standpoint, it also presents difficulty in using an integrated assessment instrument, since some faculty might interpret the assessment instruments differently; this has been evidenced in the ABET assessment reports for some of the design (outcome c) courses in recent years.

The first cohort to completely progress through the new spiral graduated in Spring 2015. Based on ABET assessment

data collected during their time in ENGR 4010, we feel that they are more prepared to enter into capstone than their predecessors. Assessment data from this past year's ENGR 4020 course will be used to verify the observations from the 4010 data, and we will continue to monitor the effectiveness of the design and project management spiral in the coming years.

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Understanding and Improving the Culture of Hackathons: Think Global Hack Local

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Abstract— Hackathons bring developers, artists and designers together around a shared challenge: ideate, plan and create an application in a highly constrained time frame. A way to socialize, solve problems, and strengthen soft and hard skills, hackathons have grown tremendously in popularity in the last half decade. Despite this growth, it has been noted that females do not participate in hackathons with the same frequency as males. Some theorize that the hackathon culture is intimidating, does not appeal to women, or that it acts to amplify pre-existing cultural biases in computing. In this paper we introduce an alternative format for hackathons to address these issues. Think Global Hack Local (TGHL) is a non-competitive, community-based hackathon that connects non-profit organizations with student developers. Students donate a weekend to solve problems that these organizations otherwise lack the resources to solve. To date, there have been two TGHL hackathons, and we have observed many interesting divergences within the culture of TGHL in comparison to other hackathons. Response has been positive, and nearly all of them indicate that they would do it again. By adopting some of these ideas, we believe that hackathons can become an environment that is more inclusive and fun for all.

Keywords—hackathon gender issues; community engagement; community-based projects; service learning

I. INTRODUCTION

For student participants, hackathons offer many promises: improving or acquiring programming skills, spending a brief but fun and immersive time with like-minded people, taking a non-trivial project from beginning to completion in a short time, competition and prizes (though many events are non-competitive), an agile prototyping environment and direct contact with potential employers. Despite what many may perceive as positive attributes, hackathons also elicit strong negative reactions from others: they can foster a competitive, male-oriented programming culture, they can encourage poor software development practices, and they can reinforce the

"nerd" stereotype. This paper explores both sides of the discussion and describes a hackathon format (Think Global Hack Local), which retains most of the positive attributes while attempting to minimize the negatives by focusing on community-based projects. From participant responses to post-event surveys, we have an understanding of what motivated these students to attend this event and what aspects they felt were positives about the event. Participants tell us that the community focus was important to them and that, as previously reported by others, the social aspects of the event have a big influence on their initial interest in participation and their willingness to come back.

II. BACKGROUND

Hackathons, hacking (or coding) marathons, have seen a surge in popularity in recent years. Now considered a staple of the technology community, such events grew primarily out of companies looking for ways to innovate within their business, but have since grown into the public domain and academia as a way to build things, advance new ideas, and improve skills. Some have become so large and garnered so much attention that many students participate as a way to help them with job search [1].

Like hackathons, game jams have grown in popularity evolving their own culture that is similar, yet slightly different than the hackathon model. Jams have been noted to focus on experimentation and innovation, rather than polished products [2]. One of the earliest jams was *Indie Game Jam 0* that took place in 2002 with 14 experimental games created over four days [3].

In [2], we see game jams characterized as ludic craft, a constructive form of play. The authors characterize them as focused on creativity, playfulness, and “gamefulness”, providing a focus on generating ideas and creating, not always on finished and polished products. This may not be a true picture of the difference between the two however, as many

hackathons do not produce finished or polished products either. However, it is important to note that many feel a jam has a different focus, or at least had a different impetus when they first began appearing on the technology scene.

We also see [2] focus time in discussion about the community that exists during a jam, emerging both from the structure of the event as well as the people participating. This is called out as an important factor in the jams. The authors conclude that the jams that tended towards playfulness facilitated more innovation.

Of the largest game jams, *Global Game Jam* (GGJ) [4] started in 2009 with concurrent game jams in 23 countries. Continuing yearly, the 2015 GGJ had 28,837 people registered for 518 jam sites in 78 countries. There were 5438 games produced [5].

A. For the Social Good

As jams and hackathons have grown in popularity, we have seen the emergence of such events around specific causes commonly associated with social good, sometimes referred to as civic hacking [6].

These events can be focused around themes. One such series of events, given the title “Game Jam 4: X”, centers around three primary themes for X: health, diversity, and research [7]. In a related effort, [8] describes a series of three hackathons in India to solve social problems sustainably; [9] describes a hackathon designed to create technologies for the homeless. The *CDC Games for Health* game jam provided a way for participants to jam on health-related issues [10]. During a recent *Global Game Jam*, Scott, Ghinea, and Hamilton [11] promoted designing games for inclusiveness (for sensory, motor, or cognitive impairments) at their jam site.

The products that come from civic hackathons can be viewed as secondary. As claimed in [12], the more interesting by-product is the versions of the civic imaginary and can transform the way people view themselves as citizens. The *CDC Games for Health* organizers saw that participant interest and awareness of health-related issues and careers increased [10]. After the focused GGJ that Scott, Ghinea, and Hamilton ran, a survey was administered showing participants were more likely to consider issues of inclusiveness in games in their future development [11].

Computing with the community in mind is not a new idea to the computer-science education community. There are many examples of projects and entire courses at all levels of the curriculum that have service learning components and/or community-based projects [13] [14] [15] [16] [17] [18] [19].

B. Academic Hacking

The popularity of hackathons and game jams has made its way into the broader academic community, with a particular rise of these events as part of conference programs. At SIGCHI 2013, a game jam was organized to allow members of the CHI community to participate and explore this model of creation as a way to focus on interacting with digital play [20]. At SIGCHI 2014, there were two hackathons, one dealing with big data and privacy issues [21], and the second using a game

jam to focus on a research question in HCI [22]. *OCDData Hackathon @ CSCW 2014* was a hackathon that focused on online communities [23]. At Group 2014, a hackathon was organized centering on online co-production systems (systems where many people are contributing to the system) [24].

Another area of academic focus when it comes to hackathons and jams is as a resource for academic study. As Fowler, Khosmood, and Arya point out in [25], given the large number of participants across the world, the GGJ provides a learning opportunity and a research platform for many [26], and has spawned several workshops around this idea [27][28][29].

Of particular academic interest is the impact of the participation on those involved in these activities. Such research shows that participants can gain skills in prototyping and collaboration [30], can have a positive correlation with academic performance [31], and can improve confidence of participants [32]. Reng, Schoenau-Fog, and Kofoed [33], discuss the importance of the social aspect of the jam as highly important to the participants.

C. Criticism of Hackathons

Even with the surge in popularity and massive amounts of participation and success stories, there remain some points of concern around hackathons. Guzdial laments that these types of events help to propel the “geek” stereotype and promote poor software design practices [34]. Given the amount of literature devoted to techniques for software development and the countless methodologies that exist for creating good software, some question if a 24-, 36-, 48-hour development cycle helps to promote those practices. In [35], we are presented with a way hackathons were used by a software company focused on security software to help improve their business. They recognize one challenge in turning the prototypes created into products that are of real business value.

That aside, the “geek” stereotype as a turnoff to women has garnered more attention. For the 2013 *Global Game Jam*, a survey was administered to participants. Of those that filled out the survey, 85.97% identified as male while only 12.54% identified as female [36].

A post on Quora gives some perspective on why women may feel out of place at hackathons, including the way they are treated by male participants (calling to mind the ongoing #gamergate scandal [37]), false perceptions of the general format (e.g. having to stay up the entire time, no showers, eating junk food), and not having a community of friends that participates [38].

Johnson’s article [39] adds onto [38] by providing suggestions for how to make hackathons more female-friendly. These include a pre-registration period just for women (though we note a high risk of making matters worse by creating a reinforced sense of exclusion by adding another layer of separation), avoiding competition, ensuring a clean and welcoming environment, broadening recruiting (such as through women’s groups on campus), watching for use of non-welcoming language in advertising, working to make beginners feel welcome, and advertising events in a gender-neutral

manner, avoiding strictly male stereotypes and images of males participating, and publishing attendees list so that women can see ahead of time that women attend (though we add privacy concerns must be kept in mind).

In an effort to address these issues, several hackathons specifically targeted at women have emerged [40] [41], including the International Women's Hackathon sponsored by Microsoft [42]. However, as with the women-only pre-registration period, such segregation arguably increases the sense of separation and distracts from the real issue of creating an inclusive, safe environment, regardless of gender.

To this end, others have taken a different approach. Instead of creating events specifically for women, they have instead focused on changing events to be more welcoming and by extension appeal to women. Spotify's hackathon had an impressive 50% female participation rate. This was achieved by specifically calling out the culture as mostly male-oriented and working to increase diversity. They reached out in advertising to women, served healthier food and removed the prizes, creating an atmosphere that was more like a science fair [43]. Brown University changed the focus of their event towards beginners, paying special attention to use of language (create and build instead of hack) [44].

StitchFest [45] adds elements to a traditional hackathon to try to appeal to a more diverse audience, such as the use of LilyPad Arduinos to design wearables. This portion of a larger hackathon saw 33% female participation, as opposed to the entire event (PennApps [46]), which had only 14.8% female participation [47].

In response to Guzdial's original post [34], Krishnamurthy brings up a correlation between hackathons/jams and the film industry's 48-hour film competitions. He refers to [48], which makes a strong case for why these competitions are important to film, many of which can be equally applied to computing like "actually starting and finishing...", "honing your craft", "it's fun". The article also focuses on the human aspect of the competition, something we see echoed in the discussion of the computing equivalents.

Similarly, we acknowledge that while there are tradeoffs, it is important to note that jams and hackathons provide unprecedented opportunities to practice agility, iteration and scoping. Many companies use such events as a way of testing students' capabilities to iterate quickly and scope effectively. Typically any such projects are thought of as proofs-of-concept, not finished products. The expectation is that development will continue after the event. Furthermore, unlike many traditional computer-science programs, jams and hackathons provide an opportunity for students to learn to work with artists and designers, an invaluable skillset that is often missing as our students graduate.

III. THINK GLOBAL HACK LOCAL

Think Global Hack Local (TGHL) [49] and its structure were inspired by industry practice and community need. Hackathons and jams are popular events for local industries in partnership with universities. At the University of British Columbia (UBC), this has been the case for some time.

Companies frequently request running hackathons on campus to allow them to put their product/service/software in the hands of students. It is both an opportunity to inspire innovation around their product and a chance to preview students for potential future hires.

A strong connection with community grew out of the UBC's CPSC 319 course entitled, "Software Engineering Project". In this course, students work throughout the term (13 weeks) on small teams (6 students) to create software for a real-world client. These projects have been solicited from the community (both the university community and beyond) for many years. Occasionally, one of the clients for the course would propose something that would be useful for them, but was not enough work to keep a team of 6 developers busy and engaged for 13 weeks, so the need went, unfortunately, unfulfilled.

Given the existing highly engaged student sub-community of hackers and jammers (Vancouver's Global Game Jam site at the UBC had over 350 participants in 2014 [50]), and given the ever-present need for software-related help in the non-profit sector, it seemed a natural next step to plan a jam around such civic need.

When designing the TGHL hackathon, a conscious decision was made to be non-competitive, and to find ways to amplify collaboration even more. The assumption was not only that students were capable of filling the needs present in the community and open to the challenge, but that the students would be intrinsically motivated to help the community.

Clients were recruited through past clients for the CPSC 319 course as well as UBC's Centre for Community Engaged Learning [51], which actively promotes efforts that put UBC students and faculty to work for the greater community good. The Centre was able to provide potential clients for this event. Students were recruited through advertisement within the Computer Science Department (posters in building, email, etc.) and asked to attend an information session, which provided food and drink along with information about the event.

A. Event Structure

TGHL follows the "typical" hackathon structure of a weekend (48-hour) time period starting on Friday evening and ending late Sunday afternoon.

On Friday evening, participants gathered for an overview of the event, any rules and regulations, and themes and goals for the weekend. Teams would be formed for each of the clients with no project overlap between teams. It was made clear that there was no competition involved—the "prize" was to create products to fulfill the needs of the clients. The introduction was followed by short pitches from the clients describing their problem and their ideas about what the solution might be.

After brief introductions, dinner was served and the participants were able to discuss the projects in greater depth with each of the clients. Students were then given an opportunity to choose a project. In order to ensure that each project had sufficient staff, organizers would ask students to move when participation was low. In almost all cases, students were willing to switch teams if needed after discussion.

After the teams were formed and requirements elicitation was completed in its initial phase, the clients left and teams were left to plan the rest of their weekend.

Saturday was a day of solid work, interrupted by meals, provided by TGHL. Most of the clients dropped by at some point during this day to chat with their teams, answer questions, and check on progress.

Sunday morning and early afternoon was working to finish up the projects. For the last two hours (starting around 4pm), the teams would demo what they had accomplished and the clients were given the floor once again to talk about their experience in the process and products.

Throughout the event mentors (typically graduate students from the Centre of Digital Media, other students, or local industry professionals) would drop by to help students design and plan their solutions, debug code, and address software and design architecture issues—a key element given concerns around fostering an educational environment and practical, best software practices.

IV. RESULTS AND OBSERVATIONS

To date, there have been two Think Global Hack Local hackathon events, one in March 2013 (TGHL 1) and one in October 2013 (TGHL 2), both with the same format. A third is planned for summer 2015. In this section, we present our observations about the participants, the events, and some of the responses from the surveys administered after the events took place.

Table I gives some demographic information about participation in these events. For TGHL 1, there were 5 projects from 5 distinct clients. The clients were: Burnaby School Board, BC Cancer Agency, SelfDesign/PCRS/PeerNetBC, PeerNetBC, and Delta Youth Orchestra. For TGHL 2, there were 8 projects from 7 distinct clients. There were no repeating clients from TGHL 1 to TGHL 2. The clients for TGHL 2 were: BC Centre for Employment Excellence, Neil Squire Society, BC Association of Family Resource Programs, Sunshine Coast Botanical Garden Society, UBC Department of Medicine, Writer's Exchange and Climb and Conquer Society Canada.

There were 35 participants in TGHL 1 (35% females) and 65 participants in TGHL 2 (30% females). Although demographic information was not collected on major systematically, the majority of the participants were observed to be computer science majors. At this time, the UBC Computer Science undergraduate program was made up of 25% women.

TABLE I. DEMOGRAPHICS OF PARTICIPATION

	TGHL 1	TGHL 2
Number of clients	5	7
Number of projects	5	8
Number of participants	35	65
Number of survey responses	32 (91%)	47 (72%)

A. Observations

Overall, the events were judged a success by the organizers and clients. The atmosphere was fun, excited and energized. A positive and collegial mood remained through the entire event.

Plenty of collaboration was observed during the events. Teams were actively encouraged to help each other and as such no competitive behaviors were observed during the events. As an example, the following was observed:

If a team had an issue with PHP, for example, they might yell out "is anyone here a PHP guru?" and someone from another team would leave their project for a bit and help with the other project.

The structure and expectations for the event led to an atmosphere that did not put an onus on the students to stay up and cram and build the entire time. Students were instead mentored around scope and realistic planning for the weekend. In fact, on the first night after project teams were created, many participants chose to go home and get a good night's sleep and return the next morning to start work.

B. Participant Feedback

Participants were asked to fill out a short survey about their experiences with TGHL at the end of the event. In this section, we will present the feedback collected from those surveys. Participation in the survey as a whole was voluntary and no questions on the survey required a response. Therefore, the number of responses varies from question to question.

Table II shows the responses to the question "Was this your first hackathon?" For both events, the number of first-time hackathon participants was greater than veteran hackathon attendees. Response rate and percentages of total are shown.

Table III summarizes some of the main reasons that were given to the free response question "What made you decide to attend?" This was a question on the survey that directly followed the first-timer question. The percentages given in the table are percentages based off of all responses to the survey (32 and 47). The categories that were tracked were responses that dealt with the following:

- Student desire to learn, gain experience, try new things
- Student desire to help non-profits, do something good for the community, work on "impactful" projects, solve real-world problems
- Student desire to be part of the social group either because friends encouraged them to attend, friends were attending, or to come to know their peers better

TABLE II. FIRST TIMERS

	Was this your first hackathon?		
	Yes	No	Did not answer
TGHL 1	23 (71%)	6 (18%)	3 (1%)
TGHL 2	40 (85%)	7 (15%)	0 (0%)

TABLE III. REASONS FOR ATTENDING

	<i>What made you decide to attend?</i>		
	<i>Learning</i>	<i>Civics</i>	<i>Social</i>
TGHL 1	6 (18%)	9 (28%)	6 (18%)
TGHL 2	19 (40%)	9 (19%)	12 (25%)

TABLE IV. LIKELIHOOD TO REPEAT

	<i>How likely are you to attend another community hackathon?</i>					
	<i>Def</i>	<i>Very Likely</i>	<i>Likely</i>	<i>Likely but not for a while</i>	<i>Not Likely</i>	<i>Did Not Ans</i>
TGHL 1 First Timer	7	1	10	1	2	2
TGHL 1 Veteran	3	3	0	0	0	0
TGHL 2 First Timer	21	1	15	0	1	2
TGHL 2 Veteran	4	0	3	0	0	0

The students could have indicated more than one of these items in their response and several did. The responses were then categorized in multiple categories. Also noted was the number of veteran and first-timer responses in each category across the two events. For veterans, learning came up in 2 responses, working with the non-profits in 4 responses, and social aspects in 3 responses.

Table IV gives the results of the question “How likely are you to attend another community hackathon?” broken down by response to the veteran question. This question was a Likert scale question with the responses being: *Definitely*, *Very Likely*, *Likely*, *Likely but not for a while*, and *Unlikely*. Placing these on a numerical scale with 5 being definitely will attend again and 1 being unlikely to attend again, first timers averaged 3.48, while veterans averaged 4 for the first event. In the second event, first timers averaged 4.08, while veterans averaged 4.14.

When looking at the response to the survey question, “What aspect of this hackathon do you like the most?” two categories of answers stood out. The first were responses that dealt with the personal and social aspect of the events, which included one’s team as well as the others at the events. The second were responses that dealt with the real world projects and community aspect of the events. Table V summarizes the number of responses in the two categories for both events.

TABLE V. MOST LIKED ASPECTS

	<i>Which aspect of this hackathon do you like most?</i>	
	<i>Social</i>	<i>Community</i>
TGHL 1	11 (34%)	12 (38%)
TGHL 2	20 (43%)	8 (17%)

Since this question was free response, participants could have mentioned both aspects in their response and would be counted in both groups in the table.

Some of the comments that stand out from this question (about most liked aspects) included:

- *Collaborating with and learning from each other*
- *Connect with the organization and put their idea to some real products*
- *Getting lots done, realizing I know more about web dev than I thought*
- *The non-competitive positive environment*
- *Meeting new people with similar interests and learning from one another*
- *Learned a lot. Also feel really fulfilled when finally done (especially it's for the community)*
- *Developing something for a client*
- *Working on a problem that has real world applications*
- *Coding with awesome people and learning new stuff*

C. Client Feedback

Clients were also asked to fill out a similar survey as the participants about their experiences with the events. Again, participation was voluntary, but the response rate from the clients was 100% for both events.

All of the clients at both events were first-time participants in a hackathon. Their reasons for participation varied, but centered on the idea of reaching out and working with the community as well as opportunities to work with the students. Many of the clients indicated that they had a specific need and this opportunity came along and it was a fit for them to attend.

For TGHL1, all of the clients indicated that they would definitely be likely to participate in a community hackathon again. For TGHL 2, 6 of the 8 clients indicated they would definitely be likely to participate again, while two indicated that they were simply likely to participate.

When asked why they were likely to participate again, 7 out of the 13 clients (54%) indicated in some form that they felt it was a good opportunity to support the students and to work with them. A few samples of those responses are:

- *Wonderful opportunity to support student learning and community partners*
- *The students are amazing to work with*
- *Really fun, great team building exercise, good cause connecting with young, smart people*
- *Great fun. Great students. Reminds me of my misspent youth*
- *How amazing all of these people were*

The clients also pointed out in 3 out of 13 responses (23%) the community partnerships that were built because of the event.

In terms of client satisfaction, the survey responses give us a snapshot of how they were feeling after the event.

- *The team really went above and beyond in taking my ideas and running with them. They were able*

to create and visualize something that has only existed in my head as a concept.

- *From our community, we will involve more. This is fantastic; we got more results than we expected! Well done.*
- *I am really happy with what my team accomplished.*

V. DISCUSSION

Many issues are brought out by the structure and nature of this hackathon. Some of the suggestions for improvement given in [38] and [39] are put into place with the TGHL structure. Further, TGHL provides another aspect to participants that has been noted by Dahlberg et al. [52] as valued by women and minority students, the social relevance of computing. In [52], the authors argue for more civic engagement and community service into outreach programs to appeal to these groups. An event of this type, while not outreach per se, provides these elements to students. This may have resulted in the higher percentage of participation of women in the events than in the general population of students enrolled in computer science as a whole.

Student reasons for attending the hackathon varied, but the number of responses in key categories was encouraging. Students (18% and 40%) viewed the opportunity as a learning experience and were attracted by the cause and helping the community (28% and 19%) as well as the social aspects (18% and 25%) of participation in the event.

The response to returning to a community hackathon can be viewed as positive by both veterans and first timers due both to the average response (in numerical form) being above 3 (neutral), as well as the actual responses being more positive than negative. In fact, only 3 total participants indicated that they were not likely to attend a future hackathon.

It is hard to tell from the data that was collected how many participants from the first event attended the second. The question was not asked specifically about the TGHL event, but rather hackathons in general. However, it is encouraging that the event is drawing so many new participants and from the free response question on motivation, it appears that the community involvement aspect is a draw for at least some of the participants. The social aspect and having friends participating was also called out by participants as a reason for attendance, all of which point back to the sense of community around these events that has been noted previously.

The participants' views on the most liked aspects of this hackathon don't differ much from the general view of this event as a social experience of value for the participants. Comments echo the value of working with the team and the great experience they had working with their team. They call out the learning experience that they had, both learning about each other and the team as well as new technologies and the exchange of ideas.

Participants also called out the community/real work aspect of these events as a positive. This was acknowledged in 38% and 19% of the comments about the positive aspect of these events. This mirrors the similar response to reasons the

students chose to come to the events (28% and 19% were because of the community aspect). There was an increase in recognition of that fact in the first event, but not the second. However, none of the students called out the community or real-world aspect as a negative at any point in the survey responses.

From the clients' perspective, they seem to indicate benefit from the experience. It is important to note that one of the most often cited things about the event was the students. The community partners were genuinely impressed with the students and their abilities and how much they were able to accomplish against the goals of the client. The growing recognition by the community of the products of the university is a valuable contribution of this type of event.

VI. CONCLUSION

Overall, we are very pleased with the success of these two events. The students arrived seemingly interested and excited to help the community, and they were seemingly very successful. In reverse, the community (clients) anecdotally "fell in love with the students". These outcomes will keep us investing in these events for the future.

Perhaps most interesting to reflect on while looking forward to our next event is what the participants and clients asked for in terms of improvements. There was a survey question that asked them for feedback for the next event.

While responses varied, several that stuck out that are on our radar for consideration are suggestions for some pre-planning from the participants. The participants mentioned wanting to put together teams beforehand to try to help balance expertise. They asked for some basic descriptions of the projects that will be worked on and also some information about the technologies that will be used.

While not possible in all cases, and requiring teams to be put together beforehand could be discouraging to newcomers, the ideas about publishing the projects could have the potential to bring people in that might not have otherwise participated. Given that some students also mentioned attending the information session in the surveys (n=5), this may be a good time to present some of the projects.

One comment from this section stands out for us:

Do not kill this program. This has to happen every year!! This is what students should be doing with their time. Solving real problems of the real world.

Two particular future challenges we are food and the "post-hackathon problem". Food is an interesting challenge—in order to keep people nourished for the weekend, food must ideally be provided. In fact, across the 79 responses to the post-hackathon survey, food was mentioned in 50 of them (63%). Some of the comments were favorable, but some complained about food choices and food quantity. Making sure that the participants are fed in an appropriate way is an expensive and interesting challenge.

The second challenge is one of follow-through. Engaging students through the event does not guarantee that students

will continue to be involved after the event ends. This can be a problem when further development remains, changes are needed, or simply clients require help with installation (many were not technically inclined). Students certainly seem passionate about the project for the weekend's event, but how can we maintain that level of passion to help students maintain a relationship with these same community partners after the event comes to a formal close?

We are committed to constantly re-assess our procedure and the event to make sure we are improving the experience and not falling into the traps criticized by others. We want to ensure that our events remain inclusive and friendly to all and that both parties (participants and clients) get out of the event what they hoped. We are facing these challenges head-on for our next event.

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Characteristics of Engineering Faculty Engaged in the Scholarship of Teaching and Learning

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Abstract—This research hypothesized that differences in the culture of engineering education as it is practiced a whole, as compared to the Scholarship of Teaching and Learning (SoTL) in engineering education, would manifest themselves through the characteristics of the faculty engaging in these activities. The research question examined was: To what extent are the faculty who engage in different areas of SoTL research within engineering similar to or different than the engineering faculty at U.S. institutions overall? The research utilized a data mining approach, assuming that the authors of the American Society for Engineering Education (ASEE) Annual Conference papers would characterize engineering faculty engaged in SoTL. The demographic characteristics of the authors of ASEE papers published in 2012-2014 on the topics of Learning Through Service (LTS), engineering ethics, and design were determined, as well as the authors of papers in the civil engineering, environmental engineering, and electrical & computer engineering divisions. The demographic characteristics of engineering faculty nationally were mined from ASEE data sources. The primary differences between engineering faculty active in SoTL compared to overall U.S. engineering faculty were: a higher percentage of assistant professors, a lower percentage of full professors, a higher percentage of women, a higher percentage employed at Baccalaureate or Master's institutions, and a smaller percentage from institutions with very high research activity. Between different engineering education topics, the primary differences were in the engineering disciplines represented, the percentage of women among the authors, and collaboration patterns evident among the paper co-authors. These data indicate the ways in which engineering faculty active in SoTL are different than their engineering faculty peers overall, and also highlights differences among engineering education topics. Further exploration is needed to determine the extent to which these differences are the result of different cultural values within each group.

Keywords—*engineering faculty; demographics; disciplines; service-learning; ethics; design; culture*

I. INTRODUCTION

Culture is defined as the beliefs, values, norms, attitudes, behaviors, and other characteristics common to the members of a particular group. Culture determines what is important to a group and can shape the members of a group to embrace dominant norms via the processes of enculturation or socialization [1,2,3]. Engineering culture has been variously

characterized as individualistic, expert, masculine, quantified, and technophilic [4,5]. It is unclear whether the current, predominant culture of engineering higher education is best situated to educate engineers who are able to address the complex challenges facing our world [6,7]. For example, Cech [8] characterized engineering as encouraging a culture of disengagement from public welfare concerns. She linked this disengagement to three cultural norms of engineering education: depoliticization, technical/social dualism, and meritocracy. The predominant engineering culture has also been criticized for limiting the ability of engineering to reflect the diversity of individuals in society [5,9-13]. Godfrey [5,14] noted differences between the cultures of different engineering disciplines. Based on a qualitative study at a single institution, electrical engineering was found to have the most masculine culture versus chemical and materials engineering which was more inclusive of both feminine and masculine characteristics; these cultural differences were reflected in the gender of the students enrolled in these disciplines. Differences between the culture of engineering in practice and the culture of engineering within higher education may also be significant; for example, education is more focused on theory, science, math, and design while practice relies more heavily on professional skills, tolerance for uncertainty, etc. [15-17].

While some topics are viewed to reside at the core of the culture of engineering education, such as calculus and design, others are perceived as “unacceptable” including “[a]bstract, philosophical concepts, such as ethics” [5, p. 441]. This is interesting given the long-standing commitment of engineering to codes of professional ethics, many of which date back to 1911-1914 [18-19]. But clearly some topics live at the periphery of engineering education, despite the fact that some faculty believe those same topics to be of critical importance.

There are signs that cultural changes within engineering education may be occurring, such as the growth in Learning Through Service (LTS) activities (i.e. service-learning, human-centered design, and co-curricular programs such as Engineers Without Borders (EWB)) [20-22]. The culture of these activities reflects caring and compassion to a greater extent than is typical for engineering [23-24]. It is unclear whether these activities are the result of systemic cultural changes in engineering education, or represent a unique sub-culture. What is known is that participant demographics in these activities are

more diverse than engineering education as a whole [25].

Within higher education the Scholarship of Teaching and Learning (SoTL) as a movement traces its origins to 1990 [26]. SoTL involves the rigorous and systematic study of teaching and/or learning in one's own course or context, and the public sharing of such work through publications and/or presentations with the intention of improving student learning and the overall educational experience beyond a single course or program [27, 28]. Does the emergence of SoTL represent a change in the culture of higher education? Or is it a distinct sub-culture? SoTL has been characterized as having a "unique (and often marginal) position within university cultures" [29]. Further, given that higher education in engineering is often perceived to have a culture that rewards specialized, disciplinary research significantly more than teaching activity [30], it is unclear if individuals focused on SoTL fit this predominant culture or represent their own sub-culture. Chalmers notes "there is little evidence that [SoTL has] contributed to any substantial change in the culture and substance of rewarding and recognizing the status of teaching relative to research" [31].

Culture is hard to directly measure, but it is believed to manifest itself in visible attributes [2]. Therefore, if there are differences in the demographic characteristics of the faculty who engage in engineering education SoTL compared to engineering faculty as a whole, this may lead us to infer that there are cultural differences. However, the demographic characteristics of the engineering faculty who engage in SoTL have not been well characterized.

The first research question explored in this research was: How do the demographic characteristics of engineering faculty active in SoTL compare to average U.S. engineering faculty? The second research question was: Are there differences in the characteristics of engineering faculty active in SoTL related to different engineering education topics or disciplines? For the purposes of the research, the characteristics of interest were defined as individual demographics (rank, gender); institutional characteristics (Carnegie classifications); and co-authoring characteristics. The methods used to explore these research questions are described in more detail below.

II. METHODS

The primary method used for this research involved data mining. Individuals active in engineering education SoTL were identified on the basis of authoring papers that were presented at the American Society for Engineering Education (ASEE) Annual Conference in 2012, 2013, and 2014. These papers may also encompass educational research (EER), but were nonetheless included. There are many similarities between SoTL and education research; distinguishing factors of EER typically include that the researcher is not the instructor, the subject of research is more than a single course or program, and that the research is informed by theory [32-34]. At the ASEE conference, the Educational Research and Methods (ERM) division includes primarily research studies while other divisions include a mixture of SoTL and engineering education research. Authors of all papers on the topics of interest were included, irrespective of whether the paper represented SoTL or EER.

The search function on the ASEE conference proceedings website was used to identify papers on selected topics [35]. These searches were conducted in October and November 2014, and February 2015. Three different topics cross-cutting engineering education were explored: design, ethics, and Learning Through Service (LTS). Design is considered a quintessential engineering activity, and as such should represent a dominant culture for engineering. Ethics is very important for the engineering profession, but is often relegated to the outskirts of engineering education. LTS focuses on people and helping, topics which are not generally widely associated with engineering but are rapidly gaining popularity among students. Three representative engineering disciplines were also explored: electrical and computer (ECE), civil, and environmental engineering. These disciplines were selected because they represent a wide range in the percentage of females among the tenured/tenure-track (T/TT) engineering faculty (11.6%, 15.4%, and 23.9% [38]). The ECE and environmental divisions might also be thought to represent different engineering cultures – "thing" centric versus "nature/people" centric [36].

For design and the three engineering disciplines, papers presented within the sessions organized by the division of interest were explored. For the LTS topic, papers were identified via search terms of interest (service learning, community service, EWB, community engagement), as well as including all papers presented in the Community Engagement in Engineering Education division. For ethics, a search approach was also used, including ethics as a search term as well as including all of the papers presented in the engineering ethics division. From among the LTS and ethics search results, the abstract of each paper was examined to determine if the main focus of the paper involved the appropriate topic. In some cases, for example, service learning was mentioned in the biography of one of the authors but was not the focus of the paper.

Once the paper was confirmed to be focused on the desired topic, the title and authors of the paper were recorded in a database (spreadsheet). The total number of authors for each paper were noted. Next, the biography of the authors that was provided with the ASEE paper was examined. This generally provided information on institutional affiliation, discipline, gender (based on the pronouns used), academic rank, and additional administrative roles (department chair or head, head, program director). The biographies also sometimes stated if the individual was a licensed Professional Engineer (P.E.) or had significant industry experience. Any degrees from international institutions were noted, as well as non-engineering related degrees, when provided. In cases where a biography for an author was not provided, an online search was conducted to locate the information. Online CVs were often found, such that the academic rank and other factors could be determined for the individual in the year of interest. Next, each paper was classified as to whether or not it met each the following criteria: authors from different engineering departmental affiliations (multi-disciplinary engineering); authors included individuals from non-engineering departments such as education (interdisciplinary); authors from different institutions; and if there were graduate or undergraduate

student co-authors. Finally, the institutional classifications by the Carnegie Foundation were determined [37].

After the relevant parameters were populated in the spreadsheet, counts were conducted on the parameters of interest. Initially, overall counts across all authors were conducted. Then the counts were redone to look only at faculty, since some papers had students, post-docs, non-faculty center directors, and other individuals as co-authors. Faculty included assistant, associate, and full professors, as well as instructors, lecturers, clinical professors, and adjunct members. It was considered that lecturers, adjunct, clinical, professors of practice, and research faculty positions were non tenure/tenure-track. Individuals who held faculty rank but had primarily moved into administrative roles (such as Dean or Provost) were still counted as faculty. The counts were then conducted specifically for unique engineering faculty, since in a number of cases the same individual might author multiple publications on the same topic across the three years of interest. Engineering faculty included individuals with degrees in engineering, engineering technology, construction management, physics, and/or architecture. To determine if there were differences in the characteristics of the engineering faculty engaged in different SoTL topics, chi-square tests were conducted in Excel.

Additional data were gathered as benchmarks for U.S. engineering faculty overall from the ASEE profiles, and more specific information from the ASEE Engineering Data Management System [38]. This provided information on the ranks of engineering faculty for the institutions with engineering degrees around the U.S. When combined with information from the Carnegie Classifications, the distribution of engineering faculty across different types of institutions (public, private, Master's, Bachelor's, etc.) could be determined. Data on the number of ASEE members in different divisions were gathered from the ASEE online member search.

III. RESULTS AND DISCUSSION

A. Ranks of SoTL Faculty

The ranks of the unique engineering faculty who authored ASEE conference papers between 2012 and 2014 on different topics are summarized in Table I; the data from the ASEE engineering faculty profiles are also shown for comparison. If an individual published in multiple years, the highest rank was counted. The results show that the ranks of the engineering faculty were similar in all of the SoTL topic areas (chi-square $p=0.14$). There were generally increasing percentages of engineering SoTL faculty at the non-T/TT (12-21%), assistant (21-28%), associate (22-33%), and full professor ranks (26-39%). Although statistically non-significant, one trend in the data was that design papers had the highest percentage of engineering faculty from non-T/TT ranks; future research might find that these individuals may have industry experience and/or less research focus and therefore are not in T/TT ranks.

TABLE I. PERCENTAGE OF ENGINEERING FACULTY AT DIFFERENT RANKS

Faculty Group	# faculty	% non-T/TT	% assistant	% associate	% full + emeritus
Design	279	21	26	26	27
Ethics	90	14	21	26	39
LTS	133	17	28	23	32
Civil Eng	185	14	27	33	26
ECE	268	16	24	24	37
Environm.	82	12	27	22	39
6 SoTL topics combined	1037	17	26	26	32
ASEE profile [38]	31038	17	18	24	41 ^a

^a. ASEE profile does not include emeritus professors

There was a significant difference between the ranks of engineering SoTL faculty and engineering faculty overall (chi-square $p < 0.001$). There were more assistant professors and fewer full professors among SoTL faculty compared to engineering faculty overall. This may indicate that younger faculty hold greater value for teaching compared to more senior faculty; over time this may help shift the culture of higher education in engineering to more balance between disciplinary research and teaching and/or education research. If this trend continues, over time as more senior faculty retire and if these younger SoTL-active faculty move into tenured and full professor ranks, the culture of engineering education may shift to place greater value on SoTL activity. There are signs that this movement may already be occurring [40].

B. Disciplines of SoTL Faculty

The disciplines of the unique engineering SoTL faculty authors on different engineering education topics are summarized in Table II. There were statistically significant differences in the engineering disciplines of the faculty who engaged in research on different SoTL topics (chi-square $p=0.0003$). Note that many individuals were associated with multiple disciplines, making accurate counts difficult. Therefore, closely related disciplines were combined: electrical and computer; civil and environmental. Mechanical engineering was over-represented among the authors of ASEE papers on LTS and in the design division. The representation of ECE faculty among SoTL authors is fairly similar to their national faculty percentage. Within the ethics papers the authors are almost twice as likely to be ECE faculty compared to mechanical faculty. Civil engineering faculty were over-represented among the authors of LTS and ethics papers, at almost twice the national faculty percentage. Chemical engineers appear under-represented among LTS authors, although the percentages are small. The results seem to indicate that particular engineering education topics are more popular within specific engineering disciplines. Design appears central to mechanical engineering. Service to society is at the core of civil engineering, compared to other engineering disciplines that tend to be more customer oriented or "business-centric". These results may indicate that there is a greater role for particular topics within the culture of different engineering disciplines, and that discipline-specific faculty are unaware of this opportunity.

The number of unique engineering faculty who authored 2012-2014 ASEE papers in the ECE, civil, and environmental divisions (268, 185, and 82, respectively) were compared with the number of ASEE members in these divisions from the directory search (881, 606, and 340, respectively); this revealed 24-31% of the division members were authors. Comparing the number of authors to the number of T/TT faculty (5811 ECE, 2511+765 civil+civil/env, 159+765 environmental+civ/env [39]), it appeared that SoTL within ECE (4.6%) was similar to civil engineering (5.6%), but somewhat higher in environmental engineering (8.9%). This may indicate differential value of SoTL among these disciplines.

TABLE II. DISCIPLINES OF ENGINEERING SoTL FACULTY

Faculty Group	# faculty	% mechanical	% ECE	% civil + environ.	% chemical
Design	279	44	22	11	5
Ethics	90	16	29	21	6
LTS	133	32	20	19	3
ASEE profile [38]	25,628	18	23	10	8

C. Gender of SoTL and Engineering Faculty

The percentage of females among the authors of ASEE papers are given in Table III. In all topics there was a decrease in the percentage of women among all paper authors, faculty authors, unique engineering faculty authors, and T/TT engineering faculty authors. Thus, there was a higher percentage of women among the individuals who collaborate with engineering SoTL faculty than among the engineering faculty themselves. For example, among the papers in the design division there were 112 student co-authors; 44% of these students were female – compared to 20% females among the faculty authors. There were also 31 unique non-engineering faculty members who co-authored design papers; among these, 52% were female.

TABLE III. GENDER OF INDIVIDUALS INVOLVED IN DIFFERENT AREAS OF ENGINEERING EDUCATION SoTL

SoTL Topic or Division	# authors			% females among authors:			
	all	faculty	engrg faculty	all	faculty	engrg faculty	engineering T/TT faculty
Design	560	411	279	30	25	20	20
Ethics	198	142	90	41	40	30	25
LTS	410	257	176	43	42	38	35
Civil	364	285	179	24	21	21	19
ECE	454	342	268	23	22	20	19
Environ.	139	108	82	48	44	46	45

There were differences in the percentage of women between the SoTL topics among all authors, faculty authors, engineering faculty authors, and T/TT engineering faculty authors (chi-square p values <0.001). The LTS and Environmental Engineering Division papers had the highest percentage of women among the authors, faculty authors, and engineering faculty authors; these topics are approaching gender parity. Future research should determine whether this parity is a result of the culture in these areas being less masculine. There was also nearly gender parity (41%) among all authors of the ASEE papers about ethics, although a number

of these co-authors were students, staff, and faculty from non-engineering disciplines; only 25% of the T/TT engineering faculty authors of these ethics papers were women.

There was a much higher percentage of women among the engineering T/TT faculty who authored ASEE papers compared to the percentage in engineering overall; ASEE reported 14.5% of all engineering T/TT faculty were women in 2013, including 23.9% women in environmental engineering, 15.4% women in civil engineering, and 11.6% women in ECE [39]. Thus, it appears that the culture within engineering education SoTL may be less masculine than engineering education overall. For example, SoTL may be associated with caring for students and their learning, and care is typically characterized as a feminine trait.

There were also differences between SoTL topics in the representation of women among engineering faculty of different ranks (Table IV). There was a similar percentage of women among the assistant, associate, and full professors in engineering among the authors of papers in the Environmental Division (44-45%). For papers on LTS, the percentage of females among the engineering faculty authors at the three T/TT ranks was also fairly similar, although highest among full professors. In contrast, the percentage of women among the full professors in engineering who authored papers on the other topics (ethics, design, ECE, and Civil Engineering; 6-17%) was much lower than the percentage of women among the engineering faculty at the lower T/TT ranks (assistant or associate professors) or non-T/TT faculty.

TABLE IV. PERCENTAGE OF WOMEN AMONG ENGINEERING FACULTY AT DIFFERENT RANKS

Faculty Group	Non-T/TT	Assistant	Associate	full + emeritus
Design	23	28	28	14
Ethics	62	21	39	17
LTS	17	28	23	32
Civil Eng	35	33	17	6
ECE	26	27	27	9
Environm	50	45	44	44
ASEE profile [39]	Not Rep.	22.8	17.0	9.4*

It is unclear if the lower percentage of women among engineering full professors is due to insufficient time for women faculty active in engineering education SoTL to advance to full professor, so-called demographic inertia [41]. Alternatively, female faculty active in engineering education SoTL may be advancing more slowly to full professor than their male peers. This could be due to in part to investing time in SoTL which is not highly valued in the predominant culture of engineering in higher education.

D. Institutions Where Faculty Employed

The institutional characteristics represented by the engineering faculty active in different SoTL topics are compared in Table V. There were similar percentages of faculty from public and private institutions among the SoTL topics (chi-square p=0.97) and as compared to engineering faculty overall (chi-square p=0.85); 70-78% at public

institutions and 22-30% at private insitutions. However, a significantly lower percentage of the SoTL faculty were employed at research institutions with very high research activity (Carnegie classification RU/VH) and a higher percentage at Baccalaureate (Bac.) or Master's (MS) institutions, as compared to engineering faculty overall (chi-square $p<0.001$, $p<0.001$). These differences likely reflect cultural differences among the institutions, where teaching and SoTL is more valued at Baccalaureate or Master's institutions and disciplinary research is a higher priority and emphasis at the RU/VH institutions. In addition, faculty teaching at Baccalaureate and Master's institutions often teach more courses per year, and as such have more opportunities to engage in SoTL activities. RU/VH institutions perhaps place little value on SoTL, resulting in lower participation of faculty from these institutions on SoTL activities.

TABLE V. INSTITUTIONAL CHARACTERISTICS OF ENGINEERING FACULTY

Faculty Group	# unique institutions	% faculty at publics	% faculty at privates	% faculty at RU/VH	% faculty at Bac. or MS
Design	133	70	30	30	36
Ethics	57	78	22	27	39
LTS	68	71	29	26	38
Civil Eng	82	75	25	20	56
ECE	126	73	27	25	40
Environm.	48	71	29	20	52
<i>ASEE profile [39]</i>	<i>351</i>	<i>74</i>	<i>26</i>	<i>54</i>	<i>16</i>

Among SoTL topics, there were not significant differences in the faculty employed at RU/VH institutions (chi-square $p=0.36$), but there were differences in the percentages of faculty working at Baccalaureate or Master's institutions (chi-square $p=0.017$). The authors of papers from the design division had the greatest similarity to overall faculty demographics, which is not unexpected given that design is at the core of traditional engineering culture. In the civil engineering and environmental engineering divisions, more than half of the engineering faculty authors were employed at Baccalaureate of Master's institutions; this implies that SoTL is not particularly common among faculty in these disciplines at doctoral and RU/VH institutions.

E. Other Characteristics of Engineering SoTL Faculty

There were five additional characteristics of the engineering SoTL faculty that were compiled: international degrees, additional administrative roles, additional non-engineering degrees, industry experience prior to academia, and Professional Engineering (P.E.) licenses; this information is summarized in Table VI.

There were differences in the percentage of engineering faculty with international degrees between the different SoTL topics (chi-square $p<0.001$). Among the authors of ASEE papers in the civil engineering division and the three cross-cutting engineering education themes, 16-20% of the engineering faculty possessed international degrees; the ECE division had the highest percentage of international degree holders among its engineering faculty authors. India and

China were the most common countries where international degrees were earned. This information might indicate that the culture in ECE departments is more inclusive of diverse backgrounds; alternatively, it may be that U.S. ECE departments simply hire many qualified individuals that hold one or more international degrees. In that case, it is unclear the extent to which those individuals are being enculturated into the traditional U.S. engineering culture, versus impacting the culture through acculturation.

TABLE VI. CHARACTERISTICS OF ENGINEERING FACULTY ACTIVE IN SoTL

SoTL topic or division	% with inter-national degrees	% with additional admin. role(s)	% with additional non engrg degrees	% with industry experience	% P.E.
Design	20	23	8	25	8
Ethics	17	28	4	21	27
LTS	16	28	4	15	16
Civil Eng	17	25	5	17	54
ECE	38	24	4	20	6
Environm	25	26	5	17	26

A high percentage (23-28%) of all of the engineering faculty authors across all topics and divisions held administrative roles, in addition to standard faculty positions. There were not significant differences between SoTL topics (chi-square $p=0.93$). These roles are often indicative of interest and time invested beyond narrow disciplinary research, such as positions as associate chairs or deans for education. It is unclear the extent to which this would also be the case for engineering faculty not involved in SoTL activities. It is a positive sign that administrators are engaged in SoTL and/or engineering research; these individuals would be in positions to make informed decisions that could improve engineering education at their institutions.

Only a small percentage of the engineering SoTL faculty appear to hold additional non-engineering degrees (4-8%); this did not differ significantly across the different SoTL topics (chi-square $p=0.37$). These were most often degrees in education or business (such as an MBA). It is unclear how this percentage compares to engineering faculty overall. However, if the culture of engineering does not place value on these degrees, they may have been under-reported in the biographies written by the authors of the ASEE papers.

The percentage of engineering SoTL faculty with known industry experience (based on the biography supplied with their ASEE paper or an online CV for individuals without an ASEE biography) ranged from 15-25% across the various engineering education topics and ASEE divisions; there were not significant differences between SoTL topics (chi-square $p=0.27$). Not surprisingly, the highest percentage of faculty with industry experience was found among the authors of papers in the ASEE design division. Design skills are likely best gained in practice, so industry experience is particularly valued among those who teach design. In contrast, at research intensive universities a number of the faculty have had no industry experience, but only academic training through degrees and post-doctoral positions. Industry experience is often not valued in hiring.

The percentages of engineering faculty with previous industry experience could not be found for comparison to the information on engineering faculty engaged in SoTL. The best data available were from a 1988 study [42] which indicated that 34% of engineering faculty had previous industry experience among those who had received their highest degree less than ten years earlier; this was significantly lower than the 68% of engineering faculty with industry experience among those who earned their highest degree more than 25 years earlier. Assuming that this trend continued, today we would expect far less than 34% of the engineering faculty would possess industry experience. More recent papers only make vague references to the percentage of engineering faculty with industry experience being “so small” [43].

Finally, there were significant differences in the percentages of the engineering faculty that were licensed P.E.s across different SoTL topics and disciplines (chi-square $p < 0.001$), ranging from 6% in ECE to 54% in Civil Engineering. This may under-represent actual P.E.s among engineering SoTL faculty, but it is likely that the cultural differences in how P.E. licenses are valued is reflected in these differences. If individuals perceive that their P.E. license are not valued within the discipline or topic, they are less likely to include it in their biography. Therefore, it appears that the culture within Civil Engineering highly values P.E. licensure, while this holds little value within the culture of ECE. In a 2009 study, 44% of the civil engineering faculty were found to have P.E. licenses [44]. Environmental Engineering and ethics also appear to hold more value for P.E. licensure than design or LTS. The fairly low percentage of engineering faculty authors of the design papers who indicated they held a P.E. license is somewhat surprising in the case of design, since in practice engineering designs must be signed off by P.E.s in order to be built or constructed. Further, seven of the program criteria under ABET (including civil and environmental engineering) specify that “faculty teaching courses that are primarily design in content are qualified to teach the subject matter by virtue of professional licensure or” similar experience; 21 disciplines do not indicate this requirement [45]. Among the engineering faculty who authored the papers in the design division, 44% were mechanical engineering; so perhaps the low percentage of the design authors with P.E. licenses reflects the culture within mechanical engineering.

F. Collaborations Among SoTL Faculty

A comparison of the co-authoring characteristics among different SoTL topics is shown in Table VI. There were differences between the SoTL topics in the number of co-authors per paper, and the percentage of papers with authors from multiple engineering disciplines, non-engineering disciplines, and student co-authors (chi-test p -values 0.04, 0.0007, 0.002, respectively). The number of authors for the ASEE conference papers ranged from 1 to 10, with an average of around 3 people. The percentages of papers authored by single individuals were 16% in the design division, 18% in the ECE Division and papers about LTS, 20% in the Environmental Engineering Division, and 23% in the Civil Engineering Division and papers about ethics. This is reflective of the individualized culture in engineering. On

average, there were more authors per paper on LTS topics compared to the other topics (chi-square $p=0.04$).

Papers with co-authors from multiple engineering disciplines were the most common among papers about LTS. This reflects the interdisciplinary nature of many LTS programs such as EWB, EPICS [46], and SLICE [47]. Nearly a third of the papers on design, ethics, and from the Environmental Division also included authors representing multiple engineering disciplines. In contrast, but perhaps not surprising, fewer than 17% of the papers from the ECE and Civil Engineering Divisions included authors from multiple engineering disciplines.

Authors from non-engineering disciplines were the most common among papers about engineering ethics followed by LTS, significantly higher compared to design papers and the papers from the disciplinary divisions. Almost half of the ethics papers included authors from non-engineering disciplines, most typically from faculty from philosophy, communication, or business. Thus, the culture of different SoTL topics appears to differentially recognize the value of collaborating with individuals having expertise outside of engineering.

Collaborations across multiple institutions did not vary significantly between different SoTL topics (chi-square $p=0.44$). Interestingly, a very low percentage of the LTS papers included authors from multiple institutions (16%), about half the multiple-institution collaborations evident among the papers on ethics (30%). The lower cross-institutional collaboration may be due to local LTS efforts that are specific to a given institution. Another potential reason may be the “newer” nature of LTS as a division (in 2012 the constituent committee formed and first offered sessions at the ASEE Annual Conference) and therefore less opportunity for LTS faculty to network and form collaborative groups as compared to the other topics.

TABLE VII. COLLABORATIONS AMONG ENGINEERING EDUCATION SoTL AUTHORS

SoTL topic	# papers	Avg # authors / paper	% papers with co-authors from:			
			multiple engineering disciplines	non-engineering disciplines	multiple institutions	student ranks
Design	179	3.1	28	24	20	39
Ethics	69	2.9	28	46	30	28
LTS	121	3.4	36	39	16	48
Civil	133	2.7	12	21	23	19
ECE	159	2.9	17	14	19	31
Enviro	45	3.1	33	29	22	44

Finally, the percentage of ASEE papers that included student co-authors varied between different topics (chi-square $p=0.002$). Nearly half of the ASEE papers on LTS had student co-authors, the highest among the SoTL topics. This reflects the integral role of students in LTS, which is focused on collaborative learning and creating learning for the benefit of students. Student voices may be the most important to reflect the affective outcomes of the experience, in addition to the diverse learning outcomes. Including students as co-authors of papers rather than treating them merely as the “subjects” of

assessment and evaluation efforts reflects a culture that values students as co-creators of their learning experiences. In contrast, the low percentage of student co-authors among civil engineering papers (19%) may reflect more of a “top down” or hierarchical culture of conveying knowledge to students. The percentage of undergraduates among the students also showed differences: 9% in ethics; 18-20% in civil and ECE; 27-33% in design, LTS, and environmental topics.

IV. LIMITATIONS AND FUTURE WORK

The primary limitation of the study is the assumption that the faculty who co-authored papers presented at the ASEE annual conference were representative of engineering faculty active in SoTL. There are a number of additional individuals who are SoTL-active but publish or present in other venues (ASEE regional conferences, FIE, journals, or local institutions). Further, strict distinctions were not made between engineering education research and SoTL; both activities are likely represented among the authors of the ASEE papers. In addition, only the authors across a three-year period were examined. However, it is hoped that these authors are representative of the larger group of engineering SoTL faculty. Future work could expand to a larger number of years (such as a decade) and additional published sources. Because culture changes slowly, this larger time range should not be an issue. In addition, indicators of culture within the papers themselves will be explored, including ideas of quantification, power distance, uncertainty avoidance, etc.

At present, a limited number of engineering disciplines and engineering education topics have been explored. Additional, timely topics within engineering education that seem to reflect emerging cultural changes could be explored. For example, the emergence of new divisions within ASEE is often driven by a critical mass of individuals with a particular concern. Exploring these could reflect cultural changes within engineering education. Other disciplines within engineering could also be examined. Mechanical engineering has experienced explosive growth in student numbers within the past 10 years [39, 48]; perhaps an attribute of the culture within mechanical engineering resonates with today’s generation of college students. Further, newer disciplines such as biomedical engineering may have unique cultures, since they are less constrained by historical precedents.

Another key consideration is to explore the number of cultures that are intersecting in these contexts. This includes the culture of engineering, the culture of higher education, cultures within particular engineering disciplines, the culture of SoTL (beyond just engineering education), institutional cultures, and cultures within specific departments. Additional and more extensive methods should be used to assess these cultures, how they interact, and which seem to dominate in particular situations (such as promotion and tenure). Individuals may feel that they are part of the dominant culture, or feel part of a sub-culture. There are also the processes of enculturation, acculturation, and cultural changes over time to consider. As SoTL grows within engineering education, will it remain a sub-culture or will it begin to infuse its values into mainstream engineering education?

V. SUMMARY AND CONCLUSIONS

The research results indicated that there were significant differences between the engineering faculty involved in SoTL as compared to U.S. engineering faculty overall in the following characteristics: distribution of faculty between T/TT ranks (faculty engaged in SoTL a higher percentage of assistant professors and fewer full professors); representation of engineering disciplines; percentage of women overall and at different T/TT ranks (higher among faculty engaged in SoTL); employment at RU/VH and Baccalaureate / Master’s institutions (lower and higher among faculty engaged in SoTL, respectively). Given the large number of differences, it appears likely that engineering faculty active in SoTL represent a distinct sub-culture within engineering higher education as a whole. This culture is perhaps more collaborative, less masculine, and less hierarchical. The specific cultural attributes that manifested in the differential predominance of faculty demographic characteristics requires further exploration.

The research also found that there were significant differences in the characteristics of the engineering faculty engaged in SoTL focused around different topics and disciplines within engineering education. These differences included: which engineering disciplines were active in selected engineering education topics; the representation of women; employment at Baccalaureate and Master’s institutions; P.E. licensure; and collaborations in SoTL with individuals from other engineering disciplines, non-engineering disciplines, and students. Thus, differences in culture in regards to the collaborative and gendered attributes appear evident. Learning through service and environmental engineering appear the least gendered or masculine, perhaps because these are more recently emergent areas of engineering education that did not carry historical male-dominance upon formation of their culture. Further research is needed to explore what specific cultural differences have led to these differences that were observed in the characteristics of the faculty who engage in engineering education SoTL.

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Using Social Network Theory to Elucidate the Impact of Diversity on the Social Processes in Design

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Abstract— Engineering design is understood to be a social activity, and requires collaboration and negotiation with diverse groups of people. Group communication literature suggests that team member interactions and communication have a major impact on a team's decision-making abilities. Furthermore, these interactions and decision-making processes are impacted by the diversity makeup of the team. In this study, we examine the ways in which communication and social processes relate to ethical issues and decisions, which we envision as interwoven throughout the design process and arise on a day-to-day basis in engineering design. Thus, this work-in-progress paper describes preliminary results about how diversity and ethics interact within engineering design contexts through the use of social network analysis.

Keywords— *social network analysis; diversity; design; ethics; technical expertise*

I. INTRODUCTION

Our study explores how team members communicate and establish patterns of interaction that relate to decision-making and ethics in design. We draw from social network theories and a communicative approach to examine how members of multidisciplinary project teams in EPICS¹ talk about, make sense of, and interact throughout the design process, especially as related to ethics. Group communication scholars have examined decision-making processes in teams extensively, finding how team characteristics such as diversity and status differences affect team decision-making and performance.

Individual team members can significantly affect the team's performance, the way members relate to one another, the type of information that is shared and discussed, and a number of other factors that contribute significantly to a team's functioning and decision-making.²⁻⁶ These effects are even more pronounced for smaller teams of people⁷, such as project teams. Researchers have found that diversity among team members has several implications. First, more diversity in terms of age and educational experience have been linked positively to team performance, flexibility, innovation and

productivity.⁸⁻¹⁰ However, research has also indicated that these more diverse work groups often encounter difficulty initially in terms of group performance and functioning.⁹

Cultural diversity also impacts a team's interactions and decision-making processes, providing both benefits and challenges. Some obvious challenges include potential language barriers, but nonverbal cultural differences can also make team interactions more difficult. Cultural diversity can offer more opinions and perspectives on problems,¹⁰⁻¹¹ and could influence the team to take into consideration a wider view of the end user of the product or its functionalities. Culture can also impact the development of team norms, the quality of discussion and inclusivity of team members, and the clarity of the decision-making process. EPICS teams, like the professional world of engineering, are often highly diverse in terms of age, educational background, level of experience with either the specific project or the program in general, and national culture. Examining how this diversity impacts ethical reasoning, both within the team and as a product of the team's efforts, can inform engineering educators about the impact of diversity on their student design teams, and offer insight on strategies to enhance the positive aspects of diverse teams and counteract negative aspects that can occur if left unchecked.

II. COMMUNICATION NETWORKS

To understand the social and communicative processes that underlie ethical decision-making in diverse teams, it is important to consider how communication networks emerge within a network of individuals. Communication networks suggest the relationships among actors and highlights the social processes that undergird these networks¹². This project examines the extent to which actors with the same gender, ethnicity, disciplinary membership, and ethical understandings interact and under what circumstances these actors sought one another out. We accounted for emerging communication networks using the theory of homophily which argues that similar actors within a network will seek one another.¹²⁻¹⁴

Following Ibarra's¹⁵ classification, we also distinguished instrumental networks as task-oriented relationships (e.g., work-related, project-focused) and expressive networks (e.g., as social or social support relationships). In the current study

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the instrumental network we explored was a task network (i.e., I work with this person regularly) and technical competence network (i.e., I can rely on this person to have the technical competence needed to get the task done). The expressive networks were friendship (i.e., I consider this person a friend) and ethical consideration (i.e., I would go to this person if I had a serious ethical concern about the project). We positioned the ethical network as an expressive relationship due to the high degree of trust related to this form of interaction.¹⁶ The classification of networks serves as a broader contextual backdrop in which our observed communication networks reside. Instrumental and expressive networks suggest different social processes that influence the relationships between actors. For example, expressive networks tend to facilitate ties among similar individuals above and beyond instrumental networks. In addition, according to Ibarra, expressive relationships are less sensitive to formal structures. Typically, people have more control over those whom they consider friends and with whom they exchange trust-laden information. Thus, it is critical to examine how these expressive networks emerge and specifically what role actor attributes play in forming certain network structures. Ibarra¹⁶ argued, “expressive network relationships...are characterized by higher levels of closeness and trust than those that are exclusively instrumental” (p. 59). Table 1 illustrates our study’s three central communication networks.

TABLE I. COMMUNICATION NETWORKS WITHIN ENGINEERING DESIGN TEAMS

Communication Networks	Definition
Work-interaction network	I work with this person regularly.
Friendship network	I consider this person a friend.
Ethical consideration network	I would go to this person if I had a serious ethical concern about the project.
Technical competence network	I can rely on this person to have the technical competence needed to get the task done.

III. ETHICS

Cheney, Christensen, Zorn, and Ganesh¹⁷ identify several contemporary issues involving the communication of ethics within organizations. First, the nature of *corporate legitimacy* has dramatically changed. Whereas decades ago the sole responsibility of a corporation was to be profitable, now organizations are called upon to be responsible to their members, communities, and other stakeholders. This contemporary issue frames the overall ethical landscape in which organizations in general and work teams in specific reside. Engineering teams are held to a standard above and beyond creating a product that is fiscally viable. Second, the rapid increase in *new technologies* is creating newer and more complex ethical dilemmas. Engineering teams in particular must consider the social impact of new innovations. As a result, it is critical to examine ethical reasoning among this particular work group. Third, *multicultural and international dynamics* challenge taken-

for-granted routines. Multiculturalism is forcing organizations to assess “normal” ways of doing business.

Diverse ethnic, cultural, and national understandings of ethics challenge the status quo of what organizations believe it means to be ethical. Thus, it is also critical to examine the extent to which diversity functions in perceiving others as ethical (or not). Finally and similar to multiculturalism, the question of *whose standards* addresses whose and what standards are being used as ethical foundations for complex decisions and outcomes. We use the Engineering Ethical Reasoning Instrument (EERI)¹⁸ as a measure of individual ethical reasoning within the engineering context. Furthermore, we explore the impact of diverse disciplines on the network. Michael Davis¹⁹ has argued that engineering ethics addresses “special morally permissible standards of conduct that, ideally, every member of a profession wants every other member to follow, even if that would mean having to do the same” (p. 93). It is important to account for the ways a group of diverse members together come to understand and interact regarding ethical considerations.

IV. SOCIAL NETWORK ANALYSIS

We are utilizing social network analysis (SNA) to explore communication networks, as well as the impact of diversity. According to Monge and Contractor,¹² SNA “at its core...consists of applying a set of relations to an identified set of entities” (p. 30). In terms of the current study, the engineering students enrolled in EPICS were the entities and the relations applied consisted of the four primary communication networks. Moreover, SNA examines relationships between these engineering students alongside their individual attributes (e.g., gender, ethnicity, disciplinary membership, and EERI score). In other words, SNA allowed us to examine to what extent individuals with similar attributes formed ties within certain communication networks.

There are also network structure influences that must be taken into consideration. *Density* refers to the connectedness of individuals within a particular network.¹² This network level measure indicates the ratio of the total number of actual links to the total possible links. Therefore, highly dense networks are highly connected representing many linkages among actors. This is important to consider because density provides context for the ways actors potentially perceive of the relationships they have with one another. That is, network density suggests whether the structure of communication networks facilitates or hinders certain relationships. For instance, highly dense networks typically facilitate stronger ties among expressive ties such as friendship.¹⁶ Therefore, due to this study’s emphasis of expressive networks it is important to consider how density facilitated communication among different communication networks. Ibarra¹⁶ sheds light on the connection between network density and relationships among contacts: “Network density, which refers to the extensiveness of contact...focuses on how a...individual is affected by relationships...” (p. 63).

V. HOMOPHILY

The theory of homophily suggests individuals select one another based on similarities.^{12,15,16} These similarities may be based on various dimensions, including but not limited to: age, gender, social class, education, race, occupation, attitudes, and beliefs. Homophily theory in social networks provides an explanation for how communication networks form.

McPherson and colleagues¹³ provided an in-depth literature review on homophily within social networks. They categorize these various dimensions into *status* homophily and *value* homophily. Status homophily typically includes demographic factors, such as age, sex, and occupation. For the current study, as stated previously, we included: gender, ethnicity, and disciplinary membership. Value homophily focuses more on internal states, such as attitudes, values, and beliefs. According to McPherson et al.,¹³ these internal states may indicate orientation toward future behavior. As indicated earlier, we are using the Engineering Ethical Reasoning Instrument (EERI) as a dimension of value homophily. We situated the EERI as such because it represents an internal set of beliefs or principles that orient individuals toward future behavior (e.g., ethical decision-making practices).

There are a few noteworthy points regarding this study's dimensions of status homophily (e.g., gender, ethnicity, and disciplinary membership). First, based on the restricted nature of the modern workplace, women are forced to form relationships with men in both instrumental and expressive networks. Studies have shown that these cross-sex ties are typically associated within instrumental networks, where expressive networks tend to present more gender homophily.^{13,15} Ibarra¹⁵ found that women formed more instrumental ties with men and particular women within expressive networks.¹² Second, race and ethnicity, historically, have been shown to be the strongest predictors for homophily in social networks.¹³ Interestingly, as with gender, findings indicate that racial and ethnic minority members typically form more cross-race ties within instrumental networks and demonstrate more racial/ethnic homophily within expressive networks. Lincoln and Miller,²⁰ as cited in Monge and Contractor,¹² "found that similarities in sex and race of organizational employees were significant predictors of their ties in a friendship network" (p. 226). Lastly, organizational or disciplinary membership homophily has also shown to account for networks structures. In the present study, we operationalized disciplinary membership as the academic major of the students given the highly multi-disciplinary nature of the program (greater than 70 majors participated in an academic year). We did not analyze disciplinary membership in terms of level of education because most students are undergraduates. Studies have shown that organizational membership homophily occur more frequently in instrumental relationships than in expressive networks.¹³

Before we address statistical approaches for social network research, we present the potential "downside" for highly homophilous groups.¹⁶ Similar groups tend to

reproduce information and provide redundant resources, and can participate in "group think".^{21, 22} For instance, highly homophilous groups may share similar viewpoints, ideas, or decision-making premises. This is a critical point for groups such as engineering teams that require original ideas to produce creative innovations. The downside of homophily has implications for ethical decision-making. Ibarra¹⁶ argued "restricting network interactions to similar others...reduces access to information from disparate parts of the social system"²³⁻²⁵ and strengthens peer group enforcement of norms concerning appropriate behavior"²⁶ (p. 61). Reinforcement of norms therefore becomes important to consider. The prevalence of certain norms over alternative approaches opens a group (e.g., engineering design teams) to the risk of ethical threats. As a hypothetical example, let us say there is a high degree of disciplinary homophily within the ethics network. This could suggest that certain disciplinary norms or design approaches are privileged without consideration to other alternatives. This could lead to certain values being embedded within the design process that ultimately could lead to greater ethical dilemmas. For these reasons, it is critical to investigate diversity within communication networks and the role diversity plays for ethical consideration, that is, how diversity functions within communication networks not whether or not there is diversity per se in teams. In terms of engineering education, it is important to understand the structures that emerge within engineering design teams. Engineering team dynamics may afford unique contexts different than in other disciplines (e.g., management, marketing, accounting).

VI. EXPONENTIAL RANDOM GRAPH MODELS FOR SOCIAL NETWORK (p^*)

Exponential random graph models for social networks (ERGM) or p^* models apply statistical premises to observed social networks²⁷. Where traditional social networks properties such as density, centrality, and betweenness provide good descriptions of network compositions, ERGM models extend social network analysis by exploring regularities within network ties. By accounting for randomness, ERGM models are able to examine whether these regularities occur above and beyond mere random chance. Following theoretical mechanisms, statistical models allow hypotheses to suggest what social processes are behind the emergence of certain structural properties.²⁷ Robins and colleagues²⁷ provide a prime example of how statistical models are able to do so:

For instance, clustering in networks might emerge from endogenous (self-organizing) structural effects (e.g., structural balance), or through node-level effects (e.g., homophily). To decide between the two alternatives requires a model that incorporates both effects and then assesses the relative contribution of each.²⁷ (p. 175)

Thus, ERGM models accounts for various networks structures at multiple levels to suggest how these structures emerge. An ERGM approach allows us to predict the propensity of ties within our observed networks by examining the statistical relationships of the simulated graphs. These graphs are produced by PNet and compared to

the observed network. Analysis using PNet utilizes Markov Chain Monte Carlo (MCMC) maximum likelihood estimation.^{27, 29, 30} The estimation process produces various simulated graphs that are compared to the observed network. To determine convergence, the *t* ratio output must be less than 0.1 in absolute value.²⁹ Parameter estimates more than twice their standard error are statistically significant.^{29, 27}

Within PNet several control parameters are used to account for the emergence of ties within a study's multiple matrices. These parameters are categorized as endogenous or exogenous effects. As Lee and Lee²⁹ indicate, "endogenous effects refer to the internal structures to form in the focal network" (p. 67). These parameters control for structural effects *within* a particular network. For instance, these effects account for local social processes that are representative of the network itself (i.e., self-organizing). On the other hand, exogenous effects refer to the attributes members bring *into* the network. In terms of the current study, gender, disciplinary membership, and ethnicity represented exogenous or node-level effects. These parameters were operationalized as categorical variables. Additionally, we used the EERI as a continuous variable to measure individual ethical reasoning. The EERI also represented an exogenous effect.

VII. METHOD

Participants for the current study included 40 EPICS students representing two teams. Team 1 included 15 students and Team 2 included 25 students. The total sample included 15 female students and 25 male students. Of the total participants, 11 (28%) were ethnic minorities, with one unreported ethnic classifications. In terms of disciplinary membership, there were 6 (15%) enrolled in First Year Engineering, and 31 (78%) in Upper levels of Engineering coursework, with 2 (5%) Non-engineering, and one unreported.

Data were collected via a social networks analysis survey. Wasserman and Faust¹⁴ present complete networks as a form of social network data. A complete network assumes all actors can have ties to all other actors. Respondents of each team, therefore, were given a complete roster of the team that included students, teaching assistants, and advisors. Each student was instructed to select other students with whom they reported that they interacted. The four relations we examined were: work-interaction, friendship, technical competence, and ethical consideration. These relations were designated as directional relations. That is, the tie or relation was recorded when one student indicated a tie to another student and/or vice versa. Thus, this analysis produced 6 distinct matrices. Team 1 produced 3 15 x 15 matrices and Team 2 produced 3 25 x 25 matrices.

VIII. PRELIMINARY FINDINGS

Preliminary findings highlight the role of technical competence within engineering design teams. One of the study's guiding propositions stated that networks would demonstrate a structural tendency for reciprocity. Beginning with Team 1, the *ethical consideration* network was not

found to be statistically significant. The three additional networks did show significant results: *work-interaction* (Estimate = 3.36, SE = 0.55), *technical competence* (Estimate = 1.11, SE = 0.42), and *friendship* (Estimate = 1.29, SE = 0.48). The results indicate these networks maintain a self-organizing effect that suggests reciprocated ties. Outside of *work-interaction*, *friendship* produced the strongest estimate.

For Team 2, the *ethical consideration* network was also not found to be statistically significant. All other networks produced significant estimates: *work-interaction* (Estimate = 4.25, SE = 0.41), *technical competence* (Estimate = 1.63, SE = 0.25), and *friendship* (Estimate = 1.71, SE = 0.38). Similar to Team 1, *work-interaction* shows the strongest probability for reciprocated ties. Simply put, Team 2 results suggest that individuals are more likely to reciprocate with those they perceive they work with on a regular basis.

Importantly, however, reciprocated ties among *technical competence* could suggest that a local structure exists where individuals perceive one another as technically competent. These findings could indicate that many of the interactions within an engineering team are rooted in an individual's perception of the other as technically competent. This self-organizing structure within engineering design contexts may suggest that technical competence or the perception of being technically competent may override traditional diversity attributes (e.g., ethnicity, race, gender) that otherwise play significant roles in homophily within *other* organizational settings (e.g., corporations, NPOs, governmental groups). In terms of ethics, this finding might also suggest that technical competence is more easily perceived or acknowledged than ethics. Individuals are more likely to reciprocate another as technically competent above and beyond reciprocating ethical concerns. Not only might technical competence be more easily ascertained or perceived than ethical considerations but our findings about the importance of technical expertise in relationships might be a consequence of the many times in which team members are evaluated in different courses based on their technical expertise. Thus, assessment of technical competence or perceived technical competence alone might make this variable more salient than other considerations, such as ethics.

This preliminary finding is important for engineering educators. Engineering education in general is characterized by frequent and constant technical assessment and evaluation. Thus, technical competence or the perception of technical competence may be an underlying feature that influences many decision-making premises within the design process, such as ethical design decisions, above and beyond diversity effects. Taking this point into consideration engineering educators interested in facilitating diversity functions may need to acknowledge the pervasive role that technical competence plays within engineering team contexts, a role that may override other considerations. At the conference, we will expand on these results and additional findings related to diversity, ethics and implications for engineering educators.

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A SITUATED LEARNING ETHICS INSTRUCTION MODEL FOR ENGINEERING UNDERGRADUATE STUDENTS

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Abstract—Undergraduate ethics instruction in engineering can be broadly divided into two models – disciplinary ethics (integrated within a course) and standalone semester-long ethics course. While both these models have educational value, they insufficiently prepare students in dealing with everyday routine ethical decision making that they might encounter in the workplace. This is because both these models barely consider the organizational or cultural context in their discussions. This study investigates the merits of using cognitive apprenticeship—a situated learning model, to enculturate millennial undergraduate students to everyday workplace ethical decision making. This quasi-experimental study was conducted at a large public Midwestern university. The study participants included a cohort of graduating seniors from the mechanical engineering class, 90% of whom had full/part time relevant work experience. In addition, 55% of them had prior standalone or disciplinary ethics instruction. Despite their work experience and prior ethics instruction, data analysis revealed that there were marked improvements in students' organizational ethical decision making. The quantitative comparative analysis indicated significant improvements in scenario-based scores between the pre and post tests. The nature and depth of the qualitative responses revealed that students appreciated situated ethics instruction because it informed them on how to deal with everyday ethical decision making in the workplace.

Keywords— *Situated learning; Workplace Ethics; Undergraduate Education*

I. INTRODUCTION

Over the decades, science and engineering advances have brought to question the role of ethics in the engineering profession, the most current prominent ones being genetic engineering, developments of drones, informatics and data management, as well as advances in nanotechnology. In his article, "Engineering ethics: some current issues," John Uff indicates that in the U.S.A, most engineering ethics developments have arisen as a result of court actions, while in Canada and Australia, ethics developments have occurred following disciplinary actions against individual engineers [1]. This raises a fundamental question: how can institutions of higher learning better prepare undergraduates who have minimal work experience for ethical professional practice? This study seeks to address this fundamental question by discussing engineering ethics instruction especially when carried out in a situated learning scenario, and draws from a

case study of a cohort of graduating mechanical engineering seniors.

II. ETHICS INSTRUCTION

In the U.S.A., engineering learning objectives are set individually by each engineering department in all institutions. However, all the objectives must address the nation-wide engineering students' learning outcomes set by the Accreditation Board of Engineering and Technology (ABET)—the not-for-profit agency that accredits programs on applied science, engineering, and technology [2]. One of the outcomes stipulates that students will have "an understanding of professional and ethical responsibility. Since ABET does not provide a specific method of assessment and the appropriate rubrics, departments decide on the methods, tools, rubrics and frequency of assessing this outcome. Whatever the forms of assessment and rubrics, most schools use the broad engineering codes of ethics set by the National Society of Professional Engineers (NSPE) as a basis for ethics instruction. These canons, however, serve a symbolic function and do little in preparing millennial graduates for ethically responsible professional practice in this dynamic global economy.

A. Overview of Engineering Undergraduate Ethics Education in the U.S.A.

Shepard et al. (2009) carried out a study to assess engineering ethics education in America. Their study sampled 100 engineering programs from 40 different institutions. They interviewed more than 200 instructors, 200 students and observed 60 classes [4]. Their study results indicated that: (i) nationally ethics education takes place in the form of (a) stand-alone courses in ethics provided within the engineering school, or broad-based ethics theory classes offered by the philosophy department, (b) disciplinary ethics modules which typically consist of a few classes dedicated to ethics discussion, (c) brief professional ethics discussions as they arise naturally in any class depending on the subject matter. (ii) Coverage of key issues in engineering ethics education was uneven across the country and in most cases minimal. (iii) In most cases, students were asked to analyze ethical real and hypothetical case studies by using the NSPE canons as a guide.

Drake et al. (2005) conducted a study to compare the effectiveness of stand-alone ethics model and disciplinary/module-based model. Their studies revealed

neither models showed significant increase in students' moral reasoning ability and ethical judgment [5].

McGinn (2003) conducted a study to test students' ability to apply knowledge acquired in ethics classes in their workplace. He sought feedback from several practicing engineers who unanimously agreed that they faced ethical dilemmas but did not feel that their engineering education adequately prepared them to handle these issues. His study revealed significant gaps between ethical realities of the workplace and current ethics instruction [6].

Overall, current engineering ethics instruction indicates no systematic and intentional uniformity when it comes to the scope and depth of coverage, as well as the stage at which students receive ethics instruction. Secondly, there is a dearth of efforts to ensure ethics knowledge is transferred from the classroom to the workplace. In this paper, we evaluate the effectiveness of cognitive apprenticeship, a situated learning approach, in enabling transfer of classroom learning to practice in the workplace.

B. Situated Ethics Education—A viable Alternative

Situated Learning Theory (SLT) was developed by Jean Lave and Etienne Wenger [7] in an effort to connect knowledge and practice. Before the advent of schools, colleges, and universities, students learned by observing the master craftsman or tradesman—a process referred to as apprenticeship. In such learning situations, knowledge and practice went hand in hand and the need to transfer knowledge from a learning context to a work context never arose [8]. Contemporary educational practices, however, separate the learning from the doing. Formal or classroom learning approaches assume that “knowledge is held in the minds of individuals and thus can be eminently transportable” to work contexts [9]. Echoing Quay's (2003) observations, Suchman (1987) says formal learning believes that, “mentalistic formulations of the individual are translated into plans that are the driving force behind purposeful behavior. Plans refer to a view of action that assumes that the actor has used past knowledge and a reading of the current situation to develop a plan from within the actor's individual cognitive process to intelligently meet the demands of the situation”. But when confronted with real-life situations, learners often are not able to readily draw from past learning and apply the learning in coherent ways to address the needs of a real-life work situation. For this reason, classroom learning is often described as abstract, decontextualized, and symbolic [10].

Situated learning principles then, help instructors show to their students how classroom learning can be applied in real-world contexts. This approach can take two forms – communities of practice and cognitive apprenticeship. Both these situated learning approaches are inspired from traditional apprenticeships.

Communities of Practice: refers to “a site of learning and action where participants coalesce around a joint enterprise as they develop a whole repertoire of activities, common stories, and ways of speaking and acting. Communities of practice

constitute reality in a particular manner and encourage specialized ways of acting and thinking” [7].

Cognitive Apprenticeship: refers to a learning method where “instructors describe out loud what they are thinking and doing and why they are doing what they are doing [11].” The process of the instructor verbalizing his/her thought process “provides the only available window into the mind of the expert [11].” Cognitive apprenticeship model of learning can be especially helpful in classroom situations where learning at the site of community of practice is not possible [12].

SLT, thus, says that learning ought to be a process of socialization of the beginner or those on the periphery of practice such as senior undergraduate students, into one's professional community. Students should learn not just about the practice but also how to be a practitioner. Context or situatedness involves a consideration of the cultural, historical, and institutional factors of the target context in the learning situation and for this reason, situated learning approaches are holistic. “Closer the match between the learning situation and the ultimate workplace situation, the easier the transfer will be [11].”

C. Millennials and Workplace Ethics

A study of generational cohorts in the workplace conducted by the Ethics Resource Center in 2009 and 2011 shows that the Millennials are the most likely to engage in misconduct [13]. The following attributes were noted in this study:

(i) Millennials lack basic literacy fundamentals, have very short attention spans, are not loyal to the employing organization, demand immediate feedback and recognition, are likely to change jobs quickly.

(ii) Millennials reported pressure to compromise standards, company policies, or the law; the youngest workers historically have observed misconduct compared to their older colleagues.

(iii) They have a tendency to integrate work and personal life, making them less likely than other generational cohorts, to draw boundaries between the two.

(iv) They grew up in the Internet age; therefore, they value confidentiality and privacy less than other age groups. In their thinking, information flow is virtually instantaneous and knowledge is meant to be shared rather than owned.

(v) Millennial workers are least likely to find it acceptable to give a cold shoulder to someone for reporting an edgy joke.

Because Millennials, of all the generational cohorts, have the least amount of life and work experience in the workplace, the cognitive apprenticeship situated learning model can be especially helpful in orienting the Millennials to the routine ethical decision making in the workplace. Cognitive apprenticeship, uses specific examples situated in authentic contexts to orient/socialize students to the various ethical scenarios they will encounter in the workplace, it provides opportunities to students to learn from experienced members of the community of practice they will be entering, and it

points the novice professional to cultural/organizational resources that they can consult when caught in an ethical dilemma.

III. CASE STUDY: SENIOR ENGINEERING STUDENTS

In this study, we develop and implement a situated learning ethics instruction in a mechanical engineering capstone design class at an institution in the Midwestern region of the U.S.A. The cultural elements that embody situated ethics instruction in our study include: (i) The use of organizational codes of ethics which are cultural tools and guides that explain terms and concepts with regards to professional conduct. In addition, they elaborate consequences of non-compliance, processes and procedures followed in case of misconduct, and point users towards appropriate resources when needed. (ii) The facilitation of the ethics instruction by an experienced practitioner who used his company’s code of ethics to explain to students the meaning of and rationale behind ethical terms and concepts used in the code – a method of instruction referred to as cognitive apprenticeship (iii) The incorporation of everyday real ethical scenarios with respect to specific ethical themes (e.g. confidentiality and data privacy, electronic communication), compiled in consultation with the practitioners that are situated in the organizational as well as the professional context.

Our study has a dual focus; situating the content as well as the method of instruction. We seek to address the following research question: What is the students’ level of understanding of the six areas of organizational codes of conduct? Towards this end, our study tests the following hypothesis: (i) prior to intervention, students will have a general understanding of the ethical themes of organizational codes, (ii) the study will provide the students with a situated understanding of professional organizational codes, (iii) the impact of the intervention will be higher in scenario-based questions that require students to elucidate on the rationale behind and the consequence of defying the six organizational codes.

A. Study Design and Study Population

We used a quasi-experimental approach in this study in which a cohort of 20 students—mechanical engineering capstone class was chosen. The mechanical engineering class is predominantly the largest at this institution; hence the subjects in the study were non-randomized. The capstone class was selected since the college assesses the ethics-related ABET learning outcomes through this course. First, the students were asked to respond to a questionnaire on whether they had prior work experience and ethics instruction. Figures 1 and 2 indicate the proportions of students that had prior ethics education either as stand-alone courses or modules incorporated into the curricula of other classes and prior work experience in engineering respectively.

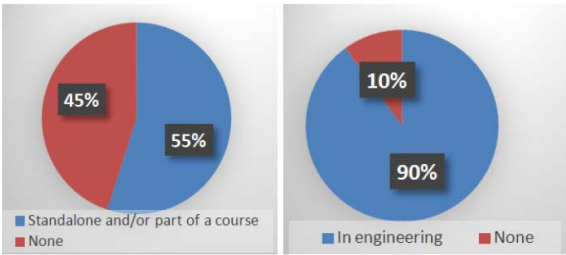


Fig. 1. Proportion of students with prior engineering ethics instruction

Fig. 2. Proportion of students with prior work experience

A matched pre-posttest evaluation questionnaire was designed with questions of varying form, depth and intensity as summarized in Table I. For the sake of brevity, only the essence and form of the questions are indicated. The students responded to the pretest a week prior to the intervention. The situated ethics instruction (herein referred to as the intervention) was facilitated by a professional mechanical engineer, who is also a lawyer in the ombudsmen office of a multinational organization in located in the U.S.A. The professional speaker engaged the students in an hour discussion of the day to day definition, description, and application of the organizational codes of ethics and how they relate to the overall engineering codes of ethics. He used real scenarios from his organization to explain how the codes are used to help identify and resolve ethical situations and some consequences of noncompliance.

TABLE I. SUMMARY DESCRIPTION OF PRE AND POST QUESTIONS

Question	Summary Description
1	Company resource documents related to organization’s codes of ethics? (open ended question)
2	Company resource offices related to organization’s codes of ethics? (open ended)
3	Meaning of confidential company information. (true/false - framed statement)
4	List three documents/records that might be considered confidential. (open ended)
5	Understanding of the meaning of proprietary information. (open ended)
6	Privacy law governance for multi-national companies. (true/false - framed statement)
7	Code of conduct violated in given contextualized misconducts (scenario analysis).
8	Definition of official records. (open ended)
9	Description of patent, copyright, intellectual property, Trademarks. (open ended)
10	Codes of ethics with regards to electronic communication. (open ended, scenario-based)
11	Records management and information security. (open ended, scenario-based)
12	Conflict of interest– design of products. (open ended, scenario-based)
13	Conflict of interest– supplier/vendor relations. (open ended, scenario-based)
14	Reporting procedures with respect to whistle blowing. (open ended, scenario-based)
15	Reporting procedures with respect to respect for fellow colleague. (open ended, scenario-based)

Following the discussion, students responded to a matching post test. Each question on the pre and post test was graded on a Likert scale of 0 to 3 depending on the required detail of response in the designed rubric, (i.e. no knowledge = 0, partially correct but low score = 1, partially correct but high score = 2, and full score = 3). We will mention here that we had a 100% response rate given that the study was weaved in as part of the syllabus. However, following IRB's stipulations for voluntary participation, the participants of this study signed a consent form allowing them to withdraw from the study at any time.

IV. DATA ANALYSIS AND RESULTS

A. Quantitative Analysis

Table II contains a heat chart indicating the number of students who had little to no prior knowledge of a particular question. The color legend is such that for the pre and post test columns, red indicates worse scored questions (i.e. number of students scoring <2), orange to green indicates the number of student responses with increasing values of scores (i.e. decreasing number of students scoring <2). Likewise, for the improvement column, moving from red to green indicates progression in improvement of score from the pre to post test (i.e. red indicates no improvement while green indicates most improvement, hence areas of engineering ethics that posted the most improvement following the discussion session).

Generally, students had prior knowledge in most areas covered by the questions. The questions whose responses

indicated substantive prior knowledge (shades of yellow to green in the pretest column) involved listing regarding examples of organizational documents, offices that deal with matters of ethics and suggestive true/false questions. Considering that most students had relevant internship experiences, it was not surprising that students demonstrated higher level of knowledge in these areas.

Student's prior knowledge was particularly low for questions 5, 6, 8, 9b, 9c, 11, 12, and 13 (indicated by increasing shades of red). Most of these questions required the students to either define and describe the meaning of a code of ethics, or match the given ethical malpractice scenario to the code that was violated in a given scenario. The most improvements from the pre-to-post responses were evident in questions 4, 8, 11, 12, and 13 (shades of green in the improvement column). We, therefore, infer that the intervention was most impactful for these questions. In addition to the above descriptive analyses of responses, we carried out a paired T-test necessary for normally distributed, homogenous quantitative data, to test if:

$$H_0: \mu_{pre} = \mu_{post} \text{ versus } H_1: \mu_{pre} < \mu_{post}$$

The results showed that the mean performance in the post test was significantly higher than the performance in the pretest at 95% confidence level. Even though paired T-test are preferred with smaller sample sizes, we are not claiming that the results in this study are generalizable, but are using them as proof of concept.

V. CONCLUSION

Practicing engineers are required to make autonomous ethical decisions based on their interactions with clients, colleagues, organization policies and culture. Literature suggests that there is a gap between ethical knowledge and practice in the engineering profession especially for the millennial generation [1,4,5,6]. This study seeks to bridge this gap by investigating the merits of using cognitive apprenticeship, a situated ethics instructional model. We demonstrate how situated learning can be used to address the gap between learning and application; how principles of everyday cognition can be used to prepare students to deal with everyday ethical decisions. The study is deliberately aimed at graduating seniors. Positioning situated ethics instruction when students are about to graduate and join the workforce can help students see the relevance of the instruction and therefore, readily make the connection between learning and application. The quantitative results as well as the qualitative data demonstrate that there is a definite value in situated ethics instruction. The quantitative results showed a marked increase in the post-test responses of the students indicating an increased ability to explain the rationale behind the organizational codes and consequences of non-compliance. A natural extension to this study will be to follow-up with this cohort of graduates in their current places of employment and seek their feedback about the value of the situated nature of ethics instruction. In other words, to find out if they were able to apply the content in the ethical decisions they have to make in their places of work.

TABLE II. HEAT CHART INDICATING STUDENTS WHO SCORED <2 IN THE PRE-POST TEST

Question	Related Code	No. of Students with Scores < 2		
		Pre-test	Post-test	Improvement
Q1	Company resource documents related to organization's codes of ethics?	3	1	2
Q2	Company resource offices related to organization's codes of ethics?	0	0	0
Q3	Meaning of confidential company information	2	0	2
Q4	List three documents/records that might be considered confidential	4	0	4
Q5	Understanding of the meaning of proprietary information	7	4	3
Q6	Privacy law governance for multinational companies	8	6	2
Q7a	Misconduct in storage of company records	4	3	1
Q7b	Misconduct in data privacy	3	1	2
Q8	Definition of official records	11	6	5
Q9a	Description of patent	2	1	1
Q9b	Description of copyright	9	7	2
Q9c	Description of intellectual property	12	9	3
Q9d	Description of trademark	1	1	0
Q10	Codes of ethics with regards to electronic communication	0	0	0
Q11	Records management and information security scenario	10	2	8
Q12	Conflict of interest scenario – design of products	11	4	7
Q13	Conflict of interest scenario – supplier/vendor relations	9	1	8
Q14	Reporting procedures with respect to whistle blowing	0	0	0
Q15	Reporting procedures with respect to respect for fellow colleague	1	1	0

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How engineering students define ‘Social Responsibility’

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Abstract— This paper presents results from engineering student responses to the open ended question “Write a few sentences explaining how you define ‘Social Responsibility’.” Through emergent coding methods it was found that students were most likely to use a disassociated, third person voice in their definitions, as opposed to a first person voice where they included themselves in the group that help the responsibility. The responsibility that students talked about was most commonly held toward a general community or society, and occasionally toward the environment or the world as a whole. In describing how the responsibility manifested itself, students talked most often about giving back or helping others, but also about a responsibility to conduct acts of service or charity. Finally, students infrequently directly cited a source of the responsibility, though some described ethical or moral foundations while others talked about an obligation due to possessing certain skills or privileges. Few differences were found in these definitions based on gender, academic rank, or major. Understanding how engineering student’s view their social responsibility as both citizen and engineer is crucial towards shaping educational approaches to develop holistic engineers, able to work across disciplinary and cultural divides toward solutions of complex social issues.

Keywords—*Social Responsibility; Ethics; Morality; Engineering Identity; Qualitative*

I. INTRODUCTION

Engineering students hold a diversity of views when asked to define social responsibility:

“I think social responsibility has a lot to do with how you were raised...For me, I feel a great debt to society because I have been blessed with a lot and have not had to face many social challenges, and that makes me want to give back so others can be as privileged.”

“Everyone in a community has an obligation to support others in the community, for the good of the community as a whole. This includes making sure everyone’s basic needs are provided for, whether through work or through structured ‘safety nets’. To accomplish this it is necessary to pay particular attention to the needs of those whose voices are typically unheard or underrepresented.”

“It is my decision if I want to help society or not. No one has the right to force me into it. I may have the ability to greatly benefit society, but it is my life and I will live it my way.”

The work of engineers sits at the interface between scientific knowledge and society. The machines, structures, electronics and software that engineers develop are rooted in the base principles of physics, mathematics, biology and chemistry, but are fundamentally developed to benefit society, thereby bridging that gap. Central to the engineering code of ethics is the mandate to “hold paramount the safety, health, and welfare of the public” [1]. In their vision of the Engineer of 2020, the National Academic talks directly about this relationship, saying “one thing is clear: Engineering will not operate in a vacuum separate from society in 2020, any more than it does now.” [2]. The Engineering Accreditation Commission of ABET highlights the importance of educating engineers to interface with society in criteria 3 (f) “an understanding of professional and ethical responsibility” and 3 (h) “the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.” [3]. The American Society of Civil Engineers’ (ASCE) Body of Knowledge reiterates a focus on professional and ethical responsibility, describing the inherent place of privilege and responsibility that civil engineers hold in society due to the profession’s “exclusivity in the design of the public’s infrastructure” [4, p. 151]. As a manifestation of this responsibility, ASCE states that the engineer should “put the public interest above all else” [4, p. 151] and thereby earn society’s trust. Other engineering disciplinary guidelines have similar language, acknowledging the centrality of the relationship between engineering and society.

Researchers have used the term social responsibility to represent a diversity of characteristics or views in education, engineering, and most other professional spheres. A national study of institutional support for “personal and social responsibility” used elements of empathy, ethical and moral reasoning, and a desire to contribute to the greater community to describe social responsibility [5]. Other studies used democratic ideals or civic participation as defining elements of social responsibility [6, 7]. A lack of social responsibility has

been explored through unethical behavior such as cheating [8]. The theoretical underpinnings of this study, rooted in the Professional Social Responsibility Development Model (PSRDM) [9] considers social responsibility as “feelings of obligation to help others as both a person and a professional, with a special focus on helping disadvantaged or marginalized populations” [p. 2].

In a provoking longitudinal study on engineering student views of public welfare beliefs, Cech found that student views decreased over their four years of education, supporting the development of a “culture of disengagement” among engineering students and then professionals [10]. This culture of disengagement, which can be considered the antithesis of good social responsibility, is characterized by a) beliefs that engineering work can be disconnected from social or political ramifications, which are seen as biasing the results (termed depoliticization); b) a cognitive separation between technical and social skills or considerations with preferential consideration given always to technical; and c) adherence to meritocratic ideologies whereby current social arrangements are seen as inherently just and fair with a lack of recognition of sources of power and privilege that may support social injustices.

Sakellariou examined the historical roots of the term ‘social responsibility’ in engineering, contrasting it with the term ‘social justice’ which is often times resisted by the engineering profession [11]. He found that the term ‘social responsibility’ was adopted by the engineering profession early in the twentieth century as a way to characterize the engineer as “creator of social good” [11, p. 254] as opposed to just employees loyal to a corporation. In this way, ‘social responsibility’ speaks to the engineer’s influence and obligation to social good, but, contrary to the term ‘social justice’, traditionally ignores issues of depoliticization and meritocracy.

These views, however, are representative of professional organizations and academics but may not be communicated to or adopted by engineering students during their academic formation. For this reason, it is crucial to learn how students see their social relationship, where those views come from, and how educational interventions could be used to positively affect them. Toward that end, this study begins the conversation by examining how engineering students view social responsibility through their definitions of the term. Student definitions were explored through the following four research questions:

RQ1. In engineering students’ definitions of social responsibility, who holds the responsibility (*voice*)?

RQ2. In engineering students’ definitions of social responsibility, who or what is the subject or recipient of the social responsibility (*subject*)?

RQ3. In engineering students’ definitions of social responsibility, what, if any, is the *source* of the responsibility?

RQ4. In engineering students’ definitions of social responsibility, how is the social responsibility enacted between the one who holds the responsibility and the subject of the responsibility (*action*)?

II. DATA COLLECTION

Between March and June in 2014, engineering students at 17 universities were solicited to complete the Engineering Professional Responsibility Assessment (EPRA) survey [12] via the online survey tool, Qualtrics®. EPRA was developed to operationalize the Professional Social Responsibility Development Model [9] and has been shown to have strong evidence of reliability and validity [12]. The tool is comprised mainly of fifty 7-point Likert-items to assess social responsibility attitudes, but also includes several open-response questions addressing the development of social responsibility. One such question, the focus of this paper, asked students to “Write a few sentences explaining how you define ‘Social Responsibility.’” This question came immediately after the Likert items, but before questions regarding influential classes on students’ views, their previous volunteer experiences, other influences to their views of community service, and demographic information.

At 15 institutions, students representing all undergraduate academic ranks and all engineering majors received the email asking for their participation, which was incentivized with drawings for gift cards at each institution; at two additional institutions only civil and environmental engineering majors were invited to participate. Graduate students were additionally included from 4 institutions if they had previously participated in a social responsibility study in 2013 [13]. The 17 universities used in the study represented a wide diversity of institutional characteristics including public and private, bachelors, masters, and doctoral granting institutions, religious, secular, and military affiliations, and a range in sizes from 150 up to over 7000 engineering students. In total, 2072 students completed the SR definition question. A summary of the respondents by demographic is given in Table 1. The response rates at individual institutions varied from 6% to 33%. Females were over-represented at 37% of the respondents, compared to about 20% of engineering undergraduate students nationally [14]. Response rates were lowest among first-year students.

III. DATA ANALYSIS

Emergent coding methods were used to analyze the write-in responses [15]. Codes focused both on the content of the response as well as the sentence formation, specifically the voice in which the definition was written. A subset of the data (220 responses) was used to determine inter-rater reliability (IRR) using Cohen’s kappa [16-18] between two reviewers. Per standard practice, codes with kappa values greater than 0.6 were considered to have ‘substantial’ agreement and codes with kappa greater than 0.8 had ‘outstanding’ agreement [19]. Codes with kappa values less than 0.6 were set aside for further refinement but some examples of other interesting elements in student responses will be discussed qualitatively in this paper to highlight the diversity of views. Potential differences in the responses between demographic groups were explored using chi-square tests, with $p < 0.05$ used to infer significant differences.

TABLE I. DEMOGRAPHIC BREAKDOWN OF SAMPLE POPULATION

Demographics	Number of respondents who defined social responsibility
Total	2072
Gender: Female	755
Male	1284
Academic Year: First-Year	243
Sophomore	490
Junior	498
Senior	518
Graduate	185
Majors: Mechanical, Aerospace, Materials	847
Civil, Environmental, Architectural, Construction	575
Computer, Software, Electrical	402
Chemical, Biological, ChemBio, Biomedical, BioME	219
Other – General, Industrial, Engr. Physics	113
Institutions: Religiously-affiliated	370
Secular	1702

Note: Students had an option to respond "Prefer not to say" to each demographic question and could also select multiple majors, therefore the sum of demographic breakdowns may not equal the total response number

IV. RESULTS & DISCUSSION

The responses varied substantially in length, ranging from 1 to 313 words with a median of 26 words and an average of 32 words. Among the responses of 3 or fewer words ($n=26$), some indicated an unwillingness to provide a definition (no, meh, no comment), others indicated that they didn't care, and some indicated that they didn't know. It is likely that the majority of the non-responses ($n=148$) also encompassed this range of attitudes. A few of these very short responses were very concise (helping others) or basically restated the term (being socially responsible). The longer responses provided opportunity for meaningful analysis; the correlation coefficient between the total number of codes assigned to a response and the response length was 0.68.

In the analysis of student open ended responses, it became clear that there were differences in both the construction and the content of the definitions. Regarding the construction of the definitions, one key theme found was which *voice* was used in the defining statement. Results from this group of codes addressed the first research question relating to who, in the definition, explicitly holds the responsibility that is being defined. Codes relating to the content of the definitions were used to answer the other research questions, namely, who were the recipients of the responsibility (*subject*), what, if any, was the stated *source* of the responsibility, and how was the relationship between the one holding the responsibility and the recipient characterized (*action*). Figure 1 presents a visual representation of the relationships between these four elements and sub-codes that were used for each. Each of these elements

will be discussed individually in the following sections and a final section will discuss interesting outliers in the student responses that shed insight into minority, but provocative perspectives of social responsibility. In the following sections, when discussing various codes, both the frequency of occurrence across the entire response population and Cohen kappa values for IRR are presented initially in parenthesis (frequency; kappa).

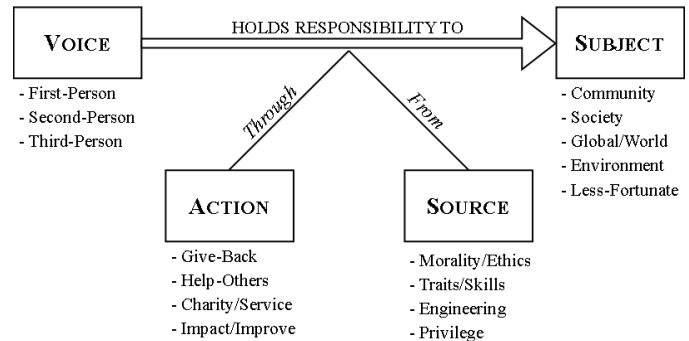


Fig. 1. Emergent topics and codes relational diagram

A. RQ1: Voice

This research question addressed the voice that students used in their definition of social responsibility (SR). It was interesting to see who the definition placed the responsibility on through the use of a first-person, second-person, or third-person voice. The focus on voice highlights whether the students directly included themselves into the group that holds the responsibility (first-person) or if they place the responsibility generally through second- or third- person. First-person was when the students talked about their personal responsibility and included themselves as being obligated to that responsibility. This responsibility was also seen in a collective voice where they talked about SR with respect to the people around them (our, us, we). An example is:

“Social responsibility is the obligation to not only treat others as I would like to be treated, but also to take the initiative to positively affect society. We as engineers have the responsibility to hold paramount the safety of the public and to provide help to society's problems.”

Second-person voice was evident when the definition addressed the reader (you, your) as having the responsibility. An example is: “Social responsibility is pulling your own weight in society. Making sure you are not a damaging part of society, and leave it the way you found it, or a little bit better.” Third-person voice was when the definition referred to a person, place, thing, or idea (he, she, it, their, each) as having the obligation to be responsible as well as definitions that had no clear subject in the construction. An example response that incorporated third-person voice was:

“Social responsibility is one's obligation to be both aware of the many different people and groups that coexist with this person and also willing to help address issues that face these other groups. One cannot just enjoy the benefits of living in

some sort of society. He or she should also feel obligated to ensure that others can enjoy the same benefits.”

The most common voice that the students used in their definition of social responsibility was third-person (61%; 0.778). Second- and first-person were less common (30%; 0.901 and 21%; 0.712, respectively). Some responses ($n=361$) contained more than one voice used in the definition. First-person voice was more common among students attending religiously-affiliated institutions (32%) than those attending secular institutions (20%). The concern with the dominance of a third person voice in definitions of social responsibility is that it could make it easier to avoid responsibilities that are held broadly, disassociating the individual from the responsibility by using ‘one’ or ‘people’ as opposed to ‘my’ or ‘our’. Alternatively, this could merely be the result of an engineering mindset that uses third person to imply objectivity, and as such is encouraged in technical writing training that many engineers receive [20]. There were not significant differences in the use of voice between genders, academic rank, or majors.

B. RQ2: Subject

In addition to the *voice* that was used in the construction of the responses, the content was also interesting, specifically the *subject* or recipient of the social responsibility. The subjects that were mentioned most frequently were a community or society, the world or some reference to the global community, the environment, and people who were less-fortunate. The following response illustrates a student’s definition involving several of these common subjects:

“Social responsibility is the duties that everyone has to make communities and societies function. Everyone has responsibilities to do what they can to improve other’s lives, and those with better social circumstances have proportionally more duties to help the less fortunate. All skill sets can be useful for social improvement.”

For this student, responsibility is held with respect to the community and society in the first sentence and then later “to help the less fortunate.” Some students mentioned that responsibility was more of an obligation globally or to the world. An example of global/world subject was: “Social responsibility in regards to engineers is the effort required by them to make the world better. Whether large sums of money are involved or not, we have a responsibility to use our knowledge to change the world.”

From the students who included a clear subject in their definition, the most common were community (38%; 0.990) and society (38%; 0.863). It was not surprising to see “community” and “society” as the most common subjects, given that ‘social’ was in the word students were asked to define. Female students more frequently described community (44%) than male students (35%). Obligations toward the global/world (10%; 0.864) or the environment (5%; 0.793) were mentioned much less frequently. Most closely related to the ideals of social justice and the definition of social responsibility used in framework of this study, “the less-fortunate” were present as the recipient of social responsibility in quite a few student definitions (16%; 0.97). An example of such a response is: “...I believe that those in any society who

are fortunate enough to be able to help others who are less fortunate should do so to their fullest capability.” Mechanical/aerospace/materials engineering majors included the less fortunate in their definitions at the highest percentage among the disciplinary clusters (19%). Students attending religiously-affiliated institutions included the less-fortunate in their definitions more frequently than those attending secular institutions (23% vs. 15%).

C. RQ3: Source

The third research question examined what students identified as the *source* of the social responsibility they defined. In their theories about the development of altruistic behavior, Schwartz and Howard [21] posited that sources of feelings of obligation to help others derived from two sources: a) internalized moral values and personal norms and b) perceived social norms of behavior. Similarly, Bar-Tel et al. theorized that individual’s initiate (or don’t) helping behavior due to perceived societal demands rooted in social understandings of acceptable behavioral norms around helping [22]. They suggested that people help because they are expected to do so and want to be viewed a good person in other’s eyes.

The majority of students didn’t speak to the source of expectations of social responsibility in their responses, though students that did oftentimes point to either internal or external sources of obligation. Students also talked about expectations of social responsibility being either individualized (up to each person) or collectively held (a result of being a member of a society). Though it proved difficult to obtain strong IRR related to external or internal sources of responsibility (and therefore discussions of frequencies of occurrence are not reliable), an example for each are:

Internal: “Social responsibility is the belief that ethically or morally you have an obligation to help society in some way. It’s a bit of a subjective concept, no one is “making” you responsible for anything. But some feel more of an obligation than others.”

External: “The responsibility of each individual to act in a manner consistent with social norms. The contribution of people to have a positive impact on their community. The inclination of people to give to their community in excess of what is expected.”

Other sources that students identified (though related to external and internal norms) were personal traits or skills (14%; 0.893), morality/ethics (6%; 0.961), personal privilege ($\kappa=0.333$), and engineering (6%; 0.857). The most common definition, traits, referred to the obligation for people who possessed unique skills, knowledge or abilities (such as engineering) to use those to help others. Here is an example: “Social responsibility involves using one’s skills to help others and behave in an ethical manner. Lack of social responsibility implies using one’s skills to harm or exploit others and have a negative impact on society.” Some students highlighted that a sense of responsibility was driven by issues of morality or ethics.

In the framing of this open-ended question, students were intentionally asked to define social responsibility in a broad manner, not specifically tying it to engineering. Six percent of the students, however, did tie their definitions to engineering. The following example portrays this: “As an engineer, our entire profession is based on improving the world around us. Therefore, it is also within our job to try to satisfy all members in an area in which we work.” As in this example, most times that students mentioned engineering it was either tied to a responsibility that engineers hold to society due to the impact that engineering work has, or because of the skills they possess as engineers. A higher percentage of seniors and juniors (9.1% and 8.5%) included engineering in their definitions than sophomores and first-year students (4.8% and 4.7%), likely reflecting the more central role of engineering in the identity of the upper-class students.

D. RQ4: Action

The final research question addressed the nature of the social responsibility held through the action or relationship that was highlighted between the holder and the recipient of the responsibility. The most common actions used in student definitions help-others (47%; 0.68) and impact/improve (47%; 0.623). A desire or obligation to help others was frequently used by students when discussing the way in which the social responsibility should manifest itself. Similarly, though not as often, students also talked about giving back (6%; 0.928) to the people or society. The use of impact or improve typically related to a desire or an ability to have a positive impact or to improve society. Students also talked about living positively, benefitting others, being a good example, or to improve individual's standard of living. An example definition that included these themes is:

“Social Responsibility is an understanding that any individual's life and choices have an impact on those of the people in their community; because of this understanding, every person should take the broader consequences (positive and negative) of their choices into consideration with the goal of improving rather than degrading the lives of those they affect.”

Students also mentioned being involved in charity or acts of service as important aspects of social responsibility (13%; 0.695). Oftentimes these definitions would point to myriad forms of charity and service including giving of time, money, talents, volunteerism, etc.

E. Outliers of Interest

One theme that was seen in the data but the two reviewers could not produce consistent inter-rater reliability was related to discussions of personal privilege as the source of one's obligation ($\kappa = 0.333$). An example of a student response related to recognition of personal privilege as the source of responsibility is:

“The opportunities I have been given in life have been numerous and vast, and I believe some of those opportunities now and in the future are chances to serve for the betterment of others. I feel 'social responsibility' is something we as members

of the human race have an obligation towards; that we should serve others for the betterment of all.”

In this example, the student points to the opportunities that they have been given and how those opportunities have given them an ability and responsibility to “serve others.” Similar to this example, oftentimes discussions of one's skills and abilities were tied with the opportunities they had been given along the way to develop those. Most of these definitions also emphasized the idea that if someone is more privileged and the opportunity comes up where they could help, then they have an obligation to use those advantages to help (“If you are in a position to help those around you then you should help them”).

The vast majority of students wrote definitions of social responsibility that were positive and attempted to pin down the bounds, nature, and source of that obligation. Some students (~2%, 0.535), however, responded to this prompt with definitions that were resistant to any forms of responsibility or hostile toward perceived social norms of responsibility. One such response was:

“Social responsibility: One that does not depend on the government to pay their way through life. One that takes life into their own hands and can self-sustain. It is not their responsibility to give handouts to those that are “too lazy” to find a job or think they are “entitled” to everything. If I see you using an EBT card and texting on your smartphone, something is wrong with this picture, because I myself can't afford a smartphone, so I have the cheaper flip phone and am not on food stamps, but am in debt because I wanted to go through higher education. Now, my taxes go to help you live, yet I'm in debt. Something is wrong with this picture...”

In this definition of social responsibility, we see that the student is criticizing social norms around government assistance. The definition is not so much a description of what social responsibility is, but seems to be a reaction to what social responsibility isn't (in his/her view). This example, and others with similar themes, seemed to support the culture of disengagement that Cech describes [10], particularly alignment with meritocratic ideologies. In this example, the reflection of conservative American social/political views around individuals who draw assistance from government programs as being “too lazy to find a job” or “think they are entitled to everything” supports this. Several other student definitions following similar messages as this one, that social responsibility was about individuals taking care of themselves and not relying on others (or the government) for help.

V. CONCLUSION

Student definitions of social responsibility presented in this paper have provided insight into how engineering students see their role society. Students were most likely to use a third person or disassociated voice in their definitions, removing themselves from directly holding said responsibility. Students often pointed to the community or society as being the recipient of that responsibility, but a minority also discussed the world as a whole, the environment, or peoples who are less fortunate. Students who directly discussed the source of the obligation pointed oftentimes to external or internal drivers, including morality or ethics, having given traits or skills, being

privileged in society, or through their roles as engineers. Finally, students most often cited helping others as the manifestation of that responsibility, but also engaging in acts of charity and service, having a positive impact, improving society, or giving back.

Knowing the ways in which students perceive their social responsibility is key in two ways: 1) it can be used as a reflection of professional messages that the current engineering education culture may be instilling in engineering students, and 2) it can provide a starting point for educators to build upon existing beliefs to strengthen engineering students' sense of personal and professional social responsibility. Seeing that students most often used disassociated or third person voices in their definitions may reflect the decontextualized problems that engineering students solve and the removal of social elements from engineering academic work. Perhaps developing a culture in engineering departments focused on how engineering interfaces with society and, more importantly, how each student as an engineer holds a responsibility in that relationship, would push students to see social responsibility as a personal, rather than abstract concept. Active- and service-learning pedagogies may be employed to help facilitate this shift. Institutional culture may also be a key component of student perceptions. Students at religiously affiliated institutions were more likely to use first-person and to refer to populations who are less fortunate in their definitions. Institutional messages around social justice or personalized religious obligations to help others may play a key factor in these differences.

Further work is needed in examining these results, specifically with respect to the relationship between student responses and other elements of the EPRA survey. Correlations between student definitions, their answers to the 50 Likert-items related to social responsibility, engagement in engineering service, or previous volunteer activities may provide useful information as to the personal experiences that helped form these views. Additionally, several themes emerged from the data (such as internal vs. external sources) that are interesting to explore but lacked good inter-rater reliability and so frequencies of occurrence couldn't be discussed. The iterative process of coding, focusing definitions and recoding takes time, but will be continued by the researchers for some of these other codes.

Educational practices in engineering need to guide students to recognize their roles as engineers in society, particularly the potential for both positive and negative impacts. This paper has presented how students see those views generally, through the task of defining the term "social responsibility." Understanding these views has set a foundation from which educators can examine the messages and practice that they employ, how they might support or oppose these perspectives, and explore ways in which they can help students further realize and internalize their social responsibility as engineers.

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Stages and Processes of Pedagogical Change - An application of TTM

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Abstract— Faculty adoption of evidence-based instructional practices and their overall approach to pedagogical change has primarily been examined through stage-based models of change. While not readily applied to education, the Transtheoretical Model of Health Behavior Change (TTM) provides a cyclic, stage-based model of change that provides processes to advance through the stages while recognizing faculty context and self-efficacy that will support their pursuit of pedagogical change. This paper compares the currently used models of change to TTM and explores the application of TTM to Engineering Education.

Keywords— *change models, evidence-based instructional practices*

I. INTRODUCTION

The amount of research dedicated to improving engineering education over the past decade has yielded a variety of innovation in new materials, strategies, and pedagogies. These, however, have not resulted in systematic change. Current reports on the adoption of evidence-based (research-based) instructional practices (EBIP) suggest limited success, indicating little connection between research and the development of effective curricular innovation. A large percentage of studies addressing educational change have applied strategies and change theories that yield moderate success.

Two commonly referenced models of adoption include Diffusion of Innovation (DoI) and the Concerns Based Adoption Model (CBAM), which have been noted as one of “the most robust and empirically grounded theoretical models for the implementation of educational innovations”. However, change theories from other fields have the potential to impact the way we study and guide pedagogical change.

The purpose of this paper is to introduce the application of the Transtheoretical Model of Health Behavior Change (TTM) to explore changes in engineering education pedagogy. This paper will address the following questions:

1. How does TTM compare to the DoI and CBAM models?
2. How does TTM inform processes that can mediate pedagogical change?

II. CHANGE THEORIES UTILIZED IN ENGINEERING EDUCATION

A large percentage of studies addressing educational change have applied strategies and change theories that yield moderate success [1-4]. In a review of change theories and models, Kezar [5] noted that change models could be evolutionary, teleological, life-cycle, political, social cognitive, and cultural. Two of the most common typologies in engineering education include the teleological and the life cycle. Teleological, focusing on intentional purpose, coincides with policy changes and imparts emphasis on change agents as well as techniques and strategies to manage change. Practices addressed in those studies have led to the development, testing, and distribution of curricular materials and “top down” policy to encourage the adoption of those practices. These approaches have had limited effectiveness in reforming STEM educational practices given the variety of contexts resulting from culture, institutional missions, and policies [1]. In contrast, life cycle typologies examine change related to phases of change that are situated on a timeline [5]. Two of the most common stage-based models include diffusion of innovation by Rogers’ and Fuller’s Concerns Based Adoption Model.

A. Diffusion of Innovation

In their work, Borrego and Henderson [4] described Diffusion of Innovation as an example of a model to guide change in an individualistic and prescribed approach. [6]. Diffusion of Innovation describes how an individual decides to adopt an innovation, noting the stages they follow (Table I), their adoption timeline, and factors associated with the adoption. However, Diffusion of Innovation is primarily focused on a specific innovation and how it is adopted by a culture until it is either a failed diffusion or reaches a critical mass of adoption.

B. Concerns Based Adoption Model

The Concerns Based Adoption Model (CBAM) has been noted as one of “the most robust and empirically grounded theoretical model[s] for the implementation of educational innovations” [7]. It explores the process of change that an individual undertakes when implementing new curricular materials and instructional practices, and how that change is affected by persons in change-facilitating roles. The model was developed out of the second component of Fuller’s stage model of teacher development [8, 9] that assessed teachers’ concerns in the context of innovation adoption [10]. The CBAM theory

and methods identify stages of concern, levels of use, and innovation configurations. Based on this model, the stages of concern regarding the adoption of an innovation proceed from awareness to informational, personal, management, consequence, collaboration, and refocusing.

TABLE I. COMPARISON OF STAGE-BASED MODELS OF CHANGE

	Diffusion of Innovation	Concerns-Based Adoption Model	Transtheoretical Model of Health Behavior Change
Stage comparison ↓	Awareness	Awareness	Precontemplation
	Interest	Informational	Contemplation
		Personal	Preparation
	Evaluation	Management	Action
	Trial	Consequence	
	Adoption	Collaboration	Maintenance
		Refocusing	Termination

III. TRANSTHEORETICAL MODEL OF HEALTH BEHAVIOR CHANGE

One of the primary limitations of these models is the strong focus on a specific innovation and the inability for a person to revert to a previous stage. With respect to teacher practice, it has been noted that when a pedagogical practice fails to work as planned, faculty will utilize strategic knowledge and are more likely to rely on their past experiences and intuition rather than empirical research [11]. In contrast to Diffusion of Innovation and Concerns Based Adoption Model, the Transtheoretical Model of Health Behavior Change, while classified as stage theory, is cyclical. It allows relapses to occur under certain situations and generically focuses on changing a specific behavior [12]. Using this perspective, teaching is classified as a behavior with changing of teaching practices that are directly related to a specific stage of change and to the associated process required for successful change. Within these change processes, strategies identified by Seymour [13] as being beneficial to engineering education [14] can be appropriately applied to advance the individual to the next stage of change. In order for change strategies to be successful, they must focus on the individual beliefs of the faculty and be capable of allowing designed interventions compatible with the context in which they are applied [1].

TTM was originally developed to integrate more than 300 theories of psychotherapy and behavior change with application to a broad range of health and mental behavior, including alcohol and substance abuse, anxiety and panic disorders, smoking cessation, and the adoption of drug regimens and exercise programs [15-17]. TTM uses a time dimension to describe both the stages of change and the process of change required to advance through the stages. In addition to stages and processes of change, Prochaska et al. [16, 17] noted that individuals pursuing behavioral change assess the pros and cons associated with the change. These pros and cons are assessments of the benefits and risks associated with improving behavior and the pros and cons of the process of change. While it is necessary to assess which stage the individual resides and the processes appropriate to advance to

the next stage of behavioral change, Prochaska et al. [16, 17] recognized that the individual requires the confidence (self-efficacy), based on the motivational constructs associated with Bandura's [18] self-efficacy theory, necessary to resist temptation and revert to a previous stage.

A. Stages of Pedagogical Change

The time component of TTM represents the core construct of several stages of change associated with a point in time that can be graphically represented as a spiral process that proceeds sequentially through stages with the possibility of relapse to a previous stage (Figure 1) [16, 17]. The stages include precontemplation, contemplation, preparation, action, maintenance, and termination.

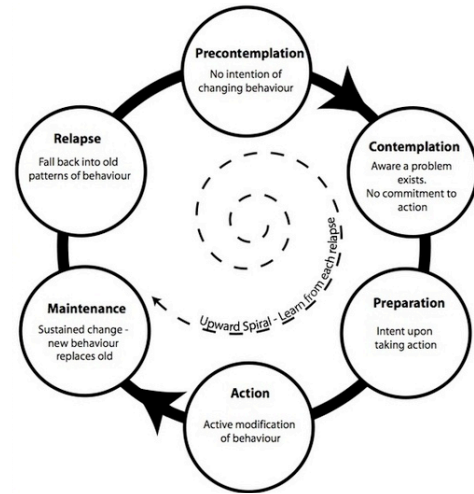


Fig. 1. TTM stages of behavioral change [16, 17]

The first stage, precontemplation, is associated with individuals who do not intend to take any action in the foreseeable future. Often these individuals are uninformed or unaware of the consequences of their behavior. They may have tried and failed to change in the past, becoming demoralized, resistant, and unmotivated with respect to change. In the educational context, these individuals can be recognized by their resistance to change and a lack of involvement in professional development activities that inform them about alternatives to their instructional techniques. These faculty may also be unaware of the need or opportunity to change their instructional approach.

The second stage, contemplation, is characteristic of individuals who are aware of the pros and acutely aware of the cons related to their behavior. Individuals can remain in this stage due to an overwhelming weight of cons and ambivalence to pros associated with changing a given behavior. Along with individuals in the precontemplation stage, these individuals are not ready for traditional action-oriented programs. In education, these programs consist of faculty development programs offered through local centers for teaching and learning, attendance at conferences, and reading education

publications. In their study of several engineering departments, Cutler et al. [19] noted that 35% of faculty had at one time implemented an evidence-based (research-based) instructional practice but no longer maintain that practice, 11% had never tried but had knowledge of the practices, and 3.2% had never heard of the practices. This indicates that almost 50% of the faculty surveyed would reside in the precontemplation or the contemplation stages rendering traditional forms of dissemination and faculty development ineffective.

The third stage, preparation, includes individuals who are intending to take action towards a behavior in the future. Typically, these individuals have a plan of action. Faculty in this stage would be members of professional education societies who receive publications and attend conferences with the interest of learning about new educational practices, as well as those independently investigating new instructional approaches. The fourth stage, action, is representative of individuals who are making specific modifications to their practices that equate to changing their behavior. Within education, these individuals may exhibit actions related to planning and developing curricula to integrate an EBIP into a course.

The fifth stage, maintenance, is characteristic of maintaining the action stage and preventing relapses to the pre-contemplation, contemplation, and preparation phases. The individual in this stage not only applies stimulus control processes to prevent triggers that encourage relapse but also develops helping relationships. Within health behavior, these helping relationships are commonly associated with support groups in health behavior, which can be interpreted as communities of practices (CoP) in education.

B. Processes of Pedagogical Change

In TTM, Prochaska et al. [17] identified the process of change as covert and overt activities that people use to progress through the stages. They have characterized 10 common processes as guides for intervention programs (Table II). In their work Prochaska, DiClemente, and Norcross [20] identified systematic relationships between the stage in which individuals reside and the processes they were applying to advance to the next stage (Table III). In order to advance through the earlier stages, individuals need to apply cognitive, affective, and evaluative processes [16]. Specifically, when

progressing from the precontemplation stage to the contemplation stage, processes associated with action are insufficient, and these individuals require processes such as consciousness raising and dramatic relief that require individuals to explore facts about incorporating EBIPs and to explore their negative emotions associated with not using EBIPs [17].

TABLE II. DESCRIPTIONS OF PROCESSES OF CHANGE IN TTM [16, 17]

Construct	Description
<i>Consciousness raising</i>	Finding and learning new facts, ideas, and tips that support the healthy behavior change
<i>Dramatic relief</i>	Experiencing the negative emotions (fear, anxiety, worry) that go along with unhealthy behavioral risks
<i>Self re-evaluation</i>	Realizing that the behavior change is an important part of one's identity as a person
<i>Environmental re-evaluation</i>	Realizing the negative impact of the unhealthy behavior or the positive impact of the healthy behavior on one's proximal social and/or physical environment
<i>Self-liberation</i>	Making a firm commitment to change
<i>Helping relationships</i>	Seeking and using social support for the healthy behavior change
<i>Counterconditioning</i>	Substitution of healthier alternative behaviors and cognitions for the unhealthy behavior
<i>Reinforcement management</i>	Increasing the rewards for the positive behavior change and decreasing the rewards of the unhealthy behavior
<i>Stimulus control</i>	Removing reminders or cues to engage in the unhealthy behavior and adding cues or reminders to engage in the healthy behavior
<i>Social liberation</i>	Realizing that the social norms are changing in the direction of supporting the healthy behavior change

TABLE III. PROCESSES ASSOCIATED WITH STAGE CHANGE IN TTM [16, 17]

	Stages of Change				
	Precontemplation	Contemplation	Preparation	Action	Maintenance
Process of Change	Consciousness raising				
	Dramatic relief				
	Environmental reevaluation				
		Self-reevaluation			
					Self-liberation
					Counter conditioning
					Helping relationships
					Reinforcement management
					Stimulus control

In order to progress through later stages individuals will require processes that rely on commitments, conditioning, and environmental controls [16]. These interactions between stages and processes imply that, in the educational context, appropriate interventions are needed for faculty to progress through the stages that lead to the maintenance or termination of past educational behaviors.

IV. CONCLUSIONS AND DISCUSSION

In order for change strategies to be successful, they must focus on the individual beliefs of faculty and be compatible with the context in which they are applied. An understanding of contextual influences (cultural norms, institutional missions, policies, leadership, values, economic, and political factors) that faculty face when they change their approach to teaching are critical to the support of their pedagogical change. By recognizing the stage of change, professional development programs and change agents can tailor interventions to meet the needs of the faculty at a particular stage.

Additional work will address the application of TTM to pedagogical change by utilizing empirical evidence to validate the stages and change processes. This validation will focus on characterizing faculty stages of change with respect to the adoption of evidence-based instructional practices and application of change processes that support their adoption.

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Engineering Ph.D. Students' Career Preferences:

Levels, Changes, and the Role of Advisors

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Abstract—The Survey of Earned Doctorates indicates that almost three fourths of all doctoral degree recipients in engineering fields found employment in industry or business, and less than one eighth of them found employment in academia. Although these observations provide insight into the employment patterns, job opportunities, and realized career transitions of recent doctorate recipients, very few systematic studies have been conducted concerning potential mismatches between the career preferences and actual employment pathways among doctoral students in engineering. This issue is of particular importance given growing concern that these career patterns reflect fundamental imbalances between the supply of doctoral students seeking academic positions and the availability of such positions. Differences in job expectations and availability can also generate considerable dissatisfaction among students and may negatively impact relationships between students and advisors. In this preliminary study, the authors are investigating career preferences among doctoral students in engineering. The more specific focus of this paper centers on level and changes in preferred career choices during Ph.D. studies, as well as the role faculty advisors play in engineering doctoral students' career decision-making processes. For the purpose of this study, the research participants will be Ph.D. students in a specific level of their graduate study. The method for collecting and analyzing data will be quantitative survey method. The findings from this study have implications for higher education policymakers, faculty advisors, and other stakeholders (e.g., representatives of industry) related to better understanding engineering doctoral students' preferred career choices and changes in those choices during the course of their Ph.D. studies. More specifically, it is expected that the results will help policymakers, administrative staff, and faculty advisors encourage doctoral students to explore multiple career paths so these students can explore and be trained for the full range of likely job opportunities they will face upon graduation. In this work-in-progress paper, the authors will be discussing the relevant literature review and the research design of this preliminary study.

Keywords—academic advisor; doctoral students; career preferences; engineering; graduate students

I. INTRODUCTION

The 2012 Survey of Earned Doctorates (SED) indicates that only 13.4% of doctorate recipients in engineering fields found employment in academia, while 72.9% found employment in industry or business, and 2.9% found employment in non-profit organizations and 1.4 % reported other employment opportunities[1]. Although these statistics

provide insight into employment patterns, job opportunities, and realized career transitions of recent doctorate recipients, very few systematic studies have been conducted concerning potential mismatches between the career preferences and actual employment pathways among doctoral students in engineering. Through this preliminary study, the authors will be investigating career preferences among doctoral students in engineering, with a focus on four specific research questions:

- RQ1: What are the preferred career paths by engineering doctoral students or which career paths do engineering doctoral students find attractive?
- RQ2: Do career preferences of engineering doctoral students change over the course of Ph.D. program?
- RQ3: To what extent, external factors are responsible for change in preferred career choices of engineering doctoral students over the course of Ph.D. program?
- RQ4: To what extent faculty advisors encourage or discourage a specific career path of their engineering graduate students?

The remainder of this paper begins by situating our work in the literature. We then discuss our research design and methods. We expect that our efforts will be of particular interest of policymakers, administrative staff, and faculty advisors as they encourage doctoral students to explore multiple career paths so that those students can explore and be trained for the full range of likely job opportunities they will face upon graduation.

II. LITERATURE REVIEW

There is a growing concern in the science and engineering community that Ph.D.-trained scholars face a shortage of available faculty positions, which are considered to be the most desired careers in many fields [2]. For example, data from the National Science Board's 2012 Science and Engineering Indicators shows that the share of full-time faculty among all academic Science & Engineering (S&E) doctorate holders fell from 88% in the early 1970s to 73% in 2008. Especially in engineering fields, data show that the share of full time faculty holders fell significantly, from 91% in the early 1970s to 76% in 2008 (Science and Engineering Indicator, 2012). In a research study based on the data from the US Survey of Doctorate Recipients from 1973 to 1999, Stephan pointed out that by the mid-1990s industry surpassed

all types of academic employment for engineering doctoral recipients. As noted above, recent data from the SED report similar shows that nearly three quarters of graduates earning doctoral degrees in engineering assume employment in industry or business settings. [3]. These observations challenge the traditional expectation that Ph.D.'s are trained to join academia [4].

Yet while government data can provide insights into current employment patterns, job opportunities, and realized career transitions, very few systematic studies have been done on the engineering doctoral career preferences, including the potential for mismatch between the observed career paths and engineering doctoral students' preferences. Some of the studies that discussed other issues related to Ph.D. career paths include: incentives for doing a Ph.D. [5], expectations and realities regarding employment [5, 4], and employability of people with a doctoral degree [7]. A recent study by Sauermann and Roach did focus on career preferences, although the focus of this study was limited to doctoral students from life sciences, physics and chemistry [8]. Given that employment opportunities, funding resources, incentives from specific jobs, and job satisfaction depend upon the particular field, additional studies are needed to determine the career preferences of engineering doctoral students and the mismatch between job availability and preferred career.

Additionally, some of the literature suggests that career preferences may change during the Ph.D. program, but there is very limited empirical evidence available to support this claim [9]. More generally, Arnett found that during emerging adulthood, people adjust their career choices from ideal to more realistic according to the requirements of the careers in their set of acceptable alternatives [10]. And in an interesting study regarding incentives of enrolling in science Ph.D. programs, Mangematin found that Ph.D. students in applied sciences do not conform to academic criteria during their Ph.D., but at the end of the Ph.D. they conform to the recruitment criteria of their expected employer [5]. Additionally, Mendoza found that students entered graduate school with very positive views on pursuing a faculty career, but as they gained experience in the graduate program they tended to value other career options such as industry [11]. A study by Sauermann and Roach found that science doctoral students' interest in academic research declined over the course of their training while other careers became relatively more attractive, but they did not look into the underlying reasons or factors associated with these changes [8].

The role of the advisor is considered to be crucial in graduate students' life. Research has shown that effective support from a faculty member has been associated with "increased job satisfaction, higher salary, faster promotion, and firmer career plans" [12]. Corcoran and Clark investigated the impact of advisors or other faculty on students' later careers or involvement in the academic community [13]. Mentoring, which is one of the key roles of the faculty advisor, is reported to be very valuable and to facilitate securing initial employment and might, in turn, result in intentional and generative career development for doctoral students [14], [15] [16]. Few studies have also looked into the role of advisor in exacerbating labor market imbalances in the

field of science, but no systematic and empirical data are available in the field of engineering [17],[18]. In the next section of this paper, we will discuss the research design of this study that will help researchers to answer research questions for this study. This section will include context and research participants, operationalization of concepts and data collection and analysis plan of this study.

III. METHODS

A. Context and Research participants

In this preliminary phase of the study, we are planning to collect and analyze data from engineering doctoral students. We focus specifically on the engineering doctoral students who have either cleared their qualifying/preliminary exams (i.e., Ph.D. candidates) or in their final year of Ph.D. program (thesis writing phase) in the three largest engineering disciplines (mechanical engineering, chemical engineering, and electrical and computer engineering) at a large research-intensive university in the U.S. Midwest. It is important that research participants should be at this particular stage or level (qualifying/preliminary exams or thesis writing phase) of their Ph.D. program because at this stage they start making career decisions and choices. One of the main reasons for selecting these disciplines is because they are the largest engineering discipline in terms of number of Ph.D. students enrolled. To recruit research participants, we are using *random* or *probabilistic sampling* strategy. We are planning to distribute this questionnaire online among engineering doctoral students of mechanical engineering, chemical engineering and industrial engineering. We are estimating the population size to be 200-250. Depending upon this, using sample size calculator, the sample size for this study will be around 132-152 doctoral engineering students for achieving 95% confidence level. I will be collecting the contact email ids from the department's administrative staff. The questionnaire is created using an online survey software. Qualtrics Surveys and will be distributed using email and other through other social media. A consent form and a cover letter will also be sent along with the questionnaire via email.

B. Operationalization

Based on four research questions, the major concepts in this study are: career paths; preferred career choices of engineering doctoral students; changes in preference over duration of the PhD program, factors influencing for changes in preferred career choices, and faculty advisor's encouragement to a specific career options. For this study, we are defining career paths as faculty job with focus on research; faculty job with focus on teaching; industry job with focus on research; government job with focus on research; or job as an entrepreneur. In this study, preferred career choices are defined as the students' perception of the most interesting career options for them, given no constraints on available job opportunities. For this study, the external factors that may influence in changes in preferred career choices are defined as passion for research, passion for teaching or training, family

responsibility, advisor's engagement, employment benefit/salary, and awareness for other career options.

C. Data Collection and Analysis

In this study, quantitative survey research method questionnaire will be used to collect and analyze the data. This questionnaire instrument consists of 8 multiple choice questions and three single answer questions. Three out of 11 questions are used to collect demographic information. The rest of the 8 questions are intended to measure the key concepts of the study, i.e., preferred career choices of engineering doctoral students, changes in preferred career choices over the time of Ph.D., factors influencing these changes, and extent of faculty advisors' encouragement to a specific career. The questions related to the preferred career choices include list of career options, e.g.: faculty job with focus on research; faculty job with focus on teaching; industry job with focus on research; government job with focus on research; job as an entrepreneur; etc. The response options related to preferred career options are based on 5 point scale ranging from 1 (extremely unattractive) to 3 (neither attractive nor unattractive) to 5 (extremely attractive). The response options related to changes in preferred career choices are based on 5-point scale ranging from 1 (certain not to pursue) to 3 (uncertain whether to pursue) to 5 (certain to pursue). The response options related to extent to which faculty advisors encourage a specific career options are also measured on a 5-point scale ranging from 1 (strongly discouraged) to 3 (neither encouraged nor discouraged) to 5 (strongly encouraged). The question related to the factors influencing career choices includes passion for research; passion for teaching; family responsibility; and salary. We will be using statistical analytical methods to analyze collected survey responses. We will be using 5 point Likert scale which is coded from level 1-5 to measure most preferred career options ranging from faculty job with focus on research; faculty job with focus on teaching; industry job with focus on research; government job with focus on research; or job as an entrepreneur.

IV. CONCLUSION

In this work-in progress paper, we discussed relevant literature review and research design of a preliminary study. In this preliminary quantitative study, we are proposing to investigate preferred career choices of engineering Ph.D. students, changes in those choices, factor influencing those changes and role of faculty advisors' encouragement in making those career decision. The findings and implications from this study will be useful to higher education policy makers, faculty advisors, and other stakeholders (e.g., representatives of industry) to understand engineering doctoral students' preferred career choices and changes in those choices during the course of their Ph.D. studies. More specifically, it is expected that the results will help policy makers, administrative staff, and faculty advisors encourage doctoral students to explore multiple career paths so that those students

can explore and be trained for the full range of likely job opportunities they will face upon graduation.

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Tracking the Spread of Research-Based Instructional Strategies

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Abstract—The adoption of research-based instruction strategies (RBIS) by faculty is generally perceived as being slow. Faculty resist change, reject data that demonstrates the effectiveness of RBIS, and prioritize research over teaching. Even when faculty attempt to use RBIS, they often do so with poor fidelity to the original design of the RBIS. By organizing faculty into communities of practice, we are observing a sudden surge in the adoption of RBIS across STEM departments. Through this work in progress we present preliminary data that we have collected to understand exactly why many faculty are now adopting RBIS. While this effort has led to the adoption of many RBIS, we focus on the adoption of personal response systems (clickers) and Peer Instruction. Preliminary data suggests that faculty adoption is being driven by community and collaborative instruction.

Keywords—change; research-based instructional strategies; communities of practice; clickers

I. INTRODUCTION

Our understanding about how to create change in engineering education primarily focuses on all the ways that change is difficult or slow. We now know that many change efforts rely on develop-disseminate models in which faculty develop new Research-Based Instructional Strategies (RBIS) and then disseminate them through publications and workshops [1-3]. These models have proven ineffective [4]. Faculty resist using RBIS due to clashes with their professional identities and challenges arising from a lack of time or access to training and development [5]. Even when faculty do attempt to implement RBIS, their fidelity of implementation is low [6].

In 2012, the College of Engineering created the Strategic Instructional Initiatives Program (SIIP) to transform and revitalize core engineering courses at the University of Illinois at Urbana-Champaign. During its three years of existence, the program has sparked the rapid spread of RBIS across the college and has created a thriving community of faculty invested in improving undergraduate instruction. For example, context-rich collaborative problem solving [7] (students

working in teams to solve difficult, real-world engineering problems) has been integrated into 14 courses in five departments and has now been practiced by 27 faculty instructors, most of whom had not been using this RBIS before SIIP [8]. Further, SIIP has expanded beyond the confines of the College of Engineering and its model is being replicated across Science Technology Engineering and Mathematics (STEM) departments in other colleges through NSF WIDER funding (DUE-1347722).

These efforts have rallied faculty around the simple message of “Teach like we do research.” Central to both SIIP and WIDER is a central model of change (See Figure 1). Somewhat counterintuitively, the primary goal of these efforts is not to stimulate the adoption of RBIS. Rather, the primary goal of these efforts is to create faculty communities of practice (CoPs) that provide an environment of shared vision and practice through which faculty seek to create collaborative, joint ownership of a target course or set of courses [2, 9]. Within these CoPs, faculty commit to an implement-evaluate development cycle for which the CoP must commit to collecting data about their innovations and using the data to inform iterative development. Finally, we expect that the adoption of RBIS will organically emerge without any particular mandates from the leadership team or administration [2]. Indeed, we have been seeing this organic emergence of RBIS adoption within our CoPs.

This work-in-progress paper provides our first steps toward understanding how and why these CoPs have supported such rapid adoption of RBIS in such a short time. In this paper, we present our preliminary efforts to track and explore the spread of personal response systems (clickers) and Peer Instruction [10, 11]. We begin by providing a brief background on the theory behind CoPs and Peer Instruction. We then describe our efforts to understand the spread of Peer Instruction and provide some lessons learned from preliminary data collection.

II. ORGANIZATIONAL CHANGE THEORY

Learning theories such as transformational learning theory [12, 13] and other situative frameworks such as Communities of Practice (CoPs) [9, 14] provide insights into why emergent, environmentally-focused change strategies can be effective. Decision-making during instruction and curriculum development is driven by faculty’s implicit epistemologies,

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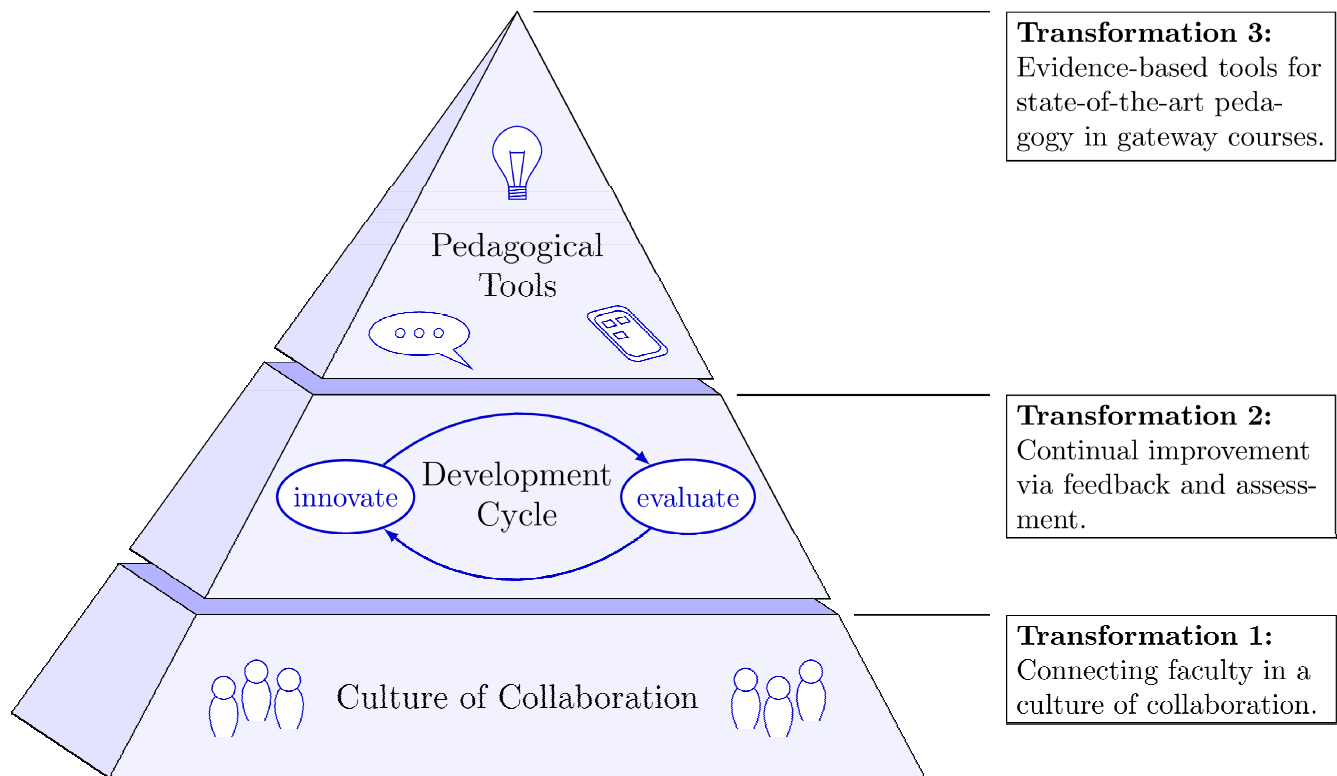


Fig. 1. Three key levels of sustainable education transformation used to guide SIIP and WIDER; Each layer supports the transformations above.

beliefs, and commitments [5, 15-17]. When these implicit value systems do not align with the implicit value systems of RBIS, faculty resist the initial adoption of those RBIS or will fail to persist in their use [17]. Transformational learning theory posits that implicit value systems can be changed only through mutual reflective engagement about communal practices such as teaching practices or curriculum design practices [12, 13]. CoPs provide a place for this mutual reflective engagement, inviting faculty to engage in continuously deeper levels with RBIS, from the periphery to the core [9].

Critically, faculty frequently have a central identity of self as expert in this classroom [5], an identity that can be at odds with student-centric RBIS. The mismatch in values can create a psychological “immune response” that seeks to guard existing identities and value systems and ward off invading identities [18, 19]. CoPs provide a safe environment for challenging this immune system, surrounding resistant faculty with respected colleagues, thus mitigating the perception of identity threat [9, 14]. Within CoPs, faculty engage in long-term situated learning, participating in community-valued practices [9, 14], creating a place for the assimilation of new values that align with RBIS.

III. DESCRIPTION OF PEER INSTRUCTION

A class that uses peer instruction is characterized by short presentations that are followed by conceptual questions. Students ponder and answer these questions, then discuss them with peers, with the goal of achieving consensus [10, 11].

After the peer discussion, the students again answer the question, and the instructor debriefs students’ responses [10, 11]. The conceptual questions play a key role in peer instruction, and should be written such that students get “a chance to explore important concepts, rather than testing cleverness or memory, and to expose common difficulties with the material” [11]. Students can provide answers to these conceptual questions through a show of hands, flashcards, or more recently, through the use of clickers [20].

While instructors have identified some challenges to using peer instruction, including the time needed to create appropriate conceptual questions, less time for lecturing, and some students’ discomfort with this method [21], students benefit greatly from this method. Peer instruction has been found to increase students’ conceptual learning and problem solving, and to decrease student attrition [20].

Interestingly, peer instruction benefits students regardless of whether students respond through clickers [20]. However, using clickers benefits instructors in a variety of ways: they “allow instructors to get precise real-time feedback,” they allow the instructor to archive student responses for future reference, and they move instructors to “shift their focus toward conceptual instruction” [20].

In their study on the fidelity of implementation of clickers, Borrego et al. identified four critical elements required for high fidelity of implementation of Peer Instruction: 1) Answer multiple-choice conceptual questions (MCQ) with distractors (incorrect responses) that reflect common student misconceptions, 2) Discuss a problem in pairs or groups, 3)

Use clickers or similar means to ‘vote’ on the correct answer of a MCQ, and 4) Provide answer(s) to a posed problem or question before the class can proceed [6]. It was observed that Peer Instruction has the lowest fidelity (11%) of implementation of all RBIS studied [6].

IV. CONSTRUCTION OF THE SURVEY

Project monitoring and evaluation revealed that many innovation CoPs created through SIIP and WIDER had begun using clickers in their classrooms. We also observed that some faculty used clickers in ways that aligned with principles of Peer Instruction, while others used alternate techniques. We decided to explore whether we could use a survey to study the spread of RBIS and their fidelity of implementation. While this particular survey focuses on clickers, we expect to use similar studies to examine other RBIS.

We constructed a survey to begin exploring two research questions.

1) How do faculty describe their own use of clickers?

2) Why did faculty decide to adopt clickers? Are the reasons for adoption of clickers different among SIIP and WIDER participants than other faculty?

The survey begins with five questions exploring when faculty first heard about clickers, how faculty first heard about clickers, when faculty started using clickers, what interactions or sources led faculty to adopt clickers, and what reasons (if any) delayed their initial adoption of clickers.

The second part of the survey explored the teaching practices that faculty used with clickers. A list of teaching practices was constructed both from the literature on Peer Instruction and from our observations of how faculty were using clickers in their classrooms. Faculty rated a list of practices (shown in Table I) on a Likert scale based on the frequency with which they used each of the teaching practices in conjunction with clickers. Three of the teaching practices (highlighted in Table I) were specifically focused on the critical components identified by Borrego et al. [6] and listed in the previous section. Faculty were also allowed to add any additional teaching practices they used that we did not list.

In addition to the Likert scale questions, faculty were asked to describe their ideal use of clickers and their perceptions of the benefits and tradeoffs of using clickers in their classrooms.

The final part of the survey was focused on tracking the spread of clickers. Faculty were asked to identify who or what persuaded them to use clickers, identify who they had persuaded to clickers, and identify others who they happened to know used clickers.

Sampling for this survey uses a snowball sampling method in which initial survey participants identify additional survey participants in their responses. This sampling method enables the sampling of targeted populations without a priori knowledge of where those populations reside. The Principle Investigators of the NSF WIDER project served as the initial seed samples for the survey.

TABLE I. FREQUENCY THAT FACULTY USE CLICKERS TO SUPPORT VARIOUS TEACHING PRACTICES. THE THREE HIGHLIGHTED ROWS CORRESPOND TO THE REQUIRED ELEMENTS OF PEER INSTRUCTION AS IDENTIFIED BY BORREGO ET AL. [6].

	Almost Never	Occasionally	Usually	Almost Always
Track Attendance	2	3	0	8
Warm-up quiz w/ feedback	3	3	4	3
Warm-up quiz w/out feedback	10	1	1	1
MCQ w/out peer discussion	6	2	4	1
MCQ w/ peer discussion	1	0	6	6
Immediately reveal MCQ performance	0	0	4	9
Instructor leads discussion after MCQ	3	3	5	2
Adjust pace of instruction	2	4	5	2
End-of-class quiz w/ feedback	9	2	1	1
End-of-class quiz w/out feedback	12	1	0	0
Collect early informal feedback	9	3	1	0

V. PRELIMINARY RESULTS

The survey has had 13 respondents at the time of publication. Due to the small sample size, we do not provide any statistical analysis of the data, but provide some initial tentative observations that we hope to explore further as we increase our sample size.

A. Why Did Faculty Adopt Clickers?

Figure 2 plots the year that faculty adopted clickers in their teaching practice against the year that faculty first heard about clickers. The earliest year reported for the use of clickers is 2005 – the year that i>clickers were invented on our campus. Not surprisingly, the first adopters were the inventors of i>clickers and their close colleagues. The only other early adopter is currently a principle investigator for the WIDER project. The majority of our sample (10 of 13) adopted clickers after the start of SIIP in 2012. A few of the senior faculty in the study heard about clickers shortly after the invention of i>clickers, but their adoption took place after being embedded into SIIP and WIDER CoPs (In Figure 2, see three data points of faculty who heard about clickers in 2006 and 2007 and adopted them after 2012).

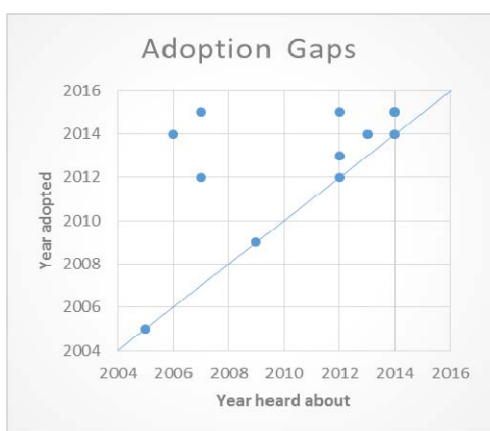


Fig. 2. Plot of the year that faculty adopted clickers in their teaching practice plotted against the year that faculty first heard about clickers. An equal-year line indicates

Awareness and adoption of clickers was driven primarily by interactions with colleagues. Figure 3 shows that most respondents heard about clickers through conversations with colleagues or observation of another instructor. Noticeably, none of the adopters first learned about clickers from publications.

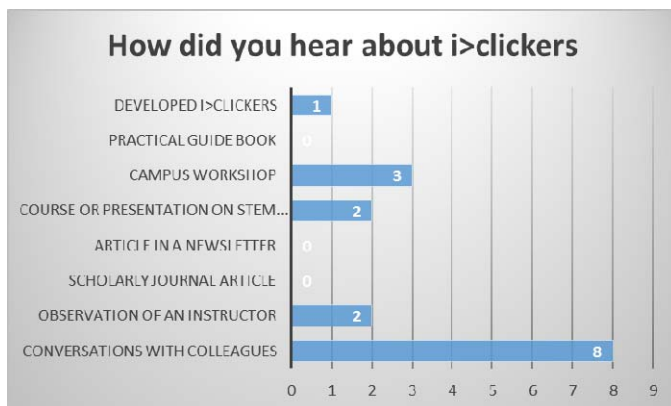


Fig. 3. Sources of faculty knowledge about clickers

Faculty's free responses to questions about why they adopted clickers similarly reflect the critical role of colleagues in their adoption as 10 of 12 responses indicate the role of colleagues in persuading them (the creator of i>clickers is omitted from these responses). Four of the respondents specifically mentioned their involvement with SIIP and WIDER CoPs.

Because of the preliminary nature of this data, exemplar quotations are provided to give readers a sense of faculty responses, but qualitative analysis of this data will occur after sampling has ceased.

"I had thought they were a great idea as soon as I heard about them; however, it was not until I took over a class in which the previous instructor had already used them that I decided to use them myself."

"Existing course format required their use. Co-teaching with an experienced instructor (Prof. X) who was using

them. He learnt about them from physics, I believe. I used them once with X in 2009, but it wasn't a great experience (bad format), so I didn't use them again until 2013 when I started using them as part of the SIIP project."

B. How Are These Faculty Using Clickers?

Confirming the observations of the principle investigators, all of the listed teaching practices in Table 1 were chosen by the faculty. While each of the teaching practices are in use, the most common self-reported teaching practices align with the critical elements of Peer Instruction and tracking attendance. These results suggest that faculty connected with SIIP and WIDER may be using Peer Instruction with a higher fidelity than reported in previous studies, but these results are preliminary and firm conclusions should not be drawn from this data.

These results also reveal that faculty use clickers using a mixture of practices that align with the critical elements of the RBIS with practices that are not supported by the literature.

Faculty's free responses seem to corroborate these observations. Again, because of the preliminary nature of this data, exemplar quotations are provided to give readers a sense of faculty responses, but qualitative analysis of this data will occur later.

"I like iClicker questions best when they reveal common conceptual problems. By using them to reveal in real-time the misunderstandings that students have, the students become highly engaged to fix their faulty understanding of course concepts. I like to use mass-misunderstanding moments to open up discussions with their neighbors as an opportunity for students to truly consider the validity of their often-flawed reasoning. Then, by following up with a re-poll, I can open the floor for a student to explain what is hopefully the proper reasoning. This opportunity can be used to provide encouragement to students to confidently express their reasoning."

"My best uses of iClickers is when I can sprinkle 3-4 questions throughout my lectures so that students stay focused and get immediate feedback on whether they understand the material. The other 'best' use is when I have a particularly tricky topic and can 'wake up' the students by showing them that a significant portion of the class is struggling with the concept."

"To test on the same question first without allowing for discussion, and then again but after discussion"

VI. FUTURE WORK

This preliminary data suggests that faculty communities and social networks play an important role in faculty awareness and adoption of RBIS. Deeper analysis of the data will commence after the snowball sampling reaches saturation. These results suggest that we should conduct social network analysis to better understand the interconnections between faculty.

We expect to expand this survey to explore the spread of other RBIS and explore the generalizability of these findings.

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Strategies for Sustaining Change in Engineering Education

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Abstract— In order to develop the engineers of the future, engineering departments need to embrace innovative, student-centered practices. The development and sustained growth of organizational improvement practices like those needed to improve engineering education depend upon an institutions' or departments' collective and individualized attention to human resources, leadership, knowledge development, revenue development and opportunities for continuous engagement. The literature in engineering education related to sustainability and curricular change indicates initial training and dissemination is necessary though not sufficient for change to take root, that all change agents need mentoring, collaboration opportunities, and venues for sharing their work, that innovative practices may vary across settings, and that a systemic effort needs continuous attention to remain robust. The paper provides CAHSI as an example of sustained innovation, and details the ways in which CAHSI was designed for sustained impact in engineering education across partnering Hispanic Serving Institutions. The paper highlights programmatic considerations and evaluation design, and describes how the results can inform leadership regarding progress and needs for sustaining change.

I. INTRODUCTION

In order to develop the engineers of the future, engineering departments need to embrace innovative, student-centered practices. Creating and maintaining pedagogical change in computer science and engineering departments is challenging, given short programmatic funding cycles and multiple demands on faculty time. This paper describes strategies employed by an alliance of eleven departments and external partners to improve educational outcomes for underrepresented students in computer science and engineering. The development of organizational capacity within this multi-institution initiative is important for engaging all members in the mission of the alliance and, over time, is crucial for contributing to sustainability of the alliance beyond the life of National Science Foundation funding. This paper situates the CAHSI model within the organizational change literature regarding how to motivate and sustain innovation in a department or institution. The paper provides CAHSI as an example of sustained innovation, and details the ways in which CAHSI was designed for sustained impact in engineering education across partnering Hispanic Serving Institutions. The paper highlights programmatic considerations and evaluation design, and describes how the results can inform leadership regarding progress and needs for sustaining change.

II. CAHSI

The Computing Alliance for Hispanic-Serving Institutions (CAHSI) is a Broadening Participation Alliance funded by the National Science Foundation. CAHSI is a cooperative effort among 11 core institutions that implements changes in computing pedagogy, research, and professional development opportunities in higher education collaborating to spread the promising practices developed at each institution. The goals of the alliance are to recruit, retain and advance Hispanics in computing. This paper documents elements of design and implementation within the organization that have supported sustainability and organizational change among member computing and engineering departments, and highlights ways in which the sustainability has been measured and monitored throughout the course of CAHSI's 10 years.

Throughout its history, CAHSI has provided deep and broad support to students and faculty at all educational stages. The CAHSI model has consistently fostered deep student engagement throughout their undergraduate and graduate experiences. For instance, in the 2013-14 academic year alone, CAHSI departments provided:

24,840 hours of introductory computing content to 552 students, nearly 2/3 were Hispanic or other underrepresented minority students.

49,335 hours of undergraduate-led supplemental instruction through peer-led team learning (PLTL) to 1,905 students, nearly 60% were Hispanic or other underrepresented minority students.

10,305 hours of coursework using the Affinity Research Group (ARG) model to 255 students; 75% were Hispanic or other underrepresented minority students.

7,800 hours of out-of-class research experiences provided to 27 students; 71% were Hispanic or other underrepresented minority students.

These opportunities for substantive technical learning and deep engagement with the discipline build students' self-efficacy, sense of mastery, and increase their aspirations to pursue graduate education and computing careers. During the last five years, 77% of all ARG undergraduate students reported that they were more likely to pursue graduate school because of their research experience; many of the remainder stated that they were already strongly committed to graduate study. CAHSI students also have higher aspirations than a national sample of computing students surveyed by the Computing Research Association. For example, 19% of

CAHSI students aspired to a doctoral degree, while only 12% of the national sample of students expressed that goal.

CAHSI has worked to sustain efforts and expand in manageable ways given shrinking governmental funding opportunities. This paper illustrates the ways in which CAHSI has made a concerted effort to leverage resources to support transformational educational practices. This paper is a case study of a long-standing collaborative organization. The data collected over 10 years of evaluation of the program describes some of the ways in which the design and implementation of the alliance across institutions has led to its longevity and impact. Building on organizational change literature, the evaluation of organizational capacity building efforts is described. Illustrative examples show how CAHSI has supported sustained curricular and co-curricular innovation in member institutions and beyond.

The research questions addressed in this paper are:

What factors of initiative design and emerging practice have supported sustainability for CAHSI?

What challenges remain in sustaining the CAHSI initiative?

III. ORGANIZATIONAL CHANGE LITERATURE

The development and sustained growth of organizational improvement practices like those needed to improve engineering education depend upon an institutions' or departments' collective and individualized attention to human resources, leadership, knowledge development, revenue development and opportunities for continuous engagement [1,2,3]. Johnson, Hays, Center and Daly [4] designate the need for *infrastructure capacity building* in change efforts. According to the authors, infrastructure capacity building objectives include the ability of the organization to:

"a) strengthen and maintain structures and formal linkages, b) strengthen, maintain, and cultivate leadership, c) increase or maintain resources to sustain innovation, d) build and maintain expertise to sustain the innovation."

A. Innovation in Engineering

Studies of innovation in engineering education have looked at the most promising practices for sustaining innovation over time and for influencing other practitioners to incorporate inclusive, student centered approaches in their classrooms to promote change. Borrego and Henderson [5] described four types of change strategies employed in educational settings, and note the strategies that honor complexity, assume changes must occur within environments rather than only at the individual level, and that emergent rather than prescribed change might have the best chance at succeeding. Similarly, Sidiqi and Adams [6] called for approaches to educational change that moved beyond diffusion or propagation approaches in which curriculum as a bounded object is passed to multiple intended users. Instead, educational change efforts that address explicit assumptions about students, learning experiences, and goals prompting innovation might be more effective in creating lasting improvements in engineering education.

A National Science Foundation funded coalition of engineering education institutions reflected on their curricular change models as they evolved over time in the partnership, and concluded in its fourth generation change model that curricular change involved persuasion, developing tools and resources that would work for multiple audiences, and a need to provide structures that support curricular use and further development [7]. The literature in engineering education related to sustainability and curricular change reflects lessons learned in the CAHSI community—that initial training and dissemination is necessary though not sufficient for change to take root, that all change agents need mentoring, collaboration opportunities, and venues for sharing their work, that innovative practices may vary across settings, and that a systemic effort needs continuous attention to remain robust.

B. Transforming practice in HSIs

Hispanic serving institutions, defined by Title V of the United States federal government as institutions with 25% or greater full time enrolled students who identify as Hispanic/Latino, have particular demographic realities that shape the way postsecondary institutions address their needs. Hispanic serving institutions may have a higher than average number of community college transfer students, and may enroll a greater proportion of students with significant financial need, as well as students with school experiences at the K12 level that did not sufficiently prepare them for the rigors of engineering education [8,9]. It is said that new educational initiatives can be expected to transfer to new sites based on the extent to which the educational sites are similar [10]. By partnering with other HSIs in transforming education in engineering, institutional agents can start from a place of common ground and develop shared and complementary expertise to transform education.

In a large scale study of transformative change among HSIs, Nunez, Hurtado, and Galdeano [11] document effective practices for engaging collaboration in Higher Education. In their research work with partnering HSIs primarily in the southern and western United States, they found four themes that related to institutional change and improved student outcomes in these strategic HSI partnerships: cross-institutional mentoring, changing mindsets, mutual encouragement and action, and the 'ripple effect'. CAHSI was designed and implemented in ways that complement these 4 themes, and the themes serve to structure the results presented in this paper for research question 1.

IV. METHODS FOR EVALUATING ORGANIZATION CHANGE IN CAHSI

Evaluating organizational change across organizations involves a multilayered, mixed methods evaluation plan that documents student outcomes, programmatic reach, and based on needs of the funder, the impact of the partnership beyond the original funded organizations. To sustain the educational initiatives that serve students in alliance departments, the alliance must have the capacity to do the following:

a) replenish and fortify the pipeline at critical educational junctures (K-16 to graduate education) through continuous improvement of initiatives and pedagogy, including outreach and retention strategies that keep students engaged in engineering and computer science;

b) hold training sessions for the broader community on research-based practices that improve recruitment, retention, and advancement of students to ensure expertise is sustained and developed at each institution,

c) develop staff and faculty in new pedagogical, co-curricular, and research practices and understanding of innovative educational reforms so that departmental and course-level improvements continue to meet the needs of students and other stakeholders

d) extend the cadre of staff and faculty who commit to the alliance's core purpose and practices.

The evaluation measures direct impact of interventions on student enrollment, retention, and advancement in computing, as compared with comparable institutions. The Integrated Postsecondary Education Data System (IPEDS) maintained by the United States Department of Education serves as a source for comparison data used in establishing key student outcomes in computing at CAHSI schools in comparison with other public and private non-profit colleges and universities. Trends indicate CAHSI schools have weathered the downturn experienced in computing in the past decade better than their peers.

To best support the changes CAHSI implemented at member institutions to support Hispanics in computing it is vital to simultaneously focused on the support structures, training and reengagement activities, recruitment strategies, and policy work necessary to sustain innovation in engineering education. This work is carried out through surveys, interviews and observations within CAHSI departments and activities that focus on organizational capacity building across and within institutions, as well as actions that link CAHSI to partners across policy, education, philanthropy, and technical communities.

V. TRANSFORMING ENGINEERING EDUCATION PRACTICES IN HISPANIC SERVING INSTITUTIONS

Results of the CAHSI evaluation to date are framed using the model provided by Nunez, Hurtado, and Galdeano [11] to describe transformative practices in higher education, specifically with regard to HSIs. In their research work documenting the change processes, they found four themes that led to institutional change and improved student outcomes in these strategic HSI partnerships: cross-institutional mentoring, changing mindsets, mutual encouragement and action, and the 'ripple effect'. The following sections detail how CAHSI was designed and implemented throughout its decade in practice in ways that support collaborative transformation. The results section highlights activities and structures put in place organizationally to maintain commitments to change in education. This paper provides illustrative data from CAHSI's 10 year history that highlight the mixed-method nature of the

evaluation and how the measurement and feedback involved in formative evaluation can influence sustainability.

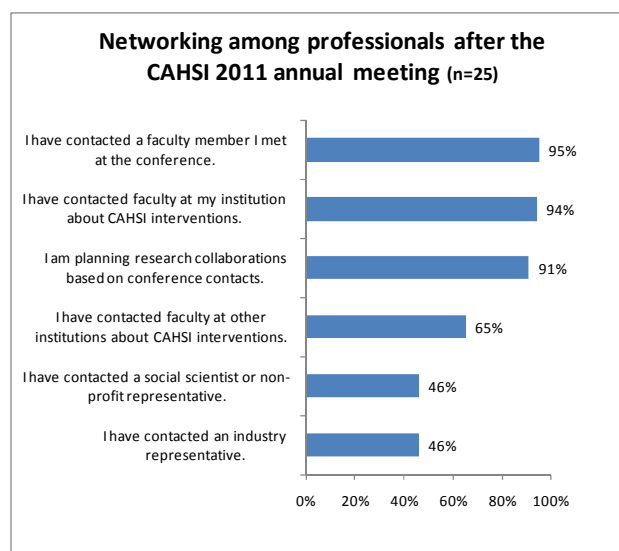
A. Cross institutional mentoring

CAHSI was designed with the implicit goal of mentoring professors across institutions. This goal is evident in the recruitment of faculty, particularly Hispanic faculty, to the annual meeting. The CAHSI annual meeting (now the Summit) provides a forum for Hispanic computing professionals and students that is not available elsewhere. No other national conference specifically fosters professional development and community among Hispanic computer scientists and engineers.

The relatively small size of the CAHSI annual meeting, its focus on student development as a central focus, and the largely Hispanic audience make it unique and valuable for attendees. Each year the annual meeting was held as a stand-alone event an overwhelming majority of both students and computing professionals reported that they had contacted someone they met at the CAHSI annual meeting in the month following the meeting. Thus, the CAHSI annual meeting is a method that fosters and enriches connections among the Hispanic computing community.

In the most recent evaluation of annual meeting faculty attendees, evaluation findings showed that professionals network with other conference attendees at a high rate. For example, faculty and industry professionals were asked to describe their networking and other professional follow-up activities in the month following the 2010 CAHSI annual meeting. Faculty contacted other faculty at their own institution at increasingly higher rates (50% in 2009, 81% in 2010, 94% in 2011). Professionals' rates of networking with faculty at other CAHSI institutions was strong (63% in 2011).

Fig. 1. Cross Institutional Mentoring: Faculty activity following annual



meeting

1) Case study: Mentoring faculty to support change

Evaluation data collection and analysis involved annual case studies to deepen understanding of specific elements of the CAHSI support network, particularly as it related to mentoring. An excerpt from a faculty member interview is used to illustrate how cross institutional mentoring can make a difference in educating Hispanics in computing.

At the time of the study, Guadalupe was a Latina tenure track assistant professor in a small public university. She viewed her career as one shaped by mentors in a network of professionals who took an interest in her professional career contributing to her capacity to expand her technical, research, and teaching skills. As an assistant professor, she needed to develop a research agenda to support her case for tenure. She noted two reasons for her desire to acquire student help in her research efforts; first, the need to produce more research; and second, to support her desire to help students.

"I needed to have a research agenda. I was worried that I wasn't going to do that. If I don't have students that work with me in my particular research area, I don't think I'll be successful because my current job is in a teaching institution transitioning to research; even if I could do my research on my own then I'm not helping really anybody."

Guadalupe's role as a professor in a transitioning institution involves the triad of interlocking roles, including service, teaching, and research. However, research in higher education consistently supports the master narrative that successful tenured professors produce research above all other job duties, including teaching and service [12,13].

At her campus, Guadalupe recruited a group of students to work with her on her research. She received small grants to support their participation and, through the CAHSI network, built relationships with more experienced Latinas in the field who mentored her in workshops that contributed to effective management of student researchers. She described the alignment between her teaching and research goals for students: *"My goals for teaching were to help students participate outside of the classroom and to get them involved in research...I want it to be really student centered."*

Her curriculum vita echoes this focus on research as a method for teaching. Her teaching statement espouses the value of both teaching and research.

My goal as a teacher is to find creative ways to facilitate active learning and outreach to potential students. I believe more than ever that teaching is all about participation; inside and outside the classroom. Currently, I am applying the (undergraduate research model) towards the creation of an interdisciplinary research group.

Throughout the interview, Guadalupe spoke of her successes in terms of student experiences and aspirations to persevere in research. For example, she described how one student changed his major to the more technical computer science major (rather than the information systems major, which tends to have more managerial and business-related coursework) and how another student was accepted at a prestigious PhD program following her experience in the research lab. She also explained how two students traveled with her to a research opportunity at a national lab for the

summer. While these experiences further her research work, her focus in the telling is on student progress, not her own development of a research agenda. And yet, inherent in the telling is the establishment of a research agenda and dissemination efforts that support her success as a professor.

The case of Guadalupe shows how mentoring a professor can be supportive of the professor's career trajectory while also ensuring transformative change in the institution. Providing students what have been called High Impact practices in higher education [14] can shift learning out of the classroom and into co-curricular practices that support retention. Faculty members need mentoring and training to make that transition sustainable and mutually beneficial for students and faculty alike.

B. Changing Mindsets

To truly make transformative changes in HSI engineering departments, it is not enough to simply inform faculty of research based pedagogical approaches that may improve student performance [15]. Instead, faculty and staff must be supported in challenging norms that serve as barriers to student achievement.

1) Informing minds with social science

Another effort CAHSI made as an organization to influence mindsets regarding Hispanic students in computing emerged at the CAHSI annual meeting in San Juan, Puerto Rico. This themed meeting brought together social scientists and educational researchers from a multitude of institutions and organizations to discuss challenges and opportunities engaging Hispanic youth in computing (<http://cahsi.cs.utep.edu/about>).

2) Evidence of changing mindsets from faculty perspectives

Evidence from faculty surveys supports the notion that CAHSI is influencing departmental culture and faculty mindsets regarding their role in education. Surveys with faculty asked respondents to compare their departments before and after the initiation of the alliance. Over a third of faculty report spending more time with students since CAHSI began (34%) and 39% responded that their colleagues spend more time with students since CAHSI began¹. Given the importance of faculty-student interaction to learning outcomes, this finding is significant in illustrating how collaboration can change mindsets that can potentially lead to higher student outcomes.²

C. Mutual encouragement and action

A norm in computing departments is an expectation of strong background knowledge in computing for incoming students [16] which researchers note privilege male students from moderate to high socioeconomic backgrounds and high performing schools [17] Initiatives that engage stakeholders from multiple institutions and are viewed as manageable to implement both challenge these norms and lead to action that

¹ 7% of participants felt their colleagues spent less time with students at the time of the study than they did before CAHSI, and the remaining respondents indicated no change.

² This paper focuses on organizational capacity for change rather than student outcomes. For more information on CAHSI's results for students please see [18,19]

provides opportunities to serve student learning needs may be particularly impactful for creating change.

1) CS-0: Policy and Pedagogy Designed for Change

The computer science zero courses (CS-0) implemented across CAHSI schools fit that description, as the purpose for including them in curricula was to serve students with limited computer science background who entered the college program at CAHSI schools. The course was relatively easy to add to a curriculum as an elective, and provided a venue for serving multiple student groups for a variety of purposes—from engaging with computer science as they took developmental courses to recruiting students from other majors into computer science, the course was flexible enough to engage instructors with multiple perspectives and yet cohesive enough in intent and scope to foster collaboration across partner institutions. The course took many forms across the differing institutions, allowing for sharing of teaching practices, computer languages, lessons, and approaches to recruitment of students. While implementation differed, the CAHSI community collaborated to try out new approaches in specialized workshops for CAHSI members, shared resources and tools via email and website dissemination, and contributed to the larger dialog about initial experiences in computing through conference papers and journal articles.

Evidence suggests that the course was successful in preparing first year students with little background who intended to study computer science. In focus groups and interviews students involved in CS-0 at CAHSI schools described an approach to learning programming that was well suited to novices as well as those having trouble with the jargon of programming in a more advanced course. They noted the importance of having an interactive, engaging instructor who was willing to answer questions students posed. As the students were interviewed towards the end of CS1, they were able to describe how the supported, structured, and visual nature of CS-0 allowed them to understand concepts they later used in more advanced programming.

2) Mutual engagement of faculty-social network analysis

Mutual engagement assumes regular contact with stakeholders in the alliance. In 2014, the evaluators implemented a social network analysis [20] to track connections made across institutions, with the leader at each institution completing a survey that documented interaction. Figure 2 depicts the interactions reported by lead faculty at each of the 11 member institutions in a given three month period. Lines indicate direct communication was reported between key stakeholders for that quarter. Thicknesses of the lines indicate the richness of that communication as it related to collaboration. While a solid, thin line connecting the shapes means the two leaders were in direct communication to share information, a thick line represents collaborative or “integrative” activity, such as coordinating a conference, or developing a grant proposal.

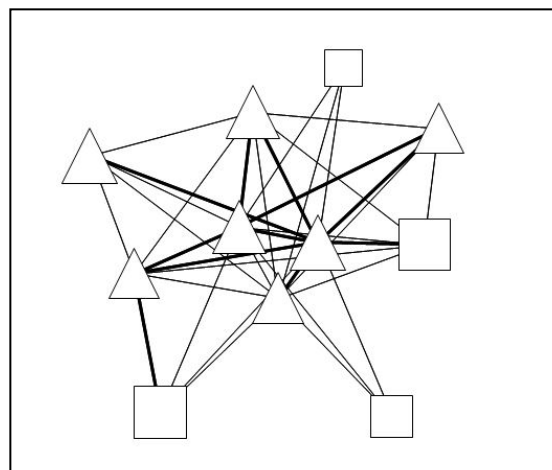


Fig. 2. CAHSI social network analysis: quarterly communication between originating institutions (triangles) and adopting institutions (squares)

The network appears robust, with all institutions showing at least three connections that are made quarterly. Nearly all originating institutions have more frequent communication with at least one other institution in the alliance. All originating institutions and two newer members engaged in integrated activities with Alliance partners during the year in question. Integrated activities involve co-development and co-organization among all member organizations, the most developed form of collaboration monitored in this survey. Intensity of collaboration is moderately but not completely correlated with frequency, meaning that some interactions occur more often between two institutions but to lesser degrees of intensity.

3) Encouragement and engagement in developing new revenue, new opportunities to support Hispanics in computing

In order to sustain, CAHSI members need to continue to find funding to support their work transforming education in engineering. This can be an area of mutual engagement that feeds the need for continuous contact across collaborators that supports collective work as it shapes transformations to come in future educational practices. In measuring CAHSI’s moves towards sustainable change, the evaluators have documented collaborative efforts to bring in funding. Five CAHSI institutions engaged in cross-institutional educational initiative proposal writing/grant implementation during the 2013-2014 school year, and two institutions submitted research collaborations that would serve CAHSI students. By proposing joint efforts, CAHSI faculty keep in contact, coordinate pedagogical change and are better positioned to collaborate regarding other efforts beyond the grant opportunity. Maintaining connection in joint enterprise is viewed as important for sustainability to be realized.

D. Ripple effects

Ripple effects occur when unintended transformations in practice, policy, or action develop out of collaborations designed to transform engineering education. Data from multiple sources and varied levels of the CAHSI organization (faculty, department, and organization as a whole) illustrate

how CAHSI's efforts have established ripple effects that transform practice.

1) CAHSI faculty impressions of departmental visibility and reputation changes since becoming engaged in CAHSI.

Though not one of CAHSI's intended goals, a positive consequence of the CAHSI alliance mentioned by a few PIs and determined anecdotally by evaluators has been the impression that the CAHSI alliance may elevate departmental visibility and reputation. According to faculty survey results, nearly a third of respondents described a change in visibility on campus or beyond campus. Six note on-campus visibility differences for the increasing number of activities, and eight describe off-campus visibility improvements related to publicity from regional press and through participation in CAHSI conferences.

This visibility may contribute to increased scholarship and increased faculty network development- 16 faculty note they participated in one or more proposals that mentioned CAHSI as relevant prior work. The majority of proposals mentioned CAHSI involvement as evidence of strong student development (via ARG, PLTL strategies) and recruitment and advancement of underrepresented students in computing. In addition, open-ended responses show that faculty are collaborating more often with peers off campus, and their students are also discovering new networking opportunities.

Opportunities to engage in educational transformation can lead to career-enhancing dissemination opportunities for faculty. When faculty see an added benefit to their careers from engaging in pedagogical improvements, they may be more personally invested in the transformation efforts. Fifteen faculty members note their dissemination of CAHSI-related efforts beyond their institution, in research venues such as Super Computing, ACM conferences, FIE, SACNAS, ITCSE, and disciplinary workshops. In fact, 21 of 35 reported they either disseminated or wrote a proposal that leveraged CAHSI results, indicating departmental investment in the initiative.

2) Departmental "ripple effects"

CAHSI departments felt ripple effects from CAHSI efforts to transform education. Some specific examples are described below. These narrative descriptions of additional ways in which CAHSI is influencing outside individuals and organizations are not intended to show systematic implementation, rather they point to creative ways in which CAHSI stakeholders are expanding their work locally, and in some instances, point to the ways in which CAHSI's reputation at the campus level is beginning to lead to greater transformation of engineering education.

A member institution in a highly urban commuter campus redefined one of the CAHSI practices to better meet the needs of students engaging in peer led team learning. The synchronous online offerings peer leaders developed for CS1 and CS2 have led to instructional innovation, primarily designed collaboratively by the peer leaders themselves. The students were able to showcase their work in online PLTL through conference participation at the Peer Led Team Learning International Society conference in May of 2014.

At another institution, a faculty member who leads student research training workshops for CAHSI was tapped by the academic dean to train other faculty members in student research skill development. The computer engineering department is thus disseminating best practices to other departments on campus to support pedagogical change.

A CAHSI initiative to support students in preparation of fellowship applications was leveraged to serve students across the campus. Institutionalization of the effort supports sustainability and may have already influenced students beyond the CAHSI computing department. The institution in question has produced a substantial number of NSF fellows in the years since FellowNet took shape.

Multiple institutions report engagement in cross disciplinary funding opportunities that leverage CAHSI pedagogical practices to bring them to more STEM departments at their own institutions. As of this writing one external, government grant was successful in securing funding.

3) Alliance "ripple effects"

CAHSI has extended its national influence through leadership, policy actions, and collaborative efforts across academic, non-profit, and industry partners. CAHSI has been listed in the national Examples of Excelencia database as an effective national initiative that accelerates Hispanic student success at the baccalaureate level. As a member of the Excelencia in Action Network, CAHSI contributes to national efforts to advance the Hispanic national agenda. CAHSI has distributed alliance advocacy across campus leaders to in turn spread CAHSI knowledge of best practices beyond the alliance—nine faculty members represent CAHSI in national and regional organizations interested in improving and diversifying the computing workforce. CAHSI has disseminated its initiatives beyond member departments, reaching 62 faculty/staff members in more than 9 disciplines at over 40 institutions, serving over 800 students.

VI. CHALLENGES TO GROWTH AND SUSTAINABILITY

While CAHSI has worked towards sustainability and growth, the organization has faced challenges. Like most distributed organizations, CAHSI depends on local leadership to implement initiatives in the classroom and in the focal departments. CAHSI has found that while departmental chair leadership has been important for supporting CAHSI, trained faculty and staff members are also necessary for implementing CAHSI. Turnover in any of these areas requires a shift of workload and additional training that takes time to address. Growth is an area of concern for CAHSI members—specifically the mechanisms for joining the organization in official ways. The organization has maintained that membership must be tied to institutions' and individuals' support of CAHSI's core purpose- to recruit, retain, and advance Hispanics in computing. The organization has evolved to include multiple "levels" of membership to acknowledge individual commitments faculty and staff might make to the CAHSI core purpose, including individual and departmental membership for CAHSI adopters, yet more

established processes may be needed to better define membership and related responsibilities and benefits.

VII. RELEVANCE AND SIGNIFICANCE

This work describes how a long term multi-institutional engineering education innovation project influenced faculty, staff and students at 11 institutions over the course of its 10 year history. Alliance design, implementation, and evaluation metrics have coalesced to maintain and grow the CAHSI alliance and its research based educational practices. The partnership has developed mentoring networks across institutions, as well as continued opportunities to work at changing mindsets about students' current abilities, capacities to learn, and future pathways. Mutual engagement in integrated activities has allowed for continuous collaboration, and helped to initiate ripple effects, or unintended but welcome expansion of the CAHSI community and its practices. Including sustainability and organizational change as a focus of evaluation has provided information about growth that may not otherwise be available. These data can be informative in shaping future alliance initiatives and outreach.

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Improving Faculty Perception of and Engagement in STEM Education

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Abstract— Science, technology, engineering and mathematics (STEM) and the important role that it plays in society and education is receiving increased attention throughout the United States. Even universities, which have been at the frontline of educating STEM professionals, are reviewing and updating their policies and responsibilities. Faculty members often find themselves torn between their commitment to scientific research and their responsibility to prepare the next generation of STEM professionals. The proposed paper will examine the following research questions: • How can universities be structured such that the efforts of faculty members who prioritize the quality of undergraduate STEM education are recognized and supported? • How can universities be structured such that the efforts of faculty members who prioritize K-12 STEM education outreach are recognized and supported? The study, which will be discussed in the proposed manuscript, was conducted at a large public research university with student enrollment in excess of thirty thousand. New faculty members at this institution were asked to complete a survey concerning STEM education and outreach in 2012 and 2014. The survey addressed the faculty member's perceptions of the following: i) personal views concerning STEM education and outreach, ii) peers' attitudes towards STEM education and outreach, and iii) the value the university system places on STEM education and outreach. This survey was coupled with a university-wide effort, which was implemented between the years of 2010 and 2014, to support and encourage faculty who were interested in STEM education and outreach. The results of this investigation support the assertion that new faculty attitudes were better with respect to STEM education and outreach in 2014 when compared to 2012. On average, new faculty felt better prepared to mentor undergraduates in STEM in 2014 than did the new faculty in 2012, with 52% and 79% reporting to be "well prepared," respectively. Additionally, new faculty reported a better overall morale in 2014 when compared to 2012 within the institution. The proposed paper will provide further details concerning the changes that were made within the institutions between 2010 and 2014 and the faculty responses to the survey.

Keywords— Faculty development; STEM education; STEM Outreach

I. INTRODUCTION

The advancement of modern society is inextricably linked to developments in science, technology, engineering and mathematics (STEM). Employment in the United States is increasingly requiring individuals who have knowledge,

expertise and training in the STEM fields.¹⁻³ Universities, especially those that have traditionally served STEM fields, are increasingly exploring methodologies for improving STEM education on and off campus. Particular attention has been paid to the preparation of students from feeder or K-12 schools through outreach. Some universities are encouraging their faculty to play an active role in STEM outreach and mentoring programs. These programs may become overly taxing on faculty who have a primary commitment to their own students and research.^{4,5} This paper explores a university program that is designed to create a balance among outreach, teaching and research amongst its faculty. Through this program, faculty are rewarded for both on- and off-campus efforts to improve STEM education.

This article examines a program at Texas Tech University (TTU) in which education and outreach are recognized and rewarded as part of the annual faculty evaluation process. New faculty members learn in the first year of employment that educational efforts, on and off-campus, are considered to be part of their job. This program moves beyond familiarizing faculty with empirically-supported teaching strategies^{4,6,7} to encouraging faculty activities in education and outreach. In order to evaluate the impact of this program, two-university-wide surveys were conducted. Changes in faculty attitudes with respect to education and outreach were tracked over a two-year period. Responses to these surveys were used to begin to answer the following research questions:

- How can universities be structured such that the efforts of faculty members who prioritize the quality of undergraduate STEM education and outreach are recognized and supported?
- Does administrative restructuring of the tenure and promotion requirements with respect to STEM education and outreach negatively affect faculty morale?

II. METHODS

The following two sections describe the participating university and the survey instruments that were used.

A. University

As of the fall 2013, TTU had an undergraduate student enrollment of approximately 27,000 with 93% of the student body consisting of state residents. On average, undergraduates

are predominantly traditional college students (e.g. recent high school graduates) with the average student age of 21 with only 10% of students 25 or older. The university has roughly 1,200 full-time instructional faculty.⁸

B. Subjects

Table 1 provides the total number of survey responses for both “New Faculty” and “General Faculty” members in the STEM disciplines. These faculty include tenured and tenure track faculty as well as instructors with teaching duties only. The group does not include graduate teaching assistants. “New Faculty” members are defined as faculty who began working at the university the same academic year as when the survey was administered, the “New Faculty” populations for 2012 and 2014 consist of two mutually exclusive samples. The “General Faculty” included faculty who were beyond their first year; this sample was not mutually exclusive from 2012 to 2014. Table 1 provides the number of individual survey responses for both new faculty and general faculty for the 2012 and 2014 surveys.

TABLE I

	2012 n	2014 n
General faculty	175	204
New faculty	21	28

C. Instruments

General and New Faculty surveys were administered in spring 2012 and spring 2014 and are displayed in Fig. 1. The General Faculty survey contained all of the questions displayed in this figure; the New Faculty survey contained only the starred questions. These surveys were designed to track faculty participation and planned participation in STEM outreach, attitudes with regard to mentoring students in STEM, and faculty morale with regard to changes to faculty evaluation. The General and New Faculty surveys differed slightly, in that the General survey was designed for an experienced faculty population and the New Faculty survey was designed for a non-experienced responding population.

General and New Faculty STEM Survey Questions: (“*” indicates question appeared on the New Faculty survey as well as general faculty survey)**

STEM Definition- In 2001 Judith A. Ramaley, the former director of the National Science Foundation’s education and human-resources division, designed a new approach to teaching education in Science, Technology, Engineering, and Mathematics (STEM). TTU has a number of related STEM and STEM Outreach programs that overlap in the area of recruiting new students, as well as in the mentoring of STEM students from underrepresented groups.

STEM:

- Are you aware of the STEM Outreach programs?***
 - ☐ Yes
 - ☐ Somewhat
 - ☐ No
- Have you participated in any STEM Outreach programs?***

- ☐ Yes
 - ☐ No
- Do you plan to participate in the STEM Outreach programs within the next year?***
 - ☐ Yes
 - ☐ No
 - Have administrators included STEM in their assessment of faculty at TTU?
 - ☐ Yes
 - ☐ No
 - Do you believe that the attitude towards STEM outreach work (funding, rewards) has changed at TTU?
 - ☐ Yes
 - ☐ Somewhat
 - ☐ No
 - ☐ Does not apply
 - Do you believe that the reward structure for STEM has changed at TTU ?
 - ☐ Yes
 - ☐ Somewhat
 - ☐ No
 - ☐ Does not apply
 - Do you believe faculty have a strong understanding of the educational benefits from STEM Outreach programs?***
 - ☐ Yes
 - ☐ Somewhat
 - ☐ No

STEM MENTORING:

- How well prepared do you feel to mentor your undergraduate students, with respect to STEM?***
 - ☐ Well prepared
 - ☐ Somewhat prepared
 - ☐ Ill-prepared
- How well prepared do you feel to be able to mentor your female undergraduate students, with respect to STEM?***
 - ☐ Well prepared
 - ☐ Somewhat prepared
 - ☐ Ill-prepared
- How well prepared do you feel to be able to mentor minority undergraduate students, with respect to STEM?***
 - ☐ Well prepared
 - ☐ Somewhat prepared
 - ☐ Ill-prepared
- How well prepared are you to mentor you older, non-traditional students (over the age of 30), with respect to STEM?***
 - ☐ Well prepared
 - ☐ Somewhat prepared

TABLE II

STEM – Change from 2012 to 2014							
Question	General Faculty				New Faculty		
	Yes %	Somewhat %	No %	Does not apply %	Yes %	Somewhat %	No %
1	-1	5	-2	-	-11	6	5
2	0	-	1	-	12	-	-12
3	2	-	0	-	9	-	-4
4	9	-	0	-			
5	0	0	6	-3			
6	-7	6	3	3			
7	3	9	-10	-	18	-24	6

☐ Ill-prepared

12. How well prepared are you to mentor students with a learning disability, with respect to STEM?*

☐ Well prepared
☐ Somewhat prepared
☐ Ill-prepared

13. How open is the line of communication between you and your STEM students?

☐ Very open
☐ Somewhat open
☐ Not open
☐ Does not apply

14. How open is the line of communication between you and your STEM advisor?

☐ Very open
☐ Somewhat open
☐ Not open
☐ Does not apply

STEM CAMPUS CULTURE:

15. Do you believe that the “campus culture” has changed since you have been a faculty member at TTU?

☐ Yes
☐ Somewhat
☐ No

16. Do you believe there is a generational gap in terms of language while teaching undergraduate students?*

☐ Yes
☐ Somewhat
☐ No

17. Do you believe there is a generational gap in terms of communication while teaching undergraduate students?*

☐ Yes

☐ Somewhat

☐ No

18. Do you believe there is a generational gap in terms of technology while teaching undergraduate students?*

☐ Yes
☐ Somewhat
☐ No

19. Do you perceive that there is a lack of trust in procedures and policies at TTU?

☐ Yes
☐ Somewhat
☐ No

20. Do you think faculty members have a role in the governance structure at TTU?

☐ Yes
☐ Somewhat
☐ No

21. Do you feel disconnected from any decision making processes within your department?

☐ Yes
☐ Somewhat
☐ No

22. Is there a structure for conflict resolution that faculty members can follow, if a problem arises?

☐ Yes
☐ Somewhat
☐ No

23. On a scale of 1 to 5 (1 low and 5 high), what do you think is the morale level of the faculty is at TTU?*

☐ 1, 2, 3, 4, 5

24. On a scale of 1 to 5 (1 low and 5 high), what do you think your overall morale level is at TTU?*

- ☐ 1, 2, 3, 4, 5
25. Do you feel that your career at TTU has progressed to your satisfaction over the past few years? **
- ☐ Yes
- ☐ Somewhat
- ☐ No
26. Please provide 3 core missions or values that you believe your department is trying to achieve. **
27. Please provide 3 core missions or values that you believe TTU is trying to achieve. **
28. Gender: Male/Female **
29. Ethnicity: Black or African American, American Indian or Alaska Native, Asian, Native Hawaiian or Other Pacific Islander, White, Hispanic or Latino, More than one race reported. **
30. Department: faculty members will fill in their department **

Fig. 1. Faculty STEM survey questions.

D. Administrative Changes

In fall 2009 TTU was awarded a pivotal NSF grant to foster a culture of STEM education and outreach on the campus.⁹ This NSF program provides funding for the integration of outreach programs and stimulates changes in the campus culture related to STEM education and outreach. This grant was the catalyst for a campus wide dialogue on tenure and promotion policies and culminated in a change to the university policies in July 2012. The critical innovation was the inclusion of outreach and engagement among the criteria to be recognized for tenure and promotion. The College of Arts & Sciences formally adopted similar criteria in September 2012.

III. RESULTS

A. General STEM Opinions

The first set of questions in both the general and new faculty surveys probed overall opinions of STEM outreach as held by the faculty. Questions 1 through 3 and question 7 appeared in both the general and new faculty surveys. Questions 4, 5, and 6 were exclusive to the general faculty survey. The first four questions addressed the faculty member's awareness of STEM outreach programs (Q1), prior participation with STEM outreach (Q2), plans to participate with STEM outreach (Q3), and whether the faculty member felt that fellow faculty members have a strong understanding of the educational benefits of STEM outreach (Q7). A summary of faculty responses to the first seven questions is provided in Table 2.

Overall the general faculty population reported little change

from 2012 to 2014. The largest changes were witnessed in questions 4, 6, and 7. Question 4 asks if the faculty believes that administrators include STEM in their assessments of the faculty members' work. The "yes" response increased from 25% to 34% from 2012 to 2014. The general faculty also displayed an increased belief that fellow faculty understand the benefits of STEM outreach (Q7) with 10% fewer responding "no" and 9% and 3% more responding "somewhat" and "yes," respectively. These may be partially explained by the new faculty of 2012 moving to the general faculty in 2014. The general faculty further displayed a negative trend with regard to question 6, which asks if the faculty member believes that the reward structure for STEM has changed. The interpretation of this response is challenging. We know that the administration sought to change the reward structure in 2012, at least in their written documents. Given there was no boundary placed on the time period that the question addressed, the faculty may have been considering a shorter time period which did not include the changes made in 2012. Faculty may be accepting the changes made in 2012 as common practice by 2014.

The data for new faculty indicated several encouraging shifts. A higher portion of new faculty members report participating (Q2) and planning to participate (Q3) in STEM outreach in 2014 when compared to 2012. This is oddly coupled with a decrease in reported awareness of STEM outreach programs (Q1). Lastly, for the final new faculty question in this section (Q7), which asks if the new faculty member believes that fellow faculty have a strong understanding of the benefits of STEM outreach, there was a polarization of the population with fewer neutral responses and an increase in both "Yes" and "No" responses. It is important to note that the positive change for the affirmative response is a factor of three larger than the negative response.

B. Mentoring

Faculty STEM interest is best served when the faculty member feels well equipped to mentor students in STEM, which is the topic covered in questions Q8 through Q12 (Table 3). The most striking change from 2012 to 2014 came from the new faculty data, with the most shifts in opinion witnessed in questions 8 and 11. These questions pertain to

TABLE III

STEM Mentoring						
General Faculty				New Faculty		
Question	Well Prepared	Somewhat Prepared	Ill-Prepared	Well Prepared	Somewhat Prepared	Ill-Prepared
	%	%	%	%	%	%
8	3	1	0	27	-20	-6
9	6	-1	-1	9	-8	-1
10	3	2	0	6	0	-6
11	2	3	-3	28	-23	-6
12	-5	14	-5	7	-19	12

TABLE IV

STEM Campus Culture – TTU Faculty and Individual Morale Level					
General Faculty					
Question	1	2	3	4	5
	%	%	%	%	%
23	-2	-12	7	7	2
24	-4	-1	-1	0	9
New Faculty					
Question	1	2	3	4	5
	%	%	%	%	%
23	4	7	-39	21	11
24	0	-10	6	-11	20

how prepared the new faculty members feel with regard to mentoring both students in general (Q8) and older, non-traditional students (Q12) with respect to STEM. The proportion of new faculty responding that they are “well prepared” increased by 27% for Q8 and by 28% for Q11.

This survey section also displays mixed results for general and new faculty concerning STEM mentoring for students with a learning disability (Q12). The general faculty reported a large increase in those feeling “somewhat prepared” with decreases to both “ill-prepared” and “well prepared.” The new faculty reported a drastic decrease in those feeling “somewhat prepared” with a slight increase in those feeling “well prepared” and a larger increase in those reporting that they feel “ill-prepared.” Both of these trends reveal that both new faculty and faculty in general could benefit with more support with regards to how to mentor STEM students with learning disabilities.

C. Faculty Morale

There is a concern that altering standards for faculty evaluation will impact faculty morale. Interestingly, there are discernible positive trends in both new and general faculty’s perception of morale (see Table 4 and Fig. 2. and Fig. 3.). The question 23 asks faculty to gauge the morale level of fellow faculty. The general faculty population reported an overall positive trend with low-end responses (1 and 2) receiving fewer responses while neutral (3) and positive attitudes (4 and 5) grew. New faculty, on the other hand, had a more divided reaction with there being a large drop in neutral responses (3) coupled with growth in both negative and

positive responses with a net larger growth in positive attitudes (4 and 5) – similar to the general faculty population.

IV. CONCLUSIONS

Returning to the research question posed at the start of this manuscript, it appears that inclusion of outreach and engagement among the criteria to be recognized for tenure and promotion may have a positive impact on faculty members’ attitudes with respect to STEM education. The most significant impact appeared to be on the new faculty. New faculty are likely to be more aware of current tenure and promotion

procedures than are their more senior counterparts. New faculty reported being more likely to have participated in STEM outreach and to be planning to participate in such activities in the future. They also reported feeling better prepared to mentor undergraduate students, including older, non-traditional students.

Encouraging trends for the general faculty came in the form of an increased awareness of administrators’ inclusion of STEM outreach during faculty evaluation. The general faculty also reported the belief that fellow faculty understand the benefits of STEM outreach. Based on the outcomes of this survey, faculty morale was not negatively impacted by the administrative changes. In general, new and general faculty reported a relatively high morale for both surveys.

These results indicate that universities seeking to improve STEM engagement and outreach should consider explicitly adding such activities to the criteria for tenure and promotion. Doing so demonstrates to the faculty member that STEM outreach is valued by the institution and thereby alleviates concern that outreach is being done at the expense of the faculty member's professional advancement. Under this model, outreach would not be treated as an add-on but rather as a regular component of the academic promotion process.

ACKNOWLEDGMENT

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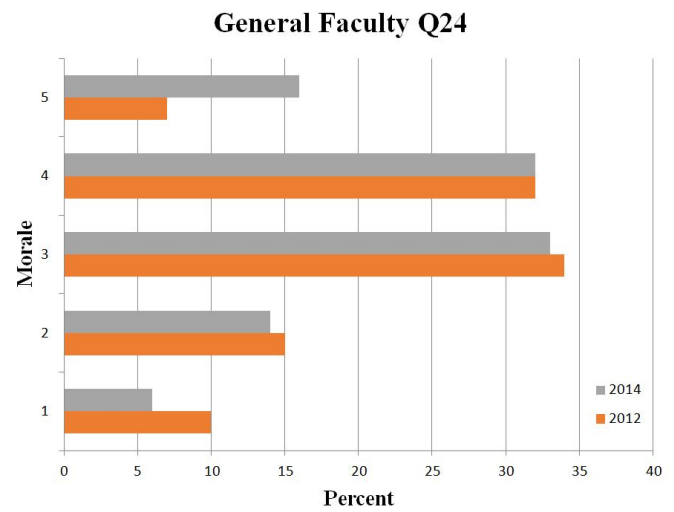
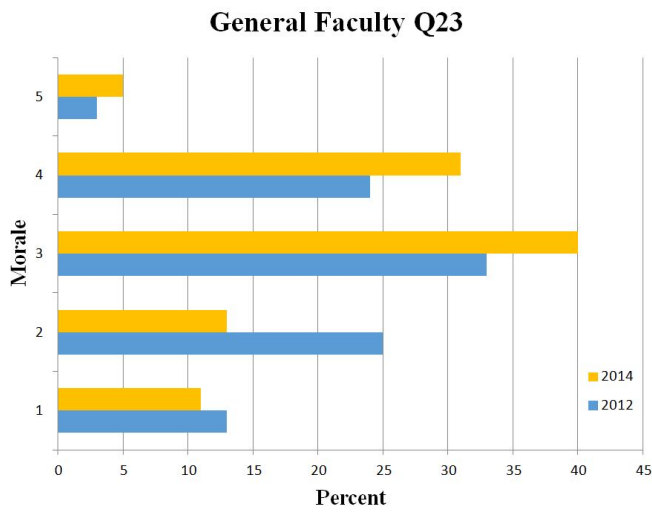


Fig. 2. Percent response for a given morale value (1-5) for 23 and 24 for both 2012 and 2014 for the general STEM faculty. Note how both graphs demonstrate a positive shift over the 2 year period measured.

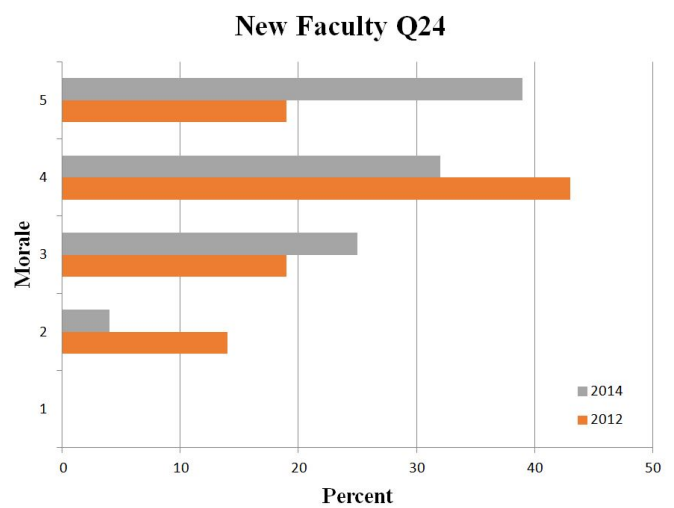
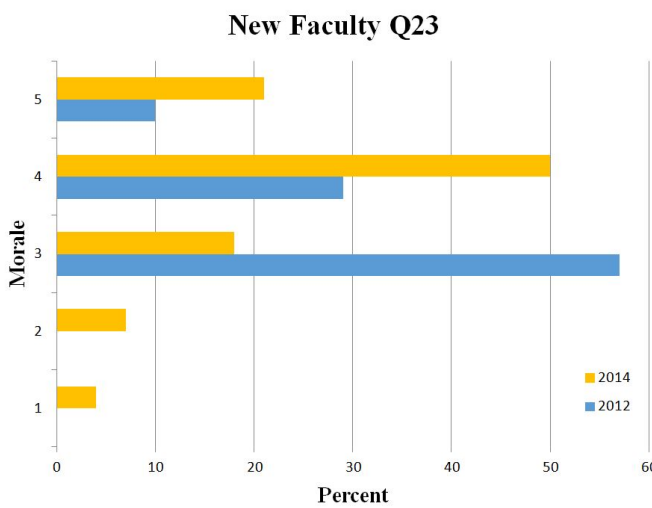


Fig. 3. Percent response for a given morale value (1-5) for 23 and 24 for both 2012 and 2014 for new STEM faculty. Note how both graphs demonstrate a positive shift over the 2 year period measured.

Using Flipped Classroom, Peer Discussion, and Just-in-time Teaching to Increase Learning in a Programming Course

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Abstract—In this paper we report on an experiment conducted in an attempt to improve further the learning environment in a basic campus course on Object-Oriented Programming and Design given to first-year engineering students studying Computer Science and Engineering. This course has for years had the same traditional set-up that is common also in other engineering schools around the world including lectures, mandatory programming assignments, and a final written exam. What we did was to substitute the lectures for in-class sessions based on a variant of the teaching method known as "flipping the classroom" combined with certain elements of Peer Discussion and Just-in-time teaching. To make all this work, we introduced a web-based MOOC tool into the course.

To be able to investigate the quantitative effects of our experiment, we had an experiment class consisting of 70 students taking the course in this new way and a control class of 57 students taking the course in the traditional way. On the final written exam, which was identical for the two classes and marked the same way, 81% of the students in the experiment class passed compared to 60% in the control class. Moreover, the share of students passing with good grades was 58% in the experiment class compared to 32% in the control class. So, not only did the share of students passing the course increase by a third, but also the share of students passing with good grades almost doubled.

Index Terms—Computer science education; engineering education; programming; blended learning; active learning; flipped classroom; peer discussion; just-in-time teaching.

I. INTRODUCTION

For more than 10 years, we have offered a basic campus course on Object-Oriented Programming and Design to first-year engineering students studying Computer Science and Engineering. This course has the same traditional set-up as is common also in other engineering schools around the world. It consists of lectures, mandatory programming assignments, and a final written exam. A course web page provides links to course material and information. The course has always been greatly appreciated by not only students but also involved professors and assistants. The only issue with the course is that, despite all praise, many students fail the examination.

In an attempt to improve matters, we conducted an experiment in which we introduced a web-based MOOC (*Massive Open Online Course*; see Ref. [1] for an overview) tool [2] and a variant of the teaching method known as "flipping the classroom" [3], [4] into the course. In short, the main idea with this method is that, rather than attending traditional

lectures, students learn course content on their own by watching recorded videos while activities traditionally considered homework, such as solving problems, is instead done in class. We changed the course in this manner, also interleaving numerous multiple-choice questions into the videos and adding elements of Peer Discussion and Just-in-time teaching [5] to the in-class sessions.

We recorded 140 videos (comprising more than 20 hours of screencasts) and grouped them into blocks roughly corresponding to the old lectures. To each in-class session, suitable problems were authored, printed, and bundled into handouts for students to work on in groups. Based on statistics provided by the MOOC tool, we could adapt the in-class sessions and prepare feedback/clarifications on content many students had misunderstood. Apart from working on solving problems, students also actively discussed pros and cons of randomly selected (and anonymized) student solutions.

To be able to investigate the quantitative effects of our experiment, we had an experiment class consisting of 70 students taking the course in this new way and a control class of 57 students taking the course in the traditional way. Both classes covered the same course content. Students were subject to the same requirements to pass. They were eventually given the same final exam, which was marked and graded in the same way. The only difference was the way the classes were taught.

On the final exam, 81% of the students in the experiment class passed compared to 60% in the control class. Moreover, the share of students passing with good grades was 58% in the experiment class compared to 32% in the control class. So, not only did the share of students passing the course increase by a third, but also the share of students passing with good grades almost doubled.

In the next section, we go through related work and underlying theory. In Section III we then describe the course and in the subsequent section we present the experiment and the two different ways the course was taught. Well-versed readers, mostly interested in the results of the experiments and their implications, can skip directly to Section V and the discussion in Section VI.

II. THEORY AND RELATED WORK

The teaching we studied is based on *Constructivism* (see, for instance, Biggs [6]) where the idea is that students construct their own understanding and knowledge of the world, through experiencing things and reflecting on those experiences, and *Active Learning* which has been described as "anything that involves students in doing things and thinking about the things they are doing" [7]. One such teaching approach, that in its modern form dates at least from the early 1990s, is the *flipped classroom* [3], [4]. Here, students are activated at home, where they learn the course material on their own, as well as at in-class sessions, where they carry out what is traditionally regarded as homework such as solving problems.

Flipped classroom as we used it in our experiment is an example of *Blended Learning* [8] where face-to-face teaching is combined with computer mediated teaching. Out-of-class, students watched recorded videos introducing course content and answered short quizzes using a web-based MOOC tool [2]. The use of videos in flipping a classroom is seen as positive by students [9]. Previous research also suggests that video lectures is at least as good as in-person lectures with respect to the effect on learning, and that interactive on-line videos in fact outperform in-person lectures [10]. The in-class sessions (see Section IV-C2) were inspired by *Inductive Learning* [11] where students learn from examples and "notice" general concepts. The design of these sessions were partly influenced by how the students as a group did on the quizzes while watching videos. Such last moment adaptation of the teaching to better fit the need of the students is an example of *Just-in-time teaching* [12]. The actual instruction was inspired by *Visible Learning* [13] in that the professor, for instance, a) defined clear goals and criteria for achieving these goals, b) was clear about organization, explanations, examples, procedures, and assessments, and c) built honest and trustful relations to the students by respecting their different backgrounds, listening to them, and showing empathy and attention. The idea is that the student's confidence in the professor creates a feeling of security, and that this leads to better results. The literature contains quite a few studies of flipped classroom and also some on using this technique in Computer Science related courses [14]–[20]. Our work complements these studies by combining flipped classroom, peer discussions, and just-in-time teaching.

III. COURSE DESCRIPTION

The course, known as *D0010E Object-Oriented Programming and Design* [21], earns the student 7.5 ECTS¹ credits once completed. The course is given in Quarter 3, a roughly 10 week long period that starts in January, and designed so that the typical student spends a total of 200 hours (1200 minutes)

¹The *European Credit Transfer and Accumulation System* [22] aims to harmonize higher educations in Europe.

D0009E Introduction to Programming	M0009M Discrete Mathematics	D0010E Object-oriented Programming and Design	D0011E Digital Design
D0015E Computer and Engineering Science	F0004T Physics 1	M0029M Calculus	M0030M Linear Algebra and Calculus
Q1	Q2	Q3	Q4

Fig. 1. Courses in Year 1 of the MSc/BSc degree programs in Computer Science and Engineering and the order in which they are given. Q1, the first quarter of study, starts in September, while Q4 ends in June.

studying in class and at home².

The course is an introductory course on the bachelor's level and part of our MSc and BSc degree programs in Computer Science and Engineering [23], [24]. These educational programs, which last for 5 and 3 years respectively, are officially accredited under public Swedish law [25] and highly inspired by the ACM/IEEE Curricula Recommendations [26]. The course is part of an "early CSE start" during the first two years of study created to ease the transition of first-year students in our degree programs into engineering studies [27]. The Fall semester, that precedes D0010E, starts with a course on programming and a course introducing the vast area of Computer Science and Engineering. This is followed by courses on Discrete Mathematics and Physics (Fig. 1).

A. Entry requirements

D0010E requires that the student has previously completed an introductory course on programming. This course need not, but should preferably, introduce structured/procedural programming so the student is familiar with fundamental computer programming concepts and can put together small solutions to simple computational problems using an imperative programming language.

B. Course aim

After the course, the successful student

- has knowledge about the scientific foundation of object-oriented programming and design as well as the proven experience gathered by programmers in this field of computer science;
- is able to carry out teamwork, where programs are designed and implemented through collaboration, both in groups where the students choose themselves whom to work with and in groups put together by others;
- can create, analyze, and critically evaluate various technical solutions in terms of the design and implementation of large computer programs by using a modern object-oriented programming language;

²In Sweden, one week of full-time study amounts to 40 hours of work and grants the successful student 1.5 ECTS credit. At our university, students normally take two courses in parallel, studying 20 hours per week in each course.

- can plan and use appropriate methods to undertake programming tasks faithful to given specifications.

C. Course content

As its name suggests, the course stands on two legs: a programming part and a design part. As these parts obviously depend on each other, when larger programs are to be created, they are in practice interwoven through-out the course.

1) *Part A: Object-oriented programing*: The first part is broad and concerned with the construction of computer programs using the basic constructions offered by modern object-oriented programming languages. Students learn how to encapsulate methods and data structures into what will be objects at run-time and implement these objects as classes based on inheritance, a mechanism for reusing code and defining types, effectively creating reusable polymorphic program parts. Topics include

- core concepts like objects (integrating code and data), classes (defining types), and inheritance (relating types and promoting code reuse);
- programming techniques based on modularization, encapsulation and information hiding;
- basic algorithms (for sorting and searching) and linked (recursive) data structures (lists, trees, and graphs);
- error-handling through both the use of rigid type systems to catch errors at compile-time and exceptions to catch errors during run-time;
- Java [28], an object-oriented programming language;
- well-known parts of Java's standard library, their use and implementation;
- graphical user interfaces (GUI:s) in Java;
- Eclipse [29], an industry-grade integrated development environment.

2) *Part B: Object-oriented design*: The second part is smaller than the programming part and introduces tools to the student to more easily create large programs working individually as well as in groups. By "large" is meant a computer program whose implementation is so intricate and full of detail that individual programmers can not be expected to keep it all in their minds. Moreover, the program is developed by several programmers working in parallel now as well as in the future to maintain and further develop the program that is assumed to never be completely finished. While no program in the course really meets this definition, students are still prepared and taught how to cope with the implementation of such programs. Topics include

- modeling of classes using *Unified Modelling Language* (UML) [30] as a tool for visualizing overall program design and aid development among programmers;
- informal reasoning based on *abstract data types* (ADT:s) and the use of contract programming (*Design by Contract*) with preconditions, postconditions, and invariants;
- basic (software) design patterns;
- external and internal documentation, typically producing webpages based on *Javadoc* for external documentation

and decorating code with internal comments for implementation specific documentation.

D. Assessment

The examination consists of five (practical) laboratory assignments with deadlines roughly every two weeks and a final written (theory) exam at the end of the course. Students are expected to spend 120 clock hours (60% of the total time devoted to the course) on practical work while the remaining 80 clock hours (40%) should be spent on learning theory.

The laboratory assignments are concerned with the implementation of object-oriented programs. Two assignments – the first and the third – are carried out individually while students carry out the other three in groups. The assignments are graded (just pass or fail) in the laboratory where students demonstrate their solutions and are questioned by the either the professor or a laboratory assistant (a last year student).

- 1) The first assignment is a crash course on Java and Eclipse in which students program static programs with no explicit creation of objects. In steps, students program and evaluate recursive programs to test *Collatz conjecture* [31] and perform exponentiation by squaring.
- 2) In Assignment 2, students are fully exposed to objects and create a simple GUI in which lines and colored rectangles drawn on a canvas represent rectangular "rooms" on a level in a building. The rooms being interconnected by one-way corridors, students effectively implement a directed graph with operations to insert and visualize new arcs (corridors) and nodes (rooms).
- 3) Assignment 3 has a cover story in which the student works in a team at a software company and gets to implement two classes as part of a larger program whose remaining parts have already been written by (imaginary) team members. The student is not handed code but only an abstract specification of the program given as a UML diagram and abstract data types.
- 4) In the 4th assignment, students implement a networked board game (*Gomoku* or *Five-in-a-Row*) for two players with an interactive GUI. Students get the networking code but must figure out how to program the clients.
- 5) Finally, the 5th assignment is to implement a general discrete event-driven simulator from scratch. The actual implementation is preceded by a design step the students must complete in order to get permission to go on with the implementation.

In contrast, the exam is given once and at the end of the course. Although it is primarily on the theoretical content of the course, it also asks the student to write down solutions in the form of (short) programs that solves computational problems and/or implement basic data structures in suitable ways. The exam is "closed book" and usually contains 5-6 problems, where some problems might consists of subproblems. Students have 5 hours to complete the exam using pen and paper only.

IV. THE TEACHING EXPERIMENT

In this section, we present the two fundamentally different ways to teach the course we are comparing in this paper. We do this in terms of the two actual classes, one being the *control class* (Class C) and the other the *experiment class* (Class E), that were given in the experiment and taught in the two different ways. To be precise, by *course* we mean a discrete study unit defining entry requirements, content, aim etc. By *class*, on the other hand, we mean a particular instance of a course given a certain time period for a specific group of students and with assigned professors, class rooms, laboratory space etc. Our two classes hence covered the same content and had the same examination, as outlined above. They were given in isolation from each other. Our aim in the experiment was to study how Class E did in relation to Class C.

A. Common to both classes

There were great similarities in how the classes were taught.

- The classes lasted 10 weeks and were taught by the same professor.
- They had the same laboratory assignments scattered over 35 practical laboratory sessions (each lasting 2×45 minutes) scheduled in computer laboratories and under the guidance of the professor and a varying set of laboratory assistants³.
- While the examination was mandatory and had deadlines students had to meet, participation in teaching activities (including laboratory sessions) were optional.
- Students in both classes had access to a simple course webpage that was written and maintained by the professor as the course proceeded. This page served as a connection point and information central for the students, and contained lecture slides, laboratory instructions, dead-lines, extra material etc.

B. Specific to the control class

This class had 57 students and was taught in a traditional manner with a total of 17 lectures (also lasting 2×45 minutes each) given by the professor using AV-equipment (no writing on blackboards) a couple of times each week through the quarter. Apart from the laboratory assignments there was no formal homework. Students were expected to read ahead in the course book, including the exercises, but no effort was made to ensure this.

Since the course had been given like this by the professor for more than 10 years, during which the course and presentation material had successively been refined, there was no real need to adopt the material further or to create new material.

C. Specific to the experiment class

The new way of teaching was carried out in the Class E and called for substantial preparatory work that essentially meant two changes compared to how Class C were taught. The first

was to substitute lectures with recorded interactive videos. The second was to introduce so called problem sessions.

1) *Videos*: For each of the lectures of Class C, except the first and the last, a set of videos was recorded based on the powerpoint slides and thus covering the same topics as the lecture. These videos were made as screencasts with the professor explaining theory and concepts while going through the slides and running demos of program snippets in Eclipse as illustrations. The average length per video was 9 minutes and a total of 140 such videos were recorded, edited, and assembled into what we call *interactive video lectures* (IVLs). In total, 15 such lectures were created.

Videos were organized into IVLs using the web-based MOOC tool [2]. Such a lecture consisted of 8-9 videos (on average). Watching a video was much like watching a video on the video service *youtube* [32]. In fact, the videos inserted into the MOOC tool were stored in *youtube* and just embedded in the tool to provide some extra options like the ability to, by a single click on a button, mark a section that was experienced as confusing or not very clearly explained.

We also created a total of 143 multiple-choice questions on the content. The MOOC tool made it possible to not only group videos into IVLs but also to interleave such questions into the videos and at specific times. This had the effect that when a student watched a video and reached a question, the viewing automatically stopped, the question was displayed, and the student was asked to pick an answer. If the student picked the right answer, the viewing was continued. If not, the student got a new chance. This, of course, made it possible to pass a question by guessing but that did not matter since the questions were not marked and did not influence the final grade the student got. The purpose of the questions was to re-enforce learning and make students reflect on what was presented. Being fully interactive, students could navigate freely and watch previously seen videos at any time, also when picking an answer.

2) *Problems sessions*: To each of the 15 IVLs, a so called *problem session* was setup and subsequently scheduled so that students had ample time to go through the IVL before the problem session. To each session, an average of 7 problems were authored. These were selected to illustrate the topics in the corresponding IVL. All problems were printed and distributed to the students as handouts at the corresponding problem session.

The reason students got paper copies of the problems was to make it simple to collect solutions and put them on display. Each problem was presented on a paper sheet printed in landscape mode and single-sided. The left half of the sheet contained the problem statement and the right half was deliberately left empty so students could write their solutions (and make notes) there. The backside of the paper was intentionally kept blank so students could write their names there should their solutions be reviewed. This made it possible to display a solution without revealing the name of the author and still be able to return solutions to their authors. By collecting $k \geq 3$ solutions, mixing them randomly, and then

³Assistants attended different laboratory sessions in a rather random pattern depending on when they did not have classes to go to themselves.

showing the students only $k-1$ of them, it was possible to keep the identity of the author of each displayed solution a secret. Anonymity increased the willingness of students to hand in their solutions so we could discuss them in class. Again, the purpose was not to mark and grade but to enable a fruitful peer discussion where students and (to some degree) the professor together commented on and criticized the solutions in public.

The room used for the problem sessions had the following crucial equipment: Two screens out of which one was connected to a document camera and the other was connected to a laptop. A problem session was carried out as follows.

Upon entering the room, students got a copy of the problem bundle and seated themselves next to fellow students they liked to work with. Seating was free but, as shown in Fig. 2, where a student decided to sit was still important because students were grouped into groups of three based on where they sat in the room. Although not required to actively cooperate, this seating arrangement was in place to motivate and make cooperation natural among the students. The professor repeatedly reminded the students to discuss in their groups (which students then typically did, to a higher degree, once reminded to do so).

The actual problem session started with a short introduction where the professor, based on statistics over student performance with the quizzes in the IVL, brought up issues and things a large proportion of the students had misunderstood. Via the MOOC tool it was possible to get a full screen that displayed a quiz question together with a histogram that plotted the answering alternatives against the share of students that had answered the various alternatives and with the correct answer pointed out. In addition, the professor could choose to answer questions asked by students while they viewed videos.

Then the following was repeated as long as there were unsolved problems in the bundle:

- The professor asked the students what problem, of those remaining, they liked to work on. It could also be, especially in the beginning, that based on student performance in the MOOC tool, the professor made the initial picks as to make sure problems essential to the whole class got worked on.
- The professor put the problem on display using a laptop connected to a video projector so all students could see.
- The professor then announced an amount of time, typically 8-10 minutes, during which students were to work on the problem in their groups, solving and writing down a solution while discussing. To make the time clear to everyone, a countdown timer was put on display on the laptop screen. To set a specific time like this was just done to have a deadline to work against. If more or less time was needed, the deadline was adjusted accordingly.
- While the students worked, the professor circulated in the room answering questions and helping students out.
- When time was up, or the professor felt many students were done, the professor called for solutions to show and discuss. To volunteer a solution was optional.
- Once at least three solutions had been collected and mixed randomly, so that no one knew who wrote which

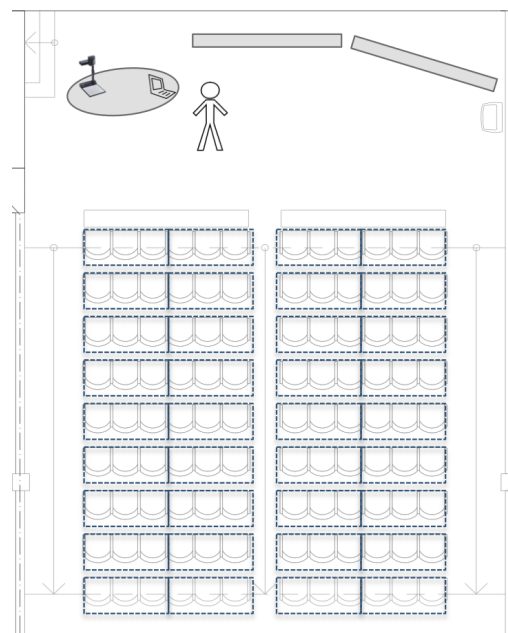


Fig. 2. Schematic view of how in-class problem sessions were carried out. Working in front of, on the sides, and along the aisle of the 108 seats making up the class room, the professor displayed problems and solutions as well as provided help to students. Shown is also how students were grouped three and three based on seating.

solution, they were put on display – one at a time. The students got to discuss the presented solutions first in their groups and then in the entire class. The latter amounted to students commenting on the solution, and each others comments. The main role of the professor was to be an enabler and get this discussion going but also to take active part and add to the discussion, if needed.

- When all solutions except one had been scrutinized this way, all solutions were once again mixed and then handed back to the students. Keeping authors of solutions unknown to the whole student group was essential to have students also volunteering solutions they were not particularly proud of and/or solutions they knew contained errors. Such partly incomplete, slightly erroneous, and even directly unsuitable solutions were, of course, still valuable to discuss.

Attendance at problem sessions was optional. Students that attended did not have to actively work on the problems. If they liked, they were welcome to just sit in passively and take notes. However, it turned out that if students attended, they also took some active part.

V. RESULTS

The experiment was conducted by giving the course in the traditional way for the control class (Class C) and in the new way for the experiment class (Class E). Class C had 57 students while 70 students took Class E. All the students had very similar educational backgrounds and abilities. The average grade point average of Class C when applying to university (a number between 10 and 20) was 16.71 with a

TABLE I
RESULTS ON THE FINAL EXAM.

Class	Size	Result			
		Fail		Pass	
		Number	Share	Number	Share
C	57	23	40%	34	60%
E	70	13	19%	57	81%

standard deviation of 1.78 while the average in Class E was 16.78 with a standard deviation of 2.46. Moreover, on the Swedish SAT⁴ the students in Class C, that had taken the test, on average achieved 1.039 (out of 2.000) with a standard deviation of 0.268 while the average in Class E was 1.053 with a standard deviation of 0.306.

Afterwards, data was assembled from different sources and summarized to be able to follow-up on the effect the new way of teaching might have had. These sources were the results on the final exam, levels of participation in problem sessions and IVLs, and statistics based on standardized questionnaire-based course evaluations students filled out directly after the course.

A. The final exam

Both classes were given the same exam which consisted of 5 problems that were to be solved individually using pen and paper only. The problems were on the following topics.

- 1) Theory and concepts.
- 2) Iterative and recursive methods (computing substrings).
- 3) Container classes (a class for a hand of playing cards).
- 4) UML class diagrams making up an inheritance hierarchy and short written specifications (create classes representing different kinds of vessels).
- 5) Linked data structures with inner nodes (a circular list).

To pass the exam, a student had to get at least 50% of the maximum score. The number of, and the share of, students failing and passing in each class is tabulated in Table I. While 60% of students in Class C passed, no less than 81% passed in Class E. Students that passed got a grade that increased with the number of correct solutions. Grades 3 (*satisfactory*), 4 (*good*), and 5 (*very good* – the best possible) were given for achieving 50, 66²/₃, and 83¹/₃ percent of the maximum score respectively. In Figure 3, the share of students in the two classes that got these grades can be seen. Note that the share of students that passed with good grades (4 and 5) was almost twice as large in Class E as in Class C. Furthermore, each problem gave between 0 and 6 points so the maximum result on the exam was therefore 30 points. Table II presents statistics on how these points were on average awarded per problem. For each problem, μ stands for the arithmetic mean of the points awarded and σ denotes the standard deviation. What this reveals is that the average number of points awarded to the students in Class E was at least half a point higher than the points awarded in Class C and this regardless of which problem we consider. A last detail we investigated was the

⁴This test is optional and, while a good result can make it easier to gain admission to higher education in Sweden [33, pp. 9], not all students take it.

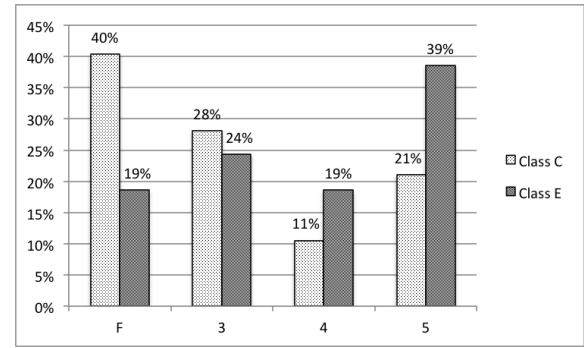


Fig. 3. Grade distribution. Grade F (*fail*) is given for achieving no more than 49 percent on the exam. 3, 4, and 5 are the passing grades.

TABLE II
AVERAGE NUMBER OF POINTS AWARDED PER PROBLEM (μ) WITH STANDARD DEVIATION (σ).

Class	Problem number									
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
C	3,7	1,6	3,3	2,3	3,7	1,8	3,7	1,8	3,4	2,4
E	4,7	0,8	4,0	2,0	4,1	1,8	4,2	1,5	3,9	2,4

TABLE III
NUMBER OF OMITTED ANSWERS.

Class	Problem number					In total
	1	2	3	4	5	
C	0	4	10	11	18	43
E	1	2	2	2	9	16

tendency of students to hand in problems. Table III details these numbers and shows that students in Class C omitted to hand in far more solutions than students in Class E.

B. Participation

The second source of data was participation, by which we mean attendance at problem sessions and number of IVLs completed. Table IV shows average participation (μ) and standard deviation (σ) for each of the two activities as well as both of them combined into one (new) teaching activity. The MOOC-tool had a built-in subsystem that tracked for each student his or her progress in the system. The participation statistics regarding the completion of IVLs was extracted from this subsystem. As for the numbers concerning the attendance at problem sessions they were based on the 11 last sessions. The attendance at the first four problem sessions are unfortunately missing and as a result these numbers are probably a bit too low to reflect the total attendance at all problem sessions. These numbers were acquired manually by the professor by having the students sign a list at the problem sessions.

C. Course evaluations

A third source of data came from the standardized questionnaires the university have the students fill out after each quar-

TABLE IV
AVERAGE PARTICIPATION IN CLASS E PER ACTIVITY MEASURED (μ) WITH STANDARD DEVIATION (σ).

Result	Participation					
	Problem sessions		Interactive video lectures		In total	
	μ	σ	μ	σ	μ	σ
Fail	3,7	3,2	4,4	4,5	8,1	6,7
Pass	6,2	4,2	9,9	5,5	16,1	8,0

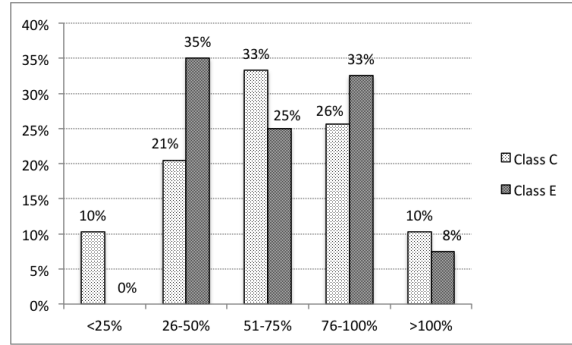


Fig. 4. Students' estimation of time spent. Spending 100% means 20 clock hours per week (the nominal amount a student should spend).

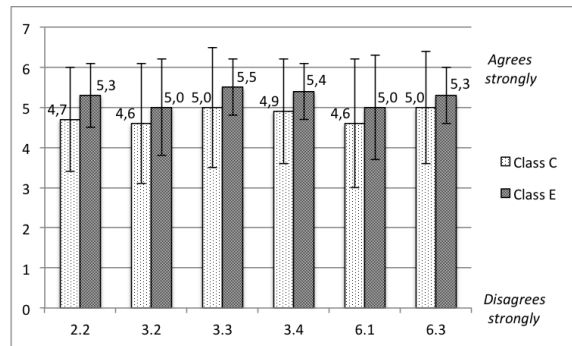


Fig. 5. Numbers (arithmetic means) showing how well students agreed with the statements from the questionnaire-based course evaluations listed in Table V. Answers could range from 0 (*Strongly disagree*) to 6 (*Strongly agree*). Error bars show standard deviations.

ter, if they like (it is not mandatory). In Class C, 47 students filled out the questionnaire and in Class E the questionnaire was filled out by 40 students. From the automatically compiled summaries of these questionnaires we chose to include in this paper only the top relevant statistics needed to be able to substantiate, at least to some degree, how students experienced their class and what they thought of it. These were the time estimates (Figure 4) and student opinions (Figure 5) on the statements listed in Figure V. On each of the questions, the students in Class E agreed more than the students in Class C⁵ even though none of the classes spent significantly more time studying than the other class.

⁵In fact, they agreed to a higher extent not only with these statements but all statements.

TABLE V
SOME RELEVANT STATEMENTS FROM THE COURSE EVALUATIONS.

Item	Statement
2.2	The contents of the course help to achieve/meet the course's aims.
3.2	It has been worthwhile attending the lectures.
3.3	The (practical) labs have been worthwhile.
3.4	The learning platforms/e-learning resources have been satisfactory.
6.1	The course workload is appropriate for the number of credits given.
6.3	My overall impression is that this was a good course.

VI. DISCUSSION

So, what does all of this tell us? What did the new way of teaching the course lead to?

A. The final exam

To start with it is clear from the results on the final exam (Table I) that Class E did better than Class C. In the class taught in the new way, the share of students that passed was up over 30% (from 60% to 81%) compared with the class taught in the traditional way. The grades also increased. As can be seen in Figure 3, this is in particular the case for the high grades awarded where 32% of students in Class C did well, and achieved grade 4 and 5, while the corresponding share of students was 58% in Class E. At the same time, the percentage of students achieving just a pass (grade 3) was roughly the same in both classes. This indicates that the new way to teach was not only superior in respect to the share of students that passed but also increased the performance of those students so that an almost twice as large a share of them managed to get good grades.

Another aspect is how the results on individual problems were affected. The numbers in Table II show that, on each problem and on average, Class E did at least half a point better than Class C. In fact, the improvement was larger on the first, simpler, problems compared to the improvement on the later, harder, problems. This indicates that learning was increased over all topics and subjects covered by the exam, and not just limited to some. Moreover, the standard deviation stayed the same or decreased. This also suggests that Class E performed more uniformly than Class C.

Yet an interesting detail is that students in Class C omitted to hand in substantially more solutions than the students in Class E (Table III). In relation to class size, in Class C students did not hand in $43/(57 \cdot 5) = 15.1\%$ of the solutions. In Class E, on the other hand, students omitted to hand in only $16/(70 \cdot 5) = 4.6\%$ of the solutions, or less than a third of what was not handed in i Class C. This could, perhaps, be seen as an increase in self-confidence in Class E when it comes to attempting to solve and hand in solutions. However, another explanation is that this is yet a symptom of the increased learning that took place in Class E. A student that knows more, and is more able, needs to spend less time coming up with solutions and are therefore likely to produce more and better solutions. We see also that fewer solutions were handed in on the harder problems than on the simpler ones. This can be explained by the fact that while wild guessing is possible on

simple theory questions, it is extremely hard (impossible) to guess at random when intricate code is asked for. All in all, we see this also as a sign of increased learning in Class E compared to Class C.

B. Participation

So far we have compared Classes C and E to argue that learning was better supported in Class E. Now, we will argue that within Class E, the difference between a successful student and a student that failed had to do with the level of participation in the new teaching activities. If we count the number of attended problem sessions and the number of completed IVLs (Table IV), we see that the students that passed did on average almost twice as much as the students that failed. This is to be expected since everything else is, as far as we know and in general, equal. For instance, laboratory work had to be completed on time and this students did (in both classes). However, one should note the relatively high standard deviations that means there was a large variation in what individual students actually did. We still interpret the numbers as indications of a positive, although weak, correlation between participation in these new teaching activities and good result on the exam.

C. Course evaluations

Turning to the course evaluation, we see that despite the difference in the results there was little difference in the time spent by students in the two classes (Figure 4). Only a small fraction of the students (8-10%) spent more than the 20 clock hours per week a student should spend when taking this course. It is only in Class C that some students did as little course work as 25% of what they were expected to do. Apart from this it is hard to differentiate between the two classes given the coarse-grained statistics (intervals of size 25%) available from the course evaluation system. Just looking at the histogram, one might think Class E on average worked more hours than Class C but that is a premature conclusion. Going to extremes, assuming all students in Class C worked as much as possible (so their time estimates all ended up on or near the upper interval boundaries) while students in Class E worked as little as possible (and their estimates ended up at the lower interval boundaries), students in Class C spent on average 12.7 hours per week and students in Class E spent 9.3 hours. If it instead was the other way around, so that hours in Class C were minimal while those in Class E were maximal, Class C spent on average 8.4 hours and students in Class E spent 13.8 hours. The truth lies somewhere in between these extremes but with no more data it is hard, if not impossible, to say exactly where. The observation we make, though, is that there is no overly dramatic difference between the classes. Students in both classes spend roughly the same time on the course and, more importantly, roughly the same share of students (90-92%) spend no more time than they should.

Finally, considering the class sizes (which are moderately large for our university) and comparing with other courses of the same sizes, both classes agreed to a remarkably high

extent with the statements in the course evaluation (Table V). However, Class E consistently agreed more than Class C (Figure 5), which indicates that students in Class E found the course more meaningful and rewarding than the students in Class C. Interesting is also the fact that the standard deviations were smaller for Class E than Class C in all cases. This shows a higher tendency in general of students to appreciate being taught in this new way rather than in the traditional way.

VII. CONCLUSION

By substituting traditional lectures for interactive video lectures and in-class sessions based on a variant of the teaching method known as "flipping the classroom" combined with certain elements of Peer Discussion and Just-in-time teaching, we have shown how learning can be increased in a course on object-oriented programming and design. Key to this result was the use of a web-based MOOC tool, for the efficient handling of the interactive video lectures, and the introduction of hands-on problem sessions into the course rather than passive lectures.

On the final exam, 81% of the students in a class taught this new way passed compared to 60% in a class taught in a traditional way where theory was taught with lectures only. The share of students passing with good grades increased to 58% compared to 32% in the class with lectures. So, not only did the share of students passing the course increase by a third, but also the share of students passing with good grades almost doubled. The increase in learning occurred on all topics and subjects covered while students spent roughly the same time on the course as before. Moreover, students appreciated to a higher extent the new way of teaching than the traditional way. All this naturally came with a price. Producing new teaching material, like videos and meaningful problems, took on average 20 clock hours per IVL and follow-up problem session. Over 300 clock hours was spent on developing this new way of teaching the course. So, from a purely economical point of view, this rather high initial development cost can probably only be justified in courses with large class sizes or courses with moderately sized classes that are given very often.

One reflection is that the students' participation in the new teaching activities was on average quite low. It would be interesting to find ways, meaningful from a learning point of view, to improve participation and see if this also further improves learning. It would also be interesting to follow up on how the students did afterwards, in other courses, to determine whether this new way of teaching has any particular long term effects.

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Learning Programming with Peer Support, Games, Challenges and Scratch

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Abstract—Helping college freshmen to learn basic computer programming is a longstanding research topic. Various environments, tools and languages have been developed to ease the initial steps of novice programmers. However, to be used to their full extent, such artifacts should be better combined with an appropriate learning approach. This work describes pre-term workshops offered to Computer Engineering undergraduate freshmen that combines the use of the Scratch learning environment with a learning approach based on peer support, game development and a strategy of challenge-response. Results are derived from quantitative data analysis: surveys and artifact analysis. Students evaluated the workshop well: they found it stimulant, lightweight, with good teaching, useful, well-organized, and conducive to learning. Results suggest the effectiveness of the approach to reduce initial difficulties for freshmen learning programming concepts.

Keywords—peer learning, programming, environments for novices, Scratch, game-based learning, challenges.

I. INTRODUCTION

For years, undergraduate computing programs have faced the challenge to teach programming to freshmen with no previous background in the field [1]. A large variety of concepts and skills is usually required, ranging from algorithmic thinking to expression in a formal language, from data structures to mastering an IDE [2]. To make matters worse, faculty typically adopt a formal approach that is usually detached from students' worries and preferences.

Previous work is prolific with alternative approaches to teach college introductory programming, especially with environments geared to the novice [2], [3]. Among such environments, Scratch is one of the most popular, originally conceived to be used by both children and teenagers, and based on design decisions that make the environment more tinkerable, meaningful and social [4].

Nonetheless, even the most well designed environment may be misused if not accompanied by appropriate teaching and learning approaches. To us, students benefit more from learning environments when an active learning approach is used. For two years, we have been perfecting an approach that combines the use of Scratch, peer support, a strategy of challenge-response, and game development. We have also applied this approach by means of freshmen workshops, usually a week before the academic term starts.

In this paper, we describe one of our latest workshops, a one-week, 20-hour pre-class workshop with freshmen of a Computer Engineering program in a state university in Brazil, offered in August 2014. The workshop intended to overcome the initial difficulties with programming that students face. Three sophomore peer students guided the workshop presented to 18 freshmen. The challenges proposed led to the gradual development of an animation in Scratch, and three classic games: Pong, Bow and Arrow, and Space Invaders. One last challenge was the development of a simple calculator to allow a smooth transition from Scratch to the C language. To evaluate our approach, we used a quantitative approach based on artifact analysis, i.e., the projects students produced, and two surveys: one right after the workshop was over, and another one month after the term started, when students finished their first project in the CS1 course¹.

Students evaluated the workshop well in various criteria: they found it stimulant, lightweight, with good teaching, useful, well-organized, and conducive to learning. Students considered stimulant the active and playful learning approach. They also evaluated Scratch as having a friendly user interface and simple working logic, especially the Lego-style block fitting. The most used blocks were interface commands (Appearance), selection and repetition structures (Control), and movement commands (Motion), which were also the ones students asserted as less difficult.

Even though most students were not using Scratch after the workshop, 70% of them asserted that the tool helped a lot to learn programming. Especially regarding selection and loop structures, 80% agreed that, to some degree, the workshop helped them to develop their first project in the CS1 course. This seems remarkably relevant since these are concepts usually hard to grasp in regular courses. On the other hand, the same did not happen with the use of variables. Though used in the games, they were not the main student concern when answering the challenges.

Results point to the effectiveness of an approach based on game development, a challenge-response strategy, peer support and programming environments for novices. The gathering of empirical evidence in this work also contributes to the field, helping to better evaluate learning initiatives and tools.

This paper is organized as such: Section II discusses

¹CS1 is the name usually given to the computer science introductory programming course.

the background for this paper and related work. Section III describes the research methods used. Then, Section IV presents results, followed by a discussion in Section V. Conclusions are derived in Section VI together with suggestions for future work.

II. BACKGROUND

In this section, we describe related work on causes for dropout and failure in CS1 courses, on programming environments for novices, and on guidelines and alternative initiatives in introductory programming courses.

A. Causes for dropout and failure in programming courses

Why is programming hard to learn? This question has been thoroughly pursued by the community of computing education for around five decades. Robins et al. surveyed the topic and describe differences between novice and expert programmers and between effective and ineffective novices. They also describe the complexity of the problem by devising a programming framework based on knowledge, strategies and mental models needed to design, generate and evaluate programs [5]. Program design involves knowledge of planning methods and algorithm design, strategies for planning and problem solving, and models of problem domain. Program generation requires knowledge of languages, libraries and tools, strategies for implementing algorithms and for coding, and models of a desired program. Finally, program evaluation requires knowledge of debugging and testing tools and methods, strategies for testing, tracing and repairing, and models of an actual program.

A survey among 67 higher education institutions all over the world reported a high variation in fail rates, reaching values as high as 60% [6]. Robins discusses the likely causes described by the academic literature to distinguish students between programmers and non-programmers [7]. Factors range between cognitive capacity, cognitive development, cognitive style, attitude and motivation. However, this author suggests that those factors do not actually predict student success, and proposes an alternative explanation, named learning edge momentum effect, where acquiring one concept eases the learning of other closely related concepts.

Another work investigates students' decisions to quit the CS1 course in high school, with reasons ranging from lack of time to lack of motivation [8]. Those reasons are affected by factors such as perceived difficulty of the course, general difficulties with time management and planning studies, or the decision to prefer something else. Low comfort level and plagiarism also play a role in dropout levels. Finally, authors explain that dropout reasons accumulate, making efficient intervention require a combination of various different actions.

Lewis et al. use structural equation modelling to investigate the effect of technical and soft skills (i.e., emotional intelligence) on the affinity (i.e., satisfaction with the CS major) and the intention to quit the CS major [9]. Unexpectedly, they found that technical skills were less important than soft skills to predict affinity. They suggest incorporating soft skills in the curriculum of computing undergraduate programs.

Part of the difficulties with learning introductory programming is related to both programming languages and development environments used in the learning process. Researchers have investigated those issues [2], [3], which we shortly describe in the following.

B. Programming learning environments

Kelleher and Pausch have developed a taxonomy of programming environments and languages for novices [3]. Two large groups of environments and languages are proposed: teaching systems, which aim to help people learn to program, and empowering systems, whose goals are to empower users to build things tailored to their own needs. Inside each group, they classify environments and languages by their approach to either ease learning or to empower users.

Guzdial describes the evolution of learning environments for novice programmers [2]. He discusses three families of programming learning environments: the Logo family, the rule-based family, and the traditional programming family. He identifies three research trends: a clear trend towards tool development with traditional language syntax; students prefer to work on computational artifacts that have meaning to them; and environments and tasks should give students immediate feedback on their work.

The trends identified by Guzdial led to the development of some popular programming learning environments, where learning happens by developing and playing games and animations in microworlds, such as in Scratch [10], Greenfoot [11], Alice [12], Robocode [13] and AppInventor [14]. Utting et al. discuss the goals, mechanisms and effects of Scratch, Alice and Greenfoot, providing an interesting account of the affordances of each tool [15].

Scratch, the tool we use in this work, is based on three design concepts: being more tinkerable, more meaningful and more social [4]. It is more tinkerable because programming happens by fitting programming blocks together, just like blocks in Lego toys. It is more meaningful for its investment in diversity and personalization, allowing their users to create different project types such as games, simulations and animations. Finally, it is more social, because of its social network that allows sharing projects, creating new projects from previous ones through mixing, and cooperating with pairs to develop collaborative projects. Scratch uses a kindergarten learning cycle that fosters creative thinking [16]. The cycle uses the steps of imagining, creating, playing, sharing and reflecting to aid in the learning process. Immediate feedback from the tool and the use of the Scratch social network allows for the cycle to be performed easily.

C. Learning introductory programming in CS1 courses

Robins and colleagues argue that most CS1 courses in a conventional curriculum are based on a lecture and lab approach, and are largely focused on knowledge, especially knowledge of language features [5]. They recommend instruction focused not only on language features, but also on program design and the combination of those features. They also suggest addressing programming mental models, such as models of control, data representation, program design and

problem domain. Finally, they reinforce the pedagogical role of lab activities as case-based problem solving sessions.

A systematic review of approaches to teaching introductory programming, based on 60 intervention reports, shows that alternative teaching interventions improve passing rates in CS1 courses by around one-third on average, when compared to a traditional lecture and lab approach [17].

Pears et al. collect and classify the literature of three decades of research on teaching introductory programming, identifying influential, synthesis and emerging work [1]. They classify 45 selected papers into four categories: curricula, pedagogy, language choice and tools for teaching. On the pedagogy category, they divide the studies of programming courses into three emphases: problem solving, learning a particular language, and code production.

Regarding assessment of alternative approaches in CS1 education, it is useful first to resort to Gross and Powers' work, which evaluates various assessments of novice programming environments [18]. They classify assessment techniques as anecdotal, analytical or empirical, and then present an evaluation rubric for the quality of such assessments, evaluating the earlier assessments with the rubric.

There is a huge amount of literature of experience reports and assessments of alternative approaches for CS1. We focus here on some papers that uses the Scratch environment for higher education. One experience with Scratch uses it during the first three weeks of a CS1 course [19]. In this course, Scratch replaces the typical course sequence devoted to algorithms and pseudo-code. Students expressed higher motivation in contrast with the regular courses. However, no changes were found in either dropout rates or obtained scores when compared to the baseline course. Another experience uses Scratch during a two-week period to provide scaffolding for novices to learn basic programming concepts, and a tool for advanced learners to remain engaged through challenging work [20]. Both experiences are similar to ours in using Scratch to introduce programming concepts during a short period. Our approach, nonetheless, is different since our workshops happen before classes start, are led by peers, and are based on challenges and free interaction with the environment, instead of regular classes.

III. METHODOLOGY

The research approach used in this work is the case study. A case study is a contemporary phenomenon delimited in space and time [21], [22]. In this approach, the researcher is interested in investigating the phenomenon in a real environment, and in all its complexity.

A. Research Design

Our case was a five-day, 20-hour workshop of introductory computer programming for Computer Engineering freshmen undergraduates, which happened in August, 2014. The workshop used a particular learning approach, based on peer support, game development, a challenge-response strategy, and a playful programming environment for novices (i.e., Scratch). The phenomenon studied was the learning process developed during this workshop.

Our data analysis approach is both exploratory and quantitative. In an exploratory case study, one tries to answer research questions related to the phenomenon with no predefined hypotheses. The quantitative analysis intends to measure variables inside the case that are related to the phenomenon. To do such, we surveyed participants and we also analyzed the artifacts (i.e., software) they produced. We also performed qualitative data analysis, but the data are still under analysis and will be reported in a later work.

Our main goal was to understand the limitations and affordabilities of the aforementioned learning approach, and the learning issues that develop during the workshop.

Our research questions were four:

- 1) How do participants assess the workshop structure?
- 2) How do participants assess the workshop learning approach?
- 3) How do participants assess the Scratch learning environment?
- 4) Which skills and knowledge do participants acquire in the workshop?

Finally, approval for this research was obtained from the Institutional Review Board at the State University of Feira de Santana (UEFS).

B. Participants

Eighteen students participated in the research: 15 male and 3 female. All of them were freshmen in the Computer Engineering Undergraduate Program at the State University of Feira de Santana (UEFS). All participants signed an informed consent form, allowing their participation in this research.

C. Workshop Planning

Our workshop was based on previous workshops we have been offering since February, 2013. The present workshop happened one week in advance of the academic term, when students are free from activities of regular courses. The workshop was conducted during five consecutive days, four hours each day, in a computer lab with one desktop computer per student. Students were invited during enrollment and through notices at the UEFS Computer Engineering web site.

The main learning goal was that, after the workshop, students could understand and apply basic concepts of algorithms and programming to develop small applications in a graphic programming language, thus, reducing potential difficulties in the first regular course on programming (CS1).

The learning approach used in the workshop was based on a combination of:

- *peer support*: three sophomore students led the workshop, helping participants to clear their doubts;
- *game development*: participants developed games in order to learn programming skills;
- *challenge-response strategy*: tutors challenged participants with small challenges during game development, instead of providing detailed explanations;

- *learning environments for novices*: the Scratch environment was used as the main tool to learn programming, avoiding issues with language syntax and compilation.

The challenges proposed led to the gradual development of an animation and three classic games: Pong, Bow and Arrow, and Space Invaders (see Table I). One last challenge was the development of a simple calculator to allow for a smooth transition from Scratch to the C language.

TABLE I. WORKSHOP SCHEDULE

Day	Challenge	Main Content
1	Animation	Motion, Looks
2	Pong	Motion, Control, Sensing
3	Pong / Space Invaders	Motion, Looks, Control, Sensing, Operators, Variables
4	Space Invaders / Bow & Arrow	Motion, Looks, Control, Sensing, Operators, Variables
5	Bow & Arrow / Calculator	I/O, Variables, Operators, Conditionals, Loops

One undergraduate tutor conducted the workshop, and was aided by two other undergraduate assistants. Initially, the tutor presented a short overview of the Scratch environment. Then, she proposed building an animation by interactively exploring the environment. Later, the tutor challenged the participants by showing the Pong game, and then asked them to produce that game. Then, she started to propose small challenges to develop parts of the game. Students actively explored the environment to answer to the challenges. Whenever they needed, tutor and assistants cleared their doubts. The same process happened with the other games.

D. Data Collection and Analysis

We used both quantitative and qualitative data collection procedures in order to deepen and enrich the research. This strategy is known as methodological triangulation. If the results of different procedures lead to the same conclusion, the research provides a higher degree of confidence [23], [24].

We used surveys and analysis of source code as quantitative data, and interviews and observations as qualitative data. However, we only describe quantitative results in this paper, since qualitative data are still under analysis. Two surveys were conducted with participants: one immediately after concluding the workshop (response rate of 72.2%, with 23% female and 77% male), and a second survey one month after term begin, right after the students had turned in their first lab assignment (response rate of 55.5%, with 20% female and 80% male). Even though the second survey was conducted *in loco*, the response rate was low because research participation was optional. Average age in both surveys was 18.6, with a standard deviation of 1.25 and 1.34, respectively, for the first and second surveys. Regarding the source code analysis, we examined only those kept in the computer desktops after the workshop, totalling nine student projects. From these, only four students fully participated in the five days of workshop.

IV. RESULTS

All the respondents of the first survey asserted that used the Internet every day. Regarding previous experience with programming, only one had thorough knowledge of the subject,

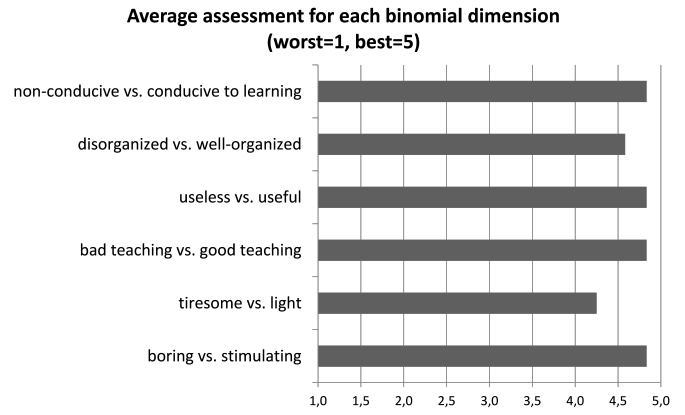


Fig. 1. Workshop Assessment

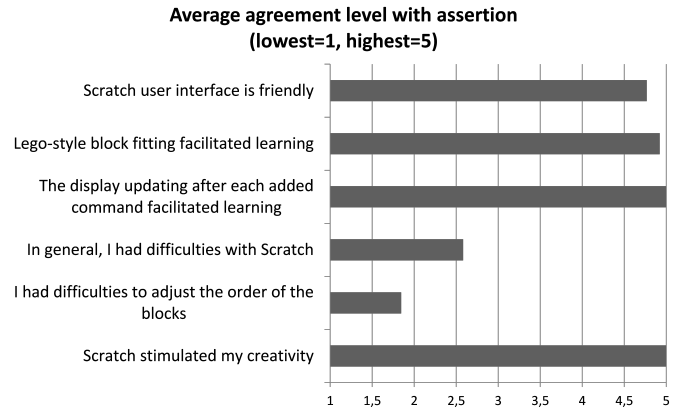


Fig. 2. Tool Assessment

while the rest had either no or few knowledge of it. None of them knew or had heard of Scratch before the workshop.

A. Workshop Assessment

We used a five-point scale between two extremes to let participants assess the workshop. For instance, one assessed criterion was the boring/stimulant dimension. The more to the left (right) the answer, the more boring (stimulant) the workshop was. The other criteria are described in Figure 1. All criteria but one had average value above 4.5. The workload was considered a little tiresome by some students.

B. Tool Assessment

Participants also assessed the tool, i.e., the Scratch programming environment, as shown in Figure 2. The friendly user interface was one of aspects best assessed, both the interface itself and the ability to immediately see code change results. Another relevant aspect was that the tool motivated participants' creativity. The playful way how coding blocks are fitted was also well valued. Few students had difficulties to use the tool (23% of partial agreement), while very few had issues with block fitting (8% of partial agreement).

C. Learning Approach Assessment

Participants assessed the learning approach used in the workshop as well. Figure 3 shows participants' opinions on

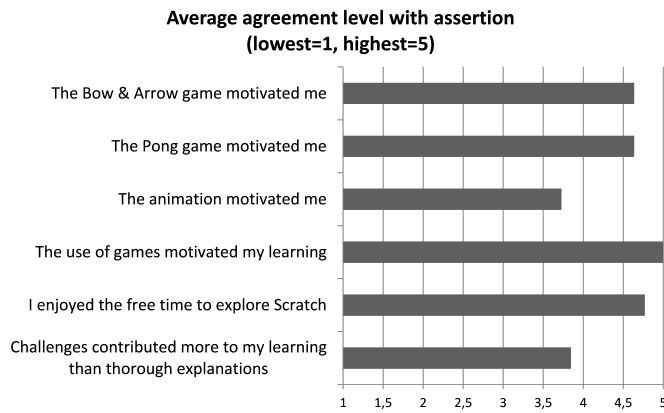


Fig. 3. Learning Approach Assessment

the learning approach we used. It is worth reminding that we provided only brief explanations of either the tool or of programming concepts, and we fostered participants to solve challenges we posed. The use of challenges had 76% of agreement to some degree, while 23% disagreed. The importance of free time to explore the tool was unanimous among participants. The adequate quantity of tutors available during the workshop also had unanimous agreement (38% partially agreeing, and 62% agreeing). Everyone fully agreed with the use of games, although there was some variation according to the particular game. The animation with the Scratch cat character was the less well assessed item. When asked to grade, between 1 and 5, how much the workshop motivated their learning, 85% of the participants graded it with 5 points.

We analyzed students' multitasking behavior, rather common in this generation [25]. Parallel access to the Internet for goals unrelated to the workshop issues was almost zero: 92% asserted that had not accessed the Net (only one student recognized using it a little). Listening to music, although not significant, was more common than Internet use. One student said he had listened a lot of music, while 62% asserted not listening to any music at all.

D. Assessment of the Knowledge Construction Process

The Scratch tool groups programming blocks by theme, one tab for each theme. The analysis of student answers about the degree of difficulty to learn each theme showed that: Variables, Operators and Sensing had the highest degree of difficulty, while Control, Motion and Looks had the lowest, as shown in Figure 4. Nonetheless, in a scale between 1 and 5 (1=none; 5=substantial), no theme had average degree of difficulty higher than 3. The themes of Pen and Sound were not assessed, since they were not used during the workshop.

Table II shows the number of coding blocks used by each student, organized by theme, for the Space Invaders game, the most complex game in the workshop. This game was developed in two days, but students 4, 5 and 7 were present in only one day. On average, each student used 450 blocks. Looks, Control and Motion were the most used blocks.

Table III shows the features implemented by each student in the Space Invaders game. Each row refers to one par-

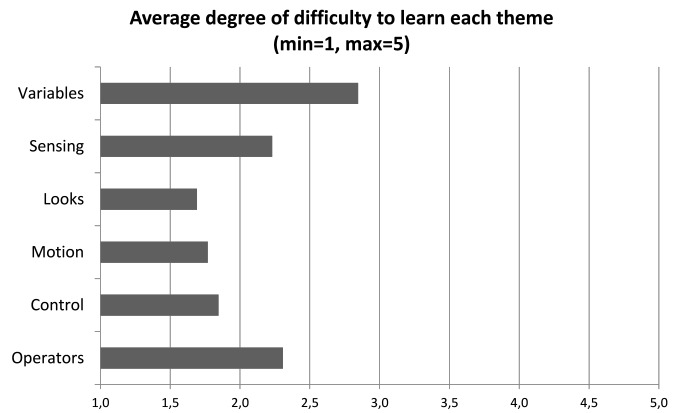


Fig. 4. Scratch Theme Assessment

TABLE II. BLOCKS PER STUDENT IN THE SPACE INVADERS GAME

	Motion	Looks	Control	Sensing	Operators	Variables	Total
Student 1	73	238	441	72	39	80	943
Student 2	183	106	218	58	52	0	617
Student 3	94	192	248	29	2	0	565
Student 4	46	47	82	31	17	28	251
Student 5	61	139	131	34	6	16	387
Student 6	110	98	201	37	0	0	446
Student 7	29	6	28	3	0	0	66
Student 8	68	42	89	21	23	30	273
Student 9	111	59	180	48	28	72	498
Average	86.1	103.0	179.8	37.0	18.6	25.1	449.6
Standard Deviation	45.6	75.6	121.5	20.3	18.6	31.3	252.2
Total	775	927	1618	333	167	226	4,046

ticular feature, while each column refers to one participant. For fully implemented features, we assign value 1. Partially implemented features receive value 0.5. And unimplemented features get zero. Averaging over the features, we noticed that seven students had a game completion average of at least 0.7. Student 7, who missed one workshop day, was below average. Students 4 and 5 had average greater or equal to 0.7, even though they also missed one day.

TABLE III. FEATURES PER STUDENT IN THE SPACE INVADERS GAME

	Student 1	Student 2	Student 3	Student 4	Student 5	Student 6	Student 7	Student 8	Student 9	Average
Life and Score	1	0	0	1	0.5	0	0	0	0.5	0.3
Game Over	1	0	1	0	0	0	0	0	1	0.3
Cannon Moving	1	1	1	1	1	1	1	1	1	1.0
Alien Moving	1	1	1	1	1	1	0.5	1	1	0.9
Alien's Costume Changing	1	1	1	1	1	0	0	1	0	0.7
Cannon's Costume Changing	1	0	1	0.5	0.5	0	0	0	1	0.4
Cannon Shooting	1	0.5	1	0.5	0.5	0.5	0	0.5	1	0.6
Alien Shooting	1	1	1	1	0.5	0.5	0	1	1	0.8
Average	1	0.7	1	0.8	0.7	0.4	0.1	0.7	0.8	-

Computing the Pearson correlation for the average blocks per student and the average features per student, we get a value of 0.69, showing strong correlation between both variables. In the Bow & Arrow game, correlation grows to 0.83. Obviously, quantity does not imply quality. But quantity of blocks is important, in this case, to successfully implement a feature.

Table IV shows the sum of blocks used for all games but the animation. Results show 5,550 blocks for all the nine students whom we retrieved the source code. Sensing, Variables and Operators were the least used blocks, while Control, Looks and Motion were the most used. We also show the number of days students have attended the workshop. The ones who came every day used more than 700 blocks, while the others used less than 600.

TABLE IV. BLOCKS PER STUDENT FOR ALL THE GAMES

	Days	Motion	Looks	Control	Sensing	Operators	Variables	Total
Student 1	5	108	288	520	80	51	100	1147
Student 2	5	232	184	337	98	64	21	936
Student 3	5	150	240	341	52	3	13	799
Student 4	4	68	47	107	36	25	34	317
Student 5	2	80	147	155	37	6	16	441
Student 6	4	146	125	253	53	1	0	578
Student 7	4	58	30	84	13	2	2	189
Student 8	4	99	70	142	35	27	34	407
Student 9	5	153	107	282	70	40	84	736
Average	-	121.6	137.6	246.8	52.7	24.3	33.8	616.7
Standard Deviation	-	55.3	86.3	144.0	26.4	32.2	55.1	321.8
Total	-	1094	1238	2221	474	219	304	5,550

Finally, to get an idea of the effects of the workshops in our CS1 course, which uses the C language, we surveyed participants right after they finished their first coding lab assignment, one month after term begin. From 10 respondents, 90% asserted that either have not used or have briefly used Scratch after the workshop. Regarding the C language, 70% fully agreed that enjoyed programming in that language, while 40% agreed in some degree that had difficulties to code in that language (with 75% of these with partial agreement).

When asked whether the use of Scratch before the term helped them to learn how to solve the first assignment, 70% asserted it did so, either reasonably or a lot. The more specific we were, the more agreement there was: 80% agreed to some degree about the learning of control structures, while 90% said so for logic operators.

V. DISCUSSION

Here we discuss our findings, in the light of our goals and the literature. Discussion is ordered by our research questions (RQ), established in III-A.

A. RQ1: How do participants assess the workshop structure?

In general, the workshop was well evaluated by the students, who considered it: (1) stimulating: in general, they kept quite entertained throughout the days, working on the challenges proposed. Being stimulating is critical in that it is their first contact with the knowledge area that they chose to pursue a career in. Moreover, the current generation has a low threshold for boredom. In this sense, another evidence

was the lack of multitasking behavior, reported by students, and observed by researchers. This type of behavior, which manifests as holding two or more usually unrelated complex tasks either simultaneously or alternately [26]. Recurring work in the literature point out to disruptions in learning when such behavior arises [27]–[29]; (2) useful: students learned skills that would be useful in the short term, in the CS1 course they began to attend a few days after the workshop; (3) organized: workshop schedule followed as planned, as described in Section III, along with well-defined goals, helped the fluency of activities with no setbacks, as perceived by participants.

Furthermore, the average workshop reviews of being conducive to learning and with good teaching by the peers were significant. Only the tiresome-light binomial scored a little low when compared to the others, maybe because the workshop took all morning shifts for five consecutive days. However, one should also consider that producing almost two games per day may have triggered some exhaustion, i.e., the workshop workload may have been excessive. Various students failed to implement all the proposed features of all the games. Therefore, either removing one of the games or rethinking the schedule in a next workshop offering should be considered.

B. RQ2: How do participants assess the workshop learning approach?

As previously stated, the workshop learning approach was based on a combination of peer support, a challenge-response strategy, game development, and a learning environment for novices. All participants agreed, to some degree, that the approach was adequate. With 18 participants for three tutors, we had a ratio of six students per tutor. Peer support is a widely used strategy in introductory programming learning, as reported in the literature: both formal and informal, in classroom or in the lab, or even outside the classroom [30]. Our approach is distinct from other experiences because the workshop is made by students and for students. Two positive consequences follow: (1) integration: since the workshop happens a week before regular classes begin, it ends up being an event where freshmen get to know each other, and integrate with senior students; (2) sense of belonging: being next to fellow senior students allows freshmen to feel they belong in that community.

The use of challenges was well received by students. The goal was that they explored both solutions and the environment in a self-directed way. Tutors gave just short explanations, and intervened only when needed or requested. In any case, that strategy led more to the use of leading questions instead of giving straight answers.

Challenges are one of the foundations of active learning, a widely discussed topic in pedagogy [31]. An example of active learning is problem-based learning (PBL), which has been widely used in computing courses [32], [33]. In PBL, challenges take the form of a problem that resembles professional practice, arousing students' interest on content knowledge, and stimulating self-directed learning, among other benefits [34]. A difference from our approach to PBL is that although we encourage discussion among students, it happens only in a few moments, while in PBL, discussion takes most of the group

meetings devoted to solving problems. By the way, similarities between challenges and PBL are welcome in our context, since our Computer Engineering undergraduate program is strongly based in PBL.

One benefit of using challenges is letting students free to advance in their own pace. Sometimes they did more than requested, making them more proactive. We had, for instance, some students who took their project home and improved them with more features. Such attitude was encouraged by the tutors.

Using games as challenges has proved a right decision. It may seem obvious, but the fact that participants rated games like Pong or Bow and Arrow more motivating than the initial animation suggests that they prefer more complex tasks, provided that they are motivating. Challenges that assume a playful facet, such as games, are relevant because such activities are part of human beings' history, and involve various elements such as rules, goals, tension and competition [35] — also present in the workplace. Indeed, we may say that game development is a challenging task, since it implies a substantial complexity in tasks of communication between objects, logical and mathematical operators, scenery, among others. In addition, the use of games adds at least two important features to the teaching-learning process: (1) everyday life: games are part of youth daily life. Thus, working with something that fascinates them, that is part of their reality, is likely to increase motivation; (2) amusement: learning by playing minimizes the view of studying as obligation, reinforcing entertainment and, hence, enhancing learning [36].

C. RQ3: How do participants assess the Scratch learning environment?

The choice of Scratch as the learning environment for beginners also facilitated the decision of merging games with challenges. First, participants strongly agreed that Scratch was favorable for game development and learning: a playful environment for creating other playful environments. Second, immediate feedback on the screen was also much appreciated. Third, avoiding issues of compilation and syntax was also welcome. Those features led to a good assessment by participants. They also had no bigger issues with using the tool, besides considering it user-friendly and leading to creativity development.

We must also highlight that, for the aforementioned factors, it is possible to build complex programs in Scratch in a relatively short time. An undergraduate student, new to programming, would likely take a long time to develop games such as Space Invaders using traditional programming languages, even at the end of the first term. But they did it after only a few days. It is worth noting that the workshop led to an average of 450 blocks used per student, for developing three games. Participants who came to every workshop day used more than 700 blocks. If we equate blocks to lines of code, we realize how much code our beginning programmers had developed in such a short period, especially when compared to the code students develop in their first CS1 classes.

Nevertheless, after the workshop, students made it clear that they did not keep using Scratch. Natural reasons for this were: they were then focused on learning a programming language, had a high workload for the courses they were

registered in, and needed to adapt to a new student routine. Another reason was that their perception of Scratch changed: Scratch was now perceived as an amateur language, while C felt as something more professional and, therefore, more relevant.

D. RQ4: Which skills and knowledge do participants acquire in the workshop?

The most used blocks were from the themes of Looks (user interface), Control (selection and repetition structures) and Motion (for moving objects in the game). These are precisely the themes that showed the least degree of difficulty for participants. Control blocks, which are usually hard for beginning programmers, were the most used blocks, while blocks of Operators and Variables were the least used. It is worth mentioning that the less implemented features in the Space Invaders game were counters (e.g., for life and score), even though the final results depended on these counters. This may likely have happened because counters require variables, one of the difficult themes according to the students.

The theme Operators, which handles logical and mathematical operators, had a greater degree of difficulty than the theme Control, responsible for selection and repetition structures. Interestingly, those structures are not usually easy to learn — hence the effort to offer this workshop — and require, a priori, a more elaborate logic than such operators. Working in a playful manner with such structures may have facilitated learning.

In summary, we finished the workshop with 5,550 blocks used (given that only nine participants provided their projects for analysis), which allows us to infer that students have really evolved in terms of introductory programming. Sensors, Variables and Operators were the topics less practiced, while Control, Looks and Motion, the most commonly used.

Finally, despite students have not kept on using Scratch, we may say that the experience contributed substantially to their learning of programming during the first month of the term. 70% asserted that the workshop helped a lot in the process of knowledge construction of the first CS1 lab project. 80% agreed, to some degree, that it helped on selection and repetition structures, and 90%, on logical operators. This result is significant, and it was precisely one of the workshop goals, suggesting that the learning approach together with the adopted tool provided a more fluid and meaningful learning of programming.

VI. CONCLUSIONS AND FUTURE WORK

This paper described a case study of a teaching and learning approach aimed at facilitating learning of programming concepts by Computer Engineering undergraduate freshmen. Our approach combined the use of the Scratch learning environment, peer support, a strategy of challenge-response, and game development. The case developed as a workshop for freshmen that lasted one week, with a workload of 20 hours. Three sophomore peer students guided the workshop, presented to 18 freshmen. The challenges led to the development of animations, games and a calculator. To evaluate our approach, we used a quantitative approach based on artifact analysis and

two surveys, one post-workshop, and another after students finished their first CS1 lab project.

Students assessed the approach well in some dimensions: stimulant, lightweight, good teaching, useful, well-organized, and conducive to learning. They also evaluated the Scratch environment as user-friendly, and with good working mechanics, especially the Lego-style blocks. Commands of interface (Looks), control structures (Control), and movement (Motion) were the most used, considered less difficult by the students. Although most students have not used Scratch after the workshop, 70% of them agreed that the environment helped them to learn programming. Regarding control structures, 80% agreed that the workshop aided them in developing their first CS1 project to some degree. This is relevant, for these are concepts usually hard to learn in regular courses. On the other hand, variables were not grasped so well, even though they had been used in the games. Results suggest the effectiveness of the approach. Moreover, the work also contributes to the field of computing education with empirical evidence, helping to better evaluate learning approaches and tools.

Further work should deal with qualitative analysis of these workshops, based on interviews and observation. We also intend to add a longitudinal dimension to the work, analyzing workshops from different terms and their evolution.

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Applying Flipped Classroom and Problem-Based Learning in a CS1 Course

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Abstract — Teaching of programming foundations has been subject of several investigations, because it is believed that the required activities can contribute to the development of students more able to solve problems and to adapt to any environment or situation. Some works have argued about the integration of Flipped Classroom and Problem-Based Learning in Computer Science courses to potentiate this kind of teaching, but fewer evidences that investigate the real application between these approaches were found. Thus, in order to enhance the Flipped Classroom in-class activities, this paper reports an experience to implement and apply Flipped Classroom and Problem-Based Learning approaches for a CS1 course. Additional concepts of programming contests, group formation and learning styles were also used. In general, the main findings suggest that the Flipped Classroom model, if well-planned and carefully designed, can benefit students. However, these initial benefits are more related to student's motivation and social behavior than those associated with grades and the effective learning. Results also indicate that PBL may be an adequate approach to enhance the face-to-face time in the inverted classroom.

Keywords—*Flipped Classroom; Problem-Based Learning; Programming Contests; CS1; Teaching Programming; Experimentation.*

I. INTRODUCTION

In spite of the existence of several investigations about the teaching of programming foundations [2, 7, 10, and 20], basic courses in Computer Science still have specific challenges to address in order to provide the students with the necessary knowledge and skills to follow the course and achieve a successful career in the workforce.

According to Partnership [9], students of the 21st century must have the following skills: 1) creativity and innovation; 2) critical thinking and problem solving; and 3) communication and collaboration. It is also necessary a model that defines the pedagogical and technological infrastructure that best support the

acquisition and development of these skills within the school context. Such infrastructure should: a) promote and evaluate students' performance; b) increase their engagement; c) facilitate communication and collaboration; and d) facilitate and maximize efficiency in the management of the results.

Considering the Horizon Report 2014 (Higher Education Edition)¹, which indicates the capable trends with practical application around the next 12 months, the Flipped Classroom (FC) model is part of a movement that is meant to be flexible, active, and more engaging for students, but particularly helping students to acquire the skills previously described.

A. Flipped Classroom

In general, Flipped Classroom refers to the model that inverts the logical organization of the classroom [3, 4, 5, 14, and 15]. However, we also consider another viewpoint to understand the FC which is consider this model as an opportunity for future changes in the classroom context for at least three main reasons. Firstly, this model can be a way to rethink learning and teaching process. As a second point, the teachers can act as learning designers. Finally, FC activities are also related or supported by other many educational theories or ideas such as Bloom's Taxonomy, User-Centered Learning, Self-Regulated Learning, Self-Determination Theory, among others.

Thus, from this model students have access to short explanations and specific materials that should be studied before each class, through any device, in any place where he/she is, such as at home, at work, on the bus. Out-class activities can be guided by e-learning and m-learning technologies, also including the adoption of Massive Open Online Courses (MOOCs) and Personal Learning Environments (PLEs) [10].

¹<http://cdn.nmc.org/media/2014-nmc-horizon-report-he-EN-SC.pdf>

In-class activities, in turn, can use available resources in classrooms and laboratories. Such activities can also be benefited from the use of already known Active Learning Strategies, such as Problem-based Learning [8, 21], and collaborative activities with teacher supervision.

B. Problem-Based Learning

According to Duch et al. [11], Problem-based Learning (PBL) is an instructional method that challenges students to “learn to learn”, working cooperatively in groups to seek solutions to real world problems. These problems are used to engage students’ curiosity and introduce or motivate the subject matter. PBL prepares students to critically thinking from the use of appropriate learning resources. The main idea behind PBL is that the starting point for the learning process should be a problem, a query or a puzzle that the student wishes to solve.

C. Programming Contests

One way to encourage students to improve their knowledge in a particular area is to encourage them to participate in knowledge contests [6] in order to solve real and interesting problems, queries or puzzles. There are several initiatives around the world, such as the Mathematical Olympiad², Portuguese Olympiad³, Astronomy Olympiad⁴, among others. When taking part in a competition, participants are shown engaged to prove their worth and knowledge.

In the Computer Science field, for instance, the number of knowledge contests is increasing, stimulated by large educational institutions, representing societies and companies that seek, in this kind of environment, students with the best performance and results. The idea is to contribute to the improvement of teaching programming concepts since students are motivated to participate.

In Brazil, for example, considering national competitions in higher education context, we can highlight the Programming Contest⁵ organized by Brazilian Computer Society (SBC), which is also the Brazilian selective for the International Collegiate Programming Contest, organized by the Association for Computing Machinery (ACM). This contest has fostered the creation of regional and local (or institutional) contests, which serve most often as internal tryouts contests for the national dispute [6]. In addition, those who become winners, more than receiving material rewards, they have the opportunity to place into their curriculum the record of participation in activities involving discipline, knowledge, dedication, teamwork, logical thinking and ability to solve the proposed problems.

In general, in Brazilian programming contests the teams are composed by three students and a set of problems, which need to be solved by them in five hours. Teams must submit their

solutions using an online judge such as BOCA⁶. The winner is the team that solves the most problems in a shorter time.

Additionally to the existence of online programming contests, such as TopCoder⁷, there are other several available tools to support programming contests training such as SPOJ⁸ (Sphere Online Judge) and UVA⁹ Online Judge. A well-known system developed in Brazil is the URI Online Judge Problems and Contests¹⁰. In short, the URI project aims to provide programming practice and knowledge sharing. Teachers can also create courses and lists of exercises for the students. They can also track the students’ progress, providing immediate feedback or interventions in their teaching method.

Teaching of programming together with the training to participate in programming contests has been a way to encourage and motivate learners to study programming techniques, in addition to increase the integration among them [18].

Whereas CS1 courses are typically based on solving problems in a particular programming language, an important issue considered in this work refers to the possibility that Programming Contests can promote problem-solving skills, as part of the PBL related activities. Thus, Programming Contests can be an attractive form of learning and improvement of programming skills [7], since PBL and Programming Contests can facilitate generic skills such as group work, planning, problem solving, independent learning, research skills, time management, writing and oral presentation, among others [8]. According to Herzber et al. [12], achieve a goal and overcome challenges can be motivating as it relates to getting the outcomes of their own labor and self-realization. In addition, motivated people tend to have more persistence and good performance.

So, in this paper we used programming contests to enhance the PBL capability. The students were encouraged to develop problem solving through programming and competitions. The next section presents the main motivation related with this work.

D. Motivation for applying FC and PBL

According to the survey conducted by Bishop and Verleger [5], there are few works employing controlled studies to determining the students’ performance in the Flipped Classroom. Moreover, Fassbinder et al. [17] identified some works that instigate the integration of Flipped Classroom and Problem-based Learning, but no studies that actually apply and investigate the integration between these two approaches were found to enhance the Flipped Classroom in-class activities.

Considering all issues discussed, in this paper we present an initiative to apply Flipped Classroom and Problem-Based

² www.obm.org.br/

³ <http://www.escrevendo.cenpec.org.br/>

⁴ www.oba.org.br

⁵ maratona.ime.usp.br/

⁶ www.ime.usp.br/~cassio/boca/

⁷ <https://www.topcoder.com>

⁸ <http://www.spoj.com/>

⁹ <http://uva.onlinejudge.org/>

¹⁰ <https://www.urionlinejudge.com.br/judge/login>

Learning approaches in a CS1 course at Brazilian Institute of Education, Science and Technology – IFSULDEMINAS – Campus Muzambinho, which is located in the countryside. Additional concepts of group formation, programming contests and learning styles were also considered.

The main findings suggest that Flipped Classroom model, if well-planned and carefully designed, can benefit students. Results also indicate that PBL may be an adequate approach for Flipped Classroom in-class activities.

The remainder of this paper is organized as follows. In Section II, we describe our first experiment for teaching CS1 in an integrated way, using Flipped Classroom and Problem-Based Learning. The main findings obtained are summarized and discussed in Section III. In Section IV, we present our conclusions and perspectives for future works.

II. THE EXPERIMENT

Our introductory programming course follows the ACM and IEEE guidelines for the first year programming courses of Computer Science, as well as the recommendations of the Brazilian Computer Society¹¹. The main subjects studied are Fundamentals of Programming, including Introduction to Computer Science, Control structures (conditional structures and repetition/loop structures), Data type (character string, array), Functions, Procedures and Recursive Calls.

For this experiment, we opted to not invert all these related subjects and neither flip the initial content (i.e., Introduction to Computer Science and Conditional Structures). So, only the repetition/loop structures were considered (“For”, “While/Do-While”). In our point of view and context, flip the teaching of repetition/loop structures was an appropriate choice for three main reasons. Firstly, the students were already familiar with their classmates and teacher. Secondly, it was possible to compare students behavior before, during and after the inversion of the content. Finally, this content enabled the inversion because it is a subject that follows that worked previously, so the students were already familiar with the definition of algorithms, problem solving and the use of structures.

A. Planning

The experiment lasted six weeks, starting in March 2014, with three face-to-face meetings per week. Each face-to-face meeting lasted two hours. About 40 students enrolled in a CS1 course participated in the experiment.

We consider an experiment “a study in which an intervention is introduced to observe its effects” [19]. Initially, in order to compare the results of Flipped Classroom application versus the traditional learning approach, students were divided into two groups (A and B), with 20 students each. While one group was participating in a traditional class, the other group was doing the Flipped Classroom in-class activities. Both groups worked at the

same time, but in different classrooms (spaces). Besides, the same content or subject was being worked in both the groups.

In the following week, the groups were switched. It is, therefore, an experimental approach based on within-subject ideas [19], in which each subject experiences all levels: control (traditional approach) and new variable (inverted approach). Results will be analyzed considering the differences between student’s motivation and grade, for both the environments (inverted and non-inverted situation).

Figure 1 shows an overview of the experimental design.

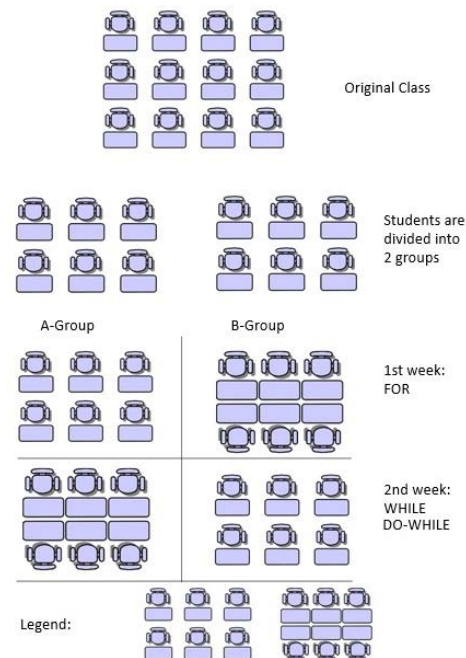


Fig. 1. Experimental Design for Applying FC and PBL.

The planning activities for each week and for each group are described next.

• Week 1: Group Formation

In order to reduce bias in the results and to create mixed ability groups, the theoretical framework used to group the students in A-group and B-group was based on the Socio-cognitive conflict and learning [16] and on the Learning Style Theory [13].

To stimulate the Socio-cognitive conflict during the activities related to the experiment, we consider data from two sources: grade point average and analyses of logical reasoning with games. Students were grouped in those who have distinct logical reasoning in solving algorithms. According to Adán-Coello et al. [1], this approach allows that, in a discussion about the different versions of programs implemented, students can perceive other solutions to the same problem and learn from controversy and knowledge exchange. As previously stated, student’s learning

¹¹ <http://www.sbc.org.br>

style was also considered in order to obtain homogeneous groups for the experiment.

Therefore, in this work the following strategies were adopted to mixed ability grouping:

Grade point average (average academic results)

Were considered the grades obtained by the students in previous assessments performed according to the traditional teaching model. These assessments measured students' knowledge on variable statements and conditional structures, such as if-then-else and switch-case. These were the subjects studied before the repetition structures. The grades were used to obtain more homogeneous groups. Both groups, A and B, had students with three different categories of grades (0-5: below to average, 6-8: average, 9-10: above average).

Analysis of logical reasoning with games

We also conducted a puzzle game activity in order to analyze the student's ability to identify the problem context as well as useful strategies for logical reasoning in his/her solution and considering the available resources. All the students had 30 minutes to play Light Bot¹². Meanwhile, teachers observed and wrote down the difficulties and the performance of each student. At the end, we obtained the completed rounds for each, as well as the number of steps needed to complete the tasks. These data were ranked.

Light Bot was used taking into account the study presented in [2]. It is an educational Flash game developed by Armor Games. The main goal of the game is to program a small robot to light up all the blue blocks on a board. This goal is achieved by giving the robot a series of instructions from a limited set of commands, such as sequential commands, functions, repetition structures (for, while, repeat) with a finite instruction space. As the levels progress, the board becomes increasingly more complicated and more sophisticated combinations of commands are needed to achieve the goal for the level.

Student's Learning Style

Learning styles were also considered in the group formation. The Felder-Soloman Index of Learning Style (ILS) questionnaire [13] is a tool that helps teachers to identify students' learning styles, according to four scales: active/reflective, sensory/intuitive, visual/verbal, and sequential/global. So, the teacher is able to identify the most appropriate learning materials for each student. The teacher can also use the learning styles to group students in order to obtain more homogeneous groups of discussion. In our experiment, we used ILS to find the existing learning styles and thus group the students with the same or complementary learning styles. Adán-Coello et al. [1] argue that these two situations appear opposite, i.e., we want to provoke the socio-cognitive conflict while we create groups of students with similar learning styles. However,

the idea is to group students who presented different solutions to the algorithms, but that can discuss these differences and reach a consensus solution in a friendly and profitable manner.

Weeks 2 and 3: Studying Repetition Structures: FOR

1st face-to-face meeting

Group A: Students received the first explanations through lectures from the teacher. After the lectures, they received a list of exercises that could be performed individually during this face-to-face meeting. At the end of face-to-face meeting, the remainder of the list should be completed outside the classroom as a homework.

Group B: Three or four days before the first face-to-face meeting, students of group B were asked to access the Sophia Learning Platform¹³ and to watch the proposed videos, do in-video quizzes, interact with learning objects and other programs that use the repetition structure FOR. Sophia Learning tool was used to help the inverted classrooms since it is a Personal Learning Environment that supports the Flipped Classroom approach. The first face-to-face meeting was based on the following activities: the teacher clarified the main students' doubts, took notes on students' performance and participation during in-class and out-class activities (in-class activities were monitored using the Sophia Learning Platform reports). After this contextualization, students had time to practice programming individually, using pencil and paper. They also had time for practicing programming in small groups.

2nd face-to-face meeting

Group A: Students took any question with the teacher. Teacher gave new lectures to complement the subject. Students continued to make a list of exercises.

Group B: Students had more practice time for programming individually and in small groups using pencil and paper. Teacher still acted as the coach and facilitator of the knowledge acquisition process.

3rd face-to-face meeting

Group A: In the Programming Laboratory, students took any questions with the teacher. Teacher gave new lectures about C programming language grammar using CodeBlocks Integrated Development Environment (IDE). Students transcribed the list of exercises previously performed to C programming language.

Group B: In the other Programming Laboratory, in the first half of the class, students had to solve programming problems individually. In the second half, students were asked for solving programming problems in small groups based on the contest style. They were grouped in teams of three members each, also using C language grammar and CodeBlocks IDE. In this last part, students used URI Judge Online to submit proposals for algorithms for the problems indicated by the teacher on URI

¹² <http://armorgames.com/play/2205/light-bot>

¹³ <http://www.sophia.org/>

System. In some sense, we made a mini-competition in order to encourage and engage students in the programming activities. The teacher still acted as the coach and facilitator of knowledge acquisition.

- **Weeks 4 and 5: Studying Repetition Structures: WHILE/DO-WHILE**

In this week, we followed the same strategies described before, in the three face-to-face meetings, but now the groups were reversed. That is, students belonging to group A (traditional classroom) attended classes of “repetition structures While/Do-While” in group B (Flipped Classroom) and vice versa. The problems to be solved were related to the use of these repetition structures.

- **Week 6: Students’ Evaluation**

In the last week, tests were applied in order to measure the knowledge acquired by the students in Repetition/Loop Structures.

B. Execution

Our proposal of applying Flipped Classroom and PBL approaches in a CS1 course is summarized in Table 1. According to Kay et al. [8], in the PBL approach, the class time is devoted to the development of problem solving skills such as:

- 1) defining a learning plan;
- 2) brainstorming to get started on a problem;
- 3) reflection;
- 4) articulation of problems and solutions;
- 5) self-assessment;
- 6) practice in active listening and other communications skills.

Table I shows our approach for the relationship between Flipped Classroom activities and PBL fundamentals. Thus, the last column associates the encouraged PBL skills for each Flipped Classroom activity proposed for CS1 courses.

TABLE I. AN EDUCATIONAL PRACTICE DESIGN TO ADOPT FLIPPED CLASSROOM AND PROBLEM-BASED LEARNING IN A CS1 COURSE.

Flipped Classroom	Activity Short Description	PBL
Out-class Activities	Lecture videos, in-video quizzes, learning objects, related example programs.	-
In-class Activities	Practice time for programming individually, using pencil and paper.	1; 2; 3; 4
	Practice time for programming in small groups, using pencil and paper.	
	Solving programming problems individually, using C language grammar, in lab.	5; 6
	Solving programming problems in small groups with a contest style, using C language grammar, in lab.	

C. Evaluation

Data was collected by teacher observations in the experiment and also using a post-test, like a survey at the end of the experiment. The survey used a Likert scale in order to get the students’ responses regarding the Flipped Classroom model, the instructional videos used for out-of-class preparation and in-class activities, and the general impact that the experiment with Flipped Classroom had on students. Items in the survey were measured using 5-point rating scales, with the answers ranging from “strongly disagree” to “strongly agree”.

Additionally, there were some items which gave students the opportunity to provide further information in an open-ended manner, such as “*What were the Flipped Classroom positives and negatives points?*”, “*Can Flipped Classroom be applied in other classes?*”, “*What improvements would you recommend for other experiences with Flipped Classroom?*”, “*What were the strengths and weaknesses of the videos and learning objects?*”, “*Do you have any other comments, criticisms or suggestions?*”.

Furthermore, control and test groups were compared for differences in learning. The comparison with historical data was evaluated for statistical significance. The main results are discussed in the next section.

III. PRELIMINARY FINDINGS

Considering the investigations carried by Fulton [3] and Herreid et al. [4], the main advantages of the Flipped Classroom model are: (1) students move at their own pace; (2) doing “homework” in class gives teachers better insight into student difficulties and learning styles; (3) teachers can more easily customize and update the curriculum and provide it to students 24/7; (4) classroom time can be used more effectively and creatively; (5) teachers using the method has reported seeing increased levels of student achievement, interest, and engagement; (6) related learning theory supports new approaches; (7) the use of technology is flexible and appropriate for 21st century learning; (8) there is more time to spend with students on authentic research; (9) students get more time working with scientific equipment that is only available in the classroom; (10) students who miss class can watch the lectures; (11) the model promotes thinking inside and outside of the classroom; (12) students are more actively involved in the learning process; and (13) they also really like it. However, for Herreid et al. [4], difficulties also exist: new students may be initially resistant since the model requires that they work at home rather than be first exposed to the subject matter in the classroom. Also, homework (readings, videos) must be carefully tailored by teachers for the students in order to prepare them for the in-class activities.

Tables II and III present the students’ perceptions about our FC/PBL approach. Notice that the results obtained in our study are consistent with those discussed by the aforementioned studies.

TABLE II. STUDENTS' PERCEPTIONS ABOUT FC STRENGTHS

"Greater interaction and more time for discussion between classmates and teachers."
"The process of understanding the problem seems to happen more easily because you will have to face the class knowing what is going on."
"More relaxed environment and easy access to the teacher to ask questions."
"It gives the student a chance to develop self-learning."
"New ideas from interactions with classmates."
"The teacher assesses the student at all times, understanding more easily his/her particular difficulties and learning objectives."
"The possibility to see the explanation (videos) as many times as necessary."

TABLE III. STUDENTS' PERCEPTIONS ABOUT FC WEAKNESSES

"Having to watch and study at home! Sometimes I do not have all the needed time because I work all day! "
"I cannot find myself in any group!"
"You need internal motivation to be the active subject of your own learning! This is a challenge because I've always been the traditional model of teaching."
"I dislike studying with people around me, I do not feel well. I prefer to carry out the activities alone!"

From the analysis of qualitative data we observed that one of the main positive results was related to communicative skills. FC in-class activities interaction among students and student-teacher was greater than those in traditional class. To confirm it, Figure 2 shows the students' attitudes towards interaction and communication in FC.

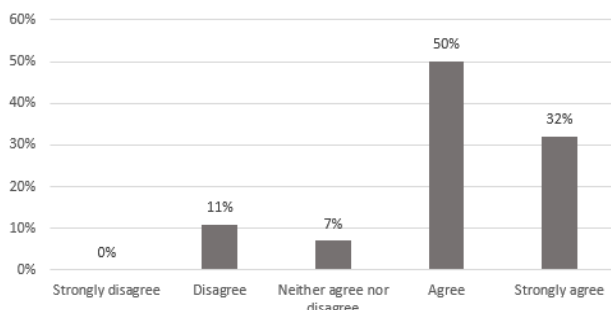


Fig. 2. Flipped Classroom allows more interaction and communication with my classmates and teachers?

Another positive result related with the FC activities is the frequency number. The number of absent students in inverted classes was practically null, whereas the percentage of absent students in the traditional classes was always between 15 and 30 per cent. In short, considering the experimental design (Figure 1), we can notice a change in the students' attitude, although this can be difficult to measure.

In contrast to the small number of absent students and the improvement of communicative skills, both positive results in

FC environment, the student's grades difference were not significant, considering traditional and inverted classes. Figure 3 shows the general average, in 100 points, for traditional and inverted classroom in two subjects: 'for' and 'while/do-while'. Although the difference was not significant, the student's grade attending traditional classes to learn about repetition structures was a little bit higher than the student's grade in inverted classes, for this experiment.

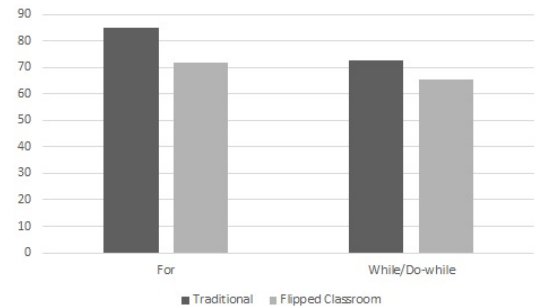


Fig. 3 – Differences between grades.

However, in general, considering the number of approved and disapproved students in the CS1 class it is possible to perceive an improvement in the results, taking into account previous year (2013) as shown in Figure 4. Of course, this experiment was applied only in repetition structures. So, more investigations about the real impact of FC approach in this kind of context still need to be performed.

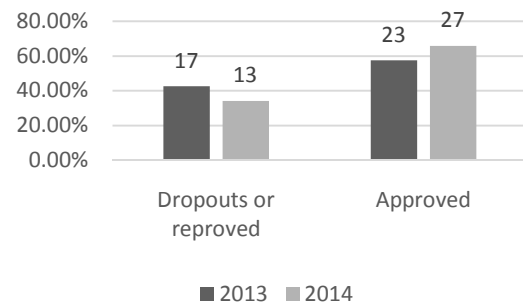


Fig. 4. Comparison of the number of approvals and disapprovals in CS1 class in the years 2013 and 2014, considering a class of 30 enrolled students.

Finally, considering post-test results, we observed that 66% of the students accessed the internet to interact with Sophia Learning in their home, while 25% have accessed outside the home (company, cafe, friend's house) and 9% have accessed at school.

IV. CONCLUSIONS AND FUTURE WORKS

In order to enhance the Flipped Classroom in-class activities, this paper reports an experience to implement and test Flipped Classroom and Problem-Based Learning approaches into a CS1 course. We used problems from the programming contests

context to increase the PBL capability and to create an active and real learning experience.

To conclude, we observed that PBL may be a good approach for the face-to-face moment of the Flipped Classroom model, but with adaptations to the context, such as PBL for teaching programming. In our context, ideas based on programming contests were used to enhance the face-to-face moment. We also presented the main steps and tools needed for this application in a context of higher education in computer science, considering teaching CS1.

As a future works we intend to replicate this experiment in order to collect more data or evidences about FC model and its effectiveness. Besides, considering the use of programming contests to improve PBL activities in Flipped Classroom in-class environment, it is possible to wait that some students can react negatively to the pressure of competitive programming, even in a team.

In addition, may also be differences between males and females behavior. However, in our context, these situations where not identified. Are questions that can be further investigated in the future.

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Programming Teaching in High Schools: an analysis based on the Discourse of Collective Subject

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Abstract— This paper presents a qualitative study about programming logic teaching in high school, based on the Discourse of Collective Subject. The project where this study is embedded aims to encourage a greater number of students in the areas of engineering and natural sciences, primarily girls. The main goal is to present how the high school students participating in this project understand issues related to computing learning and women inclusion in this area.

Keywords— high school, girl, programming logic, discourse of collective subject

I. INTRODUCTION

Nowadays, the use of computers in education is diverse, interesting and challenging than simply transmitting information to the learner. The computer can also be used to improve learning environments and help students in their knowledge construction process. ProInfo (National Programme for Information Technology in Education) is a program developed by the MEC (Ministry of Education and Culture - Brazil) to introduce the computer and telecommunications technologies – telematics – in Public School [1]. The aim of this programme is that students acquire computational concepts such as computer operating principles, programming concepts and implications of computer in society. This approach was highly reported in the United States as "computer literacy" and it was the solution that many schools in Brazil to insert the computer in the teaching-learning process. Therefore, the curriculum was increased in the "Introduction to Computer Science" course, which aims to teach computing to the student to have access to the computer. However, from an educational point of view, it has not changed the way the content of other subjects are taught [2].

However, computing goes across the use of computers for performing routine activities such as access to internet (social networking, games, etc.) and produce texts. The computer can be used to develop new programs or games with different features, an activity that involves logic programming skills that can be applied in several areas, not limited to computers. The integration of programming logic in the basic and technical education can help to solve problems in a structured and rational way. The insertion of this new knowledge can make it visible to the students the role of sciences in development [1].

Researches reveal gender differences between male and female insertion in the field of engineering/natural sciences. Boyd and Bee (2011) said that a possible reason for this participation difference is indicated by studies showing that cultural attitudes also influence the performance of girls in science and "even girls who have great performance in science during high school have less confidence in their ability to be successful in science subjects at university and, therefore, they are less likely to specialize in hard sciences in college" [3].

From a problem, the researcher must be attending if it should/must be addressed through an empirical survey of qualitative validation. The Discourse of Collective Subject (DCS) is a technique for qualitative-quantitative analysis and it aims to get the whole spectrum of possible opinions on the issues studied in the research population. Therefore, the selection of subjects must necessarily allow different opinions in the interviews universe. For this purpose, it should be chosen from all people ideas about the researched problem. Therefore, the composition of the population strata is very important to the research [4].

The work in this paper is part of a project (Project. CNPq 18/2013 MCTI/CNPq/SPM-PR/Petrobras Project – Girls and Young make Natural Science, Engineering and Computing) which aims to teach programming logic in High School, ordering to encourage more students to the areas of engineering and natural sciences, primarily girls. Particularly, the students' responses are analyzed, based in the technique of the Discourse of Collective Subject, with a questionnaire with discursive questions. These students were young people between 15 to 17 years old that study in a Public High School. In this way, the aim of this paper is to present how High School students, participants this project, understand issues related to computer education and the inclusion of women in this area.

This paper is divided into 5 sections. Section 2 presents the theoretical framework linked to the Discourse of Collective Subject. Section 3 presents the methodology used and in section 4 presents the results. Section 5 presents the conclusions and future work.

II. DISCOURSE OF COLLECTIVE SUBJECT (DCS)

The proposal of the Discourse of Collective Subject (DCS) [5] is based mainly on the assumptions of the Social Representations Theory [6]. The DCS catalogs and associates a

series of operations on the statements collected in empirical surveys through open questions, which at the end of the process result in collective statements that are made from extracts of different individual statements. Each of these collective statements has a specific and distinct opinion or position, and such statements written in the first person with the idea of producing the effect of a collective opinion [5].

The initial applications of DCS technique was health field. After, other areas became to use the collective opinions expression and processing. The aims of DCS is to demonstrate the self-expression of the collective thought or opinion, respecting the qualitative and quantitative condition of it. But how to express this collective subject as a "subject-to-talk", and not as a mathematical expression [4]?

The collective subject cannot speak because, in Portuguese, the possibilities offered are precarious, just to access directly, the collective subject, which is the pronoun "we" of the plural first person, in the absence the alternative of "collective self". However, when the collectivity is expressed in the singular first person, and it illustrates the operation of the social representations system. In addition, the DCS is a feature that enables the social representations as collective facts inherent qualitative collectivity (speeches) and quantitative (of individuals), that is, individuals can share the same views but when such individuals opine individually may transmit only a portion of the view shared content [5].

A collective subject, the in DCS, tries to reconstitute a collective subject that, while collective person, is at the same time, speaking as if he/she was an individual, that is, as a "natural" speech subject, but linking to a representation with larger content.

III. METHODOLOGY

The purpose of this paper is the implementation of a sequence of steps described below. First, the students participated in programming logic courses using Scratch' [6] tool where they developed the programming logic of knowledge in a fun and creative way. Students implemented challenges from primitive conditional, such as "if" or "while" repeat. They developed their skills without to learn primitive syntax as Java [7] and C [8] languages. In this way, they were concerned with the development of the game logic itself, without worrying about implementation details (problems of programming, such as lack of brackets or braces) [9-11].

At the end of the course, the students answered a questionnaire with 12 discursive questions. The questions were as follows:

1. Before doing this course, which is your contact with computing?
2. What computer games or video game you know/play?
3. Do you like math? If you do not like, why?
4. Do you like mathematical/logical challenges? If you do not like, why? If you like, what kind of challenges do you like?

5. Did you like this course? Why? If you did not like, why?
6. Have you had difficulties during the course? Please, explain using examples of problems.
7. What did you learn (new things)?
8. Did you think the course improved your understanding about logic and mathematics in any way?
9. Would you think in following a career in computing?
10. Were the course teachers clear in their explanations? If not, what could be improved?
11. What do you mean by computing?
12. Why do you think that there are not so many girls in computing?

All questions were tabulated and analyzed to identify main idea, and setting an anchor category (DCS methodology). Thereby, the analysis of the DCS can be carried out in order to better understand how students understand the issues related to the project.

IV. RESULTS AND ANALYSIS

For the scope of this paper, here are presented the results of the questions 11 and 12 of the questionnaire, i.e., "What do you mean by computer?" and "Why do you think that there are not so many girls in computing?". Tables 1 and 2 show the obtained results, where in the "Key Expressions" column, the exact responses of students on the questionnaire are presented, respecting the tense verbs and original writings of them; in the "Central Ideas" column, there are the interpretation of the responses; and in the "Anchor" columns are the associated theories related with each central idea. For example, when a student says "When somebody talks about computing, I think about computer, internet, social networks, games," and we put as a central idea "Study and social networks", and the "Algorithms" anchor.

Note that the DCS was composed in the singular first person, with the key expressions of similar speeches meaning from 7 (seven) people between 15 and 16 years old of a Public High School, where 6 (six) were female and 1 (one) was male.

This collective person is talking as if it were an individual, i.e., as a discourse of the subject "natural", but it represents various individuals, allowing the emergence, both qualitative and quantitative, of a collective opinion: qualitative because it is a speech with expanded content, diversified for the construction of DCS. As the questionnaire was applied with young people, some answers had orthographic mistakes, that we kept exactly as they wrote, as the discourses presented.

TABLE I. TABULATED RESPONSES OF QUESTION 11

Key Expression	Central Idea	Anchor
Before the course I thought only learned to learn to work on computers	Knowledge of computer programs	Algorithms
When somebody talks about computing, I think about computer, internet, social networking, gaming, but I did not understand very well how these things formed, to come the course, I still have doubts, but most were understood	Knowledge of computer programs Overcoming difficulties / Motivation	Algorithms Motivational Theory
Which is not only a device is us, why are we put the codes the computer computing answers	Knowledge of computer programs	Algorithms
Programs (software) designed to make life easier for someone and for others not so much	Knowledge of computer programs	Algorithms
I understood that is a well-designed system	Knowledge of computer programs	Algorithms
It is a way to learn, for communication, information that sometimes we use on a day-to-day	Knowledge of computer programs	Algorithms
Computing, for me, is something created for communication and make researches faster	Knowledge of computer programs	Algorithms

Below, the DCS1 (Learn about computer programs), which the speech represents all participants:

“When somebody talks about computing, I think about computer, internet, social networks, games, finally, programs (software) designed to make life easier for someone and for others not so much. Understood that is a well-designed system. Thus, it is a way to learn, for communication, information that sometimes we use on a day-to-day, is something created for communication and make researches faster. Before the course I thought only learned to learn to work on computers, but it is not only a device is us, why are we put the codes the computer computing answers.

DCS1: Knowledge about computer programs

In the DCS1, we can observe that the dimension about the computer understanding has been expanded from the programming logic courses, being anchored by algorithms, which is the basis for development of computer systems. Before the course, students understood the computer only as a form of communication and research. However, the idea about the computer could be programmed according to user needs makes the students realize that this is no longer a passive user and he/she becomes an active user in the system development

process. The fact that one of the student said "it is not just a device, it is ourselves" shows the active user dimension (now developer/programmer) replace in his/her mind.

The algorithms are a part of day-to-day lives. For example: when the doctor gives instructions for the use of medicines, or when we follow a cooking recipe. An algorithm can be seen as a sequence of executable actions to obtain a solution for a particular type of problem, i.e., the programs represent a special class of algorithms that can be followed by computers. However, a computer can only understand programs built into machine language, which correspond to a sequence of specific and uncomfortable instructions. To work around this problem is necessary to build more appropriate languages to become easier the programming task that it could be translated by a computer into machine language [12].

TABLE II. TABULATED RESPONSES OF QUESTION 12

Key Expression	Central Idea	Anchor
Maybe the girls think that computing is just boys area	Define the professional future Gender differences	Professional Future Sexuality
I am not discriminating but I know, as women that men have a sense of faster logic and have a interesting about technology because usually girls are more social, communicate better and prefer to be with the others, for example doing medicine, veterinary medicine, and computing is different from that	Gender differences	Sexuality
Maybe girls were not interested, even by find it more men thing than women thing.	Define the professional future Gender differences	Professional Future
I think there is so many girls because maybe they think programs very complicated .	Gender differences	Sexuality
I do not know, maybe the girls are not interested about what exists behind a "machine", they usually are interested in sites or in games, but they do not care what were developed .	Define the professional future Gender differences	Professional Future Sexuality
Because boys usually have more interest in these area since children	Gender differences	Sexuality

Below, the DCS2 (Gender differences), which the speech represents all participants:

"I think we do not have so many girls because maybe they think programs very complicated. I am not discriminating but I know, as women that men have a sense of faster logic and

have a interesting about technology because usually girls are more social, communicate better and prefer to be with the others, for example doing medicine, veterinary medicine, and computing is different from that the girls are not interested about what exists behind a "machine". They usually are interested in sites or in games, but they do not care what were developed. Boys usually have more interest in these area since children

DCS2: Computer and gender differences

In DCS2, we can observe the differences of opinion between genders that can be supported through gender and sexuality theory anchored in the idea of biological and sexual differentiation of men and women as justifying social inequalities. This idea was refuted by feminist studies that tried to demonstrate that the male and female identities are constructed every day in the social sphere, not by sexual characteristics, but rather by how these characteristics are valued and represented in different historical contexts. Starting from the perspective that gender relations and sexuality itself are historical and social constructions, we can see the existence of academic literature on the inclusion of women in the field of Science and Technology (S&T). In this sense, are basically found three approaches types, according to Garcia and Sedeño (2006): a) who turn to the presence or absence of women in career and the barriers that are imposed upon them and, in this perspective, define exclusion situations of women in that area; b) who discuss the gendered content in S & T area; c) who consider it as an epistemological field of knowledge construction, under male domination. Although the vast literature treat about this diversity, emphasizing feminist heritage of most of these interests, some researches point out the emergence of the notion of "invisibility" of women in science, on the exclusion and dispossession of women scientists [14].

More recently, a study by Beede et al. (2011), by US Department of Commerce, showed that women occupy only 24% of jobs in science, technology, engineering and mathematics (STEM) in US and it confirms data from earlier research, pointed out that they earn, on average, 12% less than men in those careers. The document "Women in STEM: A Gender Gap to Innovation" [15] was written based on 2009 data, shows the gender inequality that has remained constant over the past decade, despite increased presence of women in higher education in STEM. This research also shows that, in careers in general, women account for 48% of jobs, a rate that is halved when it comes to careers in STEM [15]. The study also highlights that women with degrees in science, technology, engineering and mathematics are less likely to acting jobs in this area than their male counterparts, and these professionals tend to occupy positions in education or health [16-19].

V. CONCLUSIONS

The rates of inclusion of women at the college level in the areas of natural sciences, such as engineering is low, but the girls begin their studies with good results in mathematics, with a strong decline as they come to transition to the academic

community, so there is a greater significant number of men. Studies show that these differences are justified by the fact that men presented a better performance with math skills than women, these differences may be strongly influenced by cultural issues [17].

The Discourse of Collective Subject aims to show a thought or collective opinion from a group, based on a qualitative condition (individual opinions) and quantitative (group ideas).

Based in these two premises, this paper presented an analysis of two questions from an applied questionnaire to a group of students who participated in a course in logic programming, focusing mainly on the understanding what means the computer and the gender difference in this area. It is noticed that the DCS1 shows that the students broadening their knowledge about computing and logic. Moreover, students understood that the computer is more than a communication media. It is a tool that they can use in a lot of other purposes and they can develop new applications in their activities.

In the DCS2, we can see that the students still have some "prejudice" as the work of women in the area of natural sciences (include computing), stepped up by the social issues (and not cognitive issues) that influence the choice of careers in these areas. According to Schwartz et al. (2006), women always been excluded to research activities in universities, promoting the idea that natural science areas are not for women (they just could access the university via parents or husbands). In this way, we can conclude that, even after many years, this sensation of women could not work in natural science/math/computing still continues in our society.

As future works, new classes of the course will be done in the public high school, trying to better understand the logic programming in education and choice of career in the sciences and computing. Thereby, we expect to attract more female audience to our graduate students. Moreover, we will include in the questionnaire questions about professional future (in this analysis it is just mentioned), to contribute to a better understanding of it.

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WebTA: Automated Iterative Critique of Student Programming Assignments

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Abstract—We introduce an interactive tool called WebTA that facilitates learning through automatic critique of student source code. Our tool provides immediate feedback to students and gives them experience with test-driven development. Students receive the benefits of cognitive apprenticeship through the feedback they receive in the tool. This facilitates tight, productive cycles of inquiry, critique and learning.

WebTA compiles each student submission and executes it over a series of shakedown tests. Immediate feedback is given concerning errors and warnings, coupled with suggestions for debugging. The tool performs a textual analysis of the students source code and critiques programming style based on standard programming guidelines. To encourage inquiry through test-driven development, edge-case coverage, and API compliance, students develop and submit their own tests to be evaluated by the software.

We report on use of WebTA in one first-year programming course and one second-year data structures course. Lab and assignment scores have improved with WebTA, and student comments attest to the effectiveness of the tool. Preliminary results indicate students receive higher grades with WebTA. One area with mixed results is WebTAs analysis of student developed JUnit tests; this feature improved API compliance but reduced edge-case testing. With these successful initial results, we offer suggestions for future development.

I. INTRODUCTION: FOSTERING INQUIRY AND CRITIQUE IN A COMMUNICATION-RICH CURRICULUM

The principles of agile development, articulated memorably in the *Agile Manifesto* [12] as “individuals and interactions over processes and tools”, “working software over comprehensive documentation”, “customer collaboration over contract negotiation” and “responding to change over following a plan”, have had resonance throughout the software industry over the past two decades. While not all software problems and environments lend themselves to full agile development, it is safe to say that the building blocks of agile (e.g. adaptive rather than predictive planning [5], minimalist documentation [10], test driven iterations [3]), are finding their way into software processes of all kinds. Software developers of the future must be literate in agile methods.

With this shift comes a change in how we approach communication. At the heart of the agile approach is a recognition that requirements, priorities and obstacles in software projects are in constant flux. Consequently, agile methods encourage patterns of constant questioning, informing and debating. We have

identified three fundamentally communication-intensive agile activities: *inquiry* (strategies for resolving unknowns, coming to a shared vision, solving problems); *critique* (systematic analysis and evaluation); *reflection* (identifying and describing one’s own implicit or explicit work process). While each involves internal cognitive or metacognitive problem solving, they are all crucially mediated through communication in a team development setting, and agile methods honor and facilitate this communication. We have reported earlier on efforts to build reflection into our students’ software process [15]; the focus of this paper is inquiry and critique, particularly in programming-intensive courses that are not typically thought of as communication-intensive.

- *Inquiry*. Agile development demands a spirit of constant questioning. The famous Extreme Programming admonition to “embrace change” [4] implies continuous interaction with stakeholders to understand ever-changing requirements, priorities and obstacles. The spirit of inquiry extends to intra-team communication; in a process of continual self-optimization, teams self-organize and problem-solve together.
- *Critique*. Agile development demands continuous attention to good design, including refactoring when changing user needs and design demands dictate. Likewise, team organization and practices also under constant review. This requires developers to be willing and able to reassess current design and practices and to articulate areas of improvement.

We wish to engage students in agile communication practices early in the curriculum, so that they become a natural part of their internalized software process. Also, by recognizing the importance of communication and engaging in it at early stages, we expect to attract and retain students who are motivated by working in teams. These students are the ideal software developers of the future, since the reality is that software development is highly social and communicative.

A. Cognitive Apprenticeship

The Cognitive Apprenticeship model [11] is a constructivist approach to learning that focuses on teaching concepts and practices utilized by experts to solve problems in realistic

environments. It has special relevance in the context of software development, particularly in the communicative skills that we are interested in, because it emphasizes making implicit processes explicit to the learner. In typical computer science or software engineering educational settings, topics like communication are often deemphasized in favor of more technical topics; in the workplace, the communication-related knowledge that experienced developers possess is internalized, complicating their ability to pass it along to new employees.

Vihavainen and Luukkainen [24], [25] utilize Extreme Apprenticeship (XA), which builds on cognitive apprenticeship. The focus of XA is transforming the student into an expert by emphasizing learning-by-doing and starting early. This is accomplished primarily through modeling activities and scaffolding. Scaffolds are correctly-timed hints and feedback. Instructors emphasize "deliberate practice" and students complete hundreds of programming exercises during the course. The deliberate effort of programming on a day-to-day basis emphasizes that students are becoming professionals.

B. CS-POGIL

Our inquiry-based curriculum is situated in the CS-POGIL (Process Oriented Guided Inquiry Learning) approach, which originated in undergraduate chemistry education twenty years ago and has only recently been to computer science [13], [16]. At the heart of POGIL is a guided inquiry learning cycle of exploration, concept invention and application. Students work in small groups with well-defined roles – similarly to teams in agile software development – to encourage accountability and engagement. Each POGIL assignment has a common structure: supply students with initial data, guide them through leading questions that allow them to construct a unifying concept explaining the data, then provide means for them to apply and validate their newly constructed concept. It is in essence an application of the scientific method in a carefully crafted classroom setting. In addition to learning the core concepts at the heart of the assignment, students get practice in team problem solving and communication.

C. Automated Assessment of Programming Assignments

Programs are comprised of well-formed structures that may be easily parsed for evaluation. As such, many automatic approaches have been developed for evaluating student programs. Often these automated assessment tools take the form of testing scripts designed to support the instructor in testing and grading programs submitted by large numbers of students. However, automated assessment can also be used to support agile development processes and provide students with feedback.

Ala-Mutka [1] describes the advantages of automated assessment as "speed, availability, consistency and objectivity" but warns that "automated tools emphasize the need for careful pedagogical design of the assessment solutions". Ala-Mutka discusses many features of automated assessment approaches. Program characteristics assessed dynamically include functionality, efficiency, and testing coverage. In addition, static

analysis tools can be used to assess program characteristics such as coding style, programming errors, software metrics, and design.

One of the primary influences on the work provided here is the JUnit Generation (JUG) Autograder [6], [7]. JUG was developed to support instructors in grading and providing feedback on homework assignments in a data structures course. It provides supplemental feedback to improve student learning, and ease of use for the assignment developer and grader. The JUG system combines unit testing, evaluation and reporting to fulfill those goals. JUG performs dynamic assessment of functionality through generated JUnit testing and efficiency through measurements of execution time. JUG influenced the dynamic assessment portion of our application that evaluates student code by applying a battery of instructor developed JUnit tests to the student's code.

Another major influence on our work is Qiu and Reisbeck's Java Critiquer [19], [20], [21]. Developed to teach students how to write clean, maintainable and efficient Java code. Java Critiquer provides individualized feedback and just-in-time learning opportunities to students. The Java Critiquer performs static assessment of programming style, programming errors, and design by using regular expressions to match snippets of code with trigger patterns in instructor created rules. When a match is found in the student's code, the rule is fired and the advice encoded therein is dispensed to the student. Students use the tool iteratively to improve their code before submission. Ali, Hosking, and Grundy [2] categorize the Java Critiquer as an analytic critic, using text-based pattern matching through instructor authored rules to provide explanations and suggestions. The Java Critiquer influenced the static assessment portion of our application that evaluates the students' programming style.

Test My Code (TMC) is an automated assessment tool developed by Vihavainen *et al.* [26] as a tool for their Extreme Apprenticeship methodology. TMC is an assessment system that enables instructors to build scaffolding into programming exercises. TMC is integrated into the student's programming environment and provides tasks for the student to work on. TMC allows for scaffolding and automated instructor-initiated feedback. Test My Code is very close to the overall goals and functionality of our project. One important difference in focus is that TMC works within an environment of high instructor-student interaction, providing the ability for instructors to iteratively and precisely identify points of critique within student code. In contrast, the personnel constraints of our teaching environment offer less intensive interplay between student and instructor. We appreciate TMC's ability to facilitate direct communication between student and instructor, but our focus is on providing automated feedback to students that are detectable through dynamic or static methods, as anticipated by the instructor. Consequently, we use automated methods for style and design feedback in addition to test-related feedback.

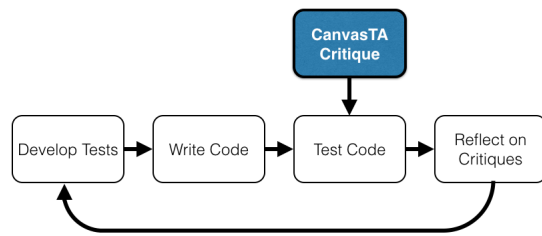


Fig. 1. WebTA development cycle.

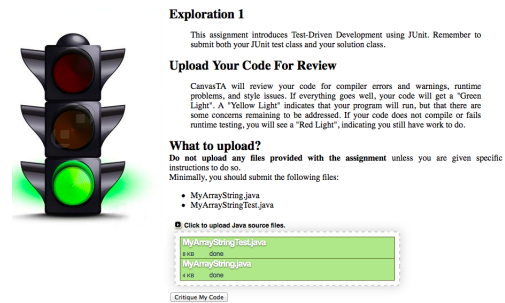


Fig. 2. WebTA startup screen.

II. WEBTA: A TOOL FOR AUTOMATED CODE CRITIQUE

WebTA is a tool developed by the authors to critique student programs in introductory computer science courses. The tool is designed to provide immediate feedback to students as they develop programmatic solutions to complex problems.

Traditional methods for teaching computer science — lecturing on abstract concepts, assigning a programming project related to the lectures, then grading the students' submitted finished products — resemble the outdated waterfall model of software development [22] in many ways:

- An instructor writes a specification and hands it off to students as an assignment.
- Students toil in isolation, without the benefit of instructor feedback or team communication.
- When they run out of time, students submit the assignment and hope for the best — not entirely sure that they interpreted the assignment in the same way as the instructor.
- Lastly, the instructor applies secret tests to the student work and assigns a grade, then moves on to the next topic, regardless of whether students have successfully constructed mental models sufficient to understand the current topic.

With WebTA, we employ an authentic approach for today's software world, teaching students test-driven agile development methods through small cycles of teaching, coding integrated with testing, and immediate feedback. We focus on this Learning Cycle [14] by providing students just-in-time code critiques for them to reflect on and feedback into a continuous development process (Fig. 1). This exposure prepares them better for today's software industry and reduces the frustration that students often experience in early programming projects, mitigating the risk of student burnout and helping with retention in computing-related majors.

Students in our introductory course work on 10–12 programming assignments per semester; of these, 5–7 are large, multi-week projects. Within these strict time bounds, students must parse the project specification, extract from this a suitable design, and implement it in code. The pace can sometimes outdo students, and they often feel they submit their assignment without a deep understanding of the project, its requirements, or a sense of the grade they will receive. In this context, the WebTA tool provides students with immediate

testing and feedback while they complete the assignment so there are no surprises at the end.

Students using WebTA are engaged in communication-by-proxy with the instructor. The instructor configures WebTA with common critiques that are triggered by errors, warnings, or textual analysis of the student's code. These critiques are issued to the students immediately; as needed by the student to support concept formation. This communication is not meant to replace instructor feedback; rather, it codifies common feedback scenarios to assist the instructor in reaching students in tight feedback loops just when the student is engaged in problem solving and learning. A particularly effective configuration is one in which students work in pairs — with appropriate mentoring in pair programming skills [17], [18] — and utilize both live feedback from the instructor and automated critique from WebTA. In this way, students get exposure to consulting and processing feedback from a range of sources.

When students connect with WebTA, a startup screen that explains the current problem and tells them which files they should upload to receive a code critique (Fig. 2). After clicking on the "Critique My Code" button, students receive an online report which includes a Critique Summary (Fig. 3). A stoplight metaphor, commonly used within the agile development community, is used to indicate student progress through the assignment. The stoplight indicators and code critiques prompt students to reflect and refactor. The critique summary includes a stoplight that tells the student at a glance if they succeeded in their programming task. A green light indicates a satisfactory state and a red light indicates serious errors.

In addition to the "pass-fail" criteria of the green-red stoplight metaphor (which are useful, especially if done in a scaffolded way like Test My Code), WebTA allows instructors to include more heuristic conditions that can be triggered when students may be diverging from "good practice", e.g. style or design issues that may not cause tests to fail. An amber light indicates the presence this type of problem. WebTA also allows for automated positive feedback. The assessment summary section also lists the parts of the critique and how the student performed in them.

Under the hood, the system has compiled their code and run it through a series of rigorous shake-down tests. Students can scroll down from the critique summary to view details of

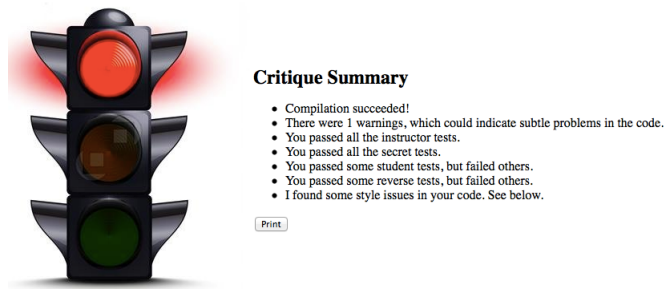


Fig. 3. WebTA critique summary.

Student Unit Tests

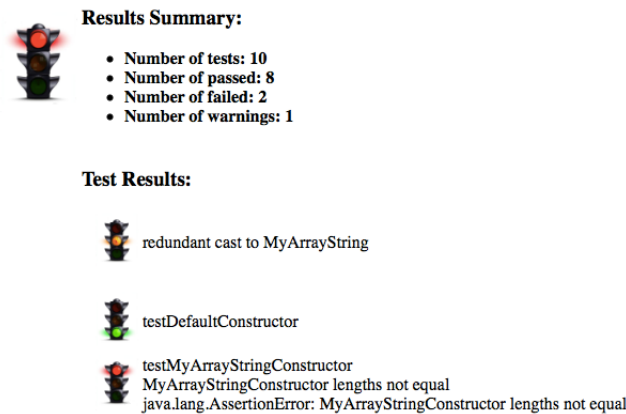


Fig. 4. WebTA student tests.

the critique, including errors and warnings generated both at compile-time and run-time. The instructor can configure the system to run both public and secret tests, run the student's own test code against their program, or assess the student's JUnit test cases to determine their ability to generate edge cases (Fig. 4).

Scrolling further down the code critique, students find a listing of each code file submitted that includes style advice generated via textual analysis of the code (Fig. 5).

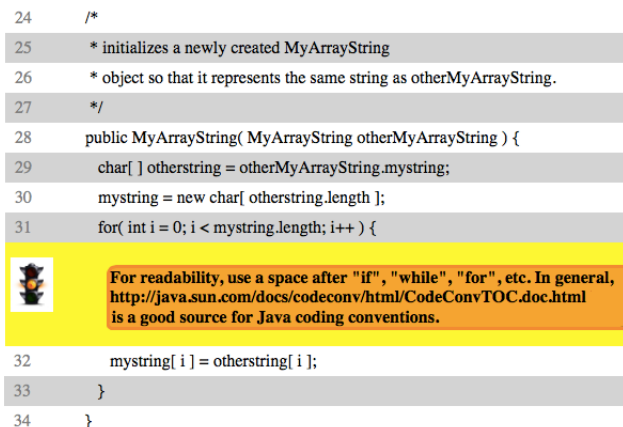


Fig. 5. WebTA style critique.

Students using WebTA are engaged in Learning by Doing [23]. Instructors provide students with authentic problems. While developing solutions to problems, students engage in an iterative conversation: developing code, receiving critiques, reflecting on feedback, and revising their solutions. WebTA applies Cognitive Apprenticeship practices that role-model authentic skills for students. Students are repeatedly exposed to patterns of coding and critiques from which they learn how to identify and communicate about issues that crop up during software development.

Features of WebTA include

- code compilation with student-friendly explanations of errors and warnings;
- rigorous, assignment-based unit test shakedown of student code, featuring both student-visible test to guide their code development and hidden tests to exercise their inquiry skills;
- evaluation of student test code, to support them as creative testers;
- textual analysis of source code, fully customizable by the instructor, to provide feedback on coding style;
- built-in plagiarism detection;
- preliminary grade assessment, for use by instructors or teaching assistants as a basis for final scores.

III. A WEBTA WALKTHROUGH

We provide a brief walkthrough of the WebTA critique process. For space reasons, we focus on the student perspective and provide a synopsis of the instructor actions.

A. Instructor setup

The instructor formulates the following assignment:

- Develop a class named *Fibonacci* that contains two methods: *fibIteration* and *fibRecursion* that given an integer n returns the long n^{th} element of the Fibonacci Sequence using iterative and recursive methods, respectively. if n is out of range, return -1.

For this problem, the instructor sets up three tests, one of them being secret. The tests, using JUnit test conventions, are as follows:

```
@Test
@CanvasTaTest( points = 5, name = "fibIterative Test.",
description = "Checks for all values of n from 0 to 9.",
hint = "Remember to track the previous two values." )
public void fibIterativeTest() {
    Fibonacci prog = new Fibonacci();
    long[] solutions = {
        0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, 377
    };
    for( int n = 0; n < solutions.length; n++ ) {
        long result = prog.fibIterative( n );
        if (solutions[ n ] != result) {
            fail( "fibIterative( " + n + " ) = " + solutions[ n ]
                + ". Your method returned " + result );
        }
    }
}

@Test
@CanvasTaTest( points = 5, name = "fibRecursive Test.",
description = "Checks for all values of n from 0 to 9.",
hint = "Remember to test for the base case." )
public void fibRecursiveTest() {
    Fibonacci prog = new Fibonacci();
```

```

long[ ] solutions = {
    0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, 377
};
for( int n = 0; n < solutions.length; n++ ) {
    long result = prog.fibRecursive( n );
    if (solutions[ n ] != result) {
        fail( "fibRecursive( " + n + " ) = " + solutions[ n ]
            + ". Your method returned " + result );
    }
}
}
// Secret Test
@Test
@CanvasTaTest( points = 5, name = "fibRecursive Edge Case",
description = "Checks for n = -1" )
public void fibRecursiveEdgeCaseTest( ) {
    Fibonacci prog = new Fibonacci( );
    long result = prog.fibRecursive( -1 );
    if ( result != -1 ) {
        fail( "fibRecursive( " + -1 + " ) = " + -1
            + ". Your method returned " + result );
    }
}
}

```

The instructor also creates (or reuses existing) rules for the style critic. Rules consist of a regular expression, that matches with a problematic code snippet, coupled with advice the instructor would give a student who wrote such code. For example, anticipating that the student might not space code within parentheses, such as:

```

for(int i = 0;i < n; i++){
    x = y;
    y = x + y;
}

```

The instructor might develop a rule whose trigger matches a form “(EXPR)” and whose advice is “For readability, use a space after (and before)”.

B. Student development

When students submit the assignment, it is uploaded to WebTA for testing and analysis. Depending on the instructor configurations, student code is compiled, tested against instructor tests, secret instructor tests, the students own tests, and the students test can even be run against an instructor solution to help students develop better coverage in testing. Furthermore, source files uploaded by the student are subjected to textual analysis to provide feedback on their programming style.

In this case, the student submits the following code skeleton, which should fail all tests.

```

public class Fibonacci {
    //Iterative method
    public long fibIterative(int n) {
        return 0;
    }
    //Recursive method
    public long fibRecursive(int n) {
        return 0;
    }
}

```

WebTA provides immediate feedback in the form of a critique report that the student can print. The critique report contains an executive summary of results, as well as a detailed listing of all errors and warnings encountered during

Submit Summary

- Compilation succeeded!
- You failed all the instructor tests.
- You failed all the secret tests.

Fig. 6. First Pass Executive Summary.

1 Compiler Errors:


 **ERROR: compiler.err.expected**
Status: Failed
Line: 5, Column: 17
';' expected

Fig. 7. Second Pass Compile Time Error.

the various kinds of analysis performed (as configured by the instructor.)

Fig. 6 shows that the students skeleton code compiled, but all tests failed as expected. So now the student tackles the *fibIterative* method, which seems like it should be easiest to implement.


```


public class Fibonacci {
    //Iterative method
    public long fibIterative( int n ) {
        long x = 0;
        long y = 1
        for( int i = 0; i < n; i++ ) {
            x = y;
            y = x + y;
        }
        return x;
    }
    //Recursive method
    public long fibRecursive(int n) {
        return 0;
    }
}

```

Oops — the student missed a semicolon on line 17 (Fig. 7). The student makes a quick fix and resubmits the code. This time, WebTA indicates that the test for *fibIterative* failed and a style issue was found (Fig. 8).

The student fixes the style issue by adding a space between the **for** keyword and the opening parenthesis. The test failure is a more difficult matter. The student adds a main method and prints the first ten values. It is evident that the results are


Test: fibIterative Test.
Description: Checks for all values of n from 0 to 9.
Hint: Remember to track the previous two values.
Status: Failed
java.lang.AssertionError: fibIterative(2) = 1. Your method returned 2


 for(int i = 0; i < n; i++) {



Style Critique
Status: Warning
Line: 6 Critique: For readability, use a space after "if", "while", "for", etc. In general, <http://java.sun.com/docs/codeconv/html/CodeConvTOC.doc.html> is good source for Java coding conventions.

Fig. 8. Third Pass: Test failure and style critique.

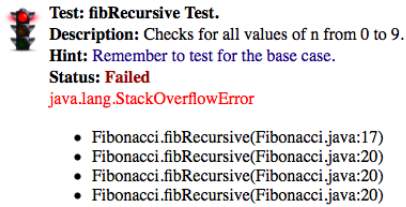


Fig. 9. Student encounters infinite recursion.

not the Fibonacci Sequence. But what is wrong? Fortunately, WebTA has provided a hint, “Remember to track the previous two values”. Taking this into consideration, the student realizes that she did not implement the formula correctly and makes some changes.

```
public class Fibonacci {
    // Iterative method
    public long fibIterative( int n ) {
        long x = 0;
        long y = 1;
        long z = 1;
        for ( int i = 0; i < n; i++ ) {
            x = y; // fib(n)
            y = z; // next fib(n-2)
            z = x + y; // next fib(n-1)
        }
        return x;
    }
    // Recursive method
    public long fibRecursive( int n ) {
        return 0;
    }
    // TEST CODE
    public static void main( String[ ] args ) {
        Fibonacci self = new Fibonacci( );
        System.out.println( "n ITERATIVE RECURSIVE" );
        for( int n = 0; n < 10; n++ ) {
            long fibI = self.fibIterative( n );
            long fibR = self.fibRecursive( n );
            System.out.printf( "
        }
    }
}
```

This time the student passes the *fibIterative* test. Moving on, the student implements and submits the *fibRecursive* method.

```
//Recursive method
public int fibRecursive(int n) {
    if ( n > 0 ) {
        return n;
    }
    return fibRecursive(n - 1) + fibRecursive(n - 2);
}
```

The *fibRecursive* test fails due to infinite recursion (Fig. 9). The student, new to recursive algorithms, spends some time on this before connecting the hint about testing the base to fact that the base case includes 0! That’s a quick fix (post epiphany).

```
//Recursive method
public int fibRecursive(int n) {
    if ( n = 0 || n = 1 ) {
        return n;
    }
    return fibRecursive(n - 1) + fibRecursive(n - 2);
}
```

The student is almost there. All Instructor Tests are passed,

Instructor Unit Tests



Success! All tests passed.

- Number of tests: 2
- Number of passed: 2
- Number of failed: 0
- Number of warnings: 0

Secret Unit Tests



Results Summary:

- Number of tests: 1
- Number of passed: 0
- Number of failed: 1
- Number of warnings: 0

Fig. 10. Student Passes Instructor Tests, But Fails Secret Test.



Submit Summary

- Compilation succeeded!
- You passed all the instructor tests.
- You passed all the secret tests.

[Print](#)

Fig. 11. Student Passes All Tests

but the Secret Test is still failing (Fig. 10). No information is given to guide the student on a secret test so the student has to resort to manual debugging and rereading the specification. In this case, the assignment says that values of n that are out of range should cause the methods to return -1. With a final modification to the code, all tests pass!

Assignment submission. When it comes time to submit an assignment, students can submit to WebTA and get immediate feedback about how well their code compiled and tested via the Assignment Submit tool. When creating an assignment, instructors set the Submission Type to External Tool and select WebTA Assignment Submit. Instructor configuration is similar to the Code Critique tool. Students see the WebTA submit page at the bottom of their assignment.

Upon submitting, students receive an executive summary of how their code performed. This does not indicate a grade. However, a preliminary grade report is saved for a human TA to review before assigning a grade.

C. Instructor evaluates submissions

Through WebTA, the instructor may view student submissions, and select a student to see the students’ code and a preliminary score assigned by WebTA. The instructor then examines the results and the student’s code, providing additional comments and feedback or grade modifications. Once a grade

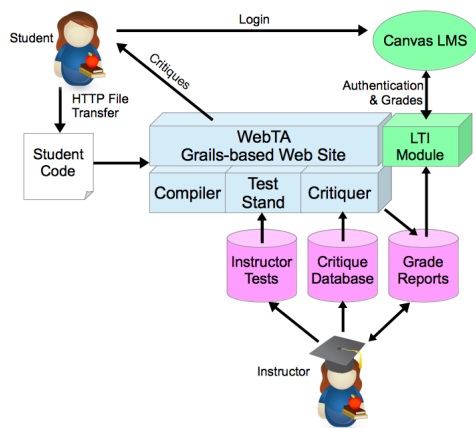


Fig. 12. WebTA architecture.

has been assigned, WebTA sends a grade report to the student.

IV. WEBTA: TOOL DESIGN AND IMPLEMENTATION

As a web application, developed on the popular Grails Framework, WebTA is comprised of several modules, data sources, components, and interaction modes (Fig. 12). At our home institution, the primary form of managing instructional materials is the Canvas Learning Management System (LMS) [9], and our design is intended to fit seamlessly into a Canvas-administered course. At the same time, we plan to furnish a flexible solution not tied to Canvas, in order to make it more broadly useful across other institutions and to satisfy the needs of instructors who do not use learning management systems.

A detachable LTI Module provides web services required for authentication with, and grade reporting back to, the Canvas LMS. In principle, the module can plugin to any other LMS implementing the LTI standard, including Blackboard or Moodle. Furthermore, the LTI Module may be replaced with another component that supports alternative authentication or access control methods, such as `.htaccess`. Indeed, current plans are to develop a web-based authentication module integrating with our institution's Student Account System for courses that do not use Canvas.

Data sources for the system include:

- *Student Code* and *Instructor Tests*, through source files uploaded to WebTA;
- The *Critique Database*, containing instructor-customizable rules for dispensing advice to the students;
- *Grade Reports*, generated by WebTA and updatable by instructors before final grades are recorded.

Our introductory computer science sequence utilizes the Java programming language. Thus our first pass at creating a Critiquer System focused on providing feedback to students on their Java code. The *Compiler*, *Test Stand*, and *Critiquer* components perform general functions specialized on analysis of Java. We plan to develop additional components specialized on C, C++, Racket, and R.

The Compiler component verifies that the submitted student code is legal, constitutes an actual program, and compiles the code. The Test Stand component validates the code by running a series of instructor defined tests against the student program.

The Critiquer uses rules to look for patterns in Errors, Warnings, Console Output, and Source Code to generate advice. Currently, this is done by simple textual analysis using regular expressions, the results of which are applied to rules in the critiquer database.

There are two modes of interacting with the system:

- *Student*. Students login to Canvas, which handles authentication and links to WebTA in a new browser tab. A drag-and-drop field is provided for uploading source code files. Uploaded files are compiled, tested, and critiqued. The student receives feedback in their browser.
- *Instructor*. Canvas is also used to authenticate faculty and graduate TAs, enabling them to access WebTA in their browser. Instructors use WebTA to setup code tests, enter rules into the critique database, and view/modify grade reports before assigning final grades.

These modes of interaction are built-into the web application and are not dictated by Canvas. After authentication, all interactions are through web pages served-up by the WebTA server.

V. PRELIMINARY RESULTS

2014-2015 was our first year of deployment. We beta tested WebTa in two courses (Intro to Programming 1, Data Structures), each with approximately 100 students enrolled. There have been growing pains: some technological, some perceptual.

Technologically, we experienced problems with server load and browser incompatibility. There was a period of time in the fall when several major browsers were pushed security updates and WebTa stopped working with all but the Chrome browser. During crunch periods around midterms and finals week, we experienced severe server lag, making it difficult for students to submit code or for WebTA to execute it within the specified thread time-out parameters. Working with our IT department, we have resolved these issues.

Unfortunately, these issues created perception problems with the students:

- “[WebTA] is also a bit difficult because we can’t access it from our own computers.”

Yet many more students have expressed an appreciation for WebTA:

- “I like [WebTA] because it shows be where my error is or which test is wrong so I can spend more time on fixing it rather than taking forever to search for the error.”
- “[WebTA] gives good input on style and how to fix my errors.”
- “I really enjoyed CanvasTA. Mostly every aspect of it was very helpful. I really loved how quick it was to simply drag and drop my .java file in and simply click to have it run its checks and turn it in. The checks and some of

Course	Semester	Mean	Median	Mode
CS1121	Spring 2015	80.4	95.0	99.8
CS1121	Spring 2014	72.4	77.7	93.2
CS2321	Fall 2014	82.9	86.6	95.4
CS2321	Fall 2013	75.0	80.8	59.4

Fig. 13. Programming project scores.

the style tips it made were also very helpful. There were some bad programming practices I've done that I never realized before until I read through its style suggestions."

WebTA was beta tested in the Fall 2014 Data Structures course and in the Spring 2015 Introduction to Programming course. Programming project scores compared to the previous year were higher (Fig. 13), but more study is required to determine if the difference in scores is solely or in part attributable to WebTA and to identify other influencing factors.

Qualitatively, we have the sense that more effort needs to focus on fading scaffolds and teaching students how to test their code.

Data Structures students were required to submit JUnit test cases with their code during both Fall 2013 and 2014 semesters. WebTA tested their JUnit tests against the assignment API. Over the course of Fall 2014 we saw marked improvement in student conformance to the specified API. However, we also noticed students who, upon failing an attempt to test an edge case, would remove their test method to eliminate the problem, instead of trying to understand the edge case and fixing their test.

A concern is that students are relying on WebTA to test their code. When asked how he used WebTA, one student responded:

- "I mainly used it for testing purposes. It was great that it gave me the results and failures so I could go back and try to figure out what went wrong. On the downside I think it made me put a little less effort in actual testing myself though I ended up having to anyway to fix some of the errors it showed."

Another student said:

- "Whenever I felt that I had working code (i.e. I fixed any bugs I could think of or the bugs pointed out by [CanvasTA]) I would submit my program file to [CanvasTA] to see if it passed or not."

Based on an informal in-class survey, second-year Data Structures students were more accepting and less critical of WebTA while first-year Intro students, who had never used a different system for assignment submission, provided more critical feedback.

VI. PLANS FOR FUTURE DEVELOPMENT

We continue to improve WebTA and are devoting significant resources to expanding its capabilities. We have several ideas for future development. The most pressing features to be worked on include:

- A new web-only authentication module for faculty who do not use Canvas.
- Improved communication between test methods and the critiquer component. One aspect of this is to implement edge case awareness so we can provide students with better feedback.
- Conditional recompilation and testing by graders. Sometimes students have one thing wrong, for example a poorly written constructor, that causes all tests to fail. A simple change to their code and recompilation might allow testing to proceed and provide instructor with a better understanding of the student's progress.
- Code parsing and semantic analysis within the critiquer component. This will enable better critiques and reduce false positives when matching rules compared to the current textual analysis with regular expressions.

We are also planning two larger-scale activities:

- In our targeted courses, we have observed "divergent" student coding behavior that does not reflect good practice despite passing automated tests. Based on these observations, we are formulating common coding antipatterns [8] and devising heuristic triggers within WebTA that detect these behaviors.
- To facilitate enhanced communication, reinforce reflection, and support lab-based pair-programming practices, we are developing an online pair-programming development environment that will be tightly integrated with WebTA. This larger system will enable us to detect and provide feedback on student communication patterns and development practices that we cannot observe by doing a post-facto analysis of code in WebTA.

Furthermore, students have suggested the following improvements:

- Code and data structure visualizations.
- Code to English translation to help them better understand their code.
- The ability to display console output and generate graphs of their data.
- Code repository. Students would like to be able to access previous versions of submitted code and have a rollback facility.

We think these student suggestions are valuable and will help us make WebTA more interactive, make the learning process more engaging, and make the development process more agile for the students.

VII. ACKNOWLEDGEMENTS

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Research on System Level Innovative Practice in Embedded Laboratory Education

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Abstract—Embedded System Curriculum at Tsinghua University is target at advanced undergraduate senior students in CS department. At the end of this course, an overall understanding about System is expected to be obtained by students who have gotten perfect software knowledge from software series curriculums and hardware knowledge from hardware series curriculums. Embedded System is unique for its close association with actual application, thus an effective laboratory education is of great importance for embedded system curriculum. In this paper, we are dedicated to reform existing experimental teaching models, methods and laboratory platform to improve system level innovation practice for CS undergraduate students. Firstly, we mainly analyzed the characteristics of embedded laboratory education and current generation students. Based on this analysis, some principles as well as a concept model that guiding the designing of embedded laboratory platform are proposed. And then we present the whole innovative embedded laboratory system in CS department of Tsinghua University. Supported by the system, some typical projects will be presented, include intelligent Greenhouse, Sunflower, intelligence handcart, intelligence spider and rotorcraft.

Keywords—system level practice, embedded laboratory education, teaching models

I. INTRODUCTION

Discussion on embedded laboratory education must considering from two aspects: the characteristics of the development of embedded technology and the role of the embedded course in the teaching system of undergraduates.

Embedded system is now playing increasingly important roles in our lives. From consumer electronics products to aerospace industry, from hot applications as smart phone and tablet computer to relatively unnoticeable applications as artificial satellite, it has impacted nearly every aspect of our lives, directly or indirectly.

The huge potentiality of embedded system has received great concern from educators that discussions about embedded system education have never ceased. Educators from around the world have proposed various kinds of innovate and creative methods and theories to promote the education of embedded system. Among these educators, it is generally accepted that the most conspicuous characteristic of embedded system is its close association with practical application.

The applications of embedded system appears in a broad scope of areas, such as small and single microcontroller applications, control system, distributed embedded control, system-on-chip, networking, embedded PCs, critical systems, robotics, computer peripherals, wireless data system, signal processing, and command and control, while additional cross-cutting skills that also important to embedded system designers include: security, dependability, energy-aware computing, software/system engineering, real-time computing, and human-computer interaction [1].

Students, in order to be a qualified embedded system designer, are expected to have hands on experience in these applications. Thus, it is in great necessity to design a highly effective laboratory system. This laboratory platform is expected to connect the abstract theory to actual applications thus better help the students apprehending the knowledge and skills of embedded system.

On the other hand, embedded laboratory education is an important part of embedded system curriculum, which is also an important part of teaching system of undergraduates. Embedded System Curriculum at Tsinghua University is target at advanced undergraduate senior students in CS department. The students have gotten perfect software knowledge from software series curriculums including Program Design, Compilation Principle, Operating System, and also have gotten perfect hardware knowledge from hardware series curriculums including Digital Logic, Principles of Computer Composition, Computer System Architecture. At the end of this course, an overall understanding about System is expected to be obtained by students. So we emphasize system level innovative practice in embedded laboratory education rather than proof-of-principle experiments taken by other CS specialized basic courses.

In this paper, we will introduce our attempt in trying to improve the embedded system laboratory education in Computer Science department of Tsinghua University. We will first discuss the characteristics of embedded system curriculum in section II, secondly discusses the feature of current generation students in section III, proposed our principles and concept model of designing Embedded System laboratory platform in section IV, finally present the implementation of embedded laboratory education in Tsinghua University in section V and some typical application projects supported by

the principles and concept model will be presented simultaneously.

II. CHARACTERISTIC OF EMBEDDED SYSTEM LABORATORY

Embedded laboratory education is different from other laboratory education in two aspects: the interaction of software and hardware and the rapid updating rate due to technology development, shown as below:

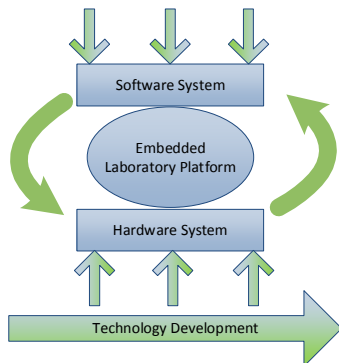


Fig. 1. Characteristic of embedded Laboratory Platform

Embedded system experiments are first characterized by their intense interaction between software and hardware. This is because an integral embedded system necessarily working on the foundation of both of them. In embedded laboratory education, neither of the two parts should be neglected; however, we have made mistakes in the past.

Embedded System at Tsinghua University is target at advanced undergraduate senior students in CS department. An overall understanding about Embedded System is expected to be obtained by students at the end of this course. However, it is discovered that students are generally incapable of designing one integral embedded system, from hardware to software, in a limited 2 credits laboratory curriculum. So we end up taking a compromise approach to require the students developing such open-sourced industrial software driver as mouse and keyboard. However, this approaches proved to be unproductive; students are discovered to comprehend only part of what they should have acquired and subsequently have poor performance in later curriculum. This is so not only because of the commonplace of the experiment task, but also because students are unable to get access to the hardware layer and fail to comprehend the embedded system as a whole.

Another notable feature of embedded laboratory curriculum is the rapid updating rate of knowledge and technology due to the deep-in of embedded system research. As is discussed in section one, sticky attachment to actual application is one critical element in embedded system laboratory education. And since radical change in embedded system technology is taken place every day, the knowledge and skills taught in embedded laboratory curriculum as well as devices and components applied in the platform would soon outdate without timely updating.

In one investigation concerning students' opinion toward the conventional laboratory platform in CS Department of

Tsinghua University, the mainly deficiency, as is revealed in the investigation, is the antiquated device and components applied in the platform. Students find little connection between the experiment platform and the recent technology and feeling no attraction in the laboratory experiments.

In conclusion, in order to design an effective embedded laboratory platform, both the software-hardware interaction and the rapid development of embedded technology should be taken into consideration. System level innovative practice is expected in the embedded laboratory education.

III. CHARACTERISTIC OF CURRENT GENERATION STUDENTS

Except for the embedded laboratory curriculum itself, student is another determinedly factor that should not be neglected. Students are participants of the experiments, how they feel about the experiment will affect the success of laboratory curriculum. However, it is discovered that the traditional laboratory approach has been increasingly unattractive for the new generation students. This is so mainly because the students evolving from one generation to another while the conventional laboratory approach stay ten years or even longer unchanged.

The new generation students, as is pointed out by Yannis Tsividis in Turning the Students On to Circuit [2], different from the older generation students in three aspects that they have been less tinkered, less patient and relied more on software. Furthermore we found the new generation students of China are more innovative and creative than the older generation ones.

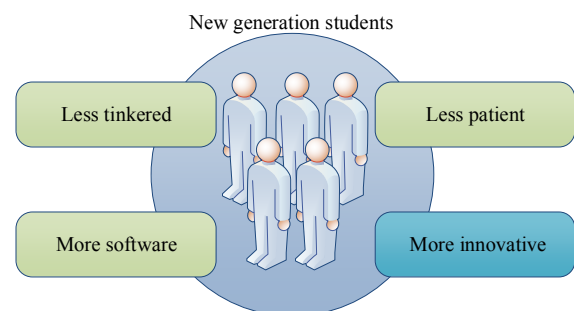


Fig. 2. Characteristics of new generation students

First of all, they are less tinkered. Most, if not all, students have growing up in such a social environment that consumerism has becoming increasingly prevalent. They would care more about function rather than the fundamental principles, appearance rather than the architecture. In short, they had little understanding about the principle of embedded system. While on the other hand, most of our laboratory platforms are specifically designed for purpose of demonstrating or verifying the principles on the text book. And thus students are generally unable to connect the over specific-designed experiments to the practical application. This very fact matters because students are much more likely to turn to other areas if they could not see the future application of the studied knowledge. Therefore, it is important to connect the laboratory platform to the updated technologies.

The second characteristic of new generation students is their lack of patience. The wide spread of internet along with the rapid life pace has cultivate the growing impatience of new generation students. They has been so used to seeing the results immediately after starting out, just as they will expect the page showing on the screen right after a mouse click. However, in conventional approaches, curriculums are often started with an overall illustrative analysis classes. It is acknowledged that these illustration are in necessity, since it help the students comprehend the overall knowledge structure of that curriculum, however, these instruction sometime push the students away because of its abstract and dry. In view above, the novel platform should provide the students some interesting and attracting “result”, such as a simple application of embedded system, in the beginning of the curriculum.

Thirdly, they believe and relay more on software. The development of embedded system, radical as it is, is usually taken as granted by the populace. In part, this situation may be due to an evolution in EE toward more intelligent, yet smaller and less visible layers that are often camouflaged by elaborate user interfaces and other icons of what the populate attributes more to computer science than to electrical engineering [3]. However, many universities are unaware of this fact. They often pay more attention on the embedded software designing and less attention on the physical layer introduction. The inappropriate concentration on software in teaching embedded system turns out reinforcing the general impression that software applications are much more important than the physical layer among students. In order to correct this bias, more attention should be placed on the hardware layer in embedded system curriculums.

Furthermore, in China the new generation students are more innovative and creative. With the progress of society and the raise of living material standards, they have unprecedented access to technology and information. Unlike the old generation students, part of which had never haven their own PC before entered the university and were starved for principles of how it works, the new generation students are curious of what new things we can create by it. The knowledge and information in curriculums are both the source material of their innovations. So the embedded laboratory system should provide opportunities to practice innovative projects.

Again, in order to design an effective experimental laboratory platform, the characteristics of current students should not be neglected.

IV. PRINCIPLES OF DESINGING EMBEDDED LABORATORY PLATFORM

In view of the discussion above, we propose several principles in designing embedded system laboratory platform:

- *Integral*: the experimental platform should be relatively complete, which means that students are able to get access not only to software but also to hardware. This principle mainly solve two problems: firstly helps correcting students’ bias that software weights more and then helps attracting the students in the beginning by building a basic but integral system.

- *Open*: this platform should endow the students with appropriate freedom to implement their creative ideas. The platform, whether software system or hardware system, should leave enough interfaces to students, so that they can construct their own embedded system on the basis of which. When applying this principle, more actual-application-related embedded systems are expected to be created by students and their passion will be aroused in the process.

From the teaching perspective, this system should also contain the following characteristics:

- *Updateable*: hardware or software of the system can be extended or updated independently without an overall system modification. As is pointed out in section II, embedded system are characterized by its raid updating rate on especially hardware devices. In order to meet need of frequent updating, the principle of being updateable should be placed in the critical position.
- *Flexible*: the content of the experiment can be tailored according to the curriculum requirement, so that it can be widely adopted. Most specific deigned laboratory platform are weak in their flexibility; their complexity could neither be reduced nor increased and it would soon be discovered that these experiments need to be redesigned in order to accommodate with the change of curriculum length.

In answering to the goals discussed above, we proposed an overall concept model of the system shown as Figure 3:

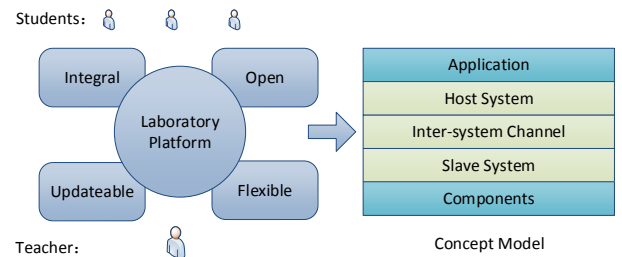


Fig. 3. Conceptual model of target system

This hierarchy concept model consists of three central layers and two peripheral layers. The central layers include host system layer, inter-system channel layer, and slave system layer while the peripheral layers include application layer and components layer. In the following we will explain why this model fulfill the goals we proposed to the best.

Integral Seeing the three central layers as a whole, this basic model consists of the major elements of one typical embedded system, from upper application to lower function components. Students will get access to each components of an integral system.

Open The top layer and bottom layer of this model are opened for students. Designer of the actual laboratory system should provide enough hardware and software interfaces to students in the top application layer and the bottom component level. These interfaces should be complete and user friendly.

Using the hardware interfaces, students are able to construct a creative embedded device by connecting other necessary module to these interfaces; using these software interfaces, students can easily employ correspondent hardware resources that provided.

Updatable The laboratory platform should be modular and layer designed and each layer should provide upper interfaces connecting upper layer and lower layer connecting the lower layer, so that any of these layers can be extended or updated as long as the modified layer interfaces are still compatible with original adjacent ones. The central layer in this model is designed as three-layer structure. This inspiration comes from the design of Phidgets [4] and it will to provide more possibility to the actual devices.

Flexible Each of these layers can be stressed or scant according to the emphasis of the curriculum, so the content and length of this curriculum can be adjusted to the curriculum length. The experimental classes can be arranged as two or more levels. The fundamental experiment may require the students to build up one basic system; in the advanced experiment, students are able to deeply research in layer in the model and thus implement their creativity.

Based on the conceptual model above, an effective embedded laboratory system can be designed without too much difficulty.

V. IMPLEMENTATION OF EMBEDDED LABORATORY EDUCATION

A. Embedded System Curriculum

Embedded System Curriculum is a specialized course for advanced undergraduate senior students in CS department. The teaching goal is to guild the students to master the method and skills of designing embedded applications from the perspective of system level rather than what is the embedded system. The students selected the course must had finished software series curriculums including Program Design, Compilation Principle, Operating System, and hardware series curriculums including Digital Logic, Principles of Computer Composition, Computer System Architecture. In Embedded System Curriculum, the students should finish a system level projects by combining the knowledge of software and hardware.

The curriculum consists 32 credit hours of coursework. Theoretically there are 16 credit hours in class and 16 credit hours in laboratory. Students also can take the experimental equipment home or to the dormitory, practice hours will prolong. Through the investigation on the students of last years, 35 practice hours are expected.

B. Embedded Laboratory Practice

Embedded Laboratory Practice is divided into two parts: the basic experiment and the advanced experiment.

The basic experiment spends 3 credit hours. Each student must finish independently. A serial of detailed experiment

guidebooks help the students to familiar of the experiment equipment and basic development methods rapidly.

The advanced experiment spends about 30 hours. The students are divided into several teams. Each teams contains up to 4 persons and customize their project of interest. The project must be guided and reviewed by the teacher and assistant at first. Every team should design and implement a system application combining with software and hardware. The basic embedded laboratory equipment which we designed must be selected and other components and devices can be added as the team demands.

C. Embedded Laboratory Equipment

In view of the discussion in section IV, we design and implement a set of embedded laboratory equipment which is described in Fig. 4.

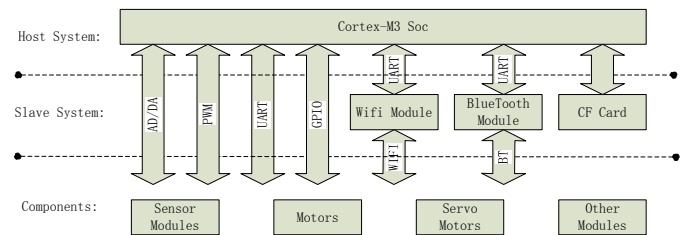


Fig. 4. Cortex-M3 based embedded laboratory equipment

We realize the conceptual model mentioned in section IV:

1) *Host System*: We use MB9B506R of FUJITSU SEMICONDUCTOR as Host System. The MB9B500 Series are a highly integrated 32-bit microcontroller that target for high-performance and cost-sensitive embedded control applications. The MB9B500 Series are based on the ARM Cortex-M3 Processor and on-chip Flash memory and SRAM, and peripheral functions, including Motor Control Timers, ADCs and Communication Interfaces (USB, CAN, UART, SIO, I2C, LIN)[5].

Based on MB9B506R, we provide 8 channels of 12 bits A/D converters, 14 channels of PWM, 8 buttons, 16 LED lights, 31 GPIOs and 4 UARTs. One 12V input, four 12V output, eight 3.3V output and four 5V output of power supply can be used by students.

2) *Slave System*: We add CF card, Bluetooth Module and Wi-Fi Module as slave system to the equipment. The CF card is the nonvolatile memory device record the temporary experimental data. With the wireless interface modules we can get the following functions:

- Add a channel to upper monitor: In debug phase, upper monitor can do remote debug to the system. In work phase, the system can upload data to upper monitor.
- Add a channel to Components layer: Some components support Bluetooth or WIFI can be added into the system.

TABLE I. RESOURCES CONSUMPTION OF THE PROJECTS

<i>Projects</i>	<i>Input Components</i>	<i>Output Components</i>	<i>Mechanical device</i>	<i>Slave system</i>
Sunflower	optical sensor	servo motor	sunflower-shaped object	N/A
Intelligent greenhouse	temperature sensor humidity sensor	fans humidifier	heating lamp refrigerator	plastic cloth storage transparent box
Remote controlled astronomical telescope	acceleration sensor	servo motor	astronomical telescope	WIFI module
Intelligence handcart	optical sensor infra-red sensor	ultrasonic sensor motors servo motors	handcart	Bluetooth module
Intelligence spider	optical sensor infra-red sensor	ultrasonic sensor servo motors	spider-shaped object	Bluetooth module
Rotorcraft	gyroscope acceleration sensor	motors servo motors	rotorcraft	Bluetooth module

- Add a channel to peer systems: Students can organize several peer systems as a whole system by Bluetooth or WIFI. The peer can be another Cortex-M3, also can be other systems such as Intel Galileo board [6], Intel Edison board [7] or other microcontroller development board.

3) *Inter-system Channel*: This layer is implicitly included in the system. MB9B506R communicate with Bluetooth Module and WIFI module by one UART channel each. With the update of Host System or Slave System, higher speed bus will be deployed in the Inter-System Channel.

4) *Components*: Students select different combinations of components according to the different choice of projects. Some typical components such as sensors, motors servo motors and mechanical parts will be suggested with supported by well revised guide books. Other components which probably add the challenge also are allowed to adopt. The modules which have well encapsulated interfaces and are easy to program are suggested to use, but sometimes necessary analog signal devices are optional.

5) *Application*: Each team selects to finish a team work project with the application background. The application project contains a system with the combination of hardware and software. Every year we will suggest one or two kinds of embedded applications different from last year. Students must finish some required functions, then improve and perfect the work as well as they can. It is also encouraged when some students will do more challenge work.

D. Embedded Laboratory Projects

Thanks to the “Maker Movement” [8], Internet provides wealth of material of embedded application projects. Sparked by maker network community, especially Intel Maker [9], we designed and reformed the experimental projects to fit the demands of laboratory practice for undergraduate students. The experimental projects should further spur system level innovation and can be controlled in college teaching.

We have finished several interesting projects in the past years. They can all implement in our embedded laboratory

equipment, the projects and resources consumption of that are list in TABLE 1.

1) Projects:

a) *Sunflower*: Use the Cortex-M3 as main controller. Make a sunflower-shaped object always face towards the light. The technical points include: AD sample the light intensity of different directions of the object; Determine the position of the light source; Control the servo motors equipped in the bottom of the object to adjust the direction by PWM.

b) *Intelligent greenhouse*: Use the Cortex-M3 as main controller. Get the data of temperature and humidity in the greenhouse and take steps to make the greenhouse suitable for plant growth. The technical points include: Transform a plastic cloth storage transparent box to a experimental greenhouse; AD sample the temperature and humidity in the greenhouse by sensors; Trig the fans by GPIO when temperature and humidity are too high; Switch the heating lamp by GPIO when temperature is too low; Turn on the humidifier by GPIO when humidity is too low; Optionally wake up the refrigerator by GPIO when temperature is too high.

c) *Remote controlled astronomical telescope*: Use the Cortex-M3 as main controller. Get and adjust the attitude of the astronomical telescope remotely. The technical points include: Adjust the focus of the astronomical telescope by PWM controlled servo motors; Adjust the attitude of the astronomical telescope by PWM controlled servo motors; AD sample the movement of astronomical telescope by acceleration sensors; Transfer the control signal by WIFI module.

d) *Intelligence handcart*: Use the Cortex-M3 as main controller. Control a four wheel driven tracked handcart. It can be remotely controlled by mobile phones, and can search the specified illuminant target in a maze. The technical points include: Control the movement through the motors the servo motors connecting the wheels by PWM and GPIO; Sample the light intensity of different directions of the handcart; Sample the distance to the obstacle by ultrasonic sensors or infra-red sensors; Transfer the control signal by Bluetooth module.

e) *Intelligence spider*: Similar to the handcart. But the movement controll is focus on servo motors arranged in the different joints other than motors besides the wheels.

f) *Rotorcraft*: Flight attitude acquisition and flight control are the key point. Due to the dangers of the propellers and crash, few teams are allowed to do this project. It is a customized project for the students preparing to take part in the embedded competition.

2) Check and examination:

There are two main types of team work evaluations: the exhibition and the competition:

a) *Exhibition*: Some of projects can be showed at the end of the semester such as sunflower and greenhouse. Every team demonstrates their achievement. The teacher and other teams can evaluate and score the teamwork. Of course more functions and delicate operations can earn a better mark.

b) *Competition*: Competition can largely arouse and stimulate creative enthusiasm of the students. We carefully made the game contents and rules for some projects such as intelligence handcart and spider. For example in intelligence handcart project, the game contents include: examine the accuracy to touch the target at a distance of 4 meters in the oblique position ahead; challenge the time to touch the target in a maze by remote controll and challenge the time to touch the illuminant target in a maze by automatic driving.

3) Support Library:

The system developers are all familiar with the datasheet and user manual of hardware components which also are not stranger to the auteur maker. But for the undergraduate students, the situation is not the same. They will be overwhelmed by these documents. So the faculty must prepare the streamlining development resources.

The support library can be gradually richer every year. The typical and guiding valued achievement of upper grade students will be collected by teacher into the support library of next year. The new generation students will get more help from that and will focus on working at new components. With the development of several years, many GPIOs, UART and AD based sensors, wireless communication modules and serval data buses are supported by our support library.

E. Achievements and Future Work

Contras to conventional embedded laboratory education, we stress the system level practice and encourage innovative work. The conventional box-shaped embedded laboratory equipment is difficult to update and deploy in the embedded applications. Some of them are more like micro integrated computers than embedded devices. And the experiment contents repeat with other experimental courses such as Principles of Computer Composition and Interface Technique of Microcomputer.

Compare with the prosperous Arduino [10], we pay more attention to the fusion of computer specialty knowledge. Arduino, also supported by Intel Galileo and Edison, has friendly and easy-to-use program interfaces. The novice, even a

pupil, can build a complex application system in a short time. But too much operate details are encapsulated to a CS undergraduate student. With the update of our system, more powerful architecture is expected to employ to meet the demands of multimedia applications. Then Arduino solutions will have been incompetent.

Besides more projects are developed, we will update the host system with powerful microprocessor. In the slave system layer, FPGA and DSP will be considered to be added in order to do concurrent real-time hardware interrupt processing which are proved inefficient processed by ARM SOC and run multimedia applications which are frequently appear in life but always largely reduce the performance of existing system.

A teaching operating system named Ucore [11] is expected to plant in our system. Ucore is developed by serval Universities of China based on XV6 of MIT. Now it is teaching in Operating System Curriculum and has been planted in the laboratory equipment of other main specialized courses in Dept. CS of Tsinghua. As a link of CS education, the Ucore planted in our embedded system will maintain the continuity and consistency of teaching content.

VI. CONCLUSION

These embedded system designing principles as well as the concept model come from the summarizing of our personal teaching experience. They mainly addressed three problems: arousing students' enthusiasm toward embedded system, doing the system level practice and giving them enough freedom to implement their creative ideas. Also, they overcome the drawback of conventional embedded laboratory education. These principles will help guiding our designing of an effective embedded laboratory platform as well as help enhancing the education of embedded system curriculum. We are expecting and having full confidence that they will play an even greater role in introducing students in to the world of embedded system.

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Team-Based Learning Course Design and Assessment in Computer Engineering

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Abstract— The flipped classroom model is gaining increasing attention in higher education, including engineering education. There are various types of models and contexts in which they are applied. Generalized research on the effectiveness of the flipped classroom is emerging, and results have been mixed. One such model is team-based learning (TBL) as originally developed by Larry Michaelsen in the late 1970s. TBL is a structured way to implement a flipped classroom approach, and has been shown to be successful in achieving deeper learning among the students. In this paper, we discuss our experience using the TBL methodology in a graduate computer engineering course on system level design of embedded systems. Specifically, we describe the course design, instructor experience adapting TBL for use in the course, including implementing an asynchronous online TBL process, and instructor reflections and student feedback on what worked well and what did not. We analyze the course content using the Florida Taxonomy of Cognitive Behavior, and assess the effectiveness of our implementation in achieving deeper learning. Additionally, we report on student perception of the new course structure and their experience using TBL.

Keywords— *engineering education, team-based learning, online learning, asynchronous teaming, embedded systems*

I. INTRODUCTION

In the last three decades, engineering institutions have made a large shift from purely lecture based teaching methodologies towards more active learning styles. This is in part due to the initiative of developing higher order cognitive skills, in addition to the technical skills required for the field [5]. Several prior studies in educational research have shown that active and student-centered teaching methodologies enable deep learning, and hence have a higher likelihood of achieving higher order cognitive skills [1, 2]. Although active-learning methodologies, such as problem-based learning (PBL) [6] and project-based learning [7], have become an integral part of several engineering curriculums via hands-on laboratory assignments and term-long projects, they pose several challenges. A few of these challenges include issues with team dynamics, lack of motivation in students for attending class meetings, and difficulty in covering the vast amount of course content that engineering courses typically have [8].

In the last decade, the flipped classroom model has gained increasing attention [9]. There are various types of models, and

contexts in which they are applied. However, the fundamental technique is that the course material is provided before class, freeing class time to apply the concepts to solve problems and interact with other students. Generalized research on the effectiveness of the flipped classroom is emerging, and results have been mixed. A commonly observed concern is related to course structure. Previous studies have reported that students feel overwhelmed when they have to search for the required material themselves and rather prefer a more structured approach [3,10]. One such structured approach to the flipped classroom model is team-based learning (TBL) [11, 31].

When implemented correctly, TBL has been shown to be an effective structure for implementing the flipped classroom model [13]. Developed by Michaelsen in the early 1970's, TBL was first adopted in medical schools [12]. Since then, it has matured and been widely disseminated in other fields, including engineering. Previous implementations in engineering courses have reported an increase in peer-assisted learning, time spent by students on task, and development of higher levels of thinking and lifelong learning skills [14, 15]. TBL is being used by a small but growing community of faculty at Iowa State University. It is promoted through the university teaching and learning center, which has offered workshops for faculty, staff and graduate students [4]. Consequently, TBL has been successfully used in several engineering courses, which served as the motivation to consider using it in a graduate-level embedded systems course in computer engineering.

In this paper we describe the instructor's experiences in implementing the TBL model and the TBL process for online students; and also reflections from the instructional team and students on what worked well and what did not. Additionally, we evaluate the effectiveness of our TBL implementation in achieving higher cognitive levels of thinking using the Florida Taxonomy of Cognitive Behaviors (FTCB). The remainder of the report is organized as follows: Section 2 provides an overview of the course; Section 3 provides details of the TBL implementation; Section 4 evaluates our implementation using FTCB and student feedback; Section 5 discusses related work in the field of TBL in engineering education; and Section 6 provides a summary of the lessons learned through our experience of converting the course structure to a TBL model, and identifies modifications for future implementations.

II. COURSE STRUCTURE AND DESIGN RATIONALE

TBL was implemented in CPRE 588, a graduate-level course in computer engineering at Iowa State University. CPRE 588 is the final course in a series of four courses in the embedded system curriculum at the university [16, 17]. In this section, we provide an overview of the course, the rationale for choosing TBL, and the detailed course structure.

A. The Embedded Systems Curriculum and Design Rationale

The first course in the series (CPRE 288) introduces students to various components of a typical embedded system and basics of embedded systems programming. The course was revitalized in 2001 to use the PBL approach in the laboratory. The second and third courses (CPRE 388 and 488) focus on system design using bottom-up and top-down approaches. They introduce students to system-level design issues and hardware-software codesign methodologies. Similar to CPRE 288, CPRE 488 was redesigned in 2008 by the author to have majority of the focus on laboratory assignments. The 3C5I model was used [17], which incorporated both Bloom's taxonomy [33] and PBL [6].

CPRE 588, the final course in the series, introduces students to Multiprocessor System On Chip (MPSOC) design using system-level design methodologies [18]. It focuses on developing models of embedded systems at different levels of abstraction and a systematic top-down design approach. However, contrary to the first three courses, CPRE 588 is a graduate level course, and is based on new research directions in embedded systems design. The material is varied and mostly referred through academic papers.

The instructor chose to redesign CPRE 588 using the TBL model after experimenting with elements of it in CPRE 388, discussing its benefits with other faculty, and participating in TBL faculty learning community seminars. Key features of TBL address common problems with other methodologies. The essentials of TBL as described by Michaelsen in [11] are:

1. Team formation
2. Student accountability
3. In-class team exercises that motivate students to think at higher cognitive levels
4. Continuous feedback from the instructor and peers.

In section III, we explain these in detail, and describe how they were implemented in our course.

B. Course Structure

The detailed course plan for a 15-week semester is given in Table I. There are two class meetings each week. In addition to TBL related activities, there were two homework assignments, a team project and a final examination. The non-TBL activities contributed to 52.5% of the class grade. The simulation assignments used SpecC, an open source language for system level design [19], and SystemC, an industry standard for designing transaction level models (TLMs) [20].

The content was organized into module as follows:

- 1) **Orientation:** Challenges of state of the art MPSOC design. TBL is introduced via a dummy application exercise.

TABLE I.
COURSE PLAN FOR CPRE 588 (SPRING 2015)

Week	Module	Activity
1	1. Orientation	Team Formation Grading rubric
2	2. System Design Methodologies	RA 2, AE 2A AE2B
3	3. Modeling and Simulation	RA 3, ML AE 3A, ML
4		AE 3A, ML AE 3B
5		AE 3C, ML AE 3C
6		AE 3D, HW 1 assigned AE 3D, RA 4
7		AE 4A AE 4A
8	4. System Synthesis	AE 4B, HW 1 due AE 4B
9	5. Estimation and Exploration	RA 5 AE 5A AE 5B
10		AE 5C, Project overview AE 5C, HW 2 assigned
11		AE 5D, Project updates AE 5D
12		Lecture
13		In-class exercise In-class exercise
14	6. Computation / Communication Synthesis	Lecture, HW 2 due Tool case study talks
15	Student Project Presentations	
16	Final Examination	

*RA: Readiness Assessment Test, AE: Application Exercise
ML: Mini Lecture, HW: Homework Assignment

- 2) **System Design Methodologies:** Abstraction levels of an embedded system, methodologies and steps in design flow.

- 3) **Modeling and Simulation:** Models for embedded systems and their relationship to languages and simulation.

- 4) **System Synthesis:** Models and methodologies for system synthesis, transaction level modeling, and its role in the system design flow. Languages and tool support for system synthesis (e.g. SpecC, SystemC).

- 5) **Estimation and Exploration:** Mapping TLMs to system architectures, the role of estimation in system-level design, metrics associated with system design space exploration, and approaches for evaluation of TLMs.

- 6) **Computation / Communication Refinement:** Refining system models to more complex TLMs. Computation is represented as software code or in a hardware description language, and communication is represented as driver code or hardware interfaces.

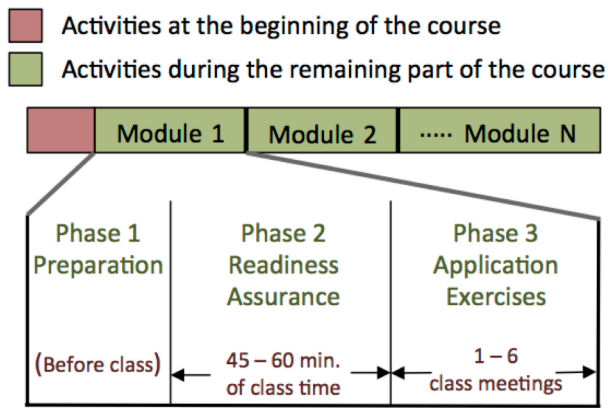


Fig. 1: Depiction of activities performed during a course taught using TBL. Activities performed for each module are broadly categorized into three phases.

III. IMPLEMENTATION OF TEAM-BASED LEARNING

In this section we describe the specifics of TBL in detail and their implementation in CPRE 588. The TBL activities performed by students during the course are depicted in Fig. 1.

A. Activities at the Beginning of the Course

Team Formation: A unique aspect of TBL is the importance given to strategically forming teams. Students were given a survey at the beginning of the course. Teams were formed by the instructor ensuring a fair distribution of students from different backgrounds, both in terms of technical skills and other characteristics. The goal was to ensure that team members bring different perspectives to the team. TBL teams are also permanent throughout a course. Effective group dynamics, such as adapting to and communicating with other members (either similar or different than oneself) and building trust, take time to develop. Essentially, teams in TBL emulate teams found in professional working environments as opposed to groups typically found in academic settings.

Negotiated Grading Scheme: Students participate in a consensus-building process to determine the weights given to selected activities in a TBL course. Each team internally agreed on a grading scheme. Representatives from each team then openly discussed proposed options during a class meeting and reached consensus regarding the grading scheme for the entire class.

B. Activities during Remainder of the Course

The course was partitioned into several modules. As depicted in Fig. 1, activities performed during each module can be broadly categorized into three phases.

Phase 1 – Preparation: At the beginning of each module students were assigned readings. Readings were selected to familiarize students with concepts required to solve the application exercises. Various methodologies like annotated lecture slides, technical publications and recorded video lectures were used, depending on the module.

Phase 2 – Readiness Assurance: As depicted in Fig. 1, each module begins with a Readiness Assurance Process (RAP). The RAP has the following components:

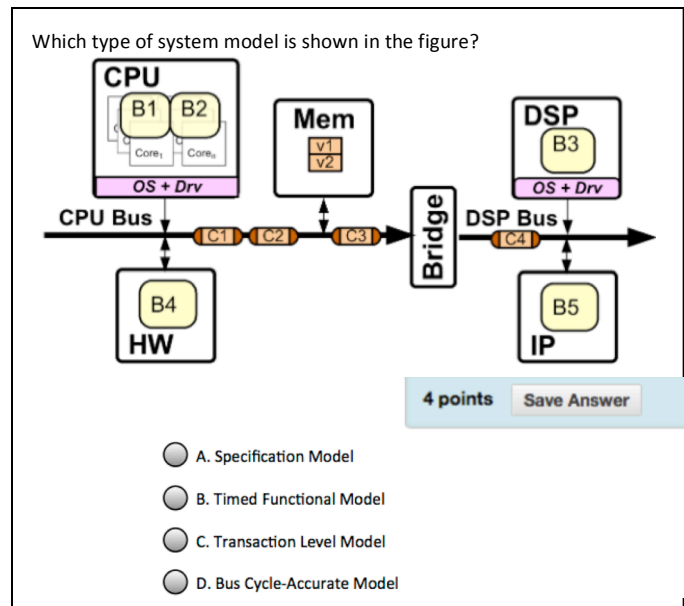


Fig. 2: Example of a Readiness Assessment question. The system model is adapted from [35].

a. Individual Tests: The first in-class activity is the Individual Readiness Assurance Test (iRAT). It is taken independently by each student and is intended to make students accountable for the preparation phase. The iRATs in CPRE 588 consisted of multiple-choice questions administered in class via the Blackboard Learn system. Fig. 2 depicts an example question from the iRAT test knowledge of fundamental concepts. Overall, iRATs contributed towards 7.5% of the course grade.

b. Team Tests: Following the iRAT, students proceed to the Team Readiness Assurance Test (tRAT), where teams take the same test as the iRAT. However, one answer is submitted for the team, and thus team members reach consensus before submitting an answer. Observe in Fig. 2 that points are denoted next to the "Save Answer" button. A team had up to three attempts on a question to obtain the correct answer. Decreasing points are allotted after the first attempt. The tRAT scoring facilitates two goals. First, to arrive at the correct answer, team members go through a process of discussion, agreeing and/or disagreeing with individual answers given during the iRAT. This improves students' ability to communicate with their peers, and thereby aids in team development. Secondly, it provides each student immediate feedback from team members regarding their own understanding of the course concepts.

c. Appeals Process and Feedback: After a tRAT, the instructor provides immediate feedback and clarifies any misunderstandings that students might have about the concepts. At this point, the instructor may choose to give a short lecture. Formal mini-lectures were prepared for modules 3 and 6 in CPRE 588 (refer to Table I). Teams are allowed to submit an appeal to the instructor if they disagree with an answer on a tRAT. A team must provide specific references from the readings. This teaches students to defend their claims using specific and clear evidence.

Below are the specification and architecture models from A. Gerstlauer, "SpecC Modeling Guidelines, Technical Report CECS-02-16, UC Irvine".

Q1. Mark areas in the figure where each of these refinement rules have been applied:

a. Behavior partitioning b. Protocol inlining c. Variable partitioning
d. Protocol insertion e. Scheduling f. Channel partitioning

TBL question: Are all of the rules applied? Why?

Q2. Develop an understanding of the code for the respective models given at the end of exercise.

TBL question: Which lines in the code correspond to the following rules:

Rule	Line number(s)
Behavior partitioning	
Variable partitioning	
Scheduling	

Fig. 3: An example question from application exercise 4A.

Phase 3 – Application Exercises: Students work in teams on application exercises (AEs) for the remaining duration of the module (refer to Fig. 1). The number and complexity of the exercises may vary. AEs consist of problems that simulate real world scenarios, and are the primary instructional tool used in TBL. They provide an opportunity for students to think at higher order cognitive levels, and thereby develop a deeper understanding of the concepts. At the same time, they are also one of the most difficult aspects of designing a TBL based course. Consequently, to facilitate the creation of effective AEs, the TBL methodology recommends using the “4S” rule:

a. Significant Problem: A significant problem creates curiosity and enthusiasm for self-directed learning. To identify significant problems for the exercises in CPRE 588, we used the “backward design” technique [32]. First, the outcomes and associated skills were listed for a given module. Working backwards, the course designers outlined the type of problems that can be solved using the enumerated skills. A few problems were then selected based on the concepts learned in the previous modules. Finally, a real world application was chosen and the selected problems were crafted into an AE.

b. Same Problem: Each team works on the same set of problems. With the same problem, students have a common basis to compare and critique answers across teams and receive feedback from other teams.

c. Specific Choice: Figures 3 and 4 give examples of a question from AEs of module 4. Notice that the “TBL question” in both exercises asks students to make a specific choice. Cognitive research has shown that deep learning is achieved when students are required to make a specific choice. For example, a code snippet was provided in AE 4A (refer to Fig. 3). If students were asked to describe the code functionality, this may result in thinking at cognitive levels 1 (knowledge) or 2 (translation) (look ahead to Table II for levels of cognition and respective indicators). However, the questions asked about specific rules in relation to the code. Thus, students were required to consider alternatives, apply concepts in a practical context, and draw conclusions. This

In the specification model given below, computational code for behaviors B1, B2, B3 and B4 are provided.

You are given the following options of hardware processing elements:

	Freq (MHz)	FP ADD	FP MUL	INT ADD	INT MUL
Proc. 1	1000	16	24	4	8
Proc. 2	850	10	20	4	6
HW	50	1	2	1	2

TBL question 1: Estimate the execution time for the following:

Behavior	On processor 1	On processor2	On Hardware
B1			
B2			
B3			

TBL question 2: If B4 executes in 10 us on both processors, choose a mapping that would result in the shortest execution time for N = 1000.

Fig. 4: An example question from application exercise 4B.

resulted in thinking at higher levels of cognition, such as, interpretation, application, and analysis. Note that while higher order levels are achieved, the low order level of knowledge is implicitly achieved as well. In this example, students would be required to have knowledge of refinement rules and be able to understand the code to solve the problems.

d. Simultaneous Reporting: All teams report out answers at the same time. This ensures that a team’s answers are not influenced by previously reported answers. It also imposes a time limit. In CPRE 588, this was done via white boards provided to each team. As shown in Fig. 4, the questions for AE 4B were complex and required significant work. However, the final answer was concise enough to be simultaneously reported (e.g., execution time, choice of mapping). Each team also recorded details about its solution on a worksheet, which served as a useful tool for the instructor to review after class. Following a report-out, teams explain their answers and feedback is provided by the instructor and other teams. Short lectures are given as needed. Overall the 4S approach supports higher order thinking by students.

C. Team-Based Learning for Online Students

CPRE 588 is part of the department's Embedded Systems Graduate Certificate Online program [26]. In the past, it has been offered in a traditional lecture format using streaming media over the web. During the spring semester of 2015, the course was offered in TBL format to the online students as well. Various tools in Blackboard Learn were used to support asynchronous online procedures for TBL activities, drawing on practices reported in the literature [24, 25].

The primary and most significant difference for the online TBL teams was not having fixed-time, and face-to-face meetings for application exercises. Online students interacted asynchronously over several days via shared web tools, such as a Blackboard Wiki or a Google Drive. Interaction with the instructor and other teams was supported through email and Blackboard discussion forums. Although effective strategies

shown to support online learning were provided [27, 28], the asynchronous mode presented challenges to several essential TBL practices, such as team development, individual accountability, and immediate feedback. Moreover, as online students had greater differences in backgrounds and interests, team members followed the prescribed procedures to varying extents. Dissatisfaction expressed by online students with TBL can be attributed to limitations of the asynchronous format and insufficient use of tools and procedures such as discussion forums. Providing structured opportunities for synchronous interaction should address some of the shortcomings. Additional data has been collected, research in the TBL community is ongoing, and more evaluation of the online approach will be pursued.

IV. EVALUATION

Two aspects of the implementation were of particular interest to the course designers:

1. Cognitive level of student learning, and
2. Student perception of TBL and the application exercises.

A. Cognitive Level of Student Learning

One of the primary reasons for choosing TBL for this course was to create a richer, deeper student learning experience. One way to assess this is by examining the cognitive level of activities in the course, such as application exercises. The Florida Taxonomy of Cognitive Behavior (FTCB) [21, 22] was used for this purpose. FTCB is a modified form of Bloom's taxonomy [33]. It expands the comprehension level of Bloom's taxonomy into translation and interpretation. Specific indicators are used to determine whether a particular cognitive level is achieved. Table II lists the seven levels of cognitive behaviors in FTCB in ascending order, with their respective indicators.

The FTCB has been used in the past to assess cognitive behavior exhibited while teaching a class [22]. Observers check which indicators, among the 55 listed in Table II, are observed during a sampling period. This period, referred to as a recording interval, enables analysis of the cognitive behaviors exhibited periodically over the duration of the class. In this study of CPRE 588, we used FTCB to score the application exercises, and each exercise was divided into recording intervals. Questions from an exercise were grouped into intervals so that the amount of work done by students within each interval was similar. Three faculty members volunteered as observers and scored the application exercises.

A.1 Cognitive Behaviors Observed in Application Exercises

Fig. 5 illustrates the distribution of the observed cognitive behaviors, averaged across the three observers. The knowledge, translations and interpretation levels are referred to as lower order behaviors, while application, analysis, synthesis and evaluation are referred to as higher order behaviors (refer to Table II). We can observe in Fig. 5 that, except application exercise 2A, more than 50% of the observations were of higher-order cognitive behaviors. This was an expected result, as exercise 2A was at the beginning of the course and most of

TABLE II.
THE FLORIDA TAXONOMY OF COGNITIVE BEHAVIOR

Lower Order Cognitive Behaviors	1. Knowledge of specifics
	1. Reads
	2. Spells
	3. Identifies something by name
	4. Defines meaning of a term
	5. Gives a specific fact
	6. Tells about an event
	1.2 Knowledge of ways and means of dealing with specifics
	7. Recognizes symbol
	8. Cites a rule
	9. Gives chronological sequence
	10. Gives steps of process, describes method
	11. Cites trend
	12. Names classification system or standard
	13. Names what fits given class, system or standard
	1.3 Knowledge of universals and abstracts
	14. States generalized concept or idea
	15. States a principle, law, or theory
	16. Tells about organization or structure
	17. Recalls name of principle, law, or theory
	2. Translation
	18. Restates in own words or briefer terms
	19. Gives concrete examples of an abstract idea
	20. Verbalizes from a graphic representation
	21. Translates verbalization into graphic form
	22. Translates fig. statements into lit. statements
	23. Translates foreign lang. into Eng. or vice versa
	3. Interpretation
	24. Gives reason (tells why)
	25. Shows similarities and differences
	26. Summarizes or concludes from obs. of evidence
	27. Shows cause and effect relationship
	28. Gives analogy, simile, metaphor
	29. Performs a directed task or process
	4. Application
Higher Order Cognitive Behaviors	30. Applies previous learning to new situations
	31. Applies principle to new situation
	32. Applies abstract knowledge in a practical situation
	33. Identifies, selects, and carries out a process
	5.0 Analysis
	34. Distinguishes fact from opinion
	35. Distinguishes fact from hypothesis
	36. Distinguishes conc. from supporting statements
	37. Points out unstated assumption
	38. Shows interaction or relation of elements
	39. Points out particulars to justify conclusions
	40. Checks hypotheses with given information
	41. Distinguishes relevant from irrelevant statements
	42. Detects error in thinking
	43. Infers purpose, point of view, thoughts, feelings
	44. Recognizes bias or propaganda
	6.0 Synthesis (Creativity)
	45. Reorganizes ideas, materials, processes
	46. Produces unique communication, divergent idea
	47. Produces a plan, proposed set of operations
	48. Designs an apparatus
	49. Designs a structure
	50. Devises a scheme for classifying information
	51. Formulates hypotheses, intelligent guesses
	52. Makes deductions from abstract symbols, prop.
	53. Draws inductive generalization from specifics
	7.0 Evaluation
	54. Evaluates something from evidence
	55. Evaluates something from criteria

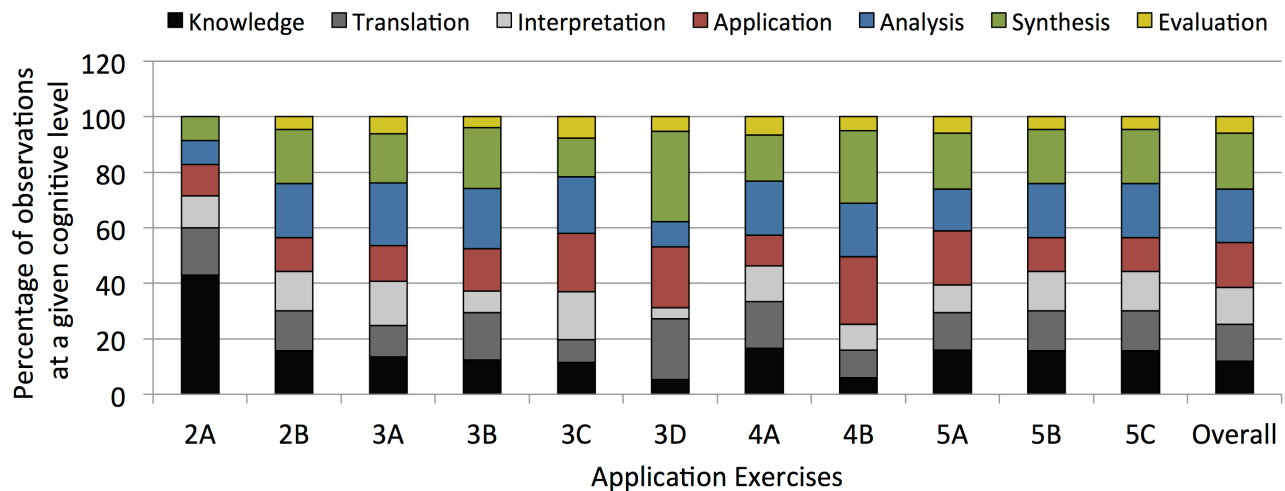


Fig. 5: Distribution of the observed cognitive levels in each of the application exercises.

the questions were designed to test knowledge regarding specific introductory material. Also, notice that 2A is the only exercise without any observations at the evaluation level.

We were expecting to observe that the number of observations of lower order behaviors would reduce in consecutive exercises within a module. A reduction can be observed in exercises from modules 3 and 4. For example, the percentage of lower-order cognitive behaviors reduces from 3A to 3D, and similarly from 4A to 4B. However, the pattern is not distinctive. Also, it does not appear in exercises from module 5. We believe that this could be due to two reasons. One, the instructional team did not designate specific cognitive levels to target while designing the exercises. They were designed to give students problems in real-world scenarios, albeit simplified enough to fit within the timeframe of a class period. Second, due to complexity of the modules, each exercise dealt with a significant amount of new material. Initial questions in an exercise were intended to test basic understanding of the new material. Thus, within an exercise itself, the distribution of lower-order behaviors reduces from first to last recording interval.

Across all exercises, 61% of the observations were of higher-order cognitive behaviors. The two most common behaviors observed were analysis (19%) and synthesis (20%). The least observed higher-order behavior was evaluation (6%). Just under 39% of the observations were of lower-order behaviors, with translation, interpretation, and knowledge having comparable usage at 13%, 13%, and 12%, respectively.

A.2 Cognitive Scores of Application Exercises

The frequencies of observed behaviors (discussed in the previous section) were used to calculate two cognitive measures for each exercise, namely mean cognitive level and total cognitive weighted score.

1) **Mean Cognitive Level:** Each cognitive level from FTCEB was assigned a value from 1 (for knowledge) to 7 (for evaluation). The frequency of observations of each level was

multiplied by the respective value and averaged over all observations. This is the mean cognitive level attained by an exercise. For example, given two observations for an exercise, one each at the synthesis and evaluation levels, the mean cognitive level would be 6.5.

Figure 6 plots the mean cognitive level for the application exercises. Consistent with explanations given in section IV.A.1, slight increases can be observed in the mean cognitive level across exercises within a given module. Notably, exercise 4B, which has the highest mean cognitive level (4.39), has the highest percentage of observations of higher-order behaviors (75%). The mean cognitive level achieved across all exercises was 4.01. A similar score was achieved by laboratory assignments in CPRE 488 [17]. Thus the in-class activities in TBL exhibited a cognitive level comparable to hands-on laboratory work.

2) **Total Cognitive Weighted Score:** A commonly used measure with FTCEB is the total cognitive weighted score [23]. This is calculated as the weighted average of the percentage distribution of observed behaviors, where the weights are 0.10 for knowledge, 0.20 for translation, 0.25 for interpretation, 0.30 for application, 0.40 for analysis, and 0.50 for both synthesis and evaluation. The total cognitive weighted score is considered a more accurate measure of the students' level of cognition compared to the mean cognitive level.

Figure 6 plots the total cognitive weighted score for each application exercise. A pattern similar to the mean cognitive level can be observed. The score increases as we progress further in a module, for modules 2, 3 and 4. An interesting result is that the score of 5A was comparable to that of 5B and 5C. Further analysis showed that the number of observations in 5B and 5C was higher compared to 5A. This resulted in the mean cognitive level for 5B and 5C to be greater than 5A. However, as shown in Fig. 5, the percentage of higher-order behaviors is greater in 5A. Thus, the weighted score of 5A becomes similar to 5B and 5C.

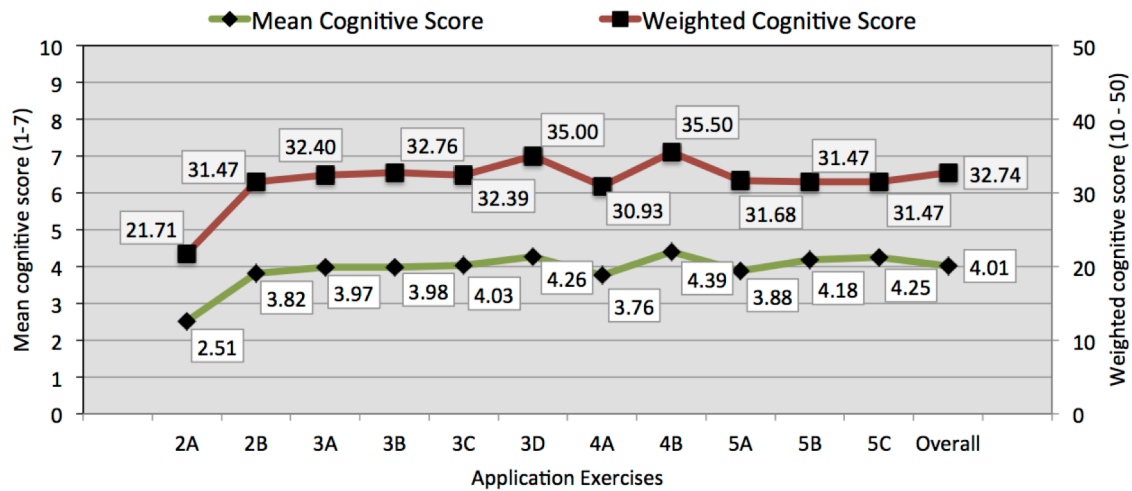


Fig. 6: Cognitive measures for each application exercise.

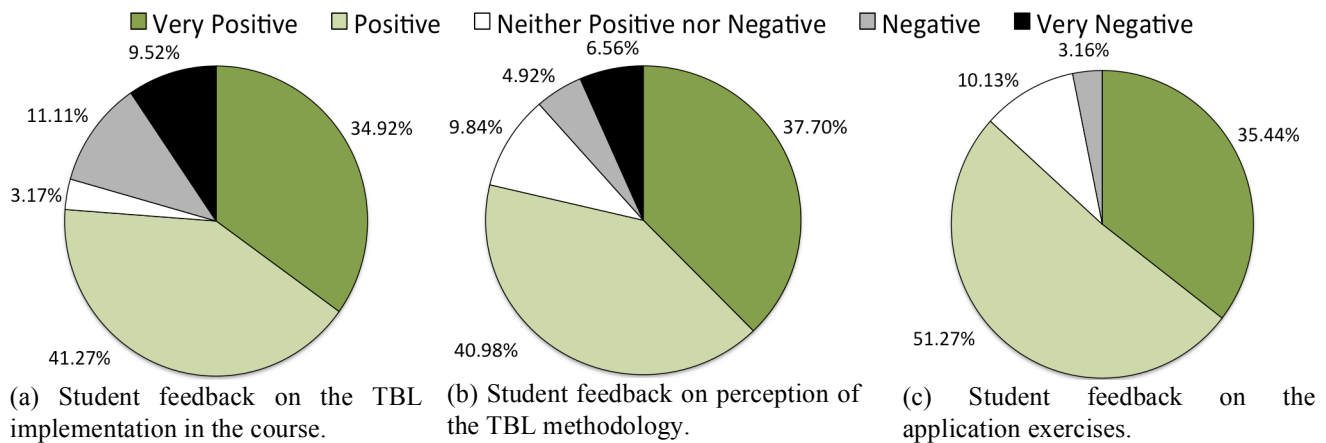


Fig. 7: Summary of student survey responses.

B. Student Perception of TBL and Application Exercises

As this was the first time CPRE 588 was taught using TBL, we were interested in getting student feedback on the new course structure. A survey was conducted via Blackboard, which consisted of questions in three areas [34]:

1. Opinion of the TBL implementation in the course
2. Perception of the TBL methodology
3. Feedback on application exercises

Sixteen (of 19) students completed the survey. All online students (7) and nine (of 12) on-campus students provided responses.

Fig. 7 summarizes the student feedback in the three areas. Over three-fourths of the responses (76%) indicated that students had a positive experience with the course implementation (refer to Fig. 7(a)). Similarly, 79% of the responses were favorable about the TBL methodology (refer to Fig. 7(b)). 21 % of the responses regarding questions pertaining to the course implementation were negative. Interestingly, only about 11% of responses to general questions on TBL in were negative. This implies that while some aspects of our first-time TBL implementation need improvement, students were receptive in general to the TBL methodology.

Figure 7(c) depicts the feedback received about the application exercises. The questions regarding application exercises received a high percentage of positive responses. Results showed that students liked learning the course concepts through problem solving. Additionally, student responses indicated that the students liked solving complex problems. Negative feedback about application exercises was lower than expected, suggesting that other aspects of the course implementation may need attention. Responses to open-ended questions in the survey pointed to concerns among some students regarding teamwork and communication issues faced by online students. Overall students perceived TBL as an effective methodology for teaching the course.

V. RELATED WORK

This section highlights the use of TBL in engineering courses. Most of the published work pertains to undergraduate courses. A graduate level example is a course on human factors in product design in industrial engineering at Iowa State [36]. It used a version of TBL in which course modules were structured around team projects and emphasized teamwork. Undergraduate examples in the literature have primarily reported on lower division courses. A well-known example of implementing Michaelsen's TBL model in

engineering is that of Hodgson et al. [30]. TBL was extensively used in the second-year engineering curriculum at the University of British Columbia, consisting of four courses. Seventy percent of the students from the TBL-based courses felt that the courses were supported their professional development, compared to only 46% from the lecture-based courses. Similar positive results were reported for learning course content and developing team skills. Students also found the courses more enjoyable.

Connell has used TBL in two sophomore-level courses in electric circuit theory for four semesters at the University of Missouri. [15] He found that freshmen and sophomore students had difficulty with self-directed learning of complex engineering content and with building on concepts learned in earlier modules in TBL. If a student was not comfortable and confident with the material as modules proceeded, enthusiasm for in-class work dropped later in the semester. He modified TBL to address these issues as follows:

1. Created intended learning outcomes (ILO) to guide students: Each module was assigned a list of ILOs. A formative assessment was conducted after each module to get feedback on level of student learning and ensure that the ILOs were achieved.

2. Shortened the readiness cycle: Connell suggested that a shorter module (2-3 class meetings) makes it easier for students to prepare and gives more opportunities for feedback if some aspects are not clear.

With the modified version of TBL, Connell found that only 10% of the students felt learning the technical content was more difficult than in a lecture-based course. Consistent with other studies, a substantial percentage of students felt that the TBL implementation improved their professional (65%) and independent learning skills (50%), while others reported no change. Ninety percent of students reported that TBL helped them develop their problem solving skills, and 85% said it improved their interpersonal skills.

Lamm used TBL in a sophomore chemical engineering problem-solving course and found that students in a TBL section performed as well as students in another section that was taught with an informal active learning approach [37]. She also reported that students developed team-building skills and improved self-study skills. Her work summarizes feedback mechanisms inherent in the TBL method and offers suggestions on the use of feedback.

Demetry used a flipped classroom approach for a large freshman course in materials science and engineering for over a decade [14]. With an unstructured implementation, the author found that all students did not actively participate in class, attendance dropped in the latter part of the semester, and problems did not give explicit attention to development of lifelong learning skills. To mitigate these issues, the author adopted techniques from TBL, including working in teams, in-class readiness assessment tests, and problems involving higher cognitive levels of thinking.

These and other published studies on using TBL in engineering provide evidence of positive results [31].

VI. LESSONS LEARNED AND CONCLUSION

The overarching goal of using TBL was to enhance student learning. We were particularly interested in supporting higher-order thinking skills. This is a common goal, often misconceived, as Felder writes: "All engineering instructors would say that they want their students to master higher-level thinking skills, but in many cases their lectures and homework assignments focus almost exclusively on Level 3. Then, if they put a high-level question on an exam (to see if the students "know how to think") and the students do poorly on it, they blame it on the students' lack of ability or poor study habits. Their criticism is misdirected. The only way people acquire skills is through practice and feedback. If we teach at Level 3, it is unfair for us to require students to figure out for themselves how to work at Levels 4, 5, and 6. The best way to facilitate the development of higher-level skills is to include high-level tasks in learning objectives, share them with the students in study guides for exams, give illustrations and practice in class and more practice on assignments; and then put the high-level questions on the exams" [29].

With this in mind, we used a cognitive behavior taxonomy in the assessment of CPRE 588 to evaluate how well we included high-level tasks in TBL activities. Although we surpassed Bloom's application level in several application exercises, and achieved a cognitive score similar to previously assessed senior-level embedded systems lab exercises, we expected a higher overall cognitive score. There may be several explanations. One may simply be, as Felder notes, the typical instructor is not well-trained to implement high-level tasks in routine class activities. Another may be that the attention of the instructional team was on implementing the TBL process and activities during this initial offering to both on-campus and online students, and less time was available to examine and tune the content to higher levels. However, another explanation is that the expectations for a higher score should be moderated. The score achieved may be relatively good compared to a traditional lecture class. It may also be relatively good if measured on a per time basis compared to labs or projects outside of scheduled class time. This is an open area for research. In any case, we anticipate that more experience with TBL and greater attention during course design to higher-order skills should lead to higher scores. In addition, the TBL community is elaborating on the use of feedback and reflection, and if these become part of the cognitive behavior assessment, the score will also increase.

Our future work includes using our experiences to define design steps for application exercises as high-level tasks in engineering courses. Roberson and Franchini's work will also inform our efforts, as they provide principles and examples for designing tasks. They state that "Course and task design need to be pointing students not toward simply knowing more... . If we want our students to become more expert in our disciplines, we need to structure their encounters with content in ways that change what they can do with knowledge." [38]. We will also provide more support for cooperative learning; more structured interaction for online students; and more reflection for all students.

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From the Browser to the Remote Physical Lab: Programming Cyber-physical Systems

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Abstract—Cyber Physical Systems (CPSs) integrate networked embedded computation systems with real-world physical installations. Programming of CPSs is not trivial, since CPSs combine traditional programming challenges and real-world timing, concurrency, and communication. This paper shows how a programming framework that allows students to implement and test CPS control programs in their Internet browsers, can improve both the students' learning experience and learning results. Students model and program a CPS application on a high abstraction level in a web page. This web page, provided by the instructor, invokes the student's code either together with the CPS as functional specification models in a virtual timing environment, or as component in a real-world system that interacts with a real remote physical implementation. Using the provided abstraction, students can incrementally design a CPS and experience challenges such as channel delays, model uncertainties, and real-time behavior, but without the need for complex low level programming or tools. For a CPS example system, we applied the framework in an embedded system design class. Our results show, the ability of a JavaScript-based programming and execution environment to design, program, and run CPSs on different levels of abstraction. Our results also indicate an increased approval from the students and a significantly improved understanding of modeling and programming in the class.

I. INTRODUCTION

Cyber Physical Systems are systems that integrate a networked embedded computation subsystem (the cyber system) with physical subsystems from the mechanic, hydraulic, or electric domain. Examples are as simple as a garage door opener to complex systems such as medical robots, self-driving cars, or the electric grid. Therefore, building cyber-physical systems requires broad interdisciplinary knowledge, including appropriate physical models, precise timing, but also correct programming and implementation skills.

Due to their focus on specific domains, classic domain-specific curriculums do not support the required overview and abstraction. As one example, specific technical implementation details such as memory addresses and port numbers still dominate the embedded systems education, but are alienating for non-computer engineers.

In recent years, a range of new colloquiums and courses were proposed to address the development of cyber-physical systems [1], [2]. Most of the approaches rely on abstract simulations in environments like Ptolemy, Matlab, or in virtual labs that focus on the physical attributes of the system. While these approaches help to educate the concepts of modeling

and physical integration, the abstraction is very high. Important concepts like timing, communication, programming, and event-handling are abstracted away so that an actual real-life implementation is not supported. The problem is not new. Already Vahid [3] described the trade-off between abstraction and implementation detail in embedded system education, and proposed a virtual computer system and a time-oriented programming model, which however only focuses on the embedded system properties.

In this paper we extend Vahid's idea to the programming of CPSs. We propose a framework that allows students to program the control system of a CPS in an abstracted but real-time oriented programming language. The programming and model abstraction is based on Process State Machines (PSMs), which model concurrent processes, communication and timing on a high abstraction level without the need to express low-level implementation details. The student programs are developed in the JavaScript programming language, which is available on most state-of-the-art internet devices. Therefore, students can practically control a virtual or real physical remote system from their laptop, tablet or even mobile phone. While the students' program is implemented and runs in the web browser, the physical system is executed on a remote location – either as virtual plant or on a real physical plant. The architecture facilitates, for instance, to run the program for a simulated virtual plant in a homework assignment, and execute the same program on a real physical system in class.

The benefits of our approach are:

- 1) the availability of a simplified in-browser programming language, which improves the accessibility of CPS programming,
- 2) the support of a experiment-driven systematic transition from PSM models, over abstract simulations and transaction-level models to an actual physical experiment,
- 3) the support for smaller CPS examples that can be addressed in student's homework but also in demonstrations and discussions in class.

In this paper we describe the methodology of our framework and outline the programming model (Section III). In section IV, we discuss the approach in detail for the educational cyber-physical system 'the Falling Ball' [4]. The results originating from a graduate system design class indicate the suitability of our approach to support the education of CPS design, both technically as well as pedagogically.

II. CURRENT CURRICULUMS AND RELATED WORK

The education of CPS has drawn increasing attention in recent years and has been addressed in a range of dedicated workshops at major conferences. Examples are CPS-Ed - Workshop on Cyber-Physical Systems Education along the CPSWeek, and WESE - Workshop on Embedded and Cyber-Physical Systems Education along the ESWeek. The workshops produced a range of compelling approaches and example systems for educational purposes. For instance [5] proposed a focused programming language for dynamic systems. The application scenario is the control of a boat in a sea with currents. The example was discussed and evaluated in a simulation environment. While relatively simple and easily understandable, the example is not trivial and reveals a range of important CPS algorithm challenges, such as the impact of discretization of continuous systems and computation delays to the correctness of the system.

One educational system that can be built in practice is the coupled tank system as discussed by [6] and further applied by [7]. The idea of the system is to balance the levels in coupled tanks with a variable inflow and outflow. [6] proposed a web-based virtual laboratory for the system, but the system can be modeled and build in practice as well, with design kits such as [8].

Another popular teaching instrument for control CPSs – both in practice as well as in simulations – are inverted pendulum systems as for instance discussed by [9]. In those systems a pendulum has to be stabilized with appropriate control mechanisms calculated on a computation platform. The pendulum systems are well-suited for the education of cyber-physical control systems. However, the emphasis on control limits its application as a simple general CPS example.

Other CPS examples include capabilities of mobile phones into the CPS research. For instance [10] applied Android platforms to automatically classify human activities based on models developed in model-based simulation tools. An extended example that facilitates teaching by sensor-driven mobile applications was discussed by [11]. However, such mobile platform is already a complex system for which the integration in a course is not trivial. Other complex use cases include the robotic systems discussed in [12], the amphibious vehicles proposed by [13], or a search and rescue robot outlined in [14]. Such complex examples are exciting and motivating for students and researcher to investigate many interesting details in designing and building CPSs. However, due to their complexity such project usually forbid a complex design analysis, and in-depth discussion of design challenges. In addition, the integration of complex use cases in course frameworks is questionable in most cases.

Recent proposed CPS courses such as the flipped classroom course by [1] or the CPS undergraduate in-class courses introduced in [2] rely on a set of smaller design examples to demonstrate the variety of CPS design challenges. Due to its accessibility is our programming framework and the falling ball example, which is discussed in this paper, a promising contribution for easy integration in such on-class or flipped classroom setups.

From the technological perspective, online submission and assessment tools for programs written by students exist and

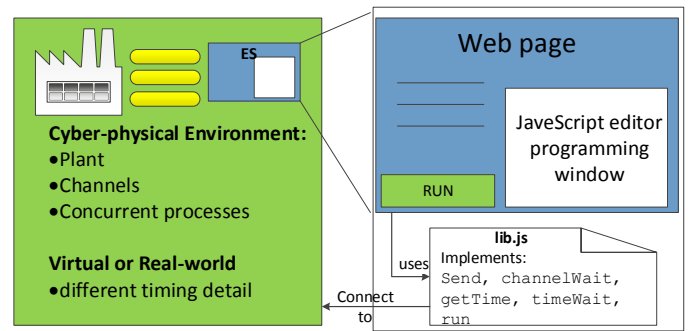


Fig. 1. Architecture of the programming framework: the instructor provides a web page with instructions and a programming window. Students write the application code in this programming window using abstract functions for communication and timing (in lib.js). The run button includes the students program in a cyber-physical run-time environment

have been reviewed in [15]. These tools, however, do not provide an interactive programming and experimentation environment and do not replace the installation of a dedicated development environment on the student's computer. Our approach does not aim at online submission but can be considered as a CPS run-time environment that can be programmed in JavaScript.

JavaScript has already been proposed as language to educate basic programming concepts [16]. The proposed works focus on development for web pages or online games. Our work does not aim for web page programming. Instead we apply the capabilities of modern browsers to directly execute JavaScript code that is typed into the editor window of a web page, which is provided by the instructor of a class.

III. JAVASCRIPT-BASED PROGRAMMING OF CPSS

In this section we discuss the technical background of the applied programming framework. We further outline the student's user experience as well as the required steps for the instructor to set up the educational programming environment.

As introduced, the primary goals of the framework are to provide

- a well-defined and easily understandable programming model,
- a clear abstraction from technical details such as timers or communication channel,
- and the flexibility for instructor to set up the CPS run-time environments ranging from timeless functional abstraction models to real-world experiments.

We realize these goals with our educational programming framework, whose architecture is illustrated in Fig. 1. When students load the instructions web page in their browser, they see a page with instructions, an editor window, and a run button. The editor window allows students to enter their JavaScript program. In this program students are encouraged to use a set of abstract platform-independent functions to access channels and the timing. These abstract high-level functions are provided by the instructor in a library file (lib.js), together with the code to access the run-time environment. Pressing the RUN button, the student's code will be included

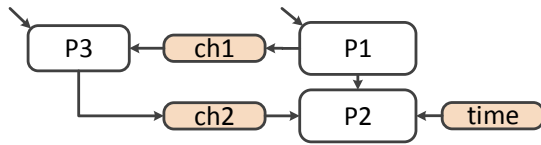


Fig. 2. Concurrent Process State Machine as basic model, containing process states (P1, P2, P3), state transitions (arrows between processes), and communication channels (ch1, ch2).

in the run-time environment and the system will be executed. Results of the run will be shown in a text box or graphically.

In the following subsections we discuss the suitability of JavaScript as a lightweight programming language, process state machines as the selected programming abstraction for the students, and the different kinds of cyber-physical environments that can be set up by the instructor.

A. Browser execution with JavaScript

As the underlying programming language we selected JavaScript for a range of reasons: JavaScript is a cross-platform scripting language and is supported by most operating systems and web browsers. Therefore, the execution of JavaScript does not require additional programs, tool chains or plug-ins on most platforms. While JavaScript code is usually embedded into the web page, with the `eval` and `globalEval` functions any use-provided code can be executed just in time. Even though JavaScript is a scripting language with an uncomplicated syntax structure, it is still very powerful, so that classes are available to build online connections or to draw images.

Another advantage of JavaScript is its popularity. According to latest statistics, JavaScript is the most popular programming language in the web [17]. From teaching perspective, the popularity has important benefits, as it results in existing knowledge and interest in the language. The broad availability of material and online support on online platforms like stackoverflow [17] is valuable for instructors and students as well.

The application of JavaScript requires to consider potential drawbacks, too. One disadvantage of the browser programming is the lack of debugging and syntax checking. The interpreter does not evaluate a line of code until this line actually is supposed to be executed, so that errors may stay unnoticed or result in unpredictable behavior. To cope with the syntax issues, we used the ACE editor [18] which provides syntax highlighting and live syntax checking. Another potential disadvantage is the low and non-deterministic performance of today's JavaScript interpreters. Since the intended size of the projects is rather small, we are convinced that the benefits such as good usability and easy understanding outweigh the listed drawbacks.

B. Programming Model and Abstraction

While the browser-based execution environment technically supports a wide range of structured and unstructured programming schemes, in our work we focus on a programming model that is based on the concept of process state machines (PSMs). The construction of a PSM model is widely considered one important first step in the design of embedded

```

if (state == 1) {
    t1 = getTime();
    send("ch1");
    state = 2;
}

if ((state == 2) && waitChannel("ch2")) {
    print("Round trip time="+(getTime()-t1));
}

```

Listing 1. Example JavaScript code for channel timing measurement (for PSM in Fig. 2).

systems [19]. PSMs allow a designer to model concurrent, communicating processes with a very concise semantic, consisting of processes (states), state transitions, and communication channels. As we will discuss later, PSMs are also suitable tools to model the behavior of the physical part and the interfaces of CPSs. As example, the PSM shown in Fig. 2 contains three processes: P1 and P2 are executed in sequential order, and P3 is a concurrent process. Between concurrent processes we allow communication and synchronization with abstract directed channels. In Fig. 2, P1 may send data to P2 via channel ch1, while P3 may send data to P2 via ch2. Due to the importance of timing for CPSs, we explicitly model timing as separate channel. Details such as the underlying platform or timing details of the channel are not considered. However, in the PSM abstraction, the implementation details of timing and channels are not important. As a result, students can use a small set of abstract function hubs to implement the PSM model. Important basic functions are:

- `waitChannel(ch)`: reads from channel ch,
- `send(ch, msg)`: writes optional message msg to channel ch. send without msg works as synchronization mechanism,
- `getTime()`: returns the time in ms,
- `waitTime(t)`: waits until time t.

These basic functions are part of the library (lib.js), provided by the instructor. Using these functions, students can implement the PSM in JavaScript independent from the underlying system.

As an example Alg. 1 shows the JavaScript code for the PSM in Fig. 2, as it can be entered in the editor box of the web page. Alg. 1 implements a round-trip time measurement between process P1-P2 and the concurrent process P3. Visible are the two states, as well as the interaction with the channel (`waitChannel` and `send`) and the time (`getTime`). Alg. 1 may be executed in a virtual environment or in the real world to measure the channel latency to a remote process. The environment is invariant to the students, but set up by the instructor within the instructions web page.

C. Setting up the Environment

One important idea of our architecture is that the application program (programmed by the students) is separated from the cyber-physical environment. Therefore students can use the same application program and apply it to cyber-physical environments on different levels of abstraction.

We consider two general run-time environments: the Virtual timing environment and the Real timing environment.

1) *Virtual timing environments*: A virtual timing environment controls the timing and progress of all system entities within the execution environment. Communication channels and the physical system are simulated. In our experiments, this virtual environment will be set up and executed as embedded JavaScript code in the browser. Both, the physical and the cyber environment are executed in the browser with the same virtual time.

In the virtual timing environment, several abstraction levels are supported. The first is the entirely functional specification model without any timing for computation and communication. More detailed transaction-level models separate communication and computation and facilitate the annotation of timings for each operation.

Benefits of the virtual timing environment are the easy and fast execution, the low organizational overhead, and the reproducible results. Since the timing is virtual, the experiments result in the very same result in every run on every device.

2) *Real timing environments*: The second run-time environment is the real-world, real-time environment. This environment does not simulate the physical part in the browser, but connects the student's program to an external physical system via real communication channels, such as the Internet. The remote physical system may be implemented either as remote virtual lab executed on a server computer, or as a real physical installation. The remote physical lab is an emulation of the real-world system executed on a powerful server. The remote lab can be used when repeated runs of an experiment by many users is not feasible for a real physical installation. The students program works as real-time control program in both cases.

For the Falling Ball example, which we discuss next, we realized both, the virtual plant (Section IV-A5) as well as the real system (IV-A6).

IV. IN-CLASS EXPERIMENT AND RESULTS

We applied the proposed framework in a graduate level course in the school of Electrical Engineering and Computer Science (EECS) at the University of California, Irvine. The basis for the course is the textbook *Embedded System Design* by Daniel Gajski et.al. [19], with extensions towards the design of CPS. The course has been taught in a regular classroom setup and included lectures and homeworks.

One of the CPSs that was modeled, programmed, and analyzed in the class, is the Falling Ball example (FBE) [4], for which we first outline the setup and the implemented models, and then discuss the results and the implications of the experiments.

A. The Falling Ball Experiments

1) *Use Case: The falling ball example*: The architecture of the Falling Ball example is illustrated in Fig. 3 (A). The goal of the system is to take a picture when a falling ball passes a camera mounted on a pole. To determine timings, the system has two motion sensors. The ball is dropped from a height initially unknown to the system, while the height of the sensors and the camera are known. This, in fact simplistic,

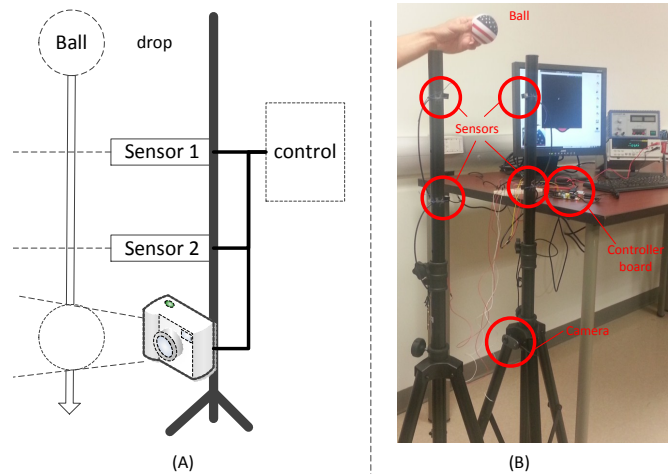


Fig. 3. Setup of the Falling Ball example: (A) as schematics, (B) in practice.

example has some interesting properties of CPSs that refer to the main challenges of CPSs.

The FBE needs exact timing. The timing relates to the physical process, which runs completely independent of any cyber processing. Even though the example can be described in a physical process, which is well understood by the developer and can be expressed in well-known mathematical equations, it is obvious that we will not achieve perfect precision – a fact that interferes with the needed accuracy requirements. The system combines various sensors and the actuator. So their cooperation affects the expected outcome of the system and needs to be regarded as an important factor.

One beneficial attribute of the Falling Ball example is the possibility to implement the system with little manual effort. A practical implementation of the FBE is shown in Fig. 3(B). The system was realized with on a Raspberry Pi Model B Revision 2.0 with Debian Linux. We further used two Honeywell Through Beam Infrared sensors (HOA6299 Series), which work by detecting an interrupt of the line of light from the emitter to the detector. The actuator is the Raspberry Pi Module camera. Two Pyle-Pro Tripod Speaker Stand poles mount sensors and camera.

We used this setting for local tests (written in ANSI C), but also as part of the course to connect the student's JavaScript programs to the real implementation (see Subsection IV-A6). Before the real-world test concluded the series of experiments, we asked the students to model and test the system on different levels of system detail.

2) *PSM modeling*: As first development step, before the control program can be expressed the system has to be modeled as Process State Machine (PSM). In the class, this modeling step was given as homework assignment and was later discussed in class. Fig. 4 shows one correct PSM for the FBE with concurrent processes in the physical and cyber part as well as the interfaces. It can be noticed that the system consists of five concurrent processes: the physical system, the two sensors, the actuator and the embedded system process. In the PSM we can already see the boundary of the embedded system, which eventually should be implemented by the students, and

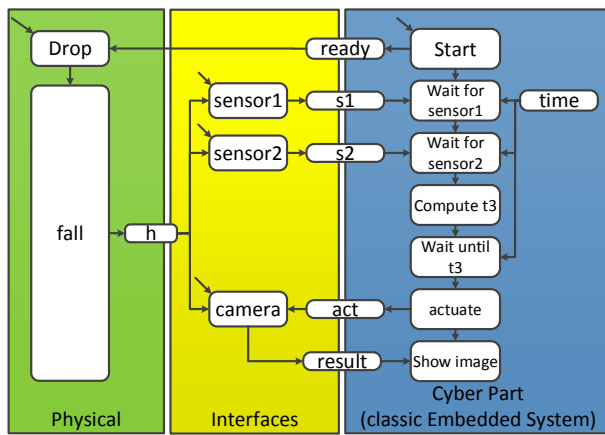


Fig. 4. Process state machine for the falling ball example: the embedded cyber system state machine (blue) interacts with the physical system via sensors and the camera actuator. Communication between the processes is modeled by directed channels.

the environment, which is provided on the web page by the instructor. The embedded system in this case consists of six states, which are implemented next.

3) *Functional Model in the virtual timing environment:* The functional specification model allows the students to implement and test the FBE with ideal (i.e. no) delays and timing uncertainties in computation and communication. The functional models of channel and physical model are executed in a virtual timing environment as invariant JavaScript code in the student's browser. The students had to write the control program, which is an implementation of the 'Cyber Part' state machine of Fig. 4.

In the class, students implemented this program together with an instructor in the editor window of the loaded web page. Alg. 2 shows one complete functional implementation of the control part of the PSM. It can be clearly seen how the program reflects the states, state transition, as well as timing and channel operations of the PSM. The only complex operation is the computation of the expected time. The equation was provided by the instructor. Running the code results in a range of print outputs and a generated graphic of the ball in front of the virtual camera (see Fig. 5).

The result of this first executable simulation is that, first, we successfully translated a PSM into actual code as part of a simulated CPS, and second, that after few milliseconds the ball is always caught slightly below the center of the camera. These observations trigger recommended discussions about the functional and timely determinism of the result (why is it always the same on all devices), about the cause why the ball is caught slightly off center (continuous vs. sampling time), and the difference between real time and simulation time.

4) *Transaction-Level Model in the virtual timing:* The transaction-level model (TLM) extends the functional model with a decoupled channel model. Thus, timing properties of computation and communication can be expressed separately, and can be modeled in more detail. Therefore, in the instruction web page students have the opportunity to parametrize the channels. The channel model uses the same syntax and semantic as the computation model, so that, as example, the

```

if ((state==0) && waitChannel("S1")) {
    t1 = getTime();
    state = 1;
}

if ((state==1) && waitChannel("S2")) {
    t2 = getTime();
    state = 2;
}

if (state==2) {
    t_diff = 0.001*(t2-t1);
    velocity = (h2-h1)/(t_diff) + (g*(t_diff)/2);
    exp = (-V+Math.sqrt((V*V)+(2*g*(h3-h2))))/g*1000;
    state = 3;
}

if ((state==3) && (wait_until(s2+exp))) {
    send("act");
    state = 4;
}

if ((state==4) && (result=waitChannel("result"))) {
    print("result =" + result);
}

```

Listing 2. JavaScript implementation of the FBE (see PSM Fig. 4).

S2 channel with a 2ms delay can be expressed as

```

if (waitChannel("S2.in")) {
    waitTime(2);
    send("S2.out");
}

```

Each computation and communication operation can be annotated with a time this operation needs, by adding the `waitTime` statement. This allows students to express a timed model of the system and experience the effect to the outcome of the simulation and need adaptations of the control program. Students have to understand the source and quantity of delays and anticipate the delays in the control program. Advanced design options include the dynamic measurement of the round trip time of the channel (see Alg. 1).

5) *Remote Virtual Plant Real-world model:* The virtual plant model is a model of the falling ball executed on a remote server. While the actual plant model is still idealistic (i.e. it does not consider air resistance or material), we see two major differences to the previous TLM example: First, real timing, and second, the use a real Internet communication channel.

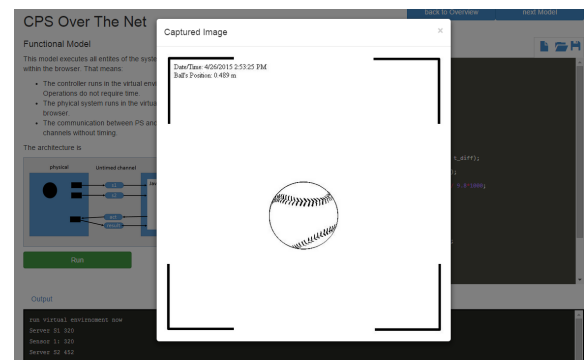


Fig. 5. Result after a successful run in the functional model: The simulated ball is caught by the camera.

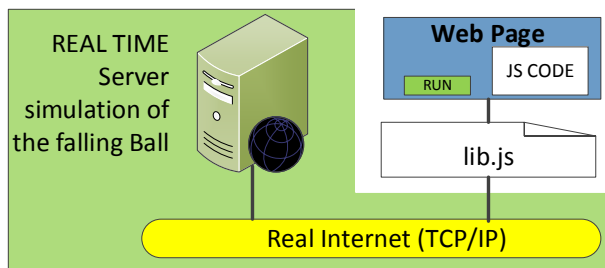


Fig. 6. Architecture of the FBE experiment with a virtual plant: the lib.js connects the student's code to a server computer, that emulates the falling ball in real time, via the Internet.

The server was implemented on an Intel Xenon machine running ASP.NET. After the server receives the signal from the 'drop' channel (compare Fig. 4), the simulator waits for a random time before simulating a drop from a random height. We included the randomness to avoid deterministic behavior that could be exploited. In the physical simulation, the server program updates the velocity and position of the ball as fast as possible (tens of microseconds resolution) in real time. Sensor signal s1 and s2 are sent to the controller, which has to process the signals and send the actuation signal at the right time under consideration of the channel delays. After receiving the 'actuate' signal, the server generates a picture of the ball at the simulated position.

While the complexity of the simulation is substantially increased, the student's control program remains unchanged. All platform-dependent code was added in the lib.js, and remains invariant to the students. The actual control program still expresses the small PSM, only with added timing anticipation.

We conducted this experiment in class to control the virtual plant, which runs on a server in another building on campus. Since we use an actual Internet connection, the experiment outcome is less deterministic. In more than half of the cases, the ball could not be caught by the camera. The result is not surprising and motivated discussion on the suitability and the need for detailed modeling of communication channels for reliable CPSs.

6) *Real-world system*: In the final experiment of this series, we replaced the virtual plant with the Raspberry Pi that accesses the sensors and the camera. In the classroom students were able to execute their JavaScript code, expressed in the web page, to control the physical system in the lab, few buildings away from the class room. This experiment required assistance in the lab. We needed to actively drop the ball. The practical part was recorded on video and projected in the class. Due to the nature of the experiment only one student at the time could run the experiment. The outcome was very similar to the virtual plant setup, since in many runs the ball could not be caught. In a successful case, however, the student received a photo of the actual ball, as shown in Fig. 7.

B. Results and Discussions of the Experiments

Admittedly, the organizational and building efforts for the final experiment are considerable. This observation increases the importance of the virtual plant setup, which already

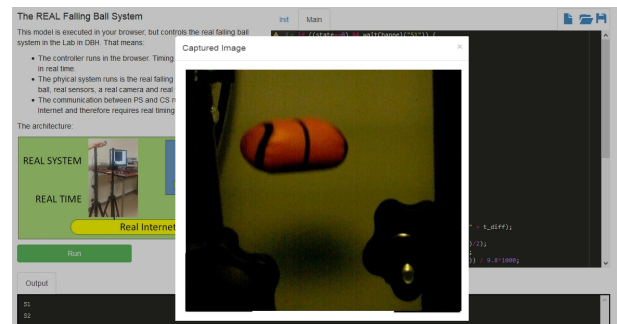


Fig. 7. Resulting picture of the falling ball. The ball appears crushed due to the slow vertical sampling (bottom to top) in the camera sensor.

includes all the timing and programming properties the students are supposed to experience. The virtual remote physical setup contains real timing of control and physical system, communication over the network, and timing uncertainties in computation and communication – all at student's hand in the Internet browser, without additional tools.

However, the practical setup adds additional benefits: First, the real experiment is a special event in usually less eventful programming and design class. In addition, the experiment gave practical closure to the design flow that started with a PSM model and which then developed to a real-world cyber-physical system that can be controlled in real time by a mobile device in the classroom. In this development process, each design step is incremental and seems very little, and therefore, is easy to understand. We studied this hypothesis in a short sentiment study. In the survey 82% of the students agreed that they understand all design steps, while the biggest challenge was the development of the PSM. Even though the real-timing experiments failed in many cases due to the unreliable communication properties, in this survey 86% of the students agreed that this particular misbehavior helped them understand the importance of good modeling and the purpose of the design flow. On a broader question, 96% of students agreed that the falling ball example helped to understand modeling or programming of embedded systems in general.

In addition to the student sentiment, we also analyzed the learning results. We compared the results of weekly graded quizzes to the results of earlier classes on the same subject. Compared to earlier classes without the new programming framework, the amount of correct answers related to model abstraction and the CPS programming improved from 80.7% to 95.3%. One particular result is an improved understanding of abstraction and the impact of channel uncertainties. As comparison, the average percentage of correct answers between the two groups for all other questions increased from 83.0% to 87.5%. The results indicate that the modeling and timing abstraction, which was a relative weakness in earlier years, now is a relative strength of the students.

One additional observation from this class was the increased number of practical student's projects that investigated the effect of communication timing and uncertainties. For instance students applied functional modeling and TLM-based time sensitivity analysis for an electric circuit breaker in the smart grid, the control of a quadcopter drone, and the control of the security and safety system in a smart building.

V. CONCLUSIONS

This paper discussed a browser-integrated development approach for the education of modeling and programming of Cyber-Physical Systems. Following our experiments in an Embedded System Design class, we can draw three conclusions:

First, we got confirmation that teaching techniques that include active programming and experiment-driven analysis are well received by students. The idea to control a real physical system from a mobile phone, a tablet or the laptop in the classroom is appealing to students and instructor. As a result, not only the student's approval improved, but also their results in quizzes on modeling-related questions improved from 80 to 95%.

The second conclusion addresses JavaScript as a suitable programming language for the instructor as well as for the students. JavaScript is a programming language with low organizational and programming overhead, as it does not need the setup of error-prone and platform-dependent tool chains. Applying JavaScript, the proposed framework runs the program, which student enter in a web page, as part of a virtual or real CPS.

Finally we can conclude that the education of CPS programming and design is feasible with smaller examples and just within an Internet browser. On different levels of abstraction and detail, students could run their program, first, as part of a CPS simulation with entirely virtual timing, then, in real-time using a virtual remote physical lab, as part of a real physical setup. The technical interfaces to the environments in all cases are provided by the instructor and hidden from the students, who can concentrate on the modeling, programming and running the experiments.

Based on these results we consider the proposed approach as promising contribution to programming exercises for embedded and cyber-physical systems in traditional class setups, but also to online classes, for which we consider an implementation in near future.

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Motivation as a key factor to improve freshmen academic performance in computer engineering courses

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Abstract—Since 2010 the Universitat Politècnica de València offers the bachelor degrees called “Grados”. The “Grados” follows the guidelines of the European Higher Education Area. Among them are specially relevant those giving students more participation on the education process and incorporating continuous evaluation.

Because of the frustrating results obtained by students of the “Physical Fundamentals of Computer Engineering” course during the 2010-2011 and 2011-2012 academic years, it was decided to examine strategies to overcome the low academic performance, but maintaining the common assessment policy.

The general idea of our proposal is provide students with freedom to prepare their own strategies. To accomplish that, new assessment events were introduced along the term. Thus, students can take a test at the end of each unit, they can also take a midterm exam, combine freely both strategies, or even take a final exam.

After applying the proposed strategies, on the one hand the final grades obtained by the students were better than in previous years, and on the other hand, the teacher observed a greater interest in the subject that leads to improve student engagement.

Keywords- continuous assessment; assessment strategies; student motivation.

I. INTRODUCTION

The Bologna process, launched in 1999, aimed to the creation of the European Higher Education Area (EHEA). As stated in [1] “the EHEA improves transparency between higher education systems, as well as implements tools to facilitate recognition of degrees and academic qualifications, mobility, and exchanges between institutions”.

The common tools includes the “European Credit Transfer and accumulation System” (ECTS) and the diploma supplement. The main goal is to ensure the recognition of study periods abroad.

According to [2]: Qualifications Frameworks are based on learning outcomes. The official Bologna seminar held in Edinburgh described learning outcomes as “the basic building blocks of the Bologna package of educational reforms”, and endorsed the proposition that this methodological approach is at the heart of the paradigm shift from teacher to student-centred learning.

Most of the Spanish Universities started the implementation of the EHEA proposals by the first time during the academic year 2009-2010.

In the “student-centred learning” paradigm the participation and continuous assessment of the students is crucial. Thus, the courses pertaining to the bachelor degree in Computer Engineering (Grado en Ingeniería Informática: GII) had to change not only how the courses were taught but also the learning strategies and the assessment procedures.

A study published by the OECD in 2010 [4] states: “on average among the 23 OECD countries for which data are available, some 30% of students in university-level education do not graduate from the program they enter”. Nevertheless, non-completion rates vary between countries - ranging from less than 10% in Japan to more than 40% in Mexico, New Zealand, Sweden and the United States. This issue is also important in our context, as about 25% of students drop-out our Computer Engineering degree during the two first academic years.

According to Feldman and Zimbler [5], “all beginning college students face enormous challenges, ranging from the academic to the social, and the first year of college marks the period of greatest vulnerability for student attrition”. Therefore, care must be taken in designing a learning environment that motivates by reducing student anxiety and minimizing dropouts. In the case of Computer Engineering degrees, this statement is especially relevant when it refers to Science and Math courses, as they may not be meeting students educational expectations, mainly focused on computer related topics.

In this paper the way how the students of the “Physical Fundamentals of Computer Engineering” course (Fundamentos Físicos de la Informática: FFI) were motivated to achieve better academic performance is presented. The proposed approach has been applied during the last three academic years, and it has evolved based on the obtained outcomes.

The rest of the paper is structured as follows: section II describes the context; section III introduces the syllabus of the FFI course; section IV is dedicated to describe the procedures and strategies used; Section V is devoted to show the results and make some discussion, and finally, in section VI, the conclusions and future work are presented.

II. CONTEXT

FFI is a first-year core subject taught during the fall term (first semester) in the Computer Engineering degree program. In particular, the approach was applied to the students enrolled in the two groups taught in Valencian language (out of 10 offered by the College) as the instructor who proposed the method was the responsible of these two groups. Below it is described the enrolment process just to understand some singularities.

In order to access to the Spanish Universities there are mainly the following options:

- 1) If a student has completed the upper secondary education, level 3 according to the International Standard Classification of Education (ISCED), the standard terminology created by the United Nations [3], he has to take the university admission test (*Prueba de Acceso a la Universidad*, PAU). Each university establishes cut-off grades to access to the degrees that it offers. Depending on the overall grade obtained by averaging the PAU test grades and the upper secondary education grades, students can apply for a particular bachelor programme in a specific university.
- 2) If a student has completed a higher vocational programme (*ciclo formativo de grado superior de formación profesional*), level 4 according to ISCED, he/she does not need to take the PAU test. Each university establishes a number of places in each programme for those having an upper technician diploma.

In our University, students who wish to enroll in any of the offered programmes, they do it according to the obtained overall grade. Thus, students having the highest grades can choose first, not only the programme they wish but also the group that they prefer. It includes the language in which the courses are given: Spanish, English, or Valencian.

In the special case of the GII degree, there are offered places for some 500 students. They are enrolled in 10 groups. Groups are named using letters: Group A, Group B, up to Group J. Groups A and B are given in Valencian, group E is given in English and the remaining groups are given in Spanish.

As stated above, one consequence of the enrollment process is that students with the best grades are gathered in specific groups. For instance, during the academic year 2012-2013, the average overall grade for the students enrolled in the two Valencian groups was 7.99 and 7.06 respectively. However, the average overall grade for the students enrolled in the two best Spanish groups was 9.40 and 8.30 respectively, while in the English group was 9.68. These differences among groups are common year after year.

III. SYLLABUS OF THE FFI COURSE

During the 2010-2011 academic year the GII programme was offered by the first time and teachers adapted the teaching and assessment methods in order to promote students participation and formative assessment.

A. Contents

Table I shows how the course contents is divided in blocks (B0 to B5) and the units (U0 to U13) that corresponds to each block.

TABLE I: Course organization in blocks and units

Blocks	Units
B0. Introduction	U0 Introduction
B1. Electrostatics	U1. Electrostatics fundamentals U2. Electrical properties of semiconductors
B2. Electrokinetics	U3. Direct current and electrical resistance U4. Power and Energy U5. Network analysis
B3. Electromagnetism	U6. Magnetic field. Magnetic forces U7. Magnetic field sources U8. Magnetic materials U9. Electromagnetic induction
B4. Sinusoidal Alternating Current	U10. Sinusoidal Alternating Current
B5. Semiconductor Materials	U11. Semiconductors U12. Conduction in semiconductors U13. The diode and the transistor

Laboratory practices.

1. Introduction to the measure devices
2. Resistance measure. Error analysis
3. The oscilloscope
4. The capacitor
5. Characterization of a direct current engine
6. Analysis of an active linear circuit
7. Resonance and filters
8. Characterization of the diode. Applications

B. Resources

All the resources are available at the institutional Portal.

C. Course organization

The FFI course usually starts on the first week of September and finishes the second week of January (15 weeks).

In each week there are planned two lecture sessions and one laboratory session. Both lectures and lab sessions last 90 minutes.

The first three lectures are devoted to review the main concepts of Calculus. In parallel, during the first week of the semester, two optional seminars of 2 hours each are offered. These seminars were especially prepared for those students coming from the vocational education and training programmes. The seminars are presented as extra sessions.

D. Assessment

FFI instructors agreed to assess students in base of the following items:

- 1) Two midterm written exams. The first one is called “MT1” and the second “MT2”. MT1 assesses blocks 1 and 2, while MT2 assesses blocks 3 to 5.
- 2) The execution of lab skills: scores obtained along the laboratory sessions (LAB)
- 3) Continuous-assessment (CA) over the course of the semester which includes: student class participation, homework assignments, observations, and so on.

Each midterm has two parts: the first part includes multiple choice questions while the second part includes open-ended questions. In the case of the first midterm, the sections are named $MT1_{MC}$ and $MT1_{OE}$ and for the second midterm the sections are named $MT2_{MC}$ and $MT2_{OE}$.

In the rest of the document the first part will be referred to as “multiple choice question part” (MC) and the second part as open-ended (OE), where students have to write and justify the obtained results.

The final grade (FG) is obtained applying the equation (1).

$$FG = 0.2 * \frac{MT1_{MC} + MT2_{MC}}{2} + 0.5 * \frac{MT1_{OE} + MT2_{OE}}{2} + 0.2 * LAB + 0.1 * CA \quad (1)$$

In order to give an extra opportunity to the students, at the end of the term, there was also a common final exam (F) divided in two parts named F1 and F2, according to the previous midterm exams.

In that case the final grade is obtained as indicated in equation (2).

$$FG = 0.2 * \frac{F1_{MC} + F2_{MC}}{2} + 0.5 * \frac{F1_{OE} + F2_{OE}}{2} + 0.2 * LAB + 0.1 * CA \quad (2)$$

At the beginning of the academic year all the common exams (MT1, MT2, F1 and F2) are scheduled.

IV. PROCEDURES AND STRATEGIES

During the academic years 2010-2011 and 2011-2012, the final grade was obtained according to equation (1) in all the groups. The exams were randomly distributed among teachers for grading.

Because of the frustrating grades obtained by students of the FFI course during these academic years (see section V.B for details), since the academic year 2012-2013, it was agreed to allow instructors to try new teaching strategies, but maintaining the common assessment policy.

In order to avoid early drop-outs and aiming at motivate students to be more engaged along the term, the instructor of the Valencian groups tried different strategies. Below are summarised the most successful ones.

- 1) Provide additional course resources to help students in their study. To accomplish that, a web page was created that includes, for each unit, examples of solved exercises and problems, as well as the exam solutions of all the previous academic years, and information about how assessment was made [6].
- 2) For each unit, a questionnaire was posted to the institutional portal. Students were invited to answer the questionnaire as homework and the corresponding score was taken into account in the CA dimension. The initiative aimed at preparing the MC part of the exams.
- 3) By the first time, during the current academic year (2014-2015), students had to answer a brief questionnaire at the beginning of the laboratory session, which was automatically assessed. As the corresponding score was taken into account in the LAB dimension, the initiative encouraged students to prepare the practices at home before attending the lab.
- 4) At the end of each unit, students were invited to take a written exam (unit exam) that follows the same structure (MC + OE) as midterm exams. As it will be explained in detail later on, scores obtained in these unit exams can replace the corresponding ones on midterm exams. See section V for details.
- 5) Students have the opportunity to improve the scores obtained so far, by taken the midterm exams, with the particularity that they can solve just the units that they want.

In order to better understand the strategies 4) and 5), below they are described in detail.

First we have to take into account the structure of midterm exams and the structure of final exam. Such structure is shown in tables II, III and IV. The structure of the MT1 is shown below in table II.

TABLE II: Sections of the MT1 exam.

Unit 1 multiple choice section	MC1
Unit 1 open-ended section	OE1
Unit 2 multiple choice section	MC2
Unit 2 open-ended section	OE2
...	...
Unit 5 multiple choice section	MC5
Unit 5 open-ended section	OE5

While the structure of the MT2 exam is:

TABLE III: Sections of the MT2 exam.

Unit 6 multiple choice section	MC6
Unit 6 open-ended section	OE6
...	...
Unit 13 multiple choice section	MC13
Unit 13 open-ended section	OE13

The nomenclature used for midterm exams is as follows: We will refer to the multiple choice section of the unit X as

MCX, while we will refer to the open-ended section of the unit X as OEX.

The structure of the final exam follows the same philosophy, as shown in Table IV.

TABLE IV: Sections of the final exam.

Midterm 1 multiple choice section	$F1_{MC}$
Midterm 1 open-ended section	$F1_{OE}$
Midterm 2 multiple choice section	$F2_{MC}$
Midterm 2 open-ended section	$F2_{OE}$

Once defined the different sections of the midterm and final exam, we proceed to detail the structure of the Unit-Test(U). Again, $U1_{MC}$ makes reference to the multiple choice section of the U test corresponding to unit 1. $U3_{OE}$ makes reference to the open-ended section of the U test corresponding to Unit 3.

In order to show how the strategies 4) and 5) are implemented, several scenarios are presented.

Note: The *Avg. Grade* of tables V to XII uses a 7-point scale, and is computing according to equation (3).

$$Avg. Grade = \left[\frac{0.2 * \sum_{i=1}^k U_{i_{MC}}}{k} + \frac{0.5 * \sum_{i=1}^k U_{i_{OE}}}{k} \right] \quad (3)$$

Lets start from the assumption that the grades obtained by two different students, in some U tests, are as shown in table V

TABLE V: Grades obtained in the Unit exams.

Student	$U1_{MC}$	$U1_{OE}$	$U2_{MC}$	$U2_{OE}$	$U3_{MC}$	$U3_{OE}$	Avg. Grade
A	10	10	8	8	3	3	4.90
B	4	4	4	4	4	4	2.80

Student A options:

- 1) Does not take the MT1 exam. In this case, table VI shows the student A scores stored for the MT1 exam.

TABLE VI: Student-A MT1 stored data.

Student	MC1	OE1	MC2	OE2	MC3	OE3	Avg. Grade
A	10	10	8	8	3	3	4.9

- 2) Takes the MT1 exam.

- a) Student A takes the MT1 but he/she decides to answer only the MC3 part. Then, he/she obtains a better grade than the one obtained in the $U3_{MC}$ exam. Table VII shows the grades obtained by student A in the MT1 exam.

TABLE VII: Student-A MT1 grades obtained.

Student	MC1	OE1	MC2	OE2	MC3	OE3	Avg. Grade
A					6		

TABLE VIII: Student-A MT1 grades stored.

Student	MC1	OE1	MC2	OE2	MC3	OE3	Avg. Grade
A	10	10	8	8	6	3	5.1

Thus, table VIII shows the MT1 grades stored for student A.

- b) Student-A takes the MT1 but he/she decides to answer only the MC3 part. Now, he/she obtains a lower grade than the one obtained in the $U3_{MC}$ exam. Table IX shows the grades obtained by student A.

TABLE IX: Student-A midterm obtained grades.

Student	MC1	OE1	MC2	OE2	MC3	OE3	Avg. Grade
A					1		

In this case it is stored the average of MC3 and $U3_{MC}$. Table X shows the stored grades.

TABLE X: Student-A midterm stored grades.

Student	MC1	OE1	MC2	OE2	MC3	OE3	Avg. Grade
A	10	10	8	8	(3+1)/2	3	4.83

Student B options:

- 1) Student-B takes the MT1 exam, and he/she has the option to solve the whole test or only some parts. For instance, he/she solves only the multiple choice parts (MC1, MC2 and MC3), and lets suppose that he/she obtains the grades shown in table XI.

TABLE XI: Student-B midterm MC1 obtained grades.

Student	MC1	OE1	MC2	OE2	MC3	OE3	Avg. Grade
B	8		6		2		

Then, the MT1 stored grades are as shown in Table XII.

TABLE XII: Student-B MT1 stored grades.

Student	MC1	OE1	MC2	OE2	MC3	OE3	Avg. Grade
B	8	4	6	4	(2+4)/2	4	3.133

The general idea of our proposal is to provide students with freedom to prepare their own study strategies. They can take a test at the end of each unit, they can also take a midterm exam, combine freely both strategies, or even take a final exam.

V. RESULTS AND DISCUSSION

To help readers to interpret the presented data, we have prepared the results presentations as follows:

Firstly, it is verified that the strictness of the teacher assessing the experimental groups (A and B) is similar to the strictness of the other teachers.

Secondly, the results obtained by the students of the FFI course is compared with another course given during the same term.

A. Teacher assessment strictness

One question that arises when preparing this work was: Given that each teacher prepares the midterm exams and grades his/her own students what happens if the teacher responsible of the experimental groups (A and B) is more or less strict than the others?

To answer such question, it was decided to compare the laboratory results during the academic year 2014-2015, because in that case all the teachers evaluates the laboratory sessions using the same strategies.

Table XIII shows the number of students passing the course in the experimental groups (A and B), and the total number of passing students in the FFI groups (including A and B). It is also shown the percentage of passing students obtained by dividing the number of passing students by the number of students taking the lab exam. Besides, the average and the standard deviation of the final grade (FG) are shown.

TABLE XIII: FFI Statistics per groups.

	Groups A and B	All Groups
#Passing	74	359
%Passing	86.04	88.72
FG average	6.74	6.77
FG std. dev.	1.92	1.69

As we can see the results are very similar.

B. Global results

In order to compare the results obtained by the students of FFI, it will be used the results obtained by the students of the course "Computer Fundamentals" (Fundamentos de los computadores: FCO). The FCO course is given at the same time than FFI.

The results are presented by academic years. The data include: the number of enrolled students in the corresponding course (#Enrolled); the number of students taking the exams (#Taking Exam); the percentage of students taking the exams (%Taking Exam), obtained by dividing the number of students taking the exam by the number of enrolled students; the average and standard deviation of the final grade (FG); the percentage of passing students (%Passing), obtained by dividing the number of passing students by the number of students taking the exam; the success rate (Success rate), obtained by dividing the number of passing students by the number of enrolled students.

It is presented:

- The global grades of FFI students. See table XIV
- The grades of FFI students enrolled in groups A and B. See table XV

- The global grades of FCO students. See table XVI
- The grades of FCO students enrolled in groups A and B. See table XVII

Then the figures with the following data are presented:

- FG. Average (figure 1)
- Percentage of passing (figure 2)
- Percentage of students who presented the exams (figure 3)
- Success rate (figure 4)

TABLE XIV: Global results of course FFI.

	2010	2011	2012	2013	2014
#Enrolled	541	614	539	558	482
#Taking Exam	380	525	425	433	449
% Taking Exam	70.24	74.5	78.85	77.6	93.2
FG. average	4.845	5.132	5.544	5.244	5.251
FG. std. dev.	2.176	1.7866	1.487	1.337	1.47
%Passing	55.53	64.38	71.53	70.67	72.6
Success Rate	39	55.05	56.4	54.8	67.6

Overall results in FFI included in Table XIV shows that percentage of students taking the exams improved after the two first academic years when different initiatives were implemented, and particularly in the last year (2014-2015) when this percentage surpassed 90%. The same applies for the percentage of passing students, above 70% in the last three academic years. However, the average of the final grade (FG) remained quite similar (above 5 in a 10-point scale) along the last four academic years. This fact occurs also when success rate is analysed, although there is an important increase in the last year (2014-2015) mainly due to the high percentage of students taking the exams.

TABLE XV: Results of FFI students enrolled in groups A and B

	2010	2011	2012	2013	2014
#Enrolled	100	NA	84	77	82
#Taking Exam	65	96	70	63	71
% Taking Exam	65	NA	83.33	81.81	86.6
FG. average	4.17	4.586	5	5.316	6.715
FG. std. dev.	2.167	0.219	1.24	1.506	1.807
%Passing	43.1	55.21	67.14	69.84	81.7
Success Rate	28	NA	59.95	57.14	70.7

Related to results obtained in the FFI experimental groups (A and B), Table XV shows that percentage of students taking the exams has also improved after the two first academic years, increasing from 65% in 2010-2011 up to more than 80% in all the remaining cases. An important rise is also observed in the FG average along these years, going to 4.17 in the first year (2010-2011) up to 6.7 in the final year (2014-2015). The same applies both for the percentage of passing students and the success rate.

Conversely, overall results in FCO (Table XVI) show different patterns. For instance, the percentage of students

TABLE XVI: Global results of FCO course

	2010	2011	2012	2013	2014
#Enrolled	547	532	472	508	450
#Taking Exam	482	430	356	404	413
% Taking Exam	88.12	80.83	75.42	79.53	91.78
FG. average	5.67	6.00	6.26	6.44	6.41
FG. std. dev.	2.26	2.11	1.97	2.21	2.09
%Passing	68.88	74.42	77.53	81.68	82.32
Success Rate	60.69	60.15	58.47	64.96	75.56

taking the exams range from 75% in 2012 to about 92% in 2014, although the percentage in 2010 was 88%. There is no a clear tendency in these figures. Concerning the FG average, values are similar although the best results are obtained in the last two years (2013-2014 and 2014-2015). The percentage of passing students improve along the years, going from 69% (2010-2011) to 82% (2014-2015). However, this is not the case for the success rate that has not a clear tendency, although the best results are also obtained in the last year (75%).

TABLE XVII: Results of FCO students enrolled in groups A and B

	2010	2011	2012	2013	2014
#Enrolled	NA	NA	NA	NA	NA
#Taking Exam	94	76	56	72	72
% Taking Exam	NA	NA	NA	NA	NA
FG. average	5.81	5.87	5.66	6.00	5.933
FG. std. dev.	2,04	2.05	1.99	2,14	2.17
%Passing	77.66	72.3	73.21	76.39	80.55
Success Rate	NA	NA	NA	NA	NA

In relation to FCO results in the same analysed groups (A and B), and supposing that students are almost the same as in the experimental groups, there are no clear patterns in the available data (Table XVII). For instance, FG average ranges from 5.66 in 2012-2013 to 6 in 2013-2014. The percentage of passing students ranges from 72% in 2011-2012 to 80% in 2014-2015.

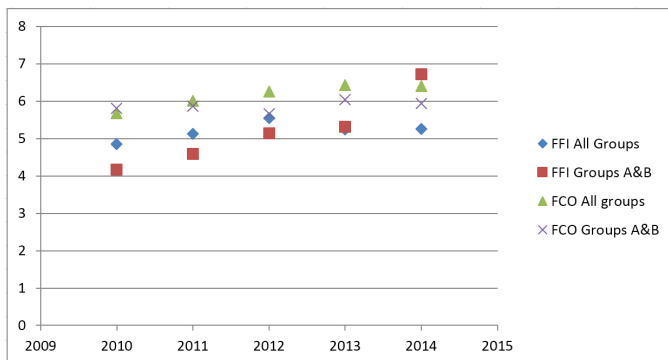


Fig. 1: The average of the final grade.

Concerning Fig. 1, we can see that from the 2010-2011 academic year up to the 2014-2015 academic year, the FG average of FFI students has been lower than the FG average of FCO students.

However, if we consider only the experimental groups A and B, from the 2010-2011 academic year up to the 2013-2014 academic year, the FG average of FFI students has been approaching to the FG average of FCO students, and during the 2014-2015 academic year the FG average of FFI students was higher than the FG average of FCO students.

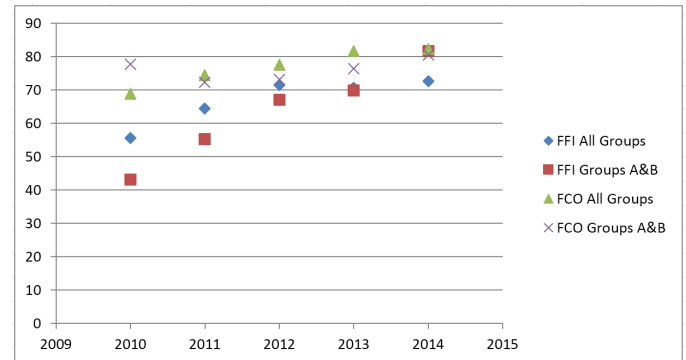


Fig. 2: Percentage of passing students.

Concerning Fig. 2, we can see that during the 2010-2011, 2011-2012, 2012-2013, and 2013-2014 academic years the percentage of passing students of FCO is always higher than the percentage of passing students of FFI. However, during the 2014-2015 academic year the percentage of passing students of FCO is lower than the percentage of passing students of FFI.

In the case of the experimental groups A and B, we can see that, during the 2010-2011 academic year, the percentage of passing students of FFI was significantly lower than the percentage of passing students of FCO.

During the 2011-2012, 2012-2013, and 2013-2014 academic years the percentage of passing students of FFI has been approaching to the percentage of passing students of FCO. Finally, during the 2014-2015 academic year both percentages are practically the same.

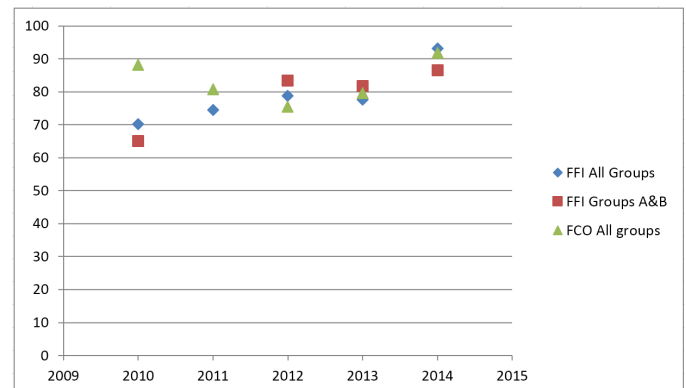


Fig. 3: Percentage of students taking the exams.

As shown in Fig 3 percentages of students taking the exams are very similar except in the 2010-2011 academic year.

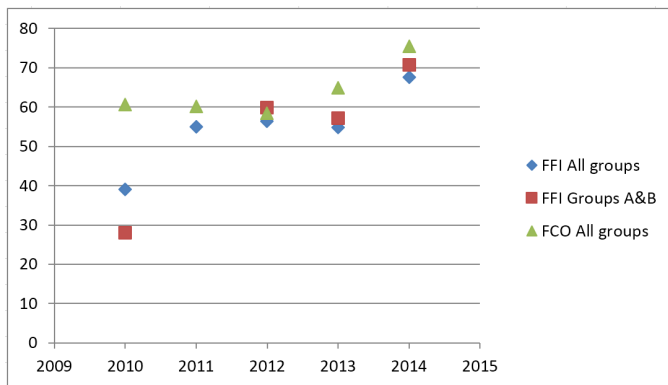


Fig. 4: Success rate.

Finally, concerning the success rate, accordingly to Fig. 4, we do not have information about FCO students of groups A and B. So we can say that the overall success rate of the FFI students during the 2010-2011 academic year was quite low (near 40%). During the 2011-2012, 2012-2013, and 2014-2015 academic years the success rate of FFI students was about 55%. However, during the academic year 2014-2015, this success rate increased to nearly 68%.

Since the 2012-2013 academic year the behavior of the experimental groups of FFI (groups A and B) is very similar to the behavior of the remaining FFI groups. An exception is noticed in the 2010-2011 academic year where the success rate of the A and B groups of FFI was really low (near 30%).

In addition to the stated improvements in the quantitative indicators, the teacher has also noticed a greater interest in the subject. For instance, about 90% of the enrolled students made 6 out of 7 unit exams. Only in one of these unit exams the percentage decreased to 70%, and it was related to the scheduling of another midterm examination in the same week. It is important to point out that before each optional exam, the instructor tried to motivate students to take these unit exams as they served them to assess their knowledge.

VI. CONCLUSIONS

To sum up, it was observed that after applying the five strategies described previously, on the one hand the final grades obtained by the students were better than in previous years, and on the other hand, the teacher perception is that students were more comfortable both in the classroom as in the lab, what contributed to reduce early drop-outs.

The key idea of our proposal has been to provide students with freedom to prepare their own study strategies. Depending on the particular student situation, they can take the unit tests, the midterm exams or a mixture. And if they prefer they can take the final exam.

Taking into account that computer engineering students generally are not very motivated to study science and math courses, the presented strategies have allowed the teacher to transmit a positive thinking along the different assessment events. At the same time, students perceive that regardless the initial results, they still have new opportunities to pass the course. Thus, if they get low grades in the unit tests, they can

improve them whether in the midterm exams or even in the final exam, what invite students to keep engaged.

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Qualitative Research on Psychological Experience

A Starting Point for Using Interpretative Phenomenological Analysis

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Abstract— This special session invites academic researchers to temporarily adopt the commitments of interpretative phenomenological analysis (IPA) in order to gain insight into psychological experiences in engineering education research. In this session, we will introduce participants to IPA as a methodology that is committed to understanding the lived experience of particular phenomenon while also recognizing that the researcher plays an interpretive role in generating such understanding. The participants will gain an introduction to *doing* IPA to systematically interpret a transcript through multiple iterations of understanding a text. This experiential learning session will be vibrant with focused activities of conducting qualitative analysis and reflecting on the process. Additionally, we will connect the intentional, analytic processes that are practiced to more holistic principles related to quality in interpretive engineering education research. The expected outcome of this session is that participants will have a robust foundation to begin or advance their inquiries using IPA or other forms of qualitative research.

Keywords- *interpretative phenomenological analysis; psychological experience; qualitative research*

I. PURPOSE STATEMENT

We propose a session that guides participants through the process of leveraging intentional techniques to interpret psychological experience in engineering education. A growing body of research is highlighting how engineering education is a process that engages *whole persons* rather than just students who learn concepts and skills (e.g., [4-10]). Consequently, engineering education researchers are increasingly attending to phenomena of embodied, psychological experience, such as emotion (e.g., [6]) and identity development (e.g., [7-10]). This special session leverages the facilitators' background with a study that employed interpretative phenomenological analysis (IPA) [11-12] as a way to gain insight into these experiences.

II. DESCRIPTION OF SESSION CONTENT

The proposed session focuses on three specific areas, which are described as follows.

A. Psychological Experience

The session will focus on psychological experience as a lens to identify under-explored phenomena in the participants' own contexts (e.g., psychological journeys of identity; emotion in engineering education). After the participants engage in an in-depth process of analyzing a common identity journey, based on an excerpt from an interview transcript, we will invite the participants to consider psychological experiences that are often invisible in their own institutional contexts.

B. Interpretative Phenomenological Analysis

The session will introduce participants to IPA as a methodology that is committed to understanding the lived experience of particular phenomenon (e.g., becoming an engineer) while also recognizing that the researcher plays an interpretive role in generating such understanding. Throughout the session, the participants will gain an introduction to *doing* IPA to systematically interpret a transcript through multiple iterations of understanding a text. They will begin by an initial reading for shallow comprehension and end with connecting the transcript to psychological themes.

C. Conducting Quality Research

The session will provide a space for participants to think through how they actually analyze text from a common interview transcript. In order to foster this development for researchers, we will share an excerpt from a transcript in our ongoing investigation related to how students undergo the psychological identity journey to become engineers.

Using this common source of data, we will then guide participants through multiple layers of interpretation of this text, thereby creating an immersive process with multiple iterations of feedback from the co-presenters. Toward the conclusion of the session, we will demonstrate how our exercise relates to the assurance of *quality* in interpretive research, using co-facilitator Walther's quality framework [3], as discussed in the following section.

III. ASSOCIATED PEER-REVIEWED PAPERS

This session is primarily associated with the Huff et al.'s previous work [1], which reflectively analyzed the embodied commitments of conducting qualitative research. Our previous work [1] was presented at the FIE 2014 conference and includes four co-facilitators as authors. In the paper, we detail the transition of one researcher in his journey from attending to the methods of research to identifying and enacting the methodology of interpretative phenomenological analysis (IPA). In the backdrop of this paper was our larger qualitative study that employed IPA to understand a rich picture of how engineering student become engineers, particularly by attending to the fuzzy boundaries between technical and social features of this identity [2]. To ground the discussion of the paper, we drew on a transcript from a single interview in this study conducted with Kevin, a graduating mechanical engineer. We transparently shared a reflexive account of conducting IPA research in order to introduce IPA as an excellent research tool for open areas of engineering education research.

Additionally, we leverage prior work by co-facilitator Walther and his colleagues [3]. Specifically, we draw on their Q3 framework for considering quality in qualitative research. Drawing on the engineering metaphor of quality management, they propose a process-oriented framework of research quality along two dimensions: a process model locates quality strategies throughout the research process, and a typology systemizes fundamental aspects of validation (theoretical, procedural, communicative, and pragmatic) and the concept of process reliability to explicate quality strategies in their fundamental contribution to substantiating knowledge claims.

IV. SESSION AGENDA

In the session, we intend for participants to form small groups of 4-6 persons. The session will incorporate a blend of activities for individual persons, small groups, and the entire assembly. We co-facilitators will divide among multiple groups to provide guidance, as needed, during the structured tasks of the session. The following is a proposed agenda, approximated for the entire 90 minute range (00:00 – 01:30).

A. Welcome and Group Introductions

(00:00 – 00:10): We co-facilitators will introduce ourselves and welcome all to the session. We will then organize the participants into small groups and facilitate introductions within these groups. During this time, we will also hand out all materials related to the session.

B. Defining Terms: Psychological Experience and Interpretative Phenomenological Analysis

(00:10 – 00:15): We will provide a brief explanation of these terms but then quickly immerse them into *doing* IPA to examine psychological experience. This activity corresponds to the steps of analysis detailed in Huff et al. [1]. Our intent here is to foster learning among the participants in IPA through shared experience before considering theoretical

features of these terms. Throughout the activity, co-facilitators will wander the room to provide feedback on the various stages of interpretation.

C. IPA Activity: Reading an Interview Excerpt

(00:15 – 00:20): We will begin by having two facilitators acting out a real interview transcript from our study on identity development. The particular transcript is an authentic account of Charlotte's struggle to transition to her full-time career as a civil engineer. We begin by reading the transcript to discuss how the transcript is a representation of a real event, both for the researcher and the participant.

D. IPA Activity: Individual Reflection of the Transcript

(00:20 – 00:25): After the interview is read, the excerpt will have certainly elicited some personal connections from the individual participants. We will use this time to allow participants to *bracket* off these personal responses by reflectively, writing them down, and then forgetting about them—for the time being.

E. IPA Activity: Descriptive Comments

(00:25 – 00:30): We will give participants the opportunity to individually *describe* what they see in individual copies of transcript. What are significant features of the transcript? What is the play-by-play among the text? Each participant will do so in a designated color of ink in the wide right-hand margin.

F. IPA Activity: Linguistic Comments

(00:30 – 00:35): We then will give participants the opportunity to document how the participant is using *language*. Each participant will do so in a different color of ink in the right-hand margin of the paper.

G. IPA Activity: Conceptual Comments

(00:30 – 00:35): Having considered the description and linguistics of the transcript, the participants will now *ask conceptual questions* of the transcript. This prepares the analysts to consider how the transcript might relate to broader psychological themes from literature.

H. IPA Activity: Connecting to Broader Themes

(00:35 – 00:45): We will close the session by guiding participants to connect sections of the transcript to broader psychological themes (see Huff et al., 2014, for a detailed description of these). Participants will note these in the *left-hand* margin.

I. Group Reflection on Activity

(00:45 – 00:55): After individuals have completed the analysis activity, we will discuss their reflections of the common activity in two layers: first among small groups and then among the entire assembly.

J. How Does Analysis Relate to Knowledge Claims?

(00:55 – 01:05): Following the activity, we will give an overview of how we would use IPA to compare particular findings in the excerpt from Charlotte's interview to

psychological themes in other interviews. Specifically, we will examine how such detailed analysis can result in relevant claims of knowledge.

K. Thinking Through Quality

(01:05 – 01:15): Using the shared analysis activity as a guide, we will walk the participants through the Q3 Framework [3] as a general form of considering quality in their own investigations.

L. Relevance of Psychological Experience

(01:15 – 01:25): We will close the session by inviting participant to consider questions of *psychological experience* that may be relevant investigations in their own institutions (e.g., the identity development of African-American males at HBCUs, the frustration of first-generation college students in an engineering science course). Responses will be written down and shared.

M. Final Group Discussion

(01:25 – 01:30): The session will close with a brief group discussion, which includes time for co-facilitators addressing participant questions.

V. ANTICIPATED AUDIENCE

We anticipate an audience of those interested in qualitative research in engineering education. Such an audience would include researcher that are new to qualitative investigations. It would also include advanced qualitative researchers who are looking to hone their skills or find others with similar interests. We also anticipate that this session will draw those who are interested in examining *experiential* features of engineering education through a psychological lens.

Furthermore, prior to the conference, we will promote the special session among the 200+ persons who have expressed interest in co-presenter Walther's ongoing research with the Q3 Framework [3]. We will also leverage co-presenter Huff's role as a contact-person in the international IPA network in order to advertise the session and conference to beginning IPA researcher across the United States.

VI. EXPECTED OUTCOMES

The expected outcome of this session is, primarily, for participants to have a robust foundation to investigate psychological experience using IPA. We expect that this session will demystify features of interpretive analysis that are seldom made explicit, giving participants confidence to dive further into understanding IPA or other qualitative approaches.

Additionally, we will collect three types of data from the session: participant contact information; the annotated transcripts; and the documented forms psychological experience that are relevant to participants. This data will help inform (1) how multiple analysts might provide various informed interpretations of a common text and (2) develop a

repertoire of topics for the engineering education community related to psychological experience.

VII. PLAN TO DISSEMINATE OUTCOMES

We intend to disseminate outcomes for the proposed session via a full-paper for the 2016 FIE Conference. We will give participants the first viewing of this paper, should they indicate their interest. Additionally, we will provide electronic resources of our own work to participants that indicate interest.

VIII. RATIONALE FOR INCLUSION AS A SPECIAL SESSION

We propose that the session described be included as a special session at FIE 2015. At the heart of this session, we are making interpretive strategies visible in an experiential learning format. Additionally, we are relying on the knowledge of our participants to socially construct the relevance and landscape of psychological experience in engineering education research. A special session at FIE provides the structural space to optimally fulfill these purposes.

IX. ACKNOWLEDGEMENTS

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Aesthetics and Emotional Engagement

Why it Matters to Our Students, Why it Matters to Our Professions

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Abstract— This special session takes the form of a guided discussion, using a hands-on flow visualization exercise as focal point. Our goals are 1) to foster conversation and document ideas about how the aesthetic qualities of engineering topics can be used to deliberately draw the emotional engagement of students; 2) to gauge how the FIE community currently views the aesthetics of engineering, and brainstorm new visions for how aesthetics could be used to improve recruitment and retention of a diverse student population as well as lead to innovative methods for the teaching and learning of core engineering content; 3) to explore the feasibility of viewing aesthetics-driven emotional engagement as a necessity and not an ancillary benefit in course design.

Keywords— *aesthetics, art, affect, design, fluid mechanics, flow visualization, engagement, engineering, physics, education*

I. DESCRIPTION OF SESSION CONTENT

Aesthetics can be defined both as a metric for art (is it art? Is it good art? [1]) and as a psychological measure of affect [2]. With a few pointed exceptions, neither definition has received much consideration in engineering education. Instead, cognitive gains, technical competence, utility, and objectivity are our most highly prized virtues. Despite improvements, the complexity of the problems that remain call for a broader approach; we propose that aesthetics and the attendant emotional engagement as possible solutions to long standing problems in diversity, technical literacy, and retention.

New emphasis is being placed on students' emotional engagement, in works such as *The Whole New Engineer* [3] and in studies relating emotion to cognitive gains [4], [5]. Issues of affect, emotion, and identity are tangled, but certainly overcoming engineering stereotypes, which often highlight being socially awkward or emotionally stunted, requires transformation of our cultural practices in education. Acknowledging that aesthetics is a valid motivation for science and engineering may provide an important avenue for increased inclusion of diverse thinkers; conversely, ignoring the aesthetic dimension of engineering masks the enthusiasm and creativity engineers have for their work. How can we lead more students to Richard Feynman's joyous reaction that, "There are all kinds of interesting questions that come from a knowledge of science, which only adds to the excitement and mystery and awe of a flower. It only adds. I don't understand how it subtracts" [6]?

This line of questioning developed from an intervention in fluid mechanics that improved students' perceptions and attitudes. Flow Visualization, a course in which engineering and art/film students make artistic images of fluid flow, has been shown to improve attitude towards a notoriously difficult topic [7]. However, efforts to extend this success to other subdomains have been only partially successful.

This workshop will generate and collect a wide range of perspectives on what aesthetics means in the context of engineering practice and education, and explore how aesthetics can generate emotional and intellectual engagement.

II. AGENDA

Participants will be in small groups (4-6 people). They will be given a small but beautiful fluid dynamics experiment to perform. This will be used as a discussion starter for the role of aesthetics in comprehending specific physics concepts and improving student engagement. Facilitators will circulate to assist discussion where needed and document report-out using video. See Table 1 for a list of activities.

TABLE I. SESSION ACTIVITIES

Activity	Time, minutes
Pre-readings drawn from EER, PER, art education, psychology and neuropsychology of aesthetics are available for participants interested in digesting contextual information prior to the session [8].	N/A
Introduce the facilitators and goals of the session; settle participants into groups	5
Groups perform Flow Visualization experiment; record results using camera phones. Participants will be asked to reflect on and document personal reactions to the experience as well.	20
Groups report-out reactions to the experiment; whole group discussion	15
Using the Flow Vis. experience as a possible model for aesthetics in their own domains, groups generate other models and discuss possible implementation strategies in formal and informal learning contexts.	20
Groups report-out previous discussion.	15
Whole group discussion on dealing with potential obstacles to these changes; Closing	15

III. BACKGROUND PAPER

A structured summary of the pre-readings and an abbreviated description of the session details is available online [8], and will be distributed to participants in hardcopy. Please note that our preliminary research in this area is being submitted as a work-in-progress to FIE, and will be referenced in the pre-readings.

IV. AUDIENCE

This session is expected to draw from several subsets of FIE attendees:

- Those who value aesthetics already, such as visually creative individuals and artists (being an engineer does not preclude membership in this group).
- Those who are interested a definition of diversity that extends beyond demographics and perspectives defined by demographics.
- Those who are interested in humanistic engineering approaches, including efforts to develop well-rounded students.
- Those who are interested in issues of the affective domain, including attitudes, beliefs, motivation, values, and identity.

V. EXPECTED OUTCOMES WILL BE REPORTED

Within two weeks of the session we will post (on YouTube) preliminary results in the form of the video recordings of the report-outs (Model consent and IRB approval will be secured as needed). Within one year we plan a peer-reviewed journal article placing a summary of the discussions in the context of a review of the appropriate literature.

VI. JUSTIFICATION AND FUTURE WORK

Aesthetics and the resultant emotional engagement are topics that are not well-represented in engineering education

research. In addition, many engineering educators are uncomfortable with these topics. We hope that in the process of facilitating this special session we will begin to establish a community of researchers and practitioners who can help move this area forward. This engagement will be possible only with the degree of interaction afforded by an FIE Special Session. Finally, this discussion, and the video record of it, can be the seed participants take home to begin this conversation at their own institutions.

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Applying PBL in Project Management Education: a Case Study of an Undergraduate Course

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Abstract— The Software Engineering sector has been demanding an education model that targets real market practices more and more exactly. This includes bearing in mind that, in the market, a software project is subject to numerous restrictions of time, budget and other resources required for its development. In this context, this article describes the application of a learning methodology based on problems, called *xPBL*. This methodology consists of elements that enable a learning environment to be built that in its essence is practical and contains real learning, and that ensure that this is supported by processes that make it possible to evaluate the effectiveness of the PBL approach from various perspectives: namely, the student's, the teacher's and that of the methodological approach itself. Based on this case study, evidence of the applicability of *xPBL* is demonstrated as is how the behavior should be understood of all stakeholders involved in the process of teaching and learning in one of the most complex disciplines of Software Engineering.

PBL; Project Management, Software Engineering Education.

I. INTRODUCTION

The coining of the term "Software Engineering" in Computer Science has thrown down major challenges for those who teach it. Obviously, the requirements of Software Engineering demand a learning environment that is not only practical but true to the reality of the market. That is, an environment that allows its students to experience in a real way, the software development process, its management constraints (scope, time, cost, risks), technological limitations and conflicts of interest between human resources, whether these are members of a software development team or customers seeking software solutions.

This is the context of what this article sets out to show. By using a teaching methodology centered on the student and on solving real problems in a real work environment, this article describes the experience of applying PBL (Problem-Based Learning) to a Planning and Project Management module which is part of the curriculum of an undergraduate degree in Information Systems (IS).

PBL was applied using a method called *xPBL* developed by the NEXT (*iNnovative Educational eXperience in Technology*) group as described in [1]. The elements of this methodology as well as some of the practical studies that preceded it are discussed briefly in Section II of this article.

It is important to point out that the NEXT group has been making a study of and applying PBL in Computer Science since 2007. Trialing was almost always carried out on post-graduate courses or courses aimed at adding to professional skills, most of which focused on enhancing specific professional skills, for a target-audience of Computer Science graduates, as described in [2], [3], [4] and [5].

Unlike previous research studies, this paper describes and discusses the application of PBL methodology on a course of the 4th semester of a still ongoing 8-semester undergraduate degree in IS, as set out in Section III, in parallel with five other highly relevant course modules, including Software Engineering, Databases and Business Processes Management. In this context, the Project Planning and Management (PPM) course module, the object of this study, competes with the modules of the same semester with respect to the availability, commitment and engagement of the students. This feature reinforces the need for a methodology supported by a real environment and real assessment processes, thereby continuously bringing students to the center of the learning to which they belong.

The application of *xPBL* methodology is described and discussed in Section III, and the evaluation process and its results are presented and discussed in Section IV.

Lastly, Section V draws conclusions and makes some final remarks on this research experience.

II. THE *xPBL* METHODOLOGY

The purpose of the *xPBL* methodology is to align methods and tools to the management of the PBL approach so that the principles that characterize it can be guaranteed when adopted for teaching Computing.

On adopting the PBL approach, characteristics such as flexibility and unpredictability should be considered, especially with regard to their impact on managing the steps and activities associated with the teaching and learning process. According to [6], the essence of PBL is that it is process-oriented. Therefore, as this is one of the main features associated with this approach, it is important to maintain alignment between the stages of the PBL process to ensure its effectiveness. These assumptions led the NEXT group to

conducting research, especially with respect to drawing up processes and metrics to plan and manage PBL. This involves, for example, concepts associated with the 5W2H technique [7], Deming's PDCA (Plan, Do, Check and Act) [8], PBL principles [9] and problem-solving models [10]. It is important to emphasize that the applicability of xPBL in case studies such as in [2], [3], [4] and [5] enabled experience to be obtained of its implementation and the continuous improvement of its processes.

To ensure PBL principles besides its educational goals are adhered to, the xPBL methodology is based on five elements: (1) Problem; (2) Environment; (3) Content; (4) Human capital and (5) Process. These elements reinforce ten principles that were established in [9]. Table I maps the ten principles associated with each element of xPBL.

TABLE I. ELEMENTS OF XPBL AND PBL PRINCIPLES (SOURCE IN: [9]).

Mapping PBL principles and elements of xPBL	
<i>PBL Principles</i>	<i>xPBL Elements</i>
1. All learning activities are anchored on a task or a problem;	Problem
2. The learner should feel he/she owns the problem, and is responsible for his/her own learning;	
3. The problem should be real;	
6. The learning environment should stimulate and at the same time challenge the learner's reasoning;	Environment
4. The task and the learning environment should reflect the reality of the professional market;	
5. The learner needs to own the process used so as to work out the solution to the problem;	Content
7. The learner should be encouraged to test his/her ideas against alternative views and contexts;	
9. The learning is collaborative and multidirectional;	Human Capital
8. The learner should have the opportunity and support to reflect on the content learned and the learning process;	Process
10. PBL is supported by planning processes and continuous monitoring.	

Learning in PBL is directed towards problem solving. The problem is always the central task to be undertaken in this process. As seen in the mapping shown in Table I, Principles 1, 2, 3 and 4 are associated with the 'Problem' element of xPBL. These principles support the idea that problems should be real and complex so that students' interest in solving them is aroused.

Regarding the 'Environment' element of xPBL, Principle 4 supports the need to simulate a real learning environment that reflects actual conditions in the labor market. This means that learning is essentially functional in an environment where students are of a mind to be immersed in practices and activities in a collaborative and multidirectional way (together with their peers, teachers and tutors).

Principles 5 and 7 refer to the "Content" element of xPBL, which reflects the need to align practices to content (whether structure, theory, foundations, model or concept). Although learning is essentially functional, the PBL methodology considers it essential to have the support of content as a

conceptual basis for the problems and that the methodology must not be confused by practical experiments in which the support of theory and monitoring the processes of how solutions are found are not prominent.

Regarding "Human Capital", principle 9 reinforces the idea of collaborative and multi-directional learning being fostered by constantly engaging students, teachers, tutors and customers with each other during the resolution process.

Finally, principles 8 and 10 associated with the element of 'process' emphasize the need to plan and monitor the processes of teaching and learning continuously by having the students reflect on their learning and conducting reviews which are consistent with the paradigm of the method. It is also pointed out that Principles 9 and 10 were defined by the authors of this article in [9].

Therefore, the authors, when defining the xPBL methodology, consider that how its elements are tackled is essential at all stages of the PDCA cycle, above all with regard to planning being aligned to its implementation.

Quality management of the processes in the cycle associated with xPBL elements can also be guaranteed by adopting techniques such as 5W2H. The five aspects associated with W and the two with H presented in the technique match the keywords given in Table II. According to the authors [1], a plan of action guided by the technique sees to it that the 5 elements are defined in a clear and organized way because they obtain answers to questions such as: "What?", "Who?", "Where?" "When?", "Why?", "How?" and "How much?".

TABLE II. 5W2H TECHNIQUE.

5W2H Technique		Questions
5W	What?	What action will be performed?
	Who?	Who will perform the action?
	Where?	Where will the action be performed?
	When?	When will the action be performed?
	Why?	Why will the action be performed?
2H	How?	How will the action be performed?
	How Much?	How much does it cost to perform the action?

As an effective management technique, 5W2H sees to it that activities associated with each xPBL element are broken down, analyzed and summarized during the planning stage. The authors objectively considered information about what should be done and when, or who will conduct a certain activity and when, while they were defining each element.

When considering the 'Problem' element of xPBL, the question "what?" of the technique refers to the set of possible, real and complex problems which are similar to real-world projects and the demands of real customers. The purpose of this element (related to the question "why?", for simplification, "why?") must necessarily be compatible with the educational objectives, with the content to be learned, besides the skills and attitudes needed to solve the problem. As in the real world, problems arise from real customers (who?) and it is they who ask for the activities and evaluate the team's results, when considering their needs. It is up to the students (who?) to select the problem from among different

requests (where?) right at the start of training (when?). This process (how?) allows students to identify and understand requests so that they can thereafter draw up an innovative plan for solving them with relevant arguments, thereby proving the feasibility of the process and its complexity. The aspect of 'how much' is not applicable to this element.

The 'Environment' element refers to definitions of actions set by coordinators, tutors and teachers (who?) before the start of a course (when?). The main actions (what?) refer to the process of forming teams because of the number of aspects and personal aspects and defining the resolution process associated with activities, roles, business models and development models (how?). IT infrastructure and physical infrastructure aspects should also be considered (what?) since the environment should reflect the real conditions of the labor market (why?). The costs for this element (how much?) are related to acquiring resources and licenses. The methodology recommends that small teams (5-7 members) be formed, where aspects such as professional experience and interpersonal skills should be considered.

In the context of Human Capital, roles and responsibilities are defined (what?) during the planning (when?) so that those involved know how to proceed correctly when implementing the PBL approach (why?). Teachers and technical tutors (who?) teach the content, coordinate activities and can be consulted about real experience in projects (how?). The PBL tutor (who?) monitors the entire process of solving the problems of the teams, and records the results of the performance and individual assessments (how?). Students and customers should also be considered in this context (who?). The aspect of 'how much does it cost' is not applicable in this element.

As for the 'content' element, it is known that this is the conceptual basis for the process of problem solving, as well as being responsible for providing the formation of students' knowledge (what?). The flexible learning associated with the PBL approach requires teachers and tutors (who?) to map the contents of different media such as books, magazines, and specialist blogs (where?). The idea is not to follow pre-defined routes, but rather to take up unpredictability as the rhythm of the solution process in practice (why? and how?).

Finally, the last element of the xPBL methodology refers to the assessment process (what?). The reference that the authors [1] stress is the authentic assessment proposed by [3] to evaluate the effectiveness of the approach under different aspects by considering the rigor associated with real practices both individually and collectively (why?). Throughout the training (when?), formative type assessments are conducted to verify that educational goals are being achieved. Summative assessments are carried out at the end of educational units to classify the students' achievement levels as to course content and foundations of the module as well as the interactions and deliveries (when?). Teachers and tutors (who?) evaluate the students (how?) under ways associated with the content, the resolution process, and the performance and development of interpersonal skills in the teaching and learning process. The students (who?) evaluate themselves, their peers, as well as

teachers and tutors and the PBL methodology itself. In the perspective of the students' evaluations, aspects such as results and customers' satisfaction derived from authentic assessment are considered. The level of customer satisfaction refers, above all, to the service provided by the team. The results of each evaluation are consolidated by the teacher in reports with varying levels of visual details using graphics and comments.

The next section describes these elements applied to the undergraduate degree with an emphasis on the management and planning of information system projects.

III. USING xPBL IN PROJECT MANAGEMENT UNDERGRADUATE COURSE

This section describes the application of the xPBL methodology in the Project Management in Information Systems module of the undergraduate course. There is a total of 60 contact hours over 4 months, the educational goal being to train students in good practices in Project Management.

To conduct the course, planning was carried out by the pedagogical team comprising the teacher of the course and four tutors: two technical tutors (with project management experience); and two PBL tutors, responsible for monitoring the learning process throughout the course. This plan followed the guideline proposed by xPBL in [1]. Based on applying the 5W2H technique to the xPBL elements discussed in Section II, the PBL approach was used to structure the module.

A. Environment

The learning environment consisted of 33 students, divided into six teams: 3 teams of 5 students and 3 teams of 6 students. Of the students, 70% of the class were between 19 and 21 years old, and the rest up to 24 years old; 80% of the class were male; and 33% of the group had no professional experience.

The criteria used to distribute the students into teams were: professional experience, age, interest in Project Management, in addition to the student's personal profile (artisan, guardian, idealist and rational), which was identified by applying a simplified version of the MBTI - Myers-Briggs Type Indicator [13]. So as to form the teams in a more balanced way, the following rules were established: (1) Each team consists of a mix of MBTI profiles; (2) At least one profile of "idealist" per team, usually related to creativity and innovation; (3) No team has all members within a single age band; (4) At least one female in each team; (5) At least half the team have some professional experience; (6) Affinities are identified from the initial dynamics.

To support the communication and dissemination of educational materials of the course, the following tools were adopted: Facebook, Dropbox, Google Drive and a WhatsApp group, which enabled greater collaboration among all stakeholders.

To plan and monitor the development of each project, the teams adopted agile management techniques by free choice. All that the teaching team required was that it should be possible to monitor the process remotely and so each team used a web tool that supported the process adopted and allowed the progress of the project to be followed by the team of tutors via

the web, whether by monitoring Tables via document repositories or the project site.

As for the classroom, the students had a whiteboard and a physical space with mobile tables and chairs, which permitted physical configurations to be arranged for groups. This was an environment that was improvised and needed to be reorganized at the start and finish of each class. Unfortunately, the organization does not have appropriate rooms for PBL, which reflect working environments found in the software industry. As to the hardware used, a notebook was made available in the classroom to each team and each team had ample access to the undergraduate laboratories (around five of them and all of which are of high quality and capacity) at the Informatics Center throughout the day.

B. Problem

The objective of the 1st. step of the course was to bring all students to the same level in Project Management concepts thus seeing to it that they could become familiar with the problem- solving approach, which is very different from traditional classes based on presenting content on PMBOK (Project Management Body of Knowledge), version 5.

In the 2nd. step of the course, students were responsible for identifying and formalizing the problem to be investigated, including ensuring the participation of a real client who was external to the academic environment. To ensure that the problems identified by the teams and the proposed solutions would be compatible with the educational objectives and training needs and skills associated with the course, teaching staff guided the teams such that the solutions were designed using WEB2.0 tools or platforms, for example: Salesforce, Content Management Systems, or other environments based on a high-level business component.

To help students understand the problem and propose a solution, a dynamic was conducted, supported by the Delisle problem-solving model [14]. The model sets out four aspects of tackling a problem that should be observed: (1) Ideas, possible solutions for solving the problem; (2) Facts, information about the problem; (3) Hypotheses, raising learning issues to solve the problem and; (4) Action Plan, strategies, resources, information, everything that leads to the solution. On having a clearer understanding of how to find solutions to the problem, the students then move on to the step of formalizing the problem. The problems were defined by each team using a template with questions related to mastering the problem, its causes, complexity, the target public's needs and so forth. To define the proposals, questions guided the students on how to evaluate possible solutions, without overlooking the strategy for achieving them, available resources and the benefits to customers. The definitions of problems were sent to the teaching staff so that they could be evaluated under the criteria of Adequacy, Complexity, Clarity, Relevance and Innovation, thereby determining if they were to be selected or adapted.

C. Human Capital

The teaching staff consisted of the teacher of the course and four tutors. The general function of these tutors was to continually support student learning. Thus, the course received support from: two technical tutors, whose competences and

experience were specific to the subjects of the course and; two PBL tutors, who helped to conduct and implement the xPBL methodology. In conducting the classes, one of the PBL tutors was always present and; at least one technical tutor attended the monitoring meetings of the projects.

Besides the four tutors and the teacher of the course (an expert on Project Management and PBL), there was a team of developers and the Project Manager, who was a student belonging to the team itself and elected by its members. Finally, there was the figure of the real client, a person representing a company or individual entrepreneur, with whom the teams had identified some demand that needed to be satisfied by using information systems.

D. Content

The course was conducted by the teacher and technical tutors for which the main reference was the PMBOK Guide version 5, and speakers on agile management approaches SCRUM [15] and KANBAN [11] were invited. Moreover, a lecture on the PBL approach and a dynamic on the process of problem solving according to Delisle's model were given [14].

The course was run in 3 modules. The 1st module focused on the overview of PMBOK v5, in order to ensure early study of the main concepts of the Project Management area; the 2nd. module focused on the phases of Initiating and Planning the life cycle of projects; and the 3rd. module focused on the phases of implementing, controlling and closing the project life cycle. With reference to the project phases that the teams experienced, the teacher defined the content planned for the course. Based on the difficulties encountered in the evaluation process (detailed in Section IV), the "on demand" content was given to the class, thereby reinforcing the points for improvement identified in the teams.

E. Assessment Process

The evaluation model implemented in this case study was structured into three levels: the first targeted the evaluation of the students according to the authentic assessment model and used five perspectives – *Content, Process, Results, Performance and Client Satisfaction*; the second targeted the degree of maturity of the PBL approach in the students' view; finally, the third focused on the final evaluation of the course, under criteria related to how the teacher planned it and performed. Figure 1 summarizes the evaluation process and the results obtained. The details of each of the levels of Figure 1 will be presented in Section IV.

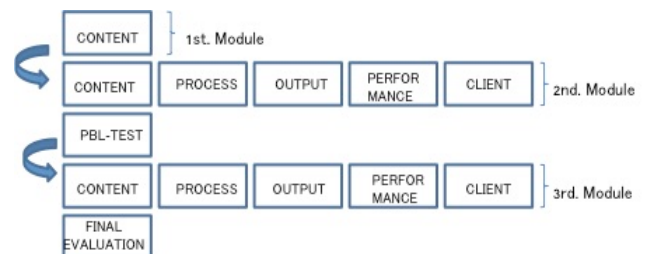


Fig. 1. Assessment Model used in the module.

IV. ANALYSIS OF RESULTS

A. Results of the Student Assessment

The assessment process was conducted in three modules: the 1st module focused on knowledge and understanding of project management concepts and fundamentals, and only applied the ‘Content’ perspective; the 2nd and 3rd modules focused on planning and project management, and considered all the perspectives of the authentic assessment.

As for the results obtained by the students, Figures 1, 2 and 3 give graphs that show the concentration of the students’ performance in the 1st, 2nd and 3rd modules, respectively, within the value scale of from 0 to 10.

It is worth pointing out that the target set by the course is an average of 7 for a direct pass, and an average of 5 for a pass subject to an evaluation of the cumulative content at the end of the course (final evaluation).

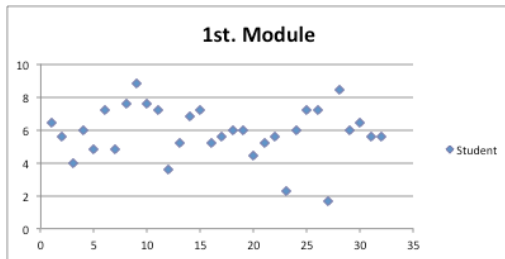


Fig. 2. Concentration of the students’ performance in the 1st module.

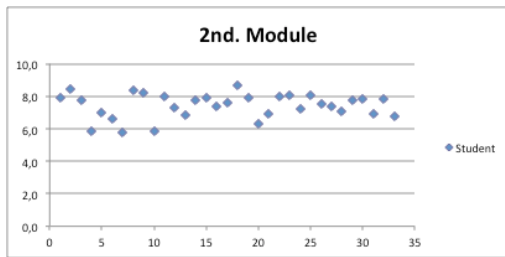


Fig. 3. Concentration of the students’ performance in the 2nd module.

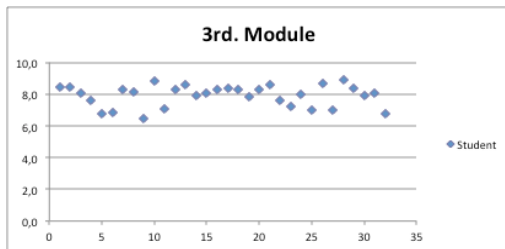


Fig. 4. Concentration of the students’ performance in the 3rd module.

Note that the results for the 1st module, reached solely by assessing the Content perspective, show performances with the highest concentration between the values of 5 to 6, unlike the results of the 2nd and 3rd modules, which have a concentration between 7 to 8 and 8 to 9, respectively.

Table III shows the types of assessment conducted within each module, and highlights the instrument used for the assessment: an objective test, based on the PMI (Project Management Institute) standards; the Meeting to start the

Project (Kickoff); the Project monitoring meeting or remote monitoring (Status Report).

TABLE III. TYPES OF ASSESSMENT PER MODULE.

Module	Individual Assessment (Summative)		Group Assessment (Formative)		
	Content	Performance	Process	Output	Client
1	1 st EV	-	-	-	-
2	2 nd EV	1 st EV	Kickoff 1 st SR	Kickoff 1 st SR	Kickoff 1 st SR
3	3 rd EV	2 nd EV	2 nd SR 3 rd SR	2 nd SR 3 rd SR	2 nd SR 3 rd SR

EV – Evaluation | SR – Status Report.

Some reasons for the results of the first module confirm the difficulties of the conventional assessment process, which is summative (a test comprising 20 to 25 questions based on a PMBOK overview) and focuses only on concepts and definitions, given individually without debate or discussion.

To develop the essentials skills that a project manager needs, the authentic assessment, recommended by xPBL methodology [3] was applied in accordance with the five perspectives:

1. *Content*, from objective evidence, aiming at concepts and foundations of the Project Management area, taught by the teacher;
2. *Process*, from assessments led by the teacher and tutors during Status Report meetings;
3. *Results*, from the deliveries made in accordance with the project planning during Status Report meetings, evaluated by the teacher and tutors;
4. *Performance*, based on assessing the 180 degree performance, where each student made a self-assessment and was rated by all members of his/her team, conducted by tutors;
5. *Client satisfaction*, based on the client’s evaluation of solutions during Status Report meetings.

To better understand the performance of the class in the 2nd and 3rd module (Figures 3 and 4, respectively), the following sections describe the performance of the teams within each of the five perspectives of the authentic assessment. To calculate the performance of each student per module, the following formula was used:

$20\% * AA(Content) + 20\% * AA(Process) + 20\% * AA(Output) + 20\% * AA(Performance) + 20\% * AA(Client\ satisfaction)$, where “AA” corresponds to the arithmetic mean of the scores related to each perspective, when there is more than one score.

1) Content perspective:

In the Content perspective, the evaluation was applied individually, based on the content and practices discussed on the course, the main reference being PMBOK version 5, and at sessions led by invited speakers on agile management approaches SCRUM [15] and KANBAN [11]. In this perspective, there were two tests of content, both objective ones, with about 20 to 25 questions: (1) Phases of Starting and Planning the project life cycle; (2) phases of Running, Controlling and Closing the project life cycle. These tests

were conducted at the end of the respective project phases and therefore were of a summative character. The value scale used followed the traditional model of from 0 to 10.

On calculating the overall average of the class, solely under the perspective of Content in the 1st and 2nd modules, we obtained a performance similar to that of the 1st module, the pass rate being about 57%. However, the chief gain from this evaluation was that the results of each objective test enabled to identify the points of most critical difficulty, and thus to work on the content in class with a view to clearing up doubts and mistakes identified in the tests.

Some other matters can be considered regarding the students' difficulty with learning theory and concepts. Unfortunately, for many students, the study habit of reading intensively about concepts and fundamentals has become a rare practice. They are connected to social media based on rapid and short answers. Despite complementary literature being recommended such as presentations, articles and podcasts, the result of the Content evaluations showed that the students did not read the content proposed, even though this is essential for a course based on a reference guide to items of knowledge. Some of the reasons that the students alleged were the competitive demands from other courses of similar complexity and public holidays associated with the World Cup which was held in Brazil in 2014. The tutors recorded these considerations which will be considered when planning future courses. These should include new initiatives to encourage reading, such as debates and discussion sessions.

2) Process perspective:

In the perspective of 'Process', the teams were evaluated by the teacher and the technical tutor who monitored the projects during four meetings: one Kickoff and three Status Report (SR) meetings. At the SR meetings, each team always answered five questions: "What is the objective of your project?"; "What's the plan?"; "What has been done?"; "What are the strengths?"; and "What are the points of improvement?". As criteria for evaluation in this perspective, the following were defined: (1) Clarity in presentation; (2) mastery of the presentation; (3) Completeness when considering the five questions; (4) understanding of Planning. Each indicator could take on one value from a simple scale of five values: "1 - Insufficient; 2 - Regular; 3 - Good; 4 - Very Good; 5 - Excellent". The graph in Figure 5 shows the teams' performance throughout the project.

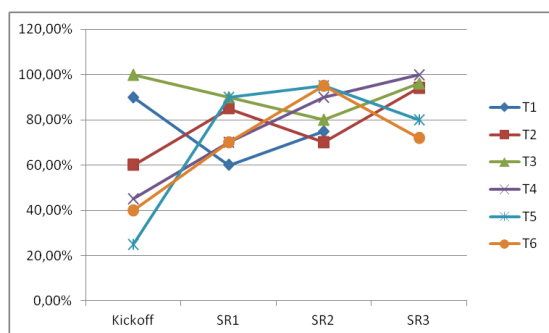


Fig. 5. Evolution of the perspective of Process.

On analyzing the graph in Figure 5, we see that the performance of most of the teams improved throughout the stages of the life cycle of the project, except team T1 team, whose project manager left the team at the end of the course.

Turning to the performance of teams T2, T3 and T4, we moreover see a significant improvement between the 1st monitoring (Kickoff) meeting and the final delivery in Status Report 3. Another interesting behavior observed in this chart was the natural "relaxation" of the teams that obtain excellent performances. It is common for teams to concentrate on other priorities when they see that the challenges were met in full at that moment, and thus this has an impact on future activities and hence their performance in the following reviews.

3) Output Perspective:

As to the perspective of Output (Figure 6), this was focused on analysis of the content of the presentations of the projects in the monitoring meetings. These analyses were conducted under the following criteria: (1) Overview of the project; (2) Planning activities; (3) Carrying out activities; (4) Strengths; (5) Points for improvement. Once again, the same simple scale of five values was used. These evaluations were conducted by the teacher and technical tutor.

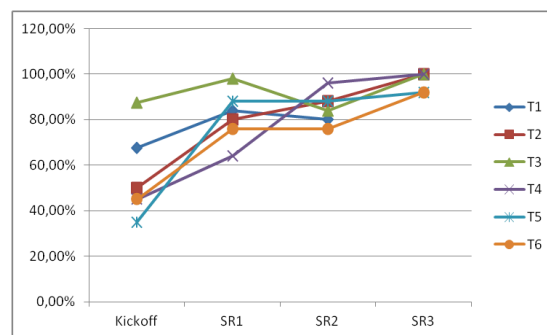


Fig. 6. Evolution of the perspective of Output.

The graph in Figure 6 also shows an upward trend but with slighter variations, thereby proving that, although students have relaxed with the process of planning and monitoring of the project after achieving excellent performances, these continued to be focused on the delivery of results, probably due to the culture of traditional teaching approaches, usually based on delivery artifacts. In addition, teams T2, T3 and T4 continued to stand out.

4) Performance Perspective:

In the perspective of Performance, eight competences were assessed: self-initiative, commitment, collaboration, innovation, communication, learning, planning and analysis. Due to the subjectivity of this analysis, this perspective used a scale of five values, with the following meanings: (1) "did not meet expectations"; (2) "partially met them"; (3) "met them"; (4) "met them very well"; (5) "exceeded expectations". This review was conducted by the PBL tutor and applied in the self-assessment format and evaluation in pairs (known as the 180 degree evaluation), where each member of a team was rated by his/her colleagues, anonymously. Since this was

undertaken by means of an online research tool, sophisticated individual reports could be obtained for each student, which showed the results of the assessment of colleagues in his/her team and his/her own assessment in a consolidated and graphic way, for each assessment criterion, including subjective comments.

On analyzing Table IV, it can be seen that teams T2, T3 and T6 stand out with respect to the performance of their members, in the eight perspectives mapped, as well as the performance of their PMs. On comparing with the perspectives of Process and Output, we see that there is a direct relationship between the best results of Performance of the Project Manager and the teams that stand out in these perspectives show the PM's influence on the conduct of the process of management and deliverables of the project.

TABLE IV. EVALUATIONS IN THE PERSPECTIVE OF PERFORMANCE.

Criteria	T1	T2	T3	T4	T5	T6
SELF-INITIATIVE	3,6 / 3,4	3,7 / 4,1	3,9 / 4,1	3,4 / 3,7	3,6 / 3,4	4,3 / 4,4
COMMITMENT	3,8 / 3,6	3,9 / 3,9	4,2 / 4,2	3,7 / 3,6	3,6 / 3,4	4,5 / 4,6
COLLABORATION	3,7 / 3,6	3,6 / 4	4,1 / 4,4	3,6 / 4	3,9 / 3,6	4,5 / 4,8
INNOVATION	3,3 / 3,3	3,8 / 3,8	4 / 4,2	3,2 / 3,8	3,2 / 3,5	4,3 / 4,5
COMMUNICATION	3,6 / 3,6	3,9 / 4,2	4 / 4,2	3,6 / 3,6	3,5 / 3,7	4,2 / 4,5
LEARNING	3,6 / 3,3	3,9 / 4	4,1 / 4,2	3 / 3,6	3,3 / 3,2	4,3 / 4,5
PLANNING	3,6 / 3,4	3,7 / 4,1	4 / 4,2	3,2 / 3,6	3,7 / 3,4	4,3 / 4,6
ANALYSIS	3,6 / 3,5	3,6 / 4	4 / 4,2	3,4 / 3,6	3,6 / 3,2	4,4 / 4,5
General average of the teams:	3,5	3,8 / 4	4,0 / 4,2	3,4 / 3,7	3,6 / 3,4	4,4 / 4,6
Average of the PM:	3 / 1,5	4 / 4,3	4,3 / 4,3	3,6 / 3,8	3,4 / 4	4,2 / 4,5

It is worth pointing out some important points about teams T1 and T6. The first was strongly impacted by the PM abandoning the project at the 3rd Status Report meeting (final delivery) after his performance had been rated by his team as unsatisfactory in the 2nd evaluation of performance. This result shows the importance of evaluation in pairs to give evidence of the performance of everyone in the team. The second point arose from the team which had high maturity in Performance but a poor performance in content. This impacted the performance of the perspectives of Process, which in this case was associated with planning and monitoring the project, which requires an understanding of PMBOK techniques.

5) Client Perspective:

Finally, the evaluation of client satisfaction was based on the following criteria: projection of confidence in interviews; understanding of the problems; clarity of presentation; quality of the solutions proposed; level of planning. This assessment used the same value scale as the perspectives of Process and Output, and was conducted by the teacher and the PBL tutors together, the client of the solution being present in the monitoring meetings (Status Report). Figure 7 shows the

results of the teams in this perspective. Looking at the graph in Figure 7, we see a direct relationship with the teams' performance in the perspective of Output.

It is worth mentioning, that the involvement of the real customer in the evaluation process is crucial to the PBL approach, given that the stakeholder who will benefit from the solution cannot be left aside. This was one of the points that the teacher most worked on after the kickoff of the project: namely, the need to bring the customer to the center of the project, keeping him/her continuously close to the processes and validating each stage of the project with him. This reinforcement led to greater performances throughout the project in this perspective as shown in Figure 7.

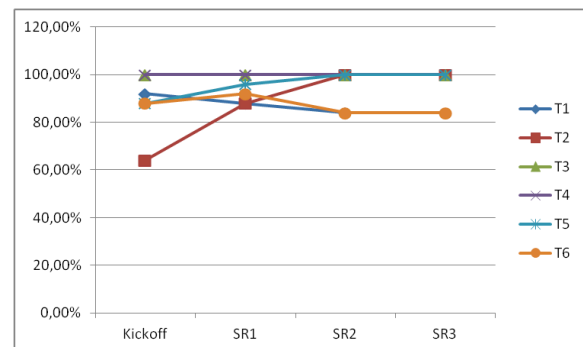


Fig. 7. Evolution of the perspective of Client Satisfaction.

B. PBL Evaluation

To evaluate the degree of PBL maturity in the course, in accordance with the proposal described in [9], the PBL-Test was applied at the end of the 2nd module. The objective of this application was to check for possible deviations from PBL and fix them in time for the 3rd module. The PBL-Test was taken by 28 students, which was therefore a representative total of more than 80% of the class. Table V shows the results of the evaluations.

TABLE V. RESULTS OF THE PBL-TEST.

PBL Principles Evaluated	Average
1. Problem (s) is at the core of the educational proposal.	0.88
2. Learner is the owner of the problem.	0.79
3. Authenticity of the problem or task is evident.	0.93
4. Authenticity of the learning environment is evident.	0.77
5. Solving the problem drives the process.	0.91
6. Complexity of the problem or task reflects the reality of the market.	0.93
7. Evaluation and analysis of how the problem was resolved follows the methodology	0.79
8. Reflexion on the content learned and the learning process is regularly and continuously made.	0.93
9. Collaborative and multidirectional learning takes place continuously.	0.96
10. Continuous Assessment takes place.	0.98
Overall Average:	8.7

In accordance with the proposal of the PBL-Test, each principle evaluated can receive a maximum value of 1.0, so the

total assessment can reach a maximum of 10 points. In [9], the authors define a maturity scale for PBL: *Level 0 - Insufficient* (overall average <7); *Level 1 - Initial* (<= 7 overall average <8); *Level 2 - Satisfactory* (<= 8 overall average > 9); *Level 3 - Good* (<= 9 overall average > 10); *Level 4 - Excellent* (overall average = 10).

From the results of Table V, we found that the PBL maturity reached level 2 in the overall average, representing the satisfactory level. Note that Principles 3, 5, 6, 8, 9 and 10 were very close to the maximum value. It is noteworthy that with regard to the Principles of lower values, little could be exploited by the teacher and tutors because these Principles related to the students' profiles and the limitations of the academic environment. As adopted action, we draw special attention to face-to-face feedback given by the teacher and technical tutors at the end of each monitoring meeting. The objective was to explore the reflection as to the solutions that the teams had adopted.

C. Final Assessment of the course

Finally, at the end of the course, a final assessment with the class was conducted in order to evaluate two aspects: the teacher's performance and the planning of the discipline. We adopted the same value scale as that for the perspectives of Process and Results. In this evaluation, 17 responses were received, representing a little more than 50% of the class.

Regarding the aspect of the Course itself, the following criteria and respective results were considered: Approach of the topic (4.2); Bibliography provided (3.8); Presentation of the Objectives (4.3); Achievement of Objectives (4.1); Contribution to the curriculum (4.2); Contribution to the training of the student (4.5); Development of critical capacity (4.3); General evaluation of the course (4.5). As to the aspect of Teacher, the following criteria and results were obtained: Presentation of ideas (4.3); Coherence of content (4.4); Mastery of Content (4.6); Relationship between theory and practice (4.4); Incentive to students (4.4); Method of Evaluation (4.0); Empathy and ethics (4.7); Teaching methodology (4.4). As a strength, the practical approach of the course which focused on real problems stood out. As points for improvement, the following matters were raised: evaluation centered only on content in the 1st module; extensive content and lack of revision sessions before the tests on content. Both in the evaluation of the course and of the teacher, the results of this evaluation showed that the students considered the course worthwhile, most results being between "Very Good" and "Excellent".

V. CONCLUSIONS

The NEXT group has been working with PBL in teaching software engineering for more than seven years. Given the many challenges of the first PBL applications in a professional master's degree of the area [2], the group's constant concern was to systematize the approach in methodological elements that improve how they are understood and adopted, while being supported by management processes and techniques. Throughout this period, and after the processes had undergone several cycles of evolution, xPBL was applied in a complete PBL cycle (planning, implementation, evaluation and

improvement) in the context of this article, unlike the case study reported in [1], in which the xPBL is formally presented.

It is also pointed out that it is the evaluation procedures that enabled us to prove our objectives were reached. Based on the five perspectives of authentic assessment, the performance of the students could be evaluated in different aspects in the PGP course. The evaluations of Content enabled the concepts and fundamentals which the students had greatest difficulties with to be identified. The Perspectives of Process, Result and Customer Satisfaction allowed the teams to be analyzed, thereby identifying the groups with greatest maturity in the process of planning and project management. The evaluation of performance allowed an individual look under interpersonal skills that, in general, are developed in PBL-based teaching approaches and, to some extent, led to collaboration between members of the same team being perceived. The evaluation of the PBL-Test allowed us to check throughout if we were really heading in the right direction. Finally, the final evaluation showed the students were satisfied with this discipline.

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Managing First PBL Experiences: Cross Competences in a Traditional Environment

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Abstract— When first introducing PBL into a traditional teaching environment, several problems tend to arise. Not changing the structure means that first PBL experiences can only be carried out by a small group of instructors. The use of technology, teamwork methods, and the sharing of individual experiences resulted in some techniques and ideas to introduce PBL successfully in our actual curriculum. This paper presents an experience using this form of active learning in a subject belonging to our Mechanical Engineering degree, which combines three essential aspects in training students: enabling them to be digitally competent according to the European Union considerations, designing and conducting active learning, and analyzing the students' motivation through their educational process. Although the experience was developed in traditional designed environments, ITs were used to ease the collaboration between students.

Keywords—Digital Competence; Problem Based Learning; Hypervideo; Motivation; Educational Innovation

I. INTRODUCTION

Higher education institutions should consider three key factors linked with today society's challenges: Firstly, the role that digital, audiovisual and communicative skills have in the education of future team-working, critical thinking, communicating and knowledge-building individuals. Secondly, the exponential reduction in costs to produce audiovisual contents caused by technological improvements during last decade. And finally, the introduction of active learning methods like Problem Based Learning (PBL) in opposition to traditional learning [1].

As a result of the technological changes occurred in recent years due to the massive use of social networks and Web 2.0 tools, the European guidelines suggested that students must assume an increasingly active role in the generation of knowledge and the exchange of digital contents during their daily communicative processes. This idea is linked to the concept of digital competence [2] and universities, as social and academic institutions should integrate these changes into their educational and communicative practices. Thus, real life learning processes must integrate digital competences.

Some researchers argue that technology can support the building of knowledge if students learn *with* technology rather

than *from* it. Learning *with* technology implies that students acquire knowledge when they are actively engaged in designing, creating and communicating technology-based products. When students learn *with* technology, they change from being learners to designers, and from knowledge users to knowledge builders [3].

In Europe, the Bologna process has been an opportunity to introduce active learning in higher education [4], but this idea is confronted against the difficulties of a change process: the changing of long-established learning processes requires great effort by academic staff and students [5]. In a first step, it is usual to find some interest in problem-based learning. This permits to introduce active learning methods like PBL into individual subjects, even when most of the academic staff simply rejects it. This results that in early stages active learning uses to be adopted with insufficient resources [6]. An important issue when implementing PBL individually is being able to facilitate each group, what usually leads also to adopt a *wandering* facilitation model [7]. This requires the facilitator to rotate between groups, adjusting the time spent with each of the groups according to their needs. In this case, communication processes can be supported and empowered by using digital technologies.

This paper presents a student-centered experience, which is linked to this approach in the adoption of PBL. Starting from challenges and problems, students provide solutions and teamwork creating knowledge. Students use different digital tools not only for searching and filtering information, but also create training materials and present their solutions and conclusions. Interactive audiovisual tools ease the exchange of information between the students and the teacher, and improve motivation and learning quality [8]. This contributes to the development of digital competences as it was established by the guidelines of the European Union [9].

This study is part of a wider study that evaluates the impact that the digital tools has on university teaching and students' motivation by using active learning methods.

II. COMMUNICATION AND CREATION OF KNOWLEDGE

A. Background

The European Union, the Council of Europe and the United Nations (UN) have all invested a great deal of effort in order to move towards an educational model that promotes students'

interactivity. This model should improve the students' critical thinking skills into a collaborative and participatory audiovisual context. It is necessary to go back to 2006 to find the European Union first publication of certain key competences regarding this purpose [10]. The Digital Competence was selected from eight key competences for lifelong learning, and was defined as *the creative, critical and confident use of ICT for the achievement of goals related to work, employability, learning, leisure, the inclusion and/or the participation in society*. The Digital Competence is also a cross competence that eases the acquisition of other competences (e.g. linguistic, mathematic, learning-to-learn, cultural and artistic skills) [2].

B. Digital Competences

The rise of social communities designed to promote the massive exchange of digital information, and the evolution of specific devices that facilitates this task, has created a new communicative scenario [11] where the interaction in the process of creating knowledge is essential, especially to future generations. These new generations will develop a great part of their social skills into these contexts, and will learn at the same time. For a decade, there has been talk of concepts aimed at a new typology of users of these communicative networks: the so-called digital natives [12], or the relatively old label, the NET Generation [13]. There is a clearly defined line where 1982 has marked a milestone in the "natural digital competence" of citizens.

Creating audiovisual contents without a specialized technical and human support was inconceivable just a decade ago. Nowadays, anyone who has access affordable technical resources (computers, mobile telephones, cameras, internet, etc.) is capable of generating audiovisual materials in an autonomous way and of disseminating immediately. This change into social communicative possibilities creates the necessity of audiovisual alphabetization for students. Educational institutions, should assume a more relevant role in this respect [14]. An important concept related to this is self-learning, which emphasizes the idea of students as builders of their own knowledge, based on the importance of their interests, concerns and existing knowledge to build new knowledge, which has been gradually incorporated as an alternative to the classic model of education [15]. This trend is a consequence of the consolidation of the main ideas of the constructivist theory of learning [16], whose fundamental premises were reflected in the Bologna Declaration in 1999. This declaration established an educational model that defines the European education and is based on three essential approaches: the importance of attention in the process of learning against teaching, lifelong learning against terminal learning, and the role of the teacher as a facilitator of competences against broadcaster of contents. In the educational context, interaction determines if the relationship between students, teachers and the environment [11, 17] is more or less active. According to the constructivist theory, it is considered that knowledge is acquired when a person interacts with an object –Piaget–, with other people –Vigotsky–, and when it is significant for the subject –Ausubel–. In short, a higher interaction of students increases their motivation, and therefore creates more significant, detailed and real-world learning [18].

In addition, the rise of the information and communication technologies (ICT), especially the audiovisual promoted educational actions that help students to generate critical thinking skills and not only a certain technical skill. For this reason, in recent years audiovisual alphabetization has been considered from different perspectives regarding several competences [2]: digital competence, informational competence and mediatic competence. Due to the terminological chaos found in literature, these concepts frequently overlap and merge. In this regard, Ferrari [2] tries to give a unifying view to the multiple approaches about competences in the universe of the audiovisual ICT, considering digital competence as a general container for the rest of sub-groups. Therefore, we assume that the concept of digital competence or digital alphabetization covers a great number of meanings and contents and thus, it is a multifaceted definition in constant metamorphosis.

C. The value of the audiovisual content

Nowadays, the tendency is to try to create an audiovisual story to express a specific personal idea, according to the author's intention and linked to creative, demonstrative, educational or informational purposes. This message is enriched with multi-channel, multi-modal and digital dialogue, which is fed by the multiple sender-receiver people who are part of the communicative circuit of the "global audiovisual conversation". In fact, if we observe some of the current participatory communication systems, like Facebook or Twitter, it is seen that all of the audiovisual publications are massive copies that come from an original source, which in many cases are anonymous (mostly disseminated without any selectivity or verification of the authenticity of the message by the users).

There is a need for digital alphabetization, not only in terms of learning techniques or controlling new devices that in most cases can be acquired "naturally", but also for the refinement of the notion of assimilation and creation of audiovisual messages by the new generations of students. One of the challenges of this experience is to provide university students with an expressive and analytic training so they are able to give their own vision.

As mentioned above, the so-called generation of "digital natives" [12] has brought a new communicative scenario in which new generations speak a new language while living –in the academic and familiar environment– with digital immigrants, that is, people who, although can integrate and adapt to the use of these technologies, continue to be "immigrants in a digital world", which differentiates them. This represents an important challenge in the area of education [12], since the current student body is not the same for whom higher education system was designed, nor most of the teacher body is adapted to current communicative languages, "fighting to teach a population who speak a completely new and different language than their own" [14].

Nowadays, communication technologies are progressing rapidly and due to their ubiquity, turn master classes [17] into an obsolete pedagogic practice. Students might wonder why they have to take a master class if the information given by the teacher can be obtained from somewhere else. Therefore, a

new figure of the university professor, closely related to the role of “guide”, facilitator of paths, adviser who provides students with information and awakens their curiosity, but always have in mind their learning interests, existing knowledge, questions and searches. However, students tend to focus on the answer, so the challenge in using digital technologies requires make the students to concentrate in the research process.

Obviously, new training designs have progressively emerged focused on facilitating dynamics of collaborative learning and increasing interaction in classrooms. For example, the teacher, without losing academic rigor, ensures that he introduces the contents and information of his curriculum in an effective, intuitive and playful way. Thus, it is the student who demands the acquisition of knowledge in order to successfully completes certain participatory, autonomous and creative “research”.

In view of the above, it is clearly suggested that there is feedback for students: increase of interaction in the classroom and development of audiovisual, informational and digital languages, in such a way that they train in analysis and educational and communicative expression.

D. Hypervideo as a tool for generating knowledge.

All the didactic resources in video format (knowledge pills, video lessons, videoconference, etc.) have a common denominator: they provide a unidirectional message sent from a transmitting source to multiple recipients. The only difference is the use of distinct means: the spoken or written words change and are transmitted into the audiovisual file recorded with the latest generation digital techniques (HD image, inclusion of recent graphic resources, etc.).

However, from the perspective of audiovisual alphabetization and modern pedagogy, the challenge is different: “The person concerned needs to develop his or her mediatic competence interacting in a critical way with the messages produced by others, and being able to produce and disseminate own messages” [19]. In short, the idea is to transform the creation of contents for education, avoiding the concept of the teacher as the absolute protagonist of the resource, and enabling students to integrate as active actors in the generation of audiovisual contents. From a pedagogical perspective, the hierarchical and vertical structure of the teaching-learning process must be replaced with a model where students increase interaction with their peers and teachers. We find two key factors: on the one hand, the need for collaborative, participatory, digital expression in the new generations provided by the new communicative forms, which have been recognized by their pedagogical efficiency; and on the other hand, the technical potential for entering, cataloguing and recycling audiovisual materials created in the context of the teaching-learning process at universities, which facilitate a closer cooperation between teachers and students. The idea is also to promote audiovisuals through the inclusion of hypervideos during the playback of the original video, enriching the video with written information, web links, graphic files, as well as embedding other videos which begins playing at a specific moment in the original video. The authors refer to this product as hypervideo, a term coming from

hypertext, which allows us to navigate “through a file” by using specific hyperlinks that take the reader, in a customized way according to particular interests, thorough a multidirectional navigation by following the different links [20].

Therefore, the user, spectator or creator becomes the protagonist of the viewing process and decides how, in what order and which elements he or she wants to receive, consume or create. And this interactivity provides an added value that a simple playback of a conventional video in the classroom lacks. On a practical level, different ways of creating hypervideos could emerge. One proposal intends to group together all audiovisual works presented by a group of students into a hypervideo and, at the same time, unify all the groups’ hypervideos of a year into a single group hypervideo. From the pedagogical point of view, it allows the implementation of a number of didactic key factors to any teaching-learning process related to motivation, self-esteem, group identity, teamwork, etc.

III. NEXUS BETWEEN PBL AND TECHNOLOGIES

The use of technological tools is increasingly related to the learning environment. Problem-based learning requires smooth and efficient knowledge sharing in order to boost teamwork, mainly when working with the “wandering tutor model”. Indeed, digital tools facilitate collaboration, and provide access to knowledge, situations or elements that would otherwise be unreachable. This idea has already begun rising over a decade ago with the popularization of wireless devices [21]. Within this approach, the teacher has to propose a number of problems or unstructured challenges that act as threads of the educational process. Regardless of the taken approach –problems or projects– the use of the technological tool catalyzes the learning process, boosting and making easier the exchange of knowledge. This makes it possible to combine the development of critical, communicative and teamwork skills with the acquisition of digital skills. Many university classrooms are not equipped to perform comfortably teamwork, however, digital tools allow the use of this learning model even in this kind of awkward spaces (Fig. 1).



Fig. 1. Working with PBL methodology in a traditional environment.

IV. MANAGING PBL EXPERIENCE

A. Previous experiences

We decided to start our experiences with several randomly selected groups of students, belonging to the Marine Engineering degree at La Laguna University. We mixed different me-

thodologies, which allowed us to create customized active learning environments to suit our needs.

Three experiences were performed by the first semester of 2013-2014 course (the corresponding distribution of students and subjects can be appreciated on Table I). These implementations were different according to the subjects involved:

- For chemistry subjects (experiences 1 and 2 on Table I) there were partial implementations, affecting just one matter and a students' experimental group. The approach for this subject, detailed in Mora et al [22], was based on projects aimed to perform experiments at the laboratory. Students familiarized with the concepts needed to perform the final practice by using challenges where students had to research to find creative answers to several questions related to their subject.
- In the third experience a complete implementation was adopted, affecting all matters and every enrolled student. In this case, the approach was mainly problem-based, as students had to create their own material from problems stated along the course, although smaller projects were also developed. Some seminars were also included as a starting point was required for students to be able to address problems and projects.

In both cases, a collaborative work scheme was followed using every technology available for creating, editing and sharing contents. Lecturers who took part in these experiences adopted the role of the facilitators [23] as wandering tutors [7]. Instead of preparing their classes with theoretical contents for solving predetermined problems later, they generated series of open questions as well as complementary activities that served as a guide to students along the search for solutions to the problems stated. Performance was far more active than in a traditional class as an open approach was undertaken, solving issues, generating debates, revising the student's work, etc.

TABLE I. DISTRIBUTION OF STUDENTS ACCORDING TO SUBJECTS

Experience	Subject	Matter	Course	Semester	Total of students enrolled	Total of students involved
1	Applied Chemistry (morning shift)	Density	1st	1 st	156	9
2	Applied Chemistry (afternoon shift)	Viscosity	1st	1 st	42	7
3	Ship's automation & Control	All	3rd	1st	42	42

The organization required working groups with randomly assigned members, excepting the case of the first experience, where students set themselves up at their own free will. The distribution of working groups and technological tools used for the three experiences is shown on Table II. At the beginning, this kind of setup seemed quite chaotic, as students were not used to this sort of teamwork, especially in the third experience, given the number of students. After one week of work, this initial disorganization become 'order inside chaos': in spite

of certain informality inside the classroom, each student knew his responsibilities inside his working group, allowing a much more dynamic setup.

We had to reconsider the study programs for adaptation to our new needs, designing problems and/or projects, and elaborating a list of challenges, guiding questions, open questions, open issues, presentations, etc., which was associated to each matter to allow the acquisition of the needed knowledge and competences by the students themselves while being oriented by their facilitators. We also considered the setting up of the learning environment defining the infrastructure requirements and the technologies to be used mixed with any chosen methodologies, while choosing the appropriate group dynamics.

TABLE II. NUMBER OF WORKING GROUPS AND TECHNOLOGIES USED FOR EACH EXPERIENCE

Exp.	Subject	Total of groups	Setup	Devices used	Technologies used
1	Applied Chemistry (morning shift)	3	Voluntary	Smartphone/ tablets & netbooks	Augmented Reality, Google Drive, Prezzi, YouTube, Moodle
2	Applied Chemistry (afternoon shift)	2	Random	Smartphone/ tablets & netbooks	Augmented Reality, Google Drive, Prezzi, YouTube, Moodle
3	Ship's automation & Control	8	Random	Smartphone/ tablets & netbooks	Google Drive, Prezzi, YouTube, MindMeister, Moodle, Hangouts, Socrative

Following this approach, real acquired competences were fed back so all previous experiences improve the following ones. Into this loop-process, assessment plays a relevant role as it also may be used for determining if the process to achieve the required competences is adequate or not. This is precisely one of the most complex aspects while adopting this kind of methods, as the acquisition of competences cannot be measured just using a theoretical written exam. Anyway, we opine that assessing requires considering both collaborative work and individual competences.

In experiences 1 and 2, the assessment method was not re-designed, since they were limited to a specific matter inside the subject, meanwhile the students were graded following the same criteria as the rest. In the specific case of experience number 3 required the design of a specific rubric which combining an individual exam with those mentioned competences.

It should be outlined that after the learning environment has been designed and started, facilitators' main task is giving support to the students and assess them continuously by using the appropriate tools.

From a teaching point of view, the experience was quite motivating as students become able to handle concepts by themselves applying knowledge otherwise unthinkable, and also completing a real challenge by lecturers involved in the experience.

B. Objectives

This experience attempts to increase the motivation of students while participating and collaborating by using ICTs, specifically those tools for creating audiovisual contents, va-

luing the students' effort during the learning process and the acquisition of competences:

- Working with Problem Based Learning (PBL) in a traditional classroom, where students solve problems and projects proposed by the teacher working in groups, by using a several ICTs.
- Generating knowledge on the basis of the work developed by the group.
- Developing digital competences by using of multiple web tools to generate data, reports, presentations, communications, meetings, etc., and creating at the end of the experience an introductory hypervideo that explains all the work developed in the subject during the four-months period.

Measuring the motivation of students during the learning process permits checking the success of the experience.

C. Description of the experience

The experience was carried out with fifty-five students enrolled in the subject Technical Office/Projects of the mechanical engineering degree of the University of La Laguna. This subject aims to provide students with skills to develop engineering projects and documents. The learning objectives of the subject are: familiarizing with the professional attributions and types of works of an engineer of this specialty, as well as the structure that the engineering projects should have. Most of the contents refer to the technical regulations that affect the different engineering projects and professional case studies.

Before the beginning of the semester of the subject it was planned the learning strategy. The subject consists of twelve topics. The instructor prepared several learning guides according to PBL.

Each learning guide included one or more topics (in case of topics with complementary aspects). The guide listed the learning objectives that students had to achieve and proposed a series of guiding questions and activities:

- A main question aimed to create discussions and thinking about the topic.
- Several specific questions, challenges or problems to guide the students through their learning process.
- An activity consisting in preparing digital shared contents like diagrams, graphics, presentations or even videos summarizing what they learnt.

D. Description of the process

The teacher introduces the learning guide for fifteen minutes. After this, provides learning contents concerning the topic for consultation, study and research. Students have Wi-Fi network in the classroom and can use tablets, smartphones and laptops to work. All students can have access to Google applications (chat, Hangouts, Drive, Docs, Calendar, YouTube), and several educational web apps that to ease collaborative work.

Students work by teams of five. One of the members of the group acts the "management" or coordinator, and has to assign tasks to each member during an initial meeting. All tasks are carried out in the classroom and, when it is required online by using videoconference tools like Google Hangouts or Trello (<https://trello.com/>) and even WhatsApp. A shared folder in Google Drive is shared for each team to keep information and using collaborative documents. During the class, the teacher/facilitator facilitates from group to group and helps students to search for information and also answers questions that arise during the learning process.

Each team prepares their final task during a last meeting in which discussing and sharing what they learnt. Students have also to check if all members achieved the proposed learning objectives. After that, in the classroom and with the supervision of the teacher, students prepare together a document to present the topic. This document is created by using free available apps on the Internet from their laptops or mobile devices. This document can consist in a poster, a presentation, animation, computer graphics, or video. The teacher proposed the students to use tools like Piktochart, Prezi, PowerPoint, PowToon, Screencast-o-matic, YouTube, Dipity, Pixton, among others. Depending on the topic, a different type of presentation was the most appropriate. Students developed digital competences and also communication skills by creating and presenting information.

Each document was shared to the rest of the students via Moodle. Individually, the teacher asked each student to present a brief report describing his or her. The team manager also had to present the minutes of the first and last meetings and make it available to the teacher using shared folder into Google Docs.

At the end of each topic, the teacher carries out a questionnaire through the online tool *Kahoot.it* to ensure that students have reached their learning objectives. Thus, the teacher is able to provide feedback to the students in real time.

As a final project at the end of the subject, each group presented a hypervideo to explain all their work and what they learnt during the whole course. The video uses links to the contents created in order to obtain an interactive video where users can navigate in a multidirectional way.

The hypervideo was created using Popcorn Maker (<https://popcorn.webmaker.org/es/editor/>), a tool from the Mozilla's WebMaker project (<https://webmaker.org/es/>), which allows to create a hypervideo by combining video, audio and images, and embedded websites, among other many possibilities. In addition, the existing hypervideos can be edited to create derivate videos easily (Fig. 2).

V. RESULTS

At the beginning of the experience, the teacher observed that students were not used to work in groups sharing tasks and discussing topics, so it was necessary to give indications on good practices and teamwork practices. It was also necessary to assist on the part of the teacher at technical tasks related to file sharing (Google Drive). After the third week, students were already familiarized with the working method and the teacher could focus on guiding the learning process by

advising on the information they found and how to organize it. All the work shows that students were able to learn all the necessary information for each of the subject's topics. The computer graphics, presentations, videos and other created files have allowed students to acquire the ability to synthesize a large amount of data learned through efficient presentations that organize the information and effectively structure the contents to remember them.

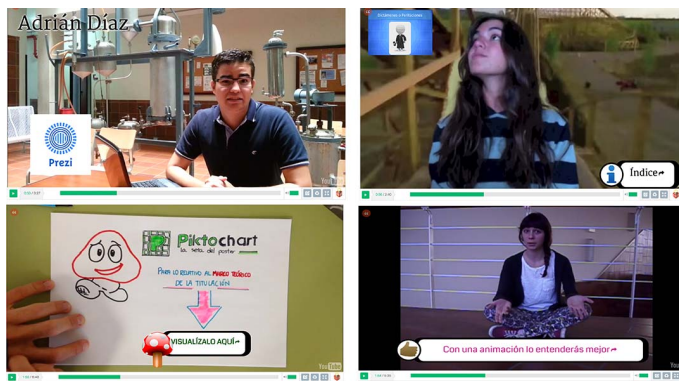


Fig. 2. Capture image of hipevideo created by students. Visualize hipevideos and other documents:
<http://www.powtoon.com/p/eMdSXs5EHqc/>
<https://prezi.com/gblwtcdcfqce/proyectos-industriales/>
<https://carlosmanuelmr.makes.org/popcorn/22ap>
https://jenny_ire_atte.makes.org/popcorn/2179
<https://grupo2otull.makes.org/popcorn/21tz>
<https://grupo1oftec.makes.org/popcorn/22oi>
<https://alu0100610765.makes.org/popcorn/210p>
<https://polplein.makes.org/popcorn/218f>

To measure the students' motivation regarding the active learning model used, we used the questionnaire associated to the MUSIC model [24, 25]. This model of academic motivation consists of five components that the academic staff should consider when designing instruction: eMpowerment, Usefulness, Success, Interest, and Caring [26]. The definitions for each of these constructs are provided in Table III.

The questionnaire consists of 26 items that provide quantitative data that students must rate using a 1-6 Likert scale to give their opinion (1 Strongly disagree-6 Strongly Agree). The instructions to administrate MUSIC, inventory items, and key to use them are provided in the User Guide for Assessing the MUSIC Model Components its authors [27].

TABLE III. THE MUSIC INVENTORY CONSTRUCTS AND THEIR DEFINITIONS TABLE STYLES

Constructs	The degree to which a student believes that:
Empowerment	he or she has control of his or her learning environment in the course
Usefulness	the coursework is useful to his or her future
Success	he or she can succeed at the coursework
Interest (situational)	the instructional methods and coursework are interesting or enjoyable
Caring (academic and personal)	the instructor cares about whether the student succeeds in the coursework and cares about the student's well-being

A. Quantitative aspects

Alpha Cronbach (Table IV) rates from 0.74 to 0.89 indicate good consistency of results and they are considered statistically reliable, despite being a small sample (n=43).

The mean values (all are about 5) indicate that students reported high values for the MUSIC model components. These results provide evidence that most students were, on average, motivated while attending the subject. Standard error values obtained in all cases ($se \approx .10$, $p = .05$) imply that student responses have tended to cluster around the average, which corresponds with the idea that their perceived motivation tends to be uniform. In this regard, the subject based on PBL has apparently succeeded at motivating students. We affirm this because the MUSIC model components have served before to predict students' motivation in higher education courses [24].

TABLE IV. CRONBACH ALPHAS, MEANS, STANDARD DEVIATIONS, AND STANDARD ERROR FOR EACH MUSIC MODEL COMPONENT

MUSIC- Model component	α	Mean (Std. Dev.)	Std. Error
eMpowerment	.84	4.95 (0.68)	.10
Usefulness	.89	5.23 (0.64)	.09
Success	.74	5.05 (0.53)	.08
Interest	.85	4.92 (0.70)	.11
Caring	.77	5.38 (0.53)	.08

The distribution of student responses is showed in the box plots, where the behavior of the medians of each of the measured components (Fig.4) is shown. This diagram shows that 50% of students rated with 5 or more all components of the MUSIC model. The lower limit which encompasses 75% of students is above 4.6 in the sense of empowerment, success and interest, and above 5 for the perceived usefulness and care. Only maximum of 3 students has rated abnormally low the different components compared with the rest of students.

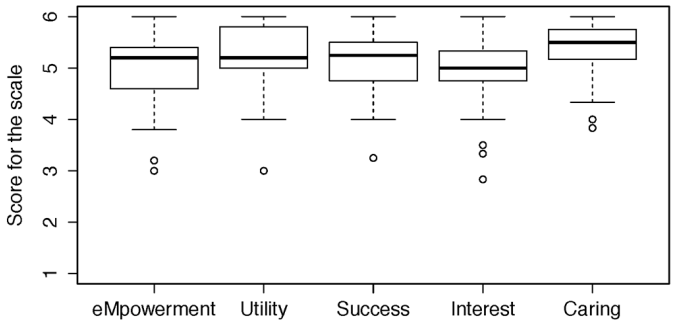


Fig. 3. Box plot. Values for median

The adopted strategy by combining the active learning with intensive use of digital tools has not discouraged students. Although it is not possible to state objectively, in the absence of a preliminary analysis, that it has been the trigger for increased motivation, its effect has been positive as the impressions of teachers. It is possible to affirm from the data that the level of student motivation is high at the end of the course, especially with regard to the feeling of usefulness of learning,

and a sense of satisfaction with the care and attention given by the teacher.

B. Qualitative aspects

The teacher has noted a more pleasant working environment in the classroom compared to the one in traditional methodologies. Students participated in class, and answered correctly the given questions without feeling intimidated. As the course progresses, students tend to work in a more autonomously and require less teacher assistance. Nowadays, the active learning method allows the teacher to have a closer attitude and students see him as a facilitator of learning.

From the analysis of student responses to the open questions given, it has been observed:

- The student feels comfortable working among peers, with his classmates and assigning tasks: "...when you work individually and don't know something, you stay in doubt. But in group, you have the peer support so close".
- The student listens to his or her classmates and learns from them by giving opinions: "...whenever someone did not understand something, we tried to explain among all".
- Students have learnt to discuss and to create the necessary information to obtain knowledge: "...each person brings to the group information that maybe others have not understood or assimilated".
- Students felt comfortable with digital tools to create documents and show information: "Nowadays the use of technology is commonplace and are fun, easy and quick tools for us".
- Students felt free to use smartphones and tablets in the classroom as work tools: "...the technologies are not a *taboo* but a learning method".
- Students and groups shared with each other information and designed ideas using creative tasks: "We used to have small meetings and present our ideas to agree on the different responses to the work".

VI. CONCLUSION

The ability to motivate students is important to achieve the teaching purpose: training students as best as possible. Even if the infrastructure of the classroom is not particularly suited to active learning, fluency in communication achieved with the use of digital tools to facilitate the process. However, digital tools should not be seen as final purpose themselves but as a mean to facilitate communication and creation within learning process.

On the one hand, students have developed their own contents to study the subject using digital tools transversally and transparently. On the other hand, problem-based learning has enabled them to work together so that the final product was not merely a sum of contributions, but the result of work planning, individual effort and an exchange of ideas providing solutions to the challenges and problems proposed.

Students take this combination naturally and, although they needed an initial impulse, they ended up using digital tools transparently embedded in problem-based learning. Despite the initial difficulties, they do not discourage along the course, and maintain a high sense of usefulness of what they learn, feeling supported by teachers.

This type of learning environments allows introducing active learning and working digital skills transparently to the students and teachers. Although it is not the ideal model of active learning, as it is linked to specific subjects and it is not structured along the entire curriculum, it introduces problems based learning into traditional classrooms, and serves as starting point.

Such actions fit with the recommendations of the European Union and the Bologna framework, and are flexible enough to focus the learning process on the students. We hope that the description of this experience will help other teachers and educational consultants to carry out their own educational strategies, and successfully introduce active learning into traditional higher education classrooms.

ACKNOWLEDGMENT

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Being a PBL Teacher in Computer Engineering: An Interpretative Phenomenological Analysis

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Abstract—Problem-based learning (PBL) is a well-known active learning approach, and it is becoming increasingly popular in computing. The Computer Engineering undergraduate program at UEFS adopts PBL since 2003. Previous studies thoroughly describe PBL course design and practices, but there is a lack of reports about the teaching experience, i.e., how faculty live the process of teaching PBL courses. Thus, we took advantage of this PBL experience to uncover such issues. We developed an interpretative phenomenological analysis (IPA) to learn the essences of being a PBL teacher, using a qualitative research methodology. Data collection and analysis entailed semi-structured interviews with five UEFS computer engineering professors, interview transcription and memo writing, open coding, code memo writing, code grouping and abstraction, and description of essences. Results led to the following essences: 1) feedback is essential for student success; 2) PBL develops better students and professionals; 3) assessment is complex and multifaceted; 4) developing good problems is a difficult skill; 5) PBL requires strong teacher engagement and background; 6) it is essential to keep a motivating scenario; and 7) good coordination and group dynamics is required. In this paper, we describe the four first essences in detail.

Keywords—PBL, problem-based learning, teaching, essence, interpretative phenomenological analysis.

I. INTRODUCTION

Problem-based learning (PBL) is a student-centered, active learning approach envisioned by physician Howard Barrows, between the 1960s and 1970s [1]. Briefly, PBL is an instructional method that uses a hypothetical case, i.e., problem, to start, guide and motivate learning. In PBL, students are constantly stimulated to learn and take an active role in their learning construction process [2]. The problem is a central element of the approach, motivating study and integrating knowledge. Problems are usually ill-defined: instead of finding one unique correct solution, students understand the problem, retrieve information, build possible solutions, evaluate options, and present results.

Nowadays, problem-based learning (PBL) is an increasingly popular learning approach, adopted not only in medical education, but also in areas such as nursery, engineering, and science [3]. In computing, PBL experience reports have been thoroughly described both in isolated courses and in integrated curricula [4].

Previous studies in computing education thoroughly describe PBL course design and practices on a range of subjects [4], [5]. However, there is a lack of reports delving into the teaching experience. We are especially concerned with a lack of knowledge on teachers' feelings and impressions of the PBL experience, i.e., how they understand, live, and feel the process of teaching PBL courses. Thus, we decided to take advantage of the eleven-year PBL teaching experience in our Computer Engineering program at the State University of Feira de Santana (UEFS) to uncover these issues.

To understand feelings and impressions, the research method of phenomenological interpretative analysis (IPA) analyzes how life experiences make sense to people who live them. In our case, we are particularly interested in the meanings that faculty realize when they live the everyday flow of experience with PBL. Building on this research approach, we decided to investigate how faculty members of Computer Engineering at UEFS live the PBL approach in their everyday lives.

More generally, we developed an interpretative phenomenological analysis (IPA) of what it means to be a teacher in a computer engineering program that is strongly based on a PBL approach. To do so, we used a qualitative research methodology based on a contemporary IPA approach [6]. IPA is useful in this context, since it helps to understand the inter-subjective experience of a small group, reducing their multiple accounts into the essences of the phenomenon. Data collection and analysis was based on Smith's IPA protocol [6].

Results led to the following seven essences: 1) feedback is essential for student success; 2) PBL develops better students and professionals; 3) assessment is complex and multifaceted; 4) developing good problems is a difficult skill; 5) PBL requires strong teacher engagement and background; 6) it is essential to keep a motivating scenario; and 7) good coordination and group dynamics is required. In this paper, for the lack of space needed to describe phenomenological accounts, which are usually deep and thorough, we describe only the four first essences from an IPA standpoint.

This paper is organized as such: Section II provides the background for this work. Section III describes the research methods. Then, Section IV presents our results. Conclusions are derived in Section V together with suggestions for future work.

II. BACKGROUND

Problem-based learning (PBL) is an active learning approach conceived between the 1960s and the 1970s in the Faculty of Medicine of McMaster University, Canada [1]. Idealized by the physician Howard Barrows, it has soon gained widespread adoption in other schools of Medicine around the world. Barrows realized the dissatisfaction of students with traditional lecture-based approaches, in a world driven by an explosion of information resources, new technologies, and growing demands on future physicians and their practices. Later, PBL spread to other educational contexts such as science in higher education [2] and elementary education [7].

In PBL, not only are students constantly encouraged to learn, but also to take an active role in the process of learning construction [2]. A problem in PBL is a trigger to motivate study. It usually follows a learning cycle, repeated for the duration of the problem [1], [2]:

- 1) Students are presented to an ill-defined problem before any preparation or study;
- 2) Students assemble in groups to organize ideas and recall previous knowledge related to the problem;
- 3) Through discussion, students pose questions, known as learning issues, that deal with aspects of the problem they do not understand;
- 4) Learning issues are ranked in order of importance, and students define learning goals for independent and group study;
- 5) Students reconvene to explore previous learning issues, and integrate new knowledge to the context of the problem.

PBL has been adopted in various computing courses throughout the world. A systematic mapping study has found 52 papers that report experiences of PBL in computing. Courses range from software engineering [8], computer programming, software quality [9], and operating systems [10], among other subjects.

In Brazil, the most well-known PBL experience in Computing has been pursued, since 2003, at the State University of Feira de Santana (UEFS). The Computer Engineering undergraduate program at UEFS adopts an integrated curriculum based on PBL [11], [12]. In this program, PBL is adopted in nine integrated courses with core subjects ranging from programming, digital systems and software engineering, to distributed systems, digital signal processing and programming language design [13]. A wide range of experience reports in courses as different as computer architecture [14] and advanced programming [15] have been published in Brazilian conferences on education in computing or engineering¹. Angelo and Bertoni have organized the results of experience reports in the various courses reports in a survey [13].

PBL is an integral part of the pedagogical project of Computer Engineering at UEFS. It is used in a curricular component named integrated study, which takes between 90 and 180 class hours and entails a mix of tutorial groups, lectures, resource meetings, and lab activities [13]. Different subjects are integrated under the integrated study. For instance,

the integrated study of advanced programming joins object-oriented programming, data structures and software design. This structure was implemented in 2003 to reinforce the interaction between theory and practice through a situation–foundation–realization cycle [11].

A tutorial group is formed by a tutor, usually an assistant professor or a teaching assistant that facilitates the learning process, and a group of up to ten students. Two students are initially assigned to work as coordinator and scribe. Sometimes, a whiteboard scribe is also assigned to take notes of group ideas and decisions. Roles are not static, there is usually role rotation between students so that everyone exercises different skills. After receiving the problem, students follow the previously described learning cycle [2], [12].

During the academic term, tutorial groups meet, usually once or twice a week, to perform the activities of a tutorial session. During this session, and following the PBL learning cycle, students read the problem, raise hypotheses and ideas to solve it, describe facts that they know, raise questions about what they do not know, and establish goals for independent study. In the following session, they reconvene to discuss what they have learned, and try to integrate the acquired knowledge to solve the problem. While there are issues still unsolved, students repeat the cycle. The tutor does not provide explanations about the subject. Instead, he or she guides students in their discussion throughout the problem. At UEFS, the PBL learning cycle is explicitly defined by eight steps: starting point, brainstorming, systematizing, question formulation, establishing learning goals, process evaluation, independent study, and follow-up [12].

Student assessment is carried out individually, taking into account both student participation and final product quality, i.e., whether the solution to the problem is appropriate according to established criteria. A final product is usually accompanied by a report. In some cases, after product assessment, tutors may discuss the pros and cons of each student's solution in a feedback session. Later, students return the revised report for a second round of assessment.

The way tutors assess students is continuous and process-based, usually resorting to various types of assessment instruments: diagnostic assessment, formative assessment, summative assessment, peer assessment and self-assessment [12], [13].

PBL has brought various benefits to Computer Engineering at UEFS: students mature both academically and professionally, they gain experience in managing teams, develop abilities of self-criticism, and learn writing and speaking skills [16].

Together with benefits, new challenges arise: the lack of resources dedicated to teachers of computing courses that adopt PBL; difficulties with student participation, especially free riders; difficulties with interpersonal relations between students; difficulties to ensure full participation of each tutor in problem design; and difficulties with administrative support to the PBL approach and curriculum [16]. Nonetheless, regardless of the challenges, most faculty of Computer Engineering at UEFS are enthusiastic advocates of the PBL approach.

¹See the *PBL at UEFS* web site: <http://www2.uefs.br/pbl/>

III. METHODOLOGY

Here we describe the theoretical framework we adopted, research design, participants, and procedures for data collection and analysis.

A. Theoretical framework

This research was developed by means of a qualitative research methodology, which is mostly exploratory in nature. Our goal here is to understand the meanings of lived phenomena in human experience. One qualitative research approach that allows reaching this goal is phenomenological research [6]. Phenomenology allows subjective aspects and implicit or even conscious motivations from individuals' everyday life to emerge in a spontaneous way.

The particular approach of interpretative phenomenological analysis (IPA) and its associated procedures [6] makes it simpler for researchers other than philosophers to reach the essences of a particular lived experience. IPA allows to understand the inter-subjective experience, i.e., how experience lived by some individuals is reduced from their multiple accounts into the essences of the phenomenon. IPA lets the everyday flow of experience lived by individuals be condensed into special meanings to them. In our case, we want to understand what it means to be a PBL teacher in a PBL-based curriculum.

B. Research design

More formally, the main goal of this study was to investigate the essences of the teaching experience for the faculty members of a Computer Engineering undergraduate program that adopts PBL as its main pedagogical approach.

The research questions that guided this study to reach the main goal were:

- 1) How do faculty understand the planning of PBL courses?
- 2) How do faculty perceive the assessment of PBL courses?
- 3) What is the view of faculty about preparing PBL problems/triggers?
- 4) How do faculty understand their conduction of a PBL tutorial group?
- 5) How do faculty provide feedback to students?
- 6) Which perceptions do faculty hold on the advantages and disadvantages of the PBL approach?
- 7) Which difficulties do faculty experience when they offer PBL courses?

C. Participants

The participants of this research were faculty members of the Computer Engineering undergraduate program at the State University of Feira de Santana (UEFS), located in Feira de Santana, Bahia, Brazil. There were five participants: three female, and two male. Participants had from two to eight years of experience with PBL, experience that begun when UEFS hired them. Most of them had previous experience with other traditional teaching approaches (e.g., lecture-lab combinations). Two of them came from the area of electronics, one from networks and systems, and two from software development.

We believe that this moment is appropriate for data collection, since the PBL approach has been used for eleven years in the institution, and it is now routine in faculty's lives. After this period, their feelings about the approach are more consolidated, making it more appropriate to collect information, and providing rich testimonials about their lived experiences.

We limited the number of participants by two criteria: first, we used Smith's IPA protocol of interviewing between five and seven individuals. Phenomenological research requires long and deep interviews, valuing more quality and depth than quantity and breadth; second, after each interview, we asked ourselves whether our questions were sufficiently answered. We ended up with five participants. It is worth noticing that we had two more participants that took part in pilot interviews, but their accounts are not described in the results.

Participants were informed about the purpose of the research, the assurance of confidentiality and anonymity, and their right to participate or not. After these explanations, they agreed to sign an informed consent form. Participants' speeches were identified with codes, starting with the letter R, and followed by sequential numbers from 1 to 5.

D. Procedures for data collection and analysis

We used semi-structured interviews. This choice was made because they are flexible, but still keep important topics in mind. With semi-structured interviews, participants can freely reflect on a theme, object or concept. They let subjective aspects and motivations, either implicit or explicit, emerge. Furthermore, they are also the main data source in interpretative phenomenological analyses.

We started with an interview guide, which was validated in two pilot interviews with two other faculty with PBL experience. Pilot interviews let researchers check whether interviews have: reliability, which is getting similar results, regardless of who interviews; validity, which is examining whether all the needed data is collected and no important data is left out during collection; and operability, which is verifying whether the vocabulary is accessible and the meaning of each question is clear. After the pilot interviews, we updated the interview guide to improve data collection in the next phase.

We scheduled interviews at UEFS, according to participants' choices of data, time and place. This let them at ease to answer the questions without external interference. Respondents answered questions freely in a time interval between 55 minutes and 1 hour and 20 minutes. We let respondents spontaneously express their thoughts and experiences, avoiding interrupting them or intervening in their speech.

The process of data collection, transcription, coding and analysis followed a mix of Smith's protocol and our own experience with qualitative research:

- 1) Perform interviews (ours lasted between 55min and 1h20min);
- 2) Write interview memos right after the end of each interview, to collect first impressions;
- 3) Transcribe interviews;
- 4) Code the interviews with open coding (which led to 440 initial codes, in our case);

- 5) Write code memos, to sketch an initial interpretation of lived experience;
- 6) Abstract codes in a second level, observing relationships between codes and participants' speeches, and group codes by their common features (at this stage, we found 170 categories);
- 7) Abstract the essences of lived experience (in our case, seven relevant themes);
- 8) Report the essences first as draft memos, then as rich accounts after thorough rewriting.

IV. RESULTS

Here we describe the essences of being a PBL teacher in Computer Engineering at UEFS, uncovered by interpretative phenomenological analysis. In short, the essences uncovered were:

- feedback is essential for student success;
- PBL develops better students and professionals;
- assessment is complex and multifaceted;
- developing good problems is a difficult skill;
- PBL requires strong teacher engagement and background;
- it is essential to keep a motivating scenario;
- good coordination and group dynamics is required.

In this section, we thoroughly describe the four first essences, using an IPA reporting approach [6]. We decided to report only four essences mainly for lack of space. The essences presented here were chosen because of their frequency in faculty's accounts. Qualitative research reports demand accounts that are thorough and deep, and it is sometimes better to report less results in deep than more superficial results [17]. It is worth noticing that the interviews were conducted in Portuguese, while accounts are described here in English.

A. Feedback is essential for student success

Feedback is an important tool in the teaching-learning process. Students accept feedback well, as this contributes to their knowledge acquisition. Teachers use some feedback forms, and the most used are: session feedback, performance feedback, report feedback, problem feedback, group feedback, and individual feedback. The timing for feedback is also crucial. Teachers can feel this timing by observing class evolution.

To Hattie and colleagues, effective feedback must answer three questions posed by teachers and students: *Where am I going?* (What are the goals?), *How am I doing?* (Is progress developing toward the goal?), and *Where should I go?* (What activities should be done to improve progress?) [18].

Feedback is an integral part of the teaching-learning process, which guides students to behave and perform according to given requirements, and lets them know how they are being seen and assessed by teachers. Lack of feedback leaves students lost, not knowing which way to follow. Feedback can be seen as a compass, giving the north to achieve the goals. *"I think that feedback is essential[...] for learning.*

The student that takes advantage of this feedback, he has a possibility to learn much more." R2; *"[...] at each session, it is necessary to give feedback and this is important so that they can evolve . [...] from feedback, the student can improve the weak points[...]"* R3; *"If there was no feedback, it is like the problem has not existed, like no knowledge has been produced here [...]"* R4; *"[...] the feedback, I think, is one of the most important things of any approach [...]"* R5; *"[...] read what you wrote, see if a person that reads this text for the first time knows what you're talking about, see if she can understand what you say, then I always bring this feedback [...]"* R1.

Performance feedback is aimed at reorienting or stimulating future behavior. It is also used to maximize the performance of an individual or a group. In the learning environment, feedback is very important because it motivates students to perform their tasks more productively. If a student gets faster feedback on something he or she is doing, accomplishments come earlier. The knowledge acquired by students needs to be consolidated somehow, and this is possible when the tutor situates students, showing where they are hitting or missing.

The feedback that teachers provide gives students a parameter of development. The sooner they are given feedback, suggestions or criticism, the easier students take them more constructively. Generally, students have a good acceptance of feedback provided by the teacher. *"[...]the reactions are varied, then, you know, I think, in general, they accept the feedback well. I keep putting myself in their place, I would accept well because I think everything we receive from criticism even being ... let's say negative, it is being part of our development. Then, in general, apparently yes, but I'm not sure..."* R5; *"I get this feedback from them, and then I later try to analyze what is not going well[...]"* R4.

A technique used by teachers is to hand out an assessment form to students. With the form in hand, students perform self-assessment. At the end of the session, the teacher collects the forms, compares them to the performance grade they had given the student, and provides feedback about it, especially when there are discrepancies.

For the teachers, conveying a correct and assertive feedback requires understanding the student who receives it, the way he or she interprets the message, and also adapting it to particular situations. To assist in this task, teachers use some ways to provide feedback: session, performance, report, problem, group, frequent, generic, individual and technical feedback. In any way, the truth is that feedback is essential for students to produce their results and remain motivated. When the teacher takes a stance of not providing feedback, he or she is depriving students of the opportunity to improve their performance. *"I have been in sessions where some tutors spend three or four sessions... Ask the students: and then? They say: I don't know. How is PBL? I don't know. Because they don't know, like, if it's going well, if it's going bad, if he's learning something, if he's not learning anything, because feedback is not given to them..."* R2.

At the end of each session, the teacher conveys students the issues to be improved. *"[...] session feedback, and then I always prefer doing it at the very end of each session [...] depending on the session, that I need to speak another ten minutes at the end of the session, to give that feedback [...]"*

in general, this session feedback, I try not point issues very individually, unless I can do that with everyone. And if I can't do it with everyone, then I prefer to speak more generally [...]" R1; "You give a negative feedback, in the next session they know what they need to improve, then you can give feedback in each session[...]" I have a feedback snapshot from each session, in each session I know what was his evolution, and then I take notes of his performance at the end of the session [...]" R3.

Session feedback enables students to realize, in time, which aspects they need to improve for better group dynamics. This is done gradually, in each session.

For performance feedback to work well, people involved in the process need to understand the real meaning of the feedback word, which is positive, an information that serves to evaluate paths and results. Feedback should always be rewarding, never punitive. Whenever punitive, it loses its educational condition and mischaracterizes its function. To apply feedback in its entirety, it is important to note the role of communication in the process, because it is through appropriate communication that feedback information flows. *"I have some students, this repeats almost every term, who kind of wait for this feedback, they like to know their performance, because they want to, they try to do something to improve, and they always want to know if I realized that they improved [...]" R1.*

Students look forward to receiving feedback: they want to know their learning progress, and which way to go. To make it work, though, it is important to be open to criticism and understand that criticism is focused on improvement, and that feedback is one of the most important steps of performance assessment. Thus, for those who receive feedback, it is important to learn to listen to criticism, as well as to reply to the teacher whenever something was not made clear or was not fully understood.

Reports are a form of assessment that the teacher uses to determine both the student's writing competence and his or her ownership of ideas in the problem solution. Right after correcting and grading reports, teachers give feedback. Students, then, learn from this feedback. *"I give feedback on the report, I prefer that they deliver me the printed report, because then I take notes, I sit with them, ask for their notes, discuss the notes with them, show the weak points, and the same thing for the presentation of the problem [...]" R3.*

When the teacher provides feedback, also provides students with a metric of their educational development. Reports are assessed for criteria such as text consistency and cohesion. This enables students to mature their writing.

Providing feedback as fast as possible is important in the teaching-learning process. Students need to have enough time to overcome the difficulties pointed out by teachers. *"[...] I tried, if I could not finish the grading, then I would tell them, but I would tell them in the next class, but I think you lose something, the best is when you can finish it in that class [...]" R5; "I give feedback at the end of the problem. When the problem ends, I give this feedback..." R2; "I do it as soon as possible, like, the student gave the final solution, at most one or two weeks after that, I give this feedback..." R4. "What I've been trying to do, and I do it until the end of the term, is: every session I do session feedback, and I always do it [...]" R1.*

It is important to reflect on what students should be told, and to provide concrete arguments when giving feedback. Finally, it is essential that the teacher create room for a frank dialogue and provide the appropriate feedback. That means establishing an environment of trust, discussing the issues, the pros and cons of the student's performance and products. Ideally, feedback should be given in each session, but this is not always possible, since it demands time. Some teachers give feedback at session beginning, which gives students the opportunity to see where they are missing and focus their efforts on their weak points. Some other teachers prefer to give feedback at the end of the problem or at the end of the term. This timing is useful for the teacher to have a broader view of the student's profile, to provide feedback with no influence of the student's behavior in a given session.

B. PBL develops better students and professionals

The PBL approach allows students to develop professional life skills. Skills of written and spoken expression, group management, independent work and learning how to learn: all of them develop a style of entrepreneurship strongly valued by the marketplace, easing the process of graduates adapting to professional life.

Some people develop capabilities of spoken and written expression easily, almost as a gift. Nevertheless, for most people, expression in an adequate professional manner is a constant exercise that involves factors such as role models, environmental stimuli, and, of course, practice. *"I clearly realize their resourcefulness to speak, to participate, this influences in class [...] students will also be more prepared to develop further research without forgetting that side, for example, of an oral presentation, got it?" R1.* When students take part in a PBL tutorial group, they develop their orality, diction, and cognitive abilities, skills considered relevant in a competitive market.

Student skills are stimulated with PBL dynamics. Students fulfill different roles such as coordinator, scribe or participant. Role changing allows fostering latent skills.

Nowadays, information is present in different forms and sources. In an environment of information overload, knowing how to search, interpret and transform information into knowledge is essential. PBL students search information to autonomously solve problems in various spheres. *"[...] I hear of the students who have already graduated, how much they are well regarded in the market for their ability to run after things [...]" R1; "[...] you realize that students... they learn to solve problems or they get better at solving problems [...]" R2; "One of the main advantages is the autonomy to solve problems, I think it shapes a lot the profile of the student who learns through PBL [...]" R4.*

Observing the development of those skills in PBL group sessions leave faculty satisfied and professionally accomplished. *"Look, I feel motivated because sometimes I am surprised by the ability that a student like this has, for example, when he faces an unknown problem, you know? So, sometimes you think the problem is going to be complex, is going to be difficult at first, but then, in the brainstorming of the first session, students already have some very interesting ideas ..." R2.*

Developing a clear, consistent and cohesive prose is a skill better accomplished by stimulating both reading and writing. In PBL, students are encouraged to write most of the time. They constantly write reports at the end of any problem. They deliver their reports to the teacher, who suggests corrections to their written text. Since there is continuous evaluation, students are able to develop or enhance their written expression along the PBL courses. “[...] first report, it may not do very well, but during the work that is being done, in the last one, his result is already better... I believe there is an evolution in the report writing process” R3; “Another interesting issue, I do not know if it is in our PBL here, or if it’s related to PBL in general, but the ability to write better...” R4; “[...] we ask for reports, it can be in the student report format, or in a paper format, so, besides the skills of speaking, clearing doubts, researching, learning on his own [...]” R5.

In tutorial sessions, students choose roles to fulfill (or have roles chosen by their tutors) in the group. The role might be of coordinator, scribe, whiteboard scribe, or simply a regular participant. Those roles also influence skill development. “they are encouraged, and in various forms, including grades, to participate in the discussions all the time, to position themselves” R1; “we can already identify students who have the leader profile ... you realize with the students that he has more of a leadership profile” R3; “exercises a bit of leadership, since he performs activities as the PBL coordinator” R4.

Learning through an approach that lets them experience some issues they will face in their future jobs helps students to develop skills required in the workplace. “[...] you can see students quietly advancing after they leave university and move to the workplace with no issues. [...]” R4.

Teachers feel that the professional accomplishment of most PBL students is a consequence of the approach. With PBL, students are constantly searching for solutions to the problems that teachers propose, which gives them a glimpse and a feeling of being in the workplace. “With regard to learning, and that I hear of students who have finished our program, how much they are well regarded in the marketplace for their ability to run after solutions [...]” R1; “[...] a student that will develop this resourcefulness, I think then he will be more prepared for the workplace[...]

R2. Developing a student’s potential depends on the teacher knowing the right moment to speak or to silence. This balance is usually linked to the teacher’s profile and his or her command of the PBL approach. “When I’m guiding the PBL session, I want to extract the maximum potential of each student” R4; “So the goal is that everyone tries to strive as much as possible in solving that problem” R4; “Sometimes he thinks he did nothing, but did something... Try to explore this knowledge to the maximum, so he produces.” R4.

C. Assessment is complex and multifaceted

Assessment is the process teachers use to better understand the level of competencies (knowledge, skills, and attitudes) acquired by students as well as to perceive the effectiveness of the teaching-learning methods and educational activities performed. Thus, the act of assessment, although complex, is essential. PBL teachers feel that, in the approach, assessment

is fair and thorough. On the other hand, it involves issues that make it difficult for the teacher.

Assessment in PBL is complex because it involves, among other factors, subjective issues. Each student is different, and those differences influence how he or she develops competencies. For such reasons, assessment has a high degree of complexity, and should be done carefully. “What? Assessing is easy? Assessing is so difficult [...] the PBL model is well defined, but the assessment, for being individualized, is a lot of work [...]” R1; “[...] assessment is complicated, it is not so trivial [...]” R4; “[...] the PBL approach, I believe it gives more work than the traditional teaching. If you do the PBL approach as it should be done, it demands more time, but it’s more pleasant, I see you’re really assessing the individual.” R3.

Assessment requires perceptions and sensibility from the teacher that go beyond the classroom. Subjectivity of the assessment makes it a complex task to accomplish. “It is not an easy task [...], because not everyone feels comfortable to be evaluated, [...] is not easy you get to them and say this: you didn’t reach the top. Oh, you didn’t research [...]” R3; “[...] sometimes the student begins very well, then he disappears, then another student gets well, and after a while he disappears as well, then both reappear, then, this way it’s very difficult[...]

R5. If the tutor participates in excess in the tutorial session, it complicates the assessment process, because one does not know whether the students were able to build knowledge or just superficially reproduced what was conveyed by the teacher. “As I told you, I have given PBL courses several times, and I don’t even feel the tutor I’d like to be, and sometimes I have a little trouble with the issue of assessment.” R1; “Excessive tutor intervention makes it difficult to assess.” R3.

Internal and external factors directly influence student learning. Thus, assessing is not a trivial process. Since assessment is a subjective act, every individual has his or her own way to see, feel, and think things out. Fully capturing those factors, making them concrete, and transferring them to objective criteria is a difficult task to accomplish. “[...] however much we try to monitor development, we can’t be sure that that student built that product alone [...]” R1; “[...] So this subjective assessment is hard, and it there has to be some mechanism to try to validate your thinking [...]” R4; “there’s the performance grade, that we try to give every session, but, of course [...], there is the issue of subjectivity ..., of your assessing student performance [...]” R5. “[...] it [assessment] is much more complete, [...] it is, say, a continuous evaluation, it is not a one-time assessment as in traditional approaches [...]” R2.

In an educational context, it is essential to stimulate students. One way to do so is building learning activities by means of challenges. The problem, a motivating element, is an essential tool in knowledge construction. We know that the student’s learning capacity depends on his or her maturity. However, it can be stimulated by means of challenges. “There are goals for every tutorial session, and they know they have to meet them to reach the evolution, the conclusion of the product, you follow the whole process.” R3.

Self-assessment is well regarded by students. It aims to

measure whether teacher assessment is balanced with students' perspectives. "[...] sometimes you can't do it in every session, but I try to assess and ask for self-assessment [...] for they realize from the start where they need to improve [...]" R3; "[...] I prepare a student assessment form, throughout the term this form is with me, and at the end of the sessions, I give my grade and ask them to self-assess [...]" R4.

Continuous assessment allows for a contextualized, flexible and interactive educational practice. The disadvantage of continuous assessment is its subjectivity. It's hard to turn the participation (or lack of) in a tutorial session into something tangible. However, students need to learn their strengths and weaknesses.

Assessment in PBL tends to be fairer than in a lecture-based approach. The fact that classes have fewer students positively influences assessment, because the teacher can monitor students more closely. "[...] I feel that it is an assessment a little more fair [...]" R1; "[...] so they do not discuss much when they see what they did, and if you justify, they don't feel so wronged [...]" R3; "I think that [...] looking at theory and PBL, I think I'm more fair in the PBL grade, because I can get closer to the student, I have more data to assess him, I have his performance [...]" R4; "[...] class of forty is impossible, there is no way you can do it, you could even try, but you couldn't be fair in the assessment [...]" In more traditional teaching, classes are generally composed of a large number of students. This prevents the teacher to make an assessment as fair as in teaching with PBL, which has smaller classes" R5.

Assessment is regarded as one of the most important tools available to teachers to achieve the main goal of the teaching-learning process. In other words, it is important to find ways to assess student learning and offer alternatives for safer student development.

D. Developing good problems is a difficult skill

The problem (or trigger) is the motivating element of PBL approach. However, there are factors that make them hard to develop.

A problem in PBL should be motivating and clear, and should mirror problems found in the marketplace or related to students' daily life. "[...] you think about various aspects related to problems. First, which knowledge will be required of the student for him to evolve [...]" R4. It is important that the teacher estimate the time to solve the problem and relate it to problem goals and content coverage. "[...] measure time against goals that must be met... don't give the solution for free, but don't leave anything too obscure to the point of being awfully unclear, and measure the time for the solution. I think those are the main challenges I see [...]" R1.

The process of developing problems that are motivating and similar to those found in the workplace is a difficult task, even though it is feasible. Teachers usually come together and create situations that subsequently turn into projects or problems, but those problems are not stored in a shared database. "We don't have a problem database, by the way, it was something that a teacher reminded this term, [...] we have so many problems already developed, and maybe we could recycle some old ideas that were good, that worked, and it's a waste we use the same

idea only once..." R1; "[...] each term it's a new problem, there is no problem database. Each session is a new problem..." R3.

Designing problems is not trivial. It requires dedication, knowledge of the topic, and the affinity to write ill-defined problems with the features required by PBL. "There are situations that students interpret in a different way, and it's part of the preparation of the problem, your leaving it a little open, I can't leave the problem completely closed, I have to leave it a bit open..." R3; "...I think I've never been that good to develop these PBL problems, it's a great difficulty [...]" R5; "[...] preparing the problems, I think it's a task that requires a lot of the tutor" R4. The PBL problem is characterized, therefore, as a trigger to encourage students to develop critical thinking and problem solving skills.

Students who are able to finish the activities before the deadline can be bored with tutorial sessions. In this situation, the teacher should motivate them by using methodological devices. "[...] it was a challenge because there is no way they do not get a little discouraged, so I tried to say so – ah, shall we will try to improve your work? How did you do it? Then I tried to bring them into discussion, so that he contributed to those colleagues who hadn't finished, but at the same time they said so – ah, I have to go there just to clear doubts of the others, and mine is already done, so I tried this balance, but it's hard..." R1. Estimating the time students will take to solve the problem is difficult as well. "[...] I had no idea how long students took to advance through each step of the problem. Neither to measure what to ask, how long it would take, and how long they should take to solve the problem... so that was a big challenge to me [...]" R3.

The problem is an integral part of the PBL approach. Since the problems integrate knowledge and are usually multidisciplinary, it is important that at least most of the teachers take part in this task, either writing or reviewing the problem, and discussing how it unfolds in the tutorial groups. "It is important that problems are discussed among tutors before they are submitted [...]" R2; "Because when we prepare the problem, we think about the goals, which contents I must address according to the syllabus, then which contents I should address here, [...] the initial idea, and prepare the problem, and everything together..." R3.

A problem is only considered finished when students receive feedback. This lets them know where they performed well or poorly. "[...] a problem only ends when students receives feedback from the tutor..." R4.

V. CONCLUSIONS

In this work, we performed an interpretative phenomenological analysis (IPA) to learn the essences of being a teacher in a problem-based learning (PBL) approach. Results led to seven essences, related to feedback, professional skills, assessment, problem design, teacher engagement, motivating scenarios, and group dynamics. Here, we described the four first essences in detail.

From the faculty point of view, we could better understand what it means to be a teacher in the active learning approach of PBL. Teachers revealed a strong difference between a lecture-based approach and PBL: instead of valuing content knowledge

and memorization, PBL values critical thinking, logic reasoning, reflection and real-world problem-solving skills.

However, PBL is not a silver bullet for all this illnesses of present-day higher education. It does not offer a satisfactory learning environment for each and every student. Students have different learning styles, and some may not adapt to a collaborative learning approach. Moreover, for being a student-centered approach, PBL requires teacher engagement and training. The approach also requires some extra hours of dedication and this may impair other faculty activities such as research and publications. However, less need to prepare lectures can make up for this additional time.

From the results, we were especially struck about the power of feedback and the value it has for students. It allows better follow-up and interaction with the teacher. With various feedback milestones, PBL lets students reflect on and evaluate their practices.

PBL promotes skills of group work, and it also stimulates individual study, according to students' interests and individual pace. Thus, it develops better students and professionals. PBL actively engages students in a process of teaching and learning, with the knowledge being constructed through collaborative work and discussion.

Results also suggest that PBL contributes to increase faculty satisfaction with teaching activities, stimulating their professional development by means of intellectual challenges posed by students in tutorial groups.

This research provides a reflection on the teaching process in the PBL approach. A major challenge consists of learning to read between the lines, looking at the details of a teaching approach in its everyday practice. We believe that IPA helped to achieve this goal, and that it is a suitable research approach for uncovering the essences of teaching experience.

Further work should deal with additional analysis and reporting of the additional three essences not described in this work: PBL requires strong teacher engagement and background; it is essential to keep a motivating scenario; and good coordination and group dynamics is required. We also intend to perform an IPA with Computer Engineering students that live the PBL experience. It also seems interesting to contrast the essences uncovered in this work with the conclusions of the case reports produced and published by UEFS faculty.

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Is Video Feedback More Effective than Written Feedback?

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Abstract— As online multimedia options grow, instructors have more diverse and interactive choices to deliver feedback for student assignments. In this paper, the authors compare the effectiveness of using screen recording software to provide video feedback on programming assignments versus traditional written feedback.

A Fundamentals of Programming class of 38 students was randomly divided into two groups. Throughout a 15-week semester, one group of students was exclusively given feedback via video and the other was exclusively given feedback via text. For the video feedback, the professor displayed the individual student program and discussed in detail any design or syntactical errors found in the code. For both groups, the authors tracked the scores on each assignment for each student, as well as the time it took to grade each assignment, which included video rendering time for the group receiving video feedback. A survey was also administered at the end of the semester to gather feedback from the students.

The results of this study are analyzed and presented in order to determine which method is more effective. The results from the survey administered to the students who received the video feedback are also included.

Keywords—*grading; feedback; video; written; effective; survey; time*

I. INTRODUCTION

Students often struggle during their first experiences with programming [1][2][3]. Feedback is often ineffective, merely listing what is wrong with the program without explaining why it is wrong or how it might be corrected [4].

Feedback of any kind is traditionally regarded as a major influence in advancing student learning and success [5][6][7]. Written feedback persists as a reliable avenue for instructors to communicate with students about concerns related to course concepts and/or content. As multimedia tools have become more available, investigations into alternative feedback modes have emerged, most notably those using visual recordings [8][9]. In fact, studies and survey results indicate a student preference for visual feedback [10][11].

A visual/audio approach to providing assignment feedback may be especially applicable to certain disciplines. Benefits from non-traditional video feedback have been reported for English composition [12]. Since writing includes both syntactic

and semantic elements, visual/audio feedback allows the instructor to express observations about style and mechanics in a more direct and personable manner. Software engineering in part requires the creation of written programs, graphical user interfaces, and design documents constructed using UML, all of which possess a strong visual component. Feedback commentary that mirrors the visually oriented nature of software design may prove equally or more effective than traditional written feedback [13].

In providing feedback for programming assignments, the instructor is confronted with the challenge of comprehensively and clearly explaining the problems in the submitted program and the strategies necessary to fix these issues [14][15]. Typing out the detailed feedback can be tedious [16].

The authors used the screen recording software package, Camtasia Studio, to record video lectures for their online courses. This software is used by many faculty members in the Computer Science department at Weber State University to record video lectures for their online classes, and the software works very well for that purpose.

The authors realized that they could use the same technology to record video feedback for students on their assignments. This method has the potential to be faster and/or more effective than traditional feedback.

II. METHODOLOGY

The study involved 38 students enrolled in a single CS1 Fundamentals of Programming using Java course during the Summer 2014 semester. The original course enrollment was 45 students, at which time the class was divided randomly into two groups. One group received only normal text feedback (Text group) and the other group exclusively received video feedback (Video group). Seven students subsequently dropped the class throughout the course of the semester, leaving 20 students in the Text group and 18 students in the Video group. The study was completed using only the data from the remaining 38 students that completed the course. The main measures of performance were assignment and exam scores. A sample assignment with associated text feedback and video feedback transcription are provided in Appendices A, B, and C.

The hypothesis was that students who received only video feedback would score better on average in the course than those who received only text feedback.

The time it took to grade each assignment was also recorded in order to determine if one particular method of feedback was more time consuming and to what degree. The dates of the submissions and the penalty for submitting the assignment late were also recorded.

To combat any inherent instructor bias to grade the students in the Text group before those students in the Video group, due to the convenience of being able to provide written feedback as compared to recording a video (where a relatively quiet environment and a microphone are required), assignments were graded in the order they were received.

Data were collected throughout the semester. To establish and maintain consistent modes of student/instructor interaction within each group, responses to student general inquiries about course topics and delivery were exclusively written for the Text group and exclusively visual for the Video group.

III. RESULTS

Fig. 1 shows results from the study:

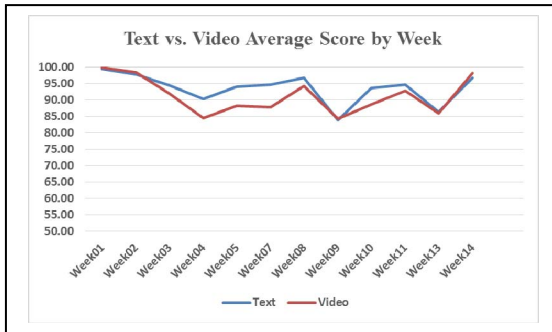


Fig 1. Average score by week for the Text and Video groups.

Interestingly, the students who received assignment feedback via text generally scored HIGHER on average than students who received assignment feedback via video. The overall assignment score average was 2.79% lower for the Video group. In a paired T-test, this difference proved to be significant, $t(11) = 2.74$, $p \leq .05$, with a p-value of 0.019.

The Video group scored 0.40% and 0.64% higher during Weeks 1 & 2, respectively, and 1.48% higher on average than the Text group on the last assignment. However, the Text group scored higher in each of the other weeks, with Week 4 displaying the largest gap between the two groups at 6.49%.

The Final Exam scores were also compared, with the Video group scoring slightly (0.84%) higher.

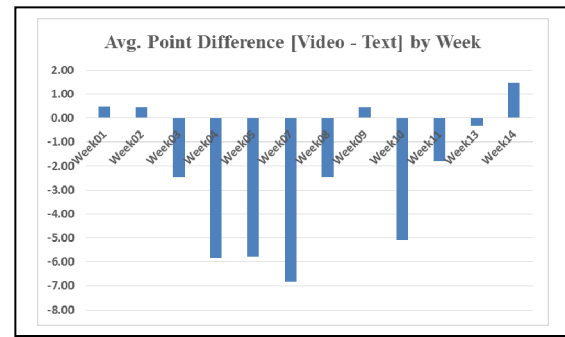


Fig. 2. The difference in the average score for the Video group in relation to the Text group.

The first two assignments for the course were both introductory, whereas the Week 3 Assignment marked the point in the course when the relative difficulty of the assignments increased significantly, thus a drop in average score for all students was expected. As shown in Figure 2, it is noteworthy that the Video group closed the relative performance gap over the course of the semester, and eventually scored better on the last assignment, which was a review assignment focused on the concept of Object-Oriented Programming.

It is also interesting to observe the trend for each group.

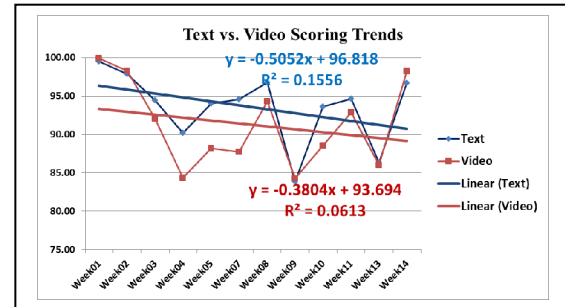


Fig. 3. Average scoring trends in the Text group versus the Video group.

Using a trend line (Fig. 3), it is easier to see that, while the overall average was lower for the Video group, the scores did not drop at the same rate as the Text group as concepts and assignments increased in difficulty. The slope for the Text group was -0.50, and the slope for the Video group was -0.38. However, the difference in trends was not statistically significant, $t(20) = -0.21$, $p \leq .05$, with a p-value of 0.837.

IV. GRADING TIME INVESTMENT

In terms of grading time, the video feedback took nearly twice as long to produce as the text feedback. Video feedback averaged 5:37 minutes to grade over the course of the semester, while text feedback averaged 2:59 minutes, a difference of 2:38 minutes per assignment. Video feedback included primarily the presentation of student programs in the development environment (Figure 4) coupled with audio commentary (Appendix C) highlighting both the successes and drawbacks associated with the student code.

However, it should be noted that 2:10 minutes of that difference included the wait time required for the video to render and upload. The videos for this course were recorded in

high definition (1024 x 768), therefore the render time could be cut significantly if the videos were recorded at a coarser resolution. The rendering time also varied widely among the work machine, home machine, and multiple laptop computers. Anecdotaly, it appears that the use of a solid-state hard drive had the largest effect on grading times; a future study could be pursued to test that theory and to determine what else might reduce rendering time.

If the rendering/upload time is removed and only the active grading time is considered, the Video grading took slightly longer on average at 3:27 minutes per assignment versus 2:59 minutes per assignment for Text grading, a difference of 28 seconds.

Using only active grading time, the video grading was slightly faster (6-8 secs) when a student scored 90-100% or below 60%. Text feedback was almost a full minute faster (51 secs) when a student scored between 60-80% on the assignment and 28 seconds faster in the 80-90% range.

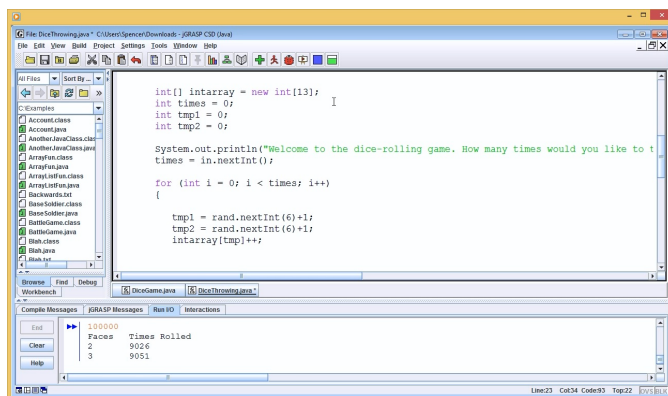


Fig. 4. Screenshot of video feedback.

V. SURVEY

At the conclusion of the course, a survey was given to the students who received video feedback during the semester. A total of 15 out of the 18 students from the Video group responded. While the scoring results were somewhat ambiguous, the survey results revealed that students were clearly in favor of Video feedback.

Question: “Do you prefer receiving assignment feedback through text or video?”

15 out of 15 (100%) of the students chose “Video”.

Question: “Which type of assignment feedback do you feel is more effective for your learning?”

15 out of 15 (100%) responded with “Video”.

Question: “Have you ever received video feedback on your assignments prior to this class?”

15 out of 15 (100%) responded with “This is the first class I have received video feedback in.”

Question: “How often did you watch the video you received as feedback on your assignments?”

10 (67%), “All of the Time”

4 (27%) “Most of the Time”;
1 (7%) “Some of the Time”

Question: “How often do you read written feedback given on assignments?”

4 (27%), “All of the Time”
6 (40%) “Most of the Time”
1 (7%) “Some of the Time”
3 (20%) “Rarely”
1 (7%) “Never”

The most interesting qualitative results were divulged through student comments.

Question: “Why do you prefer the feedback method you chose?”

Here are a sample of the responses:

“It shows me what I did wrong in a visual style with live commentary using my own work. Doesn't really leave room for error.”

“I liked it, just because I got to hear the emotion in your voice on how you really felt about the program! It makes me feel like you actually care rather than you plug it in and just grade it off the outcome and not really even care what is in there.”

“I was able to see what was wrong with my program immediately, and it was like having [the professor] there going over the assignment with me.”

“It was as if the professor was coaching me through each assignment. I really liked hearing his feedback on my assignment, and the tips he gave me that he probably would not have done through text. I loved it!”

“The videos were awesome because unlike in a face to face lecture I was able to get personal feedback on my assignment without having to spend time tracking down the teacher and also I could go back a reference it any time I wanted. I liked hearing the teacher's thoughts and it was a great way to start a conversation about what I did right or wrong and how to fix it.”

Question: “What did you most like about receiving feedback through video?”

Here are a sample of responses:

“Didn't leave room for miscommunications.”

“I didn't have to look back at the assignment to see what the prof was talking about, I could see it right there.”

“Video feedback is a visual learning tool, and I am a visual learner so it helped me to understand what I was doing wrong.”

“I like hearing a teacher's personality as well as I get to see exactly what confuses them in my work, which, in and of itself, is helpful.”

"It seems easier for [the professor] to point out the mistakes that I made and for me to know exactly what you are taking about."

Question: "What did you least like about receiving your feedback through video?"

12 of the 15 (80%) students responded "Nothing.". The other three students responded:

"Sometimes I didn't have time to watch the video and see what you said because in a text it would take me just a second to read rather than download the video and watch it."

"I had to have a fast internet connection to watch the video."

"That I had to download the feedback to my computer."

Question: "Please leave any other comments you have about the video feedback in this course"

Here are a sample of the responses:

"I felt this helped greatly in learning what I was doing wrong. So obviously this helped me move forward quicker and not lag behind in class."

"I found it very helpful. I wish other beginning (intro) programming instructors did this."

"Makes an online course seem much more interactive."

"I have none, other than I wish my other teacher's would have done something like this."

"A short [written] summary to accompany the video would make it perfect."

"I suggest that teachers use video feedback for online and in class formats. I feel that it is very useful at giving the student personal information about their assignments that will improve how they learn the material."

The survey results show unequivocally that the students had an extremely positive response to the video feedback. Over the last several years, students have been increasingly exposed to video instruction as recorded lectures and video conferencing sessions become the norm for both online and hybrid university courses. Majors in the fields of computer science and engineering are receptive to briefer, focused treatments of course topics, typically packaged as 8 to 12 minute presentation videos. Commercial online instructional sites such as Codecademy, Udacity, and Pluralsight have engaged both the aspiring and seasoned programmer with libraries of video courses on learning to code in various languages. Because student experience of the instructional context appears to be trending toward more visual interactions, the overwhelmingly positive survey reaction to video feedback may be more a matter of student expectation rather than novelty.

Although a vast majority of students who received visual feedback (93%) reported watching the videos "All of the time"

or "Most of the time," compared to 67% of text feedback students who did the same, this enthusiasm to absorb instructor commentary did not immediately translate to noticeably better overall performance in the visual feedback group. Improved student assignment results are one key measure to assess video feedback, with one current study showing a positive outcome in this area [13].

However, comments such as *"...this helped me move forward quicker and not lag behind in class"* may point toward a benefit of increased engagement from students who were potentially at risk in falling behind the course schedule, and ultimately withdrawing from the class. Visual learners may be bolstered by feedback that corresponds to their learning modality and thus encouraged to persist in continuing and successfully completing the course. Also, visual feedback might be made more effective from a performance standpoint by employing the student survey recommendation *"A short [written] summary to accompany the video would make it perfect."*

As an anecdotal note, the instructor who taught this experimental section, received the highest average student evaluation score he has ever received teaching this particular course, an outcome which could be in part attributed to the video feedback component.

VI. CONCLUSION

For this particular study, the student performance data is inconclusive. Conflicting trends emerged from this work: the Text students scored slightly higher on average, but the Video students reduced the performance gap over the course of the semester, and eventually scored better on the final assignment. The instructor observed that the first seven submissions for the initial introductory assignment arriving before the due date were Text students. Even though the groups were divided randomly, a number of the top students in the class appeared to fall in the Text group by chance, an observation that held true throughout the semester.

With a sample size of only 38 students, there is greater potential for a few students, exceptional or poor, to skew the results in one direction or the other. It will be necessary to attempt the same study in future courses and aggregate the data to see if the pattern described in this study holds. Perhaps there are reasons that students who receive written feedback perform better overall, and future studies could be aimed at delineating and identifying these specific causes.

Video feedback does take significantly longer to record, due mainly to rendering time. However, straightforward technological solutions as described earlier could significantly reduce this video processing time. If rendering time is ignored, instructor time investment in the visual feedback reports was on average 15.6% greater than instructor time investment in the textual reports. Although assuming a direct correlation between grading time and feedback quality/quantity is problematic because the two modes utilize different communication channels, it is possible that the dynamic, interactive visual format elicited a more substantive review from the instructor.

One critical piece of qualitative data reported here is that students strongly prefer video feedback to written feedback. Video feedback helped students establish a personal connection with the professor and represented an increased level of instructor investment in the process. Performance data aside, grading by video shows initial significant potential in enhancing the positive experience students have with both programming and the course instructor.

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VIII. APPENDIX A: SAMPLE ASSIGNMENT

Write a program that simulates the rolling of two dice. Use an Array to keep track of the number of times that each total number is thrown. In other words, keep track of how many times the combination of the two simulated dice is 2, how

many times the combination is 3, and so on, all the way up through 12.

Allow the user to choose how many times the “dice” will be thrown. Then, once the dice have been thrown the specified number of times, print a histogram (using the * character) that shows the total percentage each number was rolled. Each * will represent 1% of the total rolls.

Sample session:

Welcome to the dice throwing simulator!

How many dice rolls would you like to simulate? 100

Dice Rolling Simulation Results

Each "" represents 1% of the total number of rolls.*

Total number of rolls = 100.

```

2: ***
3: ***
4: *****
5: *****
6: *****
7: *****
8: *****
9: *****
10: *****
11: *****
12: **

```

Thank you for using the dice throwing simulator. Goodbye!

Submit your .java file containing the source code via WSU Online.

IX. APPENDIX B: TEXT FEEDBACK

“There are a few problems that I spotted. You were close on totaling up the dice, but it doesn't appear to be totaling quite right. I'm not actually quite sure what you're currently doing -- You total up the rolls for one die. And then you total up the rolls for the other die. Then you roll again, and add the total from ‘dt’ and ‘di’, but di will never change. ‘dt’ will change, but then you're not using the other rolls you did at all.

“All we really need is one loop that looks something like this:

```

for (int i = 1; i <= bacon+1; j++)
{
    di = r.nextInt(6) + 1;
    dt = r.nextInt(6) + 1;

    tdice[di + dt]++;
}

```


“That would total up all the rolls correctly. And then for printing the asterisks, if you used the formula for calculating the asterisks in the for loop instead of printing out the number, then I think that would work. You would just need to change the `println()` to be a `print()` so that the asterisks stayed on the same line. And then add a `println()` after you've printed all the asterisks for one line.

“You were on the right track. Hope that helps. Let me know if you have questions.”

X. APPENDIX C: VIDEO FEEDBACK TRANSCRIPTION

“Okay, Quinn. Let's look at Week 7 and see what you've got. OK? We're getting some numbers. Let me try 100. Let me try 100,000. Okay, so I'm already seeing a few problems. Obviously I think one you know. Let's see. [Reading comment from student] “I couldn't figure out to print the asterisks instead of the numbers, but better than nothing I guess.” Good point. It's better than nothing. It looks like you're doing this section correctly. The problem is this. If you... Well, no that's okay because you're doing a 2. If... How can I say this? I'm obviously struggling. [Laughs] If we get a random number out of 11, that's going to give us a number 0 through 10. We add one to it, which is going to give us 1-11. All of those numbers has an equal probability of being rolled. In other words, this: If we took a 12-sided die, if there was such a thing, and rolled it, every side of that die would have equal probability of being rolled, right? There would be a 1 in 12 chance of being rolled. But when we roll two dice, it's not equal probability of any number getting rolled. For example, a 2, you have to roll a 1 and a 1. So you roll one die and you say, “Oh, good. I got it. There's my one. One in six chance, and I got it.” What are the chances you're going to get a 1 on the other die as well? Well, it's still 1 in 6. But what ends up happening is you have to multiply those together to figure out the probability, so it's a 1 in 36 chance because there are two dice. And so what we get is, for a 2, we have to roll a 1 and a 1. That's the only way to roll a 2. Or a 12, you can only roll a 6 and a 6. But for a 7, I can roll a 1 and a 6, or a 2 and a 5, or a 3 and a 4, or a 4 and a 3, or a 5 and a 2, or a 6 and a 1. All of those get me the 7. Any of those combinations. And so there is a much higher probability of rolling a 7 than there is of rolling a 2 or a 12. So anyway, that's a long explanation. But just saying we can't do one simulation. What we needed to do was say, “Give me one die, `nextInt(6) + 1`. Then give me another one out of 6 + 1. Add those together. And then store that number instead.” And that would have gotten you the correct results. It will look more like a sideways pyramid. On the ends, 2 and 12 will be really low. But in the middle, at 7, it will be high. And then the idea of the asterisks. Now, assuming we've done this right. And I think we can even just do it. I probably shouldn't just do it,

but I'm just going to. [Laughs] This is “`tmp1`”, out of 6, plus 1. This is “`tmp2`”, out of 6, plus 1. And we need it out of 13 [in the array] if we're going up to 12. 0 through 12. And then we won't even use 0 or 1. I take the result of that, so instead of just “`tmp`”, I say “`tmp1 + tmp2`”. And that's going to give me my results. And you'll see in the numbers that this works out a lot better. So I roll 100, I got 4, 10, 15, 18, etc. in the numbers. So my middle are the big numbers, and then low numbers on the extremes. Okay? Once I have that, then all I need to do is... right now you're printing this number, which is how many times that particular number was rolled. Well, instead of doing that... I'm going to take that part out, and make this a “`.print()`”, because we're going to finish off this statement. So I start this statement with a “`.print()`”. I say this is the number, and I'll actually just start at 2 and go up through 12. And then I can just say this. I can say, “After I print the number, I need to figure out how many asterisks I'm going to print.” “`int numAsterisks`”, and I'll set it to 0. And then, I can say, “Set the number of asterisks equal to whatever that number it is I'm pulling.” Ok? That's the number. And what do I need to divide that by? Well, I've got to figure out how many times I rolled that number, which is “`times`”. So divide those, and then multiply it by 100 to make it an actual, instead of .3 for 30%, to make it an actual 30. The only problem when I do it this way is that I'm going to get a zero always, because it's integer division, and this number is smaller than this number. So I'm always going to get a 0, with a remainder of this. So, instead, what I'm going to do -- This is a little trick, I think I actually talked about it in the help video actually -- I'm going to multiply it by 100 in the first place. If I roll this 30 times, 30 times 100 is 3000. Divided by 100 rolls will give me 30. And once I have that number of rolls, it's as simple as saying, “Okay, so for an `int “j”`, because I can't use “`i`” – I'm in the middle of a loop, start wherever we want, but I'll start at 0, and go so it equals the number of asterisks. And then “`j++`”. For every single number of asterisks that I have, I'm going to “`.print()`” – Not “`println()`”, just a “`print()`” – One asterisk. Okay? And then after I get done with that line, then I will go to a new line. So do a “`println()`” to go to the next line. And that way, I get this nice pretty histogram, with the numbers looking like we talked about, low on the outside. It doesn't matter if we do 1,000,000 rolls, it still looks super nice. We're missing commenting in the program, so that's a problem. But the rest looks good. You were most of the way there. Just those things we talked about. So hopefully that's helpful to look at it together. Let me know if you have any questions or comments. Thanks.”

New Methodology to Differentiate Instructional Strategies for ESL Learners in the Indian Context

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Abstract—Many students struggle with reading when whole group instruction forms the core of the reading program. This is especially true when teaching second language students. The proposed intervention methodology combines multiple proven methods to improve reading skills in students. The study focused on using differentiated instruction and multiple assessments such as Informal Reading Inventory (IRI), Qualitative Spelling Inventory (QSI), Running Records, Dynamic Indicators of Basic Early Literacy Skills (DIBELS), High-frequency words and phonological awareness. After the usage of the said tools, students learnt to follow a firm reading routine, respect classroom procedures, work in teams and solve problems independently. This five-month study examined the benefits of the differentiated instruction with thirty six 5th grade students, who were the second language English learners in a school in the state of Karnataka, India. The key findings from this study indicated that differentiating instruction and using small group instruction assisted and improved students' reading and writing proficiency. With our proposed method, 94% of the students improved their reading comprehension by a minimum of three grade levels. An unexpected benefit was a positive change in attitude and behavior of the students along with increased confidence.

Keywords— *Informal Reading Inventory (IRI), Qualitative Spelling Inventory (QSI), Running Records, Dynamic Indicators of Basic Early Literacy Skills (DIBELS), High-frequency words*

I. INTRODUCTION

Teaching English in India as a second language is indeed a challenge. Often teachers are neither proficient in spoken English, nor are they trained in classroom management skills, the skills that teachers require to have in order to manage a large group of multi-leveled students.

To be an effective English teacher for second language learners, Echevarria, Frey, and Fisher state that a teacher has to be aware of four sections - access, climate, expectations and language instruction [1]. The word 'climate' here refers to the conditions that are present in classrooms. It is said that the effective teachers create a positive climate in the classrooms using a variety of ways. To say, they show respect and patience towards the students [1]. A widely used adage in educational circles says that the teachers should first examine their own educational practices and make changes when the

students are not successful. A change in the teachers will lead to change in the students.

Also, many years of research has shown that a teacher's expectations directly influence the performances of the students [1]. Therefore, it is important to first state specific instructional objectives to the students before a lesson is being taught. This would provide a framework for the students. Without this framework, it is easy for English language learners to be distracted while the lesson is being taught [1]. Although vocabulary development is a significant part of language acquisition, oral language, grammar, and other literacy skills also play a major part. Teachers use phonemic awareness to help students understand many layers of language acquisition.

Our intervention methodology combined several methods to improve reading skills in students. The students learnt classroom routines, rules, procedures and guidelines for five months, the duration of the entire research. Students practiced the classroom procedures, learnt how to work in teams and solved problems independently.

The various assessments used in this study include an Individual Reading Inventory (IRI), Running Records, Qualitative Spelling Inventory (QSI), High-frequency word list and Dynamic Indicators of Basic Early Literacy Skills (DIBELS). All these practices were new to the participants of the research, including teachers, students, administration and parents. This paper will show how the assessments were administered among students, elevated their reading levels and motivated them to perform better.

II. BACKGROUND

The current educational system encourages students to use rote-learning techniques to memorize the chapters and also to prepare for the examinations. This is a widely accepted method, and teachers instruct students using whole group instruction with a focus on rote memorization. There have been several studies to show that the obsolete practice of rote memorization is inappropriate for many subjects and may not prove beneficial in all the circumstances [2]. In her research, Fata-Hartley [2] pointed out that the rote learning does not induce actual learning in students. Rather, for the actual learning to take place, there should be active engagement from the part of the students.

In another research, Vygotsky and Bruner too encourage students to acquire knowledge through active participation. The backbone of the curriculum in US schools is Vygotsky's Zone of Proximal Development, popularly known as ZPD. The ZPD concept states that the students can learn to do independent works when an adult or a more competent peer assists them [3]. A teacher or an educator can recognize a child's ZPD, the area between what a child can do by himself and where the child will require assistance, through his/her watchful eyes or by testing through asking questions, and by determining a student's individual learning techniques.

In addition, it is important to provide a calm classroom atmosphere for the effective learning to take place. Good classroom management strategies can provide this effective learning environment for students. Calm environment in classrooms proves productive because it enables the teachers to take a proactive approach to classroom misbehaviors, a key factor in good classroom management. Behavioral learning theories state that the misbehaviors persist over time if maintained by some 'reinforcer' such as a teacher or a peer group, or by both [4]. Therefore, it is necessary to identify the 'reinforcers' to reduce the misbehaviors. Praise is usually a powerful motivator for many students to reduce misbehaviors. That is, to appreciate students when doing the right things. To say, if students often move away from their seats without permission, praising them when they sit back and get to work can reduce this misbehavior.

III. METHODOLOGY

A. Assessments used in the Method

The research applied a set of assessments to align students to their correct grade level. They were as follows:

- The QSI put the students in the preliminary reading group.
- The IRI assessed reading comprehension level of students.
- The Running Records checked if the words the students read were correctly/incorrectly pronounced.
- The DIBELS assessed each student's reading fluency.
- The High-frequency words list tested students at three separate junctures of the research - at the beginning, mid-level and post research.

Qualitative Spelling Inventory (QSI), a similar method like spelling test, also considered to be the baseline or pre-assessment test was first initiated for the assessment. The QSI assessment consisted of a list of 25 words, where each word represented different spelling patterns that were progressively more difficult. Among the several levels of inventories, primary, elementary and upper level that exists for QSI, this research undertook an Elementary Spelling Inventory (ESI) for students as they belong to elementary school. Subsequently, each student was administered with a bi-monthly test, a method to examine their mastery of the studied attributes of the words.

Conducting such tests helped our researchers to examine the retention capability of students, which in turn helped gear instruction. Thus, using the original QSI that each child had done at the beginning of the study (in October 2014), the researchers conducted mini-lessons and taught students several word sorting games which in turn helped them understand word patterns.

Mini-lessons

The researchers spent five to fifteen minutes teaching mini-lessons on various topics such as reading comprehension strategies, English grammar or other text related factors. Sometimes mini-lessons were taught to the whole class, and at other times the students were taught in small groups. In our research, we used mini-lessons to correct grammatical errors that students consistently made in their writing. We also conducted mini-lessons, when we felt the students needed extra help to comprehend a reading lesson we had taught. We used questioning strategies to help the students. For example, we started the lesson by talking about why people ask questions. Then, we used this strategy to ask them questions about the stories that they were reading about. We made a list of questions, then evaluated the questions, choosing the ones that focused on the big ideas that helped students understand the story better. [16].

A. Quantitative Spelling Inventory

The QSI test enabled the placement of students into four reading groups and revealed the spelling deficiencies of each student. Students generally moved on a continuum through the various spelling stages, namely; Emergent, Letter-Name, Within-Word, Syllables and Affixes, and Derivational Relations Spelling^[7]. This research ceased at the Syllables and Affixes stage and administered the inventory, resulting in four reading groups.

The intervention for each reading group was varied. For example, the Within-Word Spelling group differentiated between short vowel and long vowel words, as it was their area of deficiency. The group required training on short and long vowels, hence, a few rules to differentiate between cut-cute, hat-hate, slid-slide etc. were taught to the students. While teaching, students were initially made to pronounce the words in the list, following which several word sorts were used to teach the concepts. The students were also made to write down the words in their spelling notebooks. Word sorts are word study to assist students to focus on conceptual and phonological features of words and to identify recurring patterns they possess. For example, students sort words (written on cards) such as *stopping*, *bugging*, and *running* they discovered the rule for doubling the final consonant in short vowel words before adding the *ing* at the end of the word. [15].

The whole class was also deficient about the concept of blends, digraphs, and diphthongs. Blends are two or more consonants, when combined together makes a single sound. (for example *br*, *cl*, *sp*, etc.). Digraphs are two or more consonants combined together make a single sound. (for example *ch*, *sh*, etc). Lastly, diphthongs which are two vowels when combined make a certain sound and the sound of neither

vowel is heard. (for example *oi* as in *foil* etc). [7]. They also required training to sort the words into categories. Such trainings were provided. Vowel patterns were taught using 'word sorting', a process of separating a group of words into piles with similar features. For example, we taught them to sort pictures using the same beginning consonant sounds or medial vowel sounds. This format of teaching was followed for the entire class for the entire duration of the research.

Assessments have become a necessity in the 21st century classrooms. The present education system analyzes the achievement level of students through annual tests, administered by school districts and federal education agencies. To better this system, a number of teachers use Quantitative Spelling Inventory (QSI), published in the book 'Words Their Way: Word Study for Phonics, Vocabulary and Spelling Instruction' (Bear et. al., 2008). The legitimacy and dependability of this spelling inventory are indisputable. Also, they are easy and quick to administer in any classroom environment.

There are several different levels of the spelling inventory, Primary, Elementary and Upper Spelling Inventories. This research has used Elementary Spelling Inventory (ESI) which is specifically used for elementary school grades from 1st to 6th grade. Generally, there exists co-relation between the spelling test score and standardized reading scores (Bear, et. al., 2008). Thus, from the researchers' past and the current experience, when students attempt and achieve a high score at this spelling inventory, they are also counted as good readers.

In conclusion, using the Guttman Scalogram analysis, it had been noted that the coefficient of reproducibility had an average of 0.91 (Bear, 1982, 1992).

A. Running Records and Informal Reading Inventory

Running Records and IRIs are primarily used to document the development of the students with suitable academic (leveled) reading material. Running Records enable the teachers to analyze the oral reading skill of the students. It would also help to understand their ability to solve reading problems.

During this research, Running Records were collected at three different periods:

- 1) Prior to beginning the research to get a baseline score
- 2) At the mid-point of the research (November 2014)
- 3) At the end of the research (February 2015)

The book used for narrative reading is Flynt & Cooter's *Reading Inventory for the Classroom (RIC)*. Alongside, reading inventory was also administered. The below methodology is used to implement the Running Records and IRI on the same day to the student:

Initially, the Running Record was introduced to each student. They were then tested for their oral reading competency right outside their classroom. The duration of these tests (running records and IRIs) took the researchers approximately 15-20 minutes per child. The students read

aloud a narrative passage to the researchers, during which, the running records were documented. Documentation involved penning down the words that the students read correctly and the type of errors they made while they read. Students repeated the read passage as the next step.

The assessment of comprehension was also taken by asking students questions from the reading. Comprehension is measured by the student's ability to recap the passage they read and to answer questions about the passage. The questions were both evaluative and inferential, to examine student's ability to use literal and higher level thinking. They also tested their knowledge of vocabulary. The IRI chose for the purpose was *Reading Inventory for the Classroom (RIC)*, written by Flynt and Cooter. The book was chosen as it contains a miscue analysis grid for each passage and focuses on vocabulary building.

IRI and Running Records diagnose various difficulties students face in word identification, fluency and comprehension [8]. They help students with higher-level thinking like synthesis, evaluation and analysis. For enhancement of comprehension of higher-level concepts, graphic organizers were also used. Constructivists like Vygotsky and Bruner has advocated this type of learning within school systems (used in the U.S.A) [9]. The experience of hearing ideas from peers, experiment them and obtaining feedbacks are ways to advance the cognitive scaffold and to maintain the higher-order of learning [10].

B. Dynamic Indicators of Basic Early Literacy Skills

DIBELS is another tool that is used to evaluate the students' reading fluency and provides oral passages that measure the reading speed for each grade level. Usually this test is individually administered to each student. However, we administered the test in small groups. For the first 10 days, the test was supervised once in a day, thereafter, once in a week until the 8th week. As the days passed, a better motivation to perform well was seen among the students. They also showed an improved competition with each other and compared each other's scores on a regular basis.

C. High-frequency Words

High-frequency words are the words that are most frequently used in the English language. Example: 'who', 'and' or 'the'. School districts across the US require students to study high-frequency words for each grade level. Thus, students in the US have to know 500-600 words by the time they are in 5th grade. Many of these words are difficult for non-English speakers to learn because they are not easily decodable, i.e., difficult to extract the true meaning of the word [8]. The other complicating factor is that these words do not individually carry any meaning. So, for example, it is easier to explain what a 'spider' is, rather than words such as 'what' and 'how'.

D. Phonological Awareness

Early phonological awareness helps a student understand the structure of spoken language, that it consists of sentences and that those sentences are further made up of individual sounds called phonemic awareness. Acquiring this

phonological awareness is important because it later builds the foundation for success in phonics and spelling^[11]. We showed students how to 'chunk' words. We started teaching students this concept by explaining the common features that words have. For instance, by adding a consonant 'h' or 'm' to long vowel words that end in 'ike', or short vowel words that end in 'en', we arrive at words such as 'hike' and 'mike' or 'hen' and 'men' respectively.

IV. STRATEGIES

The first author taught the students various strategies during the entire duration of the research. These strategies worked well in the study and the students made great progress.

In the beginning of the research, the lessons included scaffolds, giving the students the structure that they were used to. Currently, the teachers structure their classroom using whole group instruction. Therefore, at the beginning, the whole group instruction was maintained and eased the students slowly into small group instruction before commencing differentiated instruction in the class. This process took over seven weeks. Rigorous and firm classroom rules were implemented in order to achieve the necessary structure. This structure was the backbone of the classroom, hence, the rules were firmly followed and the students accepted the consequences that were set in place at the beginning of the research.

Implementation of classroom jobs was another factor that contributed towards daily and weekly form of positive reinforcement. For instance, only students who listened, and adhered to our classroom rules, and were who exhibited on task behavior, were assigned weekly jobs. They were taught clearly that this is the scenario in the real world, where only people who work hard and do their jobs properly are able to maintain their jobs. During the early part of our research, as a move to teach students on framing questions, we structured questions that students might ask and modeled various questions for them. As the weeks passed, the students themselves began generating the questions^[12]. This was one among the many scaffolding strategies taught to the students.

Also, every time a book was read or taught a lesson, we stopped and thought out aloud. In his studies, Wilhelm^[13] have shown that teachers who follow this routine, make children aware of the thinking style of capable readers and the way they process the information read. This approach motivated the students to ask more questions, thereby, encouraging more learning. According to educational psychologists, there are two different types of motivation — intrinsic and extrinsic. Intrinsically motivated are those activities people perform, and find fulfillment and joy from the activities itself. They require no external encouragement^[14]. Extrinsic motivations demand external rewards, by praise, prizes, grades, recognition et cetera. We used both types of motivations and the students thrived with the attention, praise and other academic rewards such as better grades during the research study.

V. THE STUDY

A. Participants

Our study was done with 36 fifth grade students over a period of five months.

The study offered supplementary English language classroom instruction to Kannada (language spoken in the state of Karnataka in India) speaking students, many of whom had low reading comprehension and vocabulary levels.

Of the 36 students selected to participate in the study, 21 were male (58%) and 15 were female (42%) students.

B. Procedure

The study was divided into three phases — pre-testing, mid-level and post-testing. The methods used to test the students' knowledge are detailed below:

During pre-testing (or testing prior to actually beginning the study), the researchers gave the students a list of over 480 words. The parameters of fluency, accuracy, and the speed with which the students were able to pronounce each word on this list were tested. In the beginning of the study, during October 2014, each student was tested for fifteen to twenty minutes in order to get a baseline score. This process took three days of testing for all the students. This method was again repeated in November 2014 to obtain a mid-point reading score and then again in February 2015 to obtain the final score. Based on the results obtained, the class was divided into four reading groups.

During the mid-level testing, in addition to the method used during the pre-testing, the list of words was included as a game that the students could play during their literacy rotation time. The students were allowed to practice the list of high-frequency words at home. As the weeks went by, researchers coached the students on gaining automaticity, accuracy and speed. This in turn, improved the students' reading comprehension. The children looked forward to the reading classes and waited anxiously for the lessons we had planned. They were required to work within their assigned reading groups for 20 minutes each day for the duration of the study. Using leveled books, they were tested for 'reading fluency' and were taught phonological awareness and comprehension skills. In school, children are taught to pronounce the speech sounds in English. As they learn to pronounce these sounds, they learn to talk and they also learn to associate these sounds with letters as they learn to read and write^[5]. As stated earlier in this paper, the phonological system is important for both reading and writing.

The post-testing was conducted in the same manner as the pre-testing. The test enabled us to analyze the students reading comprehension skills after completing the previous two levels. Responses of the students reading comprehension score were statistically analyzed using the SPSS software and R.

C. Results

We conducted a repeated measure ANOVA to analyze the improvement in the reading comprehension skills of the students learning, which was tested within the duration of five

months. Table 1 shows the means and standard deviations (SD) for improvement in reading comprehension.

TABLE I. DESCRIPTIVE STATISTICS

Time points	mean	sd	n
Pre-Test	2.17	1.73	36
Mid-Test	4.92	2.39	36
Post-Test	6.44	1.97	36

Table 2 shows the overall significant difference between the means at different time points. A repeated measures ANOVA done with a Greenhouse-Geisser correction determined that mean, reading comprehension score differed significantly between the time points ($F(1.92, 67.11) = 143.866, P < 0.05$). The results presented in table 2 show an overall significant difference in the mean score.

TABLE II. TESTS OF WITHIN-SUBJECTS EFFECTS

Source		df	F	Sig.	Partial Eta Squared
Time	Greenhouse-Geisser	1.92	143.866	.000	0.804
Error (Time)	Greenhouse-Geisser	67.11			

The table 3 presents the results of the Bonferroni post hoc test, which allows us to discover which specific means differed.

TABLE III. PAIR-WISE COMPARISONS TABLE

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.
Pre-Test	Mid-Test	-2.750*	.277	.000
	Post-Test	-4.278*	.231	.000
Mid-Test	Pre-Test	2.750*	.277	.000
	Post-Test	-1.528*	.257	.000
Post-Test	Pre-Test	4.278*	.231	.000
	Mid-Test	1.528*	.257	.000

Post hoc tests using the Bonferroni correction revealed a significant improvement from pre-test to mid-test ($P < 0.05$) and between mid-test to post-test ($p < 0.05$). The post-test score showed a remarkable improvement in reading comprehension skills among the students. Specifically, the results suggest that the integrated method implemented elicits a statistically significant improvement in reading comprehension.

Fig. 1 shows the estimated marginal means of students' reading comprehension score over a period of time. Before conducting the treatment, the students' mean score was lower.

Their mean score improved significantly after the students followed the learning process in the mid-test. This progress continued until the post-test, subsequently the students' means score increased.

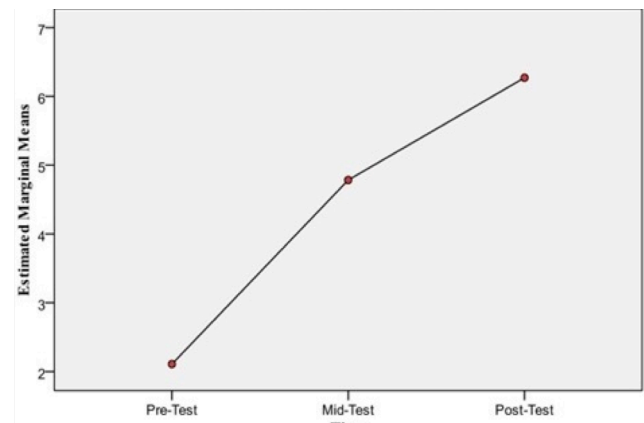


Fig. 1. Estimated marginal mean of student's reading comprehension score

VI. DISCUSSION

The assessments were a huge motivational factor and encouraged all the students towards higher achievement levels. Perhaps due to cultural factors, none of the students in the study wanted to be associated with the lower reading group. This motivated the children. The other factor that played into students' motivation was classroom rules and consequences.

With our proposed method of Differentiated Instruction, students increased their grade levels by an average of 4.3. In the initial measurement, 86% of the 5th grade students were reading below grade level. At the end of five month, all the students in the research study had improved his/her reading level by at least three grade levels. There were many factors that played into the success of this research however a large portion was due to the motivation of each student. 66.6% of the students were assessed at Grade 6 or above and 16.6% at a 9th Grade level in the final measurement.

The final result of the high-frequency word tests revealed that the new methodologies used influenced the students positively, though on an average, the overall increase in percentage was only 1.6%. These small increases of high-frequency words had a big influence on reading comprehension with most of the large increases coming from students who tested initially at Grade 0, 1, or 2 levels.

The fluency test (DIBELS) not only motivated students, but also increased their fluency scores where 66% of the students doubled their reading fluency score. It was seen that overall, the class scores increased by 2.1 grade levels in five months. At the beginning of the test, only 14% of the class was at grade level 5 or higher, but at the end of the five months, 75% of the class was at least at grade level 5. Note that it is possible that the grade levels attained were higher, but the researchers only had reading fluency measurements up to 6th grade level.

On average, 94.4% of the students in our study improved their reading comprehension by a minimum of three grade levels or more. We found that the mistakes the Indian students made differed greatly from the mistakes made by students of the same age in the U.S.A. For example, the Indian children had a difficult time understanding prepositions and prepositional phrases. We implemented a much more rigorous classroom management system than the existing one, supplemented existing text books with leveled books, taught grammar in context using mini-lessons and worked on common errors to help improve learning English as a second language.

Generally, reading and writing go hand-in-hand and this was also the case in this research. In the research, a writing rubric was implemented and we were able to perform the initial baseline and the mid-level (7 weeks) reading. However, the final reading could not be collected due to time constraints in the study. The mid-level readings after just seven weeks showed an average overall improvement of 45 percent, an impressive overall result.

VII. CONCLUSION

To sum up the research:

- 94% of the students improved their reading comprehension by three grade levels or more.
- 80% of the students in the research improved in the high-frequency knowledge and automaticity by an average of 1.6%.
- The reading fluency of students scoring 5th grade or higher was improved from 25% to 75% by the end of five months.
- The writing skills of students improved by 45% in seven weeks.

To explain our research metaphorically, just as the electricity charges an electric fan and rotates its blades, the assessments and classroom rules stimulated the various reading groups in the classroom. The assessments, classroom rules and consequences energized the students in the class, encouraging them to learn, enhancing their enthusiasm. The students moved into higher reading groups as the weeks passed, and they engaged with their own learning at their own developmental level. Individual conferences permitted us to outline expectations to the students.

At the end of the study, parent-teacher conferences were conducted. Majority of parents commented that there is an overall improvement for their children in both reading comprehension and fluency. Besides, they stated that there is an improvement in children's social behavior. In short, they were very pleased with the outcome of the research.

When considering the scenarios of Indian students, it has to be noted that they do not practice spoken English in the universities. Many of these students hail from rural backgrounds, where English is hardly spoken and considered a novelty. Consequently, these students are accepted into university, where the language of communication (both

written and spoken) are in English. Naturally, they will encounter a difficulty in understanding their professors and the text books.

However, if IRIs and QSIs were administered on a regular basis to each incoming student, it would remove students' difficulty in dealing with English language. Perhaps, students who fail at the university level may actually be failing due to their lack of skills in English language.

These key findings from this study, thus conclude that the differentiating instruction and using small group instruction assist and improve students reading and writing proficiency.

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Starting From Scratch

Developing a Pre-Service Teacher Training Program in Computational Thinking

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Abstract—This paper details a series of pre-professional development interventions to assist teachers in utilizing computational thinking and programming as an instructional tool within other subject areas (i.e. music, language arts, mathematics, and science). It describes the lessons utilized in the interventions along with the instruments used to evaluate them, and offers some preliminary findings.

Keywords—Computational Thinking, K-12, teacher professional development, Scratch

I. INTRODUCTION

The inclusion of Computational Thinking (CT; a problem-solving approach associated with the field of Computer Science) into a student's K-12 experience has been gaining ground in recent years. Bolstered by inexpensive, ubiquitous computing technology and associated with changing strategies for answering questions and solving problems in a wide range of science and engineering fields [1], CT has been identified among the critical 21st century skills all students should develop [2], and has even been incorporated into the latest emerging national educational standards in the United States: the Common Core State Standards [3] and the Next-Generation Science Standards [4]. Underlying this thematic push are arguments derived from growing market demands, concerns about national security, and a desire for social equity.

Yet bringing CT into the K-12 realm is also rife with challenges which must be addressed – as was demonstrated by the earlier CT integration movements like that associated with the LOGO programming language emerging in the 80's [5]. Chief amongst these is preparing future K-12 teachers to tackle the challenge of teaching CT. This paper describes one approach to tackling this problem piloted at Kansas State University as a partnership between the Department of Computing and Information Sciences and the Department of Curriculum & Instruction. This approach was derived from both the literature and practical experiences emerging from our NSF-supported GK-12 Program, INSIGHT. In addition to the discussion of the professional development approach, we provide some evidence supporting its efficacy and suggestions for future directions.

II. RELATED WORK

With the increasing popularity of tools like Scratch, Snap, Alice, Blockly, TouchDevelop, and other introductory programming tools, computer science outreach has expanded significantly. Code.org, The Hour of Code, and Computer Science Education Week have exposed numerous K-12 students and teachers. Some workshops focus on K-12 students, such as [6], but provide research and advice for best practices like curriculum, content delivery, interfacing with schools, and even classroom layout. Other workshops tend to not only focus on the students, but also to directly train teachers, so that they be able to blend CT and CS into their classrooms. CS4HS has funded face-to-face workshops, like [7, 8, 9], that have shown to not only increase participants understanding of CT and CS, but also how to integrate it as a part of their curriculum. CS4HS has also began introducing MOOCs targeted for training K-12 teachers [10]. While reaching a significantly larger audience, this particular MOOC is still in its infancy stage; however, it has shown promise in delivering CT and CS training to K-12 teachers with a broader impact than traditional workshops. Other workshops include CSbots [11], which has worked alongside CS4HS to also develop introductory CS curricula for K-12.

While these interventions have helped develop curricula and approaches for teaching CS at the K-12 level, they have targeted in-service teachers and have been delivered as supplemental programs. Participants for these programs therefore embody a degree of self-selection: they have an interest in CT and have chosen to pursue it, which likely means they have a stronger degree of interest and confidence than the general body of teachers. If CT is truly to be integrated into the K-12 educational system, then it must also be addressed in *pre-service* teacher education, with future teachers who are less enthusiastic about CT. Our intervention targets this broader pre-service teacher audience, and seeks to develop methods for approaching them that can overcome fears and concerns they may hold about CT and CS.

III. INTERVENTION DESIGN

A challenge that emerges in trying to bring computational thinking into the current standards-driven K-12 educational system is finding time where it can be taught. The importance of high-stakes testing to school funding has had the practical

effect of increasing scrutiny on all activities students and teachers engage in. In most cases, this has the practical effect of aligning classroom teaching with test-taking norms: concentrating instructional time on tested content, teaching content in fragmentary pieces, and utilizing teacher-dominated pedagogical techniques [12].

Thus, to provide both a motivation and justification for using CT tools in the classroom, we chose to develop our example lessons which tied directly to these three subject areas. Hence, each lesson we employed needed to directly support not only CT instruction, but instructional efforts within the subject area it was embedded. This approach comes with additional benefits: it emphasizes the nature of CT as a *process* to be utilized rather than an end unto itself while also grounding the use of CT within the student's pre-existing sphere of experiences.

In designing our intervention, we drew upon Social Cognitive Theory and its concept of self-efficacy – an individual's belief that they can accomplish a particular task requiring a particular skill – which in turn shapes the learner's efforts and attitude towards the learning. Under this theory, self-efficacy can be improved in the following ways, listed in order of effectiveness [13]:

1. *Enactive Attainment* (mastery experiences) happens when the individual personally and successfully carries out a task requiring the skill in question, establishing that they can, indeed, accomplish it. Such experiences must be carefully balanced in terms of difficulty – tasks that are too easy are dismissed as trivial, and tasks that are too hard can lead to frustration and lowered self-efficacy.
2. *Vicarious Experiences* occur when the learner observes a peer carrying out the activity successfully, which leads the learner to believe that they should be able to accomplish it as well. It is critical that the learner consider the person they are observing a peer *in relation to the task*, simply being in the same cohort is not enough.
3. *Verbal Persuasion* occurs when the teacher (or other person) talks the learner into believing they are capable of carrying out the task.
4. *Psychological State* refers to the need for the learner to be in a receptive state for learning – calm, relaxed, and rested. Agitated, anxious, or self-conscious emotional states can short-circuit the learning process, countering the benefits of the above approaches.

Our intervention approach was built around all four of these factors. We carefully selected experiences that would be both attainable and challenging, and arranged them in increasing complexity. Our intervention was carried out in a classroom where students sat together in small groups around tables, and could observe one another succeeding at the task. Throughout the presentation we emphasized how the tools and approach we were using was appropriate for even elementary students (and thus, should be approachable for college students). Finally, we carefully structured the exercises to build from comfortable domains of knowledge to the pre-service teachers, and made

sure they knew success or failure in this intervention was not tied to a grade, only their participation.

IV. THE EXERCISES

For our two-hour intervention we designed three exercises. For each exercise, we opened with a brief discussion of what we were going to accomplish, followed by a brief follow-me demonstration using an overhead projector where we introduced the programming concepts as we used their related blocks, and then we let the students continue on their own, while instructors circulated through the classroom to address questions as they arose. We believe scaffolding the experiences in this way helps reduce the students' anxiety, ensures they have encountered and used all the skills needed to complete the task, yet it also leaves them to carry out the bulk of this work personally, leading to a sense of personal mastery. Once the class completed the task, we held a brief class discussion about how this introductory experience could be used and expanded upon in the classroom, as well as identifying specific CCSS and NGSS standards that mapped to it. Full exercise lesson plans and associated materials can be found on our website [14].

A. Scratch Music

The first exercise was selected from the domain of music education for several reasons: the domain was familiar to all of our students and it is also very far from their conception of what programming is. Nonetheless, both musical notation and programming are forms of symbolic representation, and sheet music, as a representation of notes to be played in a sequence, maps very well to imperative styles of programming like that embraced by Scratch.

The exercise itself consisted of transcribing notes from sheet music into Scratch "play note (n) for (b) beats" blocks. We demonstrated starting the program with a "When Green Flag is Clicked" block, and attaching the first few notes, then the students were turned loose to continue transcribing the music. As only a single Scratch block was required for the bulk of the program, this allowed students to focus on the physical act of connecting the blocks in sequence, and the mental act of applying the correct meaning to that block (by selecting the right note and duration). The task also offered immediate and ongoing feedback, as the students could click the green flag and hear the program play through all they had completed – and the choice of a familiar song, Beethoven's "Ode to Joy," ensured they would recognize any mistakes.

While the task was repetitive, it bore clear purpose and reward in that the students could hear the song coming together. Moreover, it remained mentally challenging throughout, without becoming overwhelming. Our approach was also open to inquiry: many students asked if (1) they could speed the music up, and (2) change the instrument playing. Rather than telling them how, we shared that there were blocks for both, and encouraged them to try to figure out how. Similarly, many students were able to realize how to play the bass line by starting a second script on their own. We would then have one of the first adopters of these techniques demonstrate what they had learned to the class; this ensured the students had all seen these blocks in use the end of the lesson.

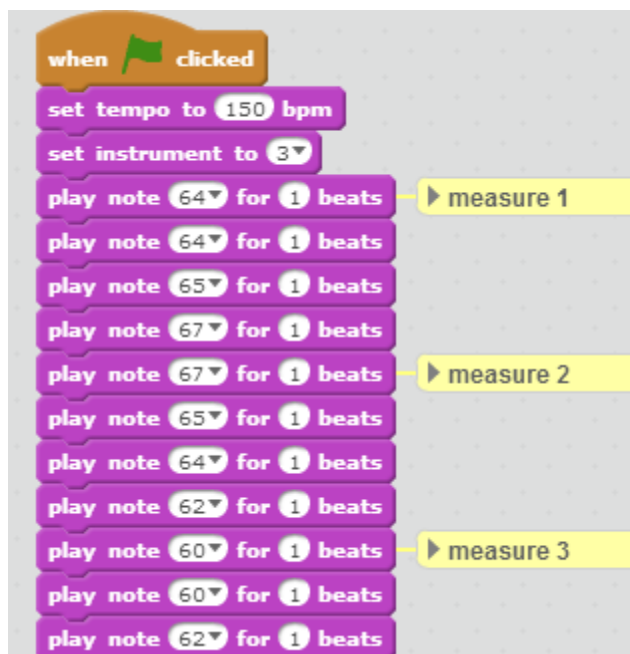


Fig. 1. Fragment of a music program written in Scratch; note how the commands snap together like puzzle pieces emphasizing the sequence of execution.

Before the discussion, we also introduced the use of operators to calculate the number of measures to wait before playing the second and third notes in the bass clef chords.

In this way, we quickly built the students' concept of *sequences*, as well as setting the conceptual foundations for *events*, *operators*, and *parallelism*. Moreover, the practice of playing the song as the students were building it firmly established the practice of *testing and debugging* early on. In addition, the song was short enough that all students were able to finish it in the allocated time, leading to both a definite sense of mastery and a diffusion of anxiety associated with programming.

B. Scratch Play

The second activity consisted of adapting a one-page script into what we called a *Scratch Play* – a multimedia animation carried out by a Scratch program. This exercise expanded considerably on the first one, introducing many features of Scratch including the *stage* – the area where multimedia actions unfold, *backdrops* – different images that can appear as the background of the stage, *sprites* – animated characters that appear on the stage and can be programmed with blocks, and *costumes* – different images the sprite can take on as their appearance. It also made use of many blocks from the *looks*, *motion*, *control*, and *events* palettes, a considerable departure from the first program which only used the *sound* palette.

Here we began by discussing the script and what challenges it posed. It involved three parts: the *dramatis personae* – the characters of the play, *stage directions* which indicated what those characters were physically doing, and the *dialogue* – what the characters were saying. After this brief discussion, we walked the students through choosing a backdrop and sprites to play the roles in the play. The students were invited



Fig. 2. The completed Scratch Play unfolding on the stage.

to choose any sprites and backdrops from Scratch's built in library, not just the ones we were using, and many did so – helping them to establish the program as “their own” and also embodying the perspective of *expressing*.

We then led the class through programming the first part of the script – demonstrating the blocks needed to get a sprite to speak, and rapidly switching costumes to create animations. We also introduced two ways of controlling timing – the use of “broadcast message” and “when I receive message” blocks, as well as “wait (n) seconds” blocks. Once all the necessary blocks and techniques had been introduced, we allowed the students to finish the exercise on their own, again circulating through the classroom to address questions.

This exercise delved much deeper into computational thinking concepts, including: *loops* (for creating animations from repeated costume changes), *events* (for coordinating different sprite's activities), and *parallelism* (as each sprite operates independently, at the same time). It also reinforced the practice of *testing and debugging*, as well as *being incremental and iterative*, and *abstracting and modularizing*. While this exercise required far fewer blocks than the music one, the variety and interaction of these blocks and multiple sprites made it more challenging, and in some ways, more rewarding.

C. Drawing Shapes

Our third exercise brought us into a more traditional programming area – using Scratch's turtle graphics functionality to draw shapes. In Scratch, each sprite can be equipped with a “pen” which, when “down,” draws lines on the stage as the sprite moves across it. By moving the sprite a set distance, rotating, and then repeating, a variety of shapes can be drawn. We focused on drawing regular polygons, starting with a triangle, for which we walked the students through the entire process. Once students had the triangle working, we challenged them to draw a square, and circulated through the classroom assisting students with questions. Students who finished quickly were challenged to draw more challenging

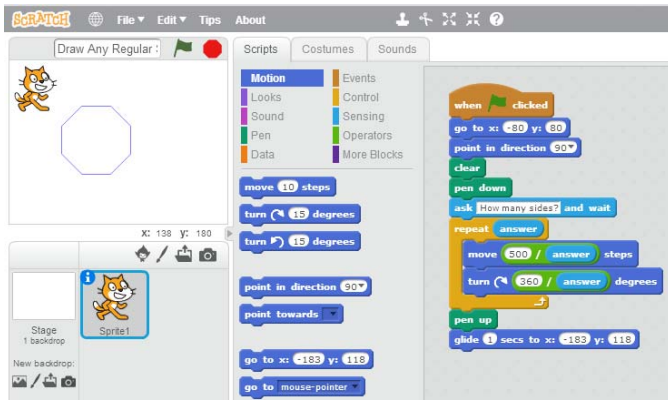


Fig. 3. Completed Scratch program for drawing any regular polygon, showing both the stage and programming area of the editor.

shapes, until everybody had drawn at least two regular polygons successfully.

At this point, we had students demonstrate drawing their different shapes, and compared the programs to see the similarities and differences, drawing out the observation that programs only differed in the number of sides drawn, the angle the sprite turned, and the distance it traveled between turns. From this, we suggested creating a general solution to draw any regular polygon, and introduced Scratch's "ask" and "answer" blocks as a way of implementing this. Working from student suggestions, we programmed and tested a general solution on the overhead.

This exercise led to some very fruitful discussion about how using Scratch can enhance learning. For example, when discussing how to calculate the angle the sprite needs to turn in the general solution, nearly every class suggested using the formula $180/\text{sides}$, drawing from their well-established understanding that the sum of the interior angles of a triangle is 180 degrees. However, the angles the Scratch sprite was turning were exterior angles – as such they add up to 360 degrees. Thus, students quickly saw that the exercise could lead to deeper theorizing and conceptualization of concepts introduced elsewhere. Moreover, nearly every student, once equipped with a general solution, tried to draw a shape with hundreds or even thousands of sides, resulting in a circle. We were able to capitalize on this curiosity pointing out that this is one way computers render circles – as an approximation formed by line segments or even points. Moreover, we pointed out that this process of approximation is the foundation of calculus, and by giving their students experiences with it now, they were laying the groundwork for future mathematics learning.

D. Closing Demonstrations and Discussion

To wrap up the intervention, we demonstrated several other Scratch projects we had developed for simulating a simple ecosystem in a drop of water (complete with a simplified representation of the chemical reactions involved in photosynthesis and respiration), and an engineering simulation to determine the optimal launch angle of a catapult (involving the transformation and transferal of energy from potential spring energy through rotational inertia and into ballistic motion). We then led a brief class discussion where students

suggested other ways Scratch could be used as part of their future teaching endeavors.

V. EVALUATION

To evaluate our approach, we developed a simple survey instrument – Teachers' Self-Efficacy in Computational Thinking (TSECT) – intended to capture a sense of the student's self-efficacy in utilizing programming and computational thinking within their future teaching endeavors. This survey was given as a pre- and post-test before and after the intervention; as this would consume part of our available time, it was kept short. A second, more nuanced version of the TSECT instrument was developed for our second iteration of the intervention, more closely based on Bandura's suggestions for measuring self-efficacy.

A. First Intervention

For the first intervention a series of ten items were adapted from existing self-efficacy instruments found in the literature, using a five-point Likert scale. The instrument's face validity was considered in the selection of items by the authors, who are all computer scientists with teaching experience. Item wording for this instrument can be found in table 1 below.

While the intervention was experienced by all students in the class, participation in the study was voluntary. Of the 126 students who began the survey, 2 answered no questions, and 8 did not answer any questions in the post-assessment; these students were left out of the analysis. Of the remaining 116 surveys, 9 contained missing values (0.3%) with no discernable pattern; these were classified as MCAR by the researchers and addressed with multiple imputations with five sets of imputed values, performed with SPSS 22.

A principal components factor analysis suggested the first

TABLE I. ITEM WORDING FOR FIRST TSECT INSTRUMENT

Item	Wording
1	I feel confident using computer technology.*
2	I feel confident writing simple programs for the computer.
3	I know how to teach programming concepts effectively.
4	I can promote a positive attitude towards programming in my students.
5	I can guide students in using programming as a tool while we explore other topics.
6	I feel confident using programming as an instructional tool within my classroom.
7	I can adapt lesson plans incorporating programming as an instructional tool.
8	I can create original lesson plans incorporating programming as an instructional tool.
9	I can identify how programming concepts relate to Common Core Standards
10	I can identify how programming concepts relate to Next Generation Science Standards.
Note: All items used a five-point Likert scale with options of: Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree.	

* Item excluded from TSECT scale measure

item “I am comfortable with computer technology” was too general to contribute meaningfully to the TSECT construct. Accordingly, a scale for TSECT was constructed by summing items 2 through 10. These nine items loaded onto one factor that accounted for 66% of the variance in TSECT. Chronbach’s Alpha was 0.935; the scale had good reliability.

A t-test of the pre and post-survey TSECT scale revealed a statistically significant increase in TSECT from pre ($M = 21.50$, $SD = 8.16$) to post ($M = 31.75$, $SD = 6.45$), $t(107) = 13.613$, $p < .0001$. Cohen’s effect size ($d = 1.316$) indicated a large positive effect.

This corresponded well to the researchers’ informal observations during the intervention – when the subject for the class session – the use of programming in education – was introduced, there was a palpable sense of rising anxiety on the part of the students. Yet by the conclusion of the session, the students were deeply engrossed with the activities, joking with one another, and eager to discuss other ways they might use programming in their future classrooms.

B. Second Intervention

For our second intervention, the instrument was significantly revised based on Bandura’s recommendations, which included focusing on specific skills and asking participants to rate their confidence on a 0-100 scale. We aligned items to lessons used in the intervention and content and practices identified in the Scratch assessment framework. We further separated the instrument into two theoretical constructs: Self-Efficacy for Computational Thinking (SECT) and Teaching Self-Efficacy and for Computational Thinking (TSECT). This instrument was again evaluated for face validity by the authors, who are all computer scientists with teaching experience. The item wording of these new instruments are found in Table II and III below.

Unlike the first intervention, the second intervention was plagued with technical difficulties, mostly arising from the switch in platforms from laptops to iPads (the College of Education had undergone a 1:1 adoption program between the first and second interventions, and had specifically requested the intervention be run on these newly-adopted iPads). Scratch is programmed on Adobe Flash, which is not natively supported on iOS. The intervention was accordingly adjusted to use Scratch Jr. (a native iOS app created by the Scratch team targeting younger students), and Scratch run in the Puffin browser. Unfortunately, while Puffin/Scratch had worked in the researchers’ tests, a new version of both was released days before the intervention, and the results of the interaction were buggy at best. We were also concerned that the interaction between Scratch and the Puffin browser would not allow for Scratch to play music (and Scratch Jr. lacks music blocks), so we struck the first exercise from the lineup and replaced it with an overview of Hopscotch, a similar but more limited and proprietary block-based programming framework.

Much like the first cohort, participation was voluntary, but even though the class sizes were comparable, far fewer

TABLE II. ITEM WORDING FOR THE SECOND TSECT INSTRUMENT

Item	Wording
<i>Items Aligned with CT Concepts</i>	
I can teach students to write programs that ...	
1	execute a step-by-step sequence of commands
2	uses loops to repeat commands
3	respond to events like pressing a key on the keyboard
4	do more than one thing at the same time
5	only execute some commands when a specific condition is met
6	perform arithmetic operations like addition and subtraction
7	can store, update, and retrieve values
8	can ask the user a question
<i>Items Adopted from earlier TSECT Instrument</i>	
With my future classes, I can ...	
9	promote a positive attitude towards programming
10	guide students in using programming as a tool as we explore other topics
11	use programming as an instructional tool
12	adapt lesson plans incorporating programming to meet my students’ learning level
13	Create original lesson plans using programming as an instructional tool
14	Recognize how programming relates to the Common Core State Standards
15	Recognize how programming relates to the Next Generation Science Standards
Note: All items used a 100-point scale where 0 = cannot do 50 = moderately I can do 100 = highly certain I can do	

submitted survey results. Of the 33 surveys entered, 7 contained no responses, and 4 did not contain post-survey results. These were left out of the analysis. Of the remaining 22 surveys, 17 contained missing values (77%). There was a clear pattern – missing items were concentrated in the pre-assessment; when only the post-assessment was considered, only 9 contained missing values (40%) and no discernable pattern was found. Surveys with less than 75% of items answered were left out of the analysis, and case-wise deletion was used for missing values.

TABLE III. ITEM WORDING FOR THE SECT INSTRUMENT

Item	Wording
<i>Items Aligned with Intervention Activities</i>	
I can write a computer program to ...	
1	draw shapes
2	animate characters
3	tell a story
4	play music
5	model plant growth
<i>Items Aligned with CT Concepts</i>	
I can create a computer program which ...	
6	executes a step-by-step sequence of commands
7	uses loops to repeat commands
8	responds to events like pressing a key on the keyboard
9	does more than one thing at the same time
10	only executes some commands when a specific condition is met
11	perform arithmetic operations like addition and subtraction
12	can store, update, and retrieve values
13	can ask the user a question
<i>Items Aligned with CT Practices</i>	
When creating a computer program I ...	
14	make improvements one step at a time, and incorporate new ideas as I have them
15	run my program frequently to make sure it does what I want, and fix any problems I find
16	share my programs with others and look at others' programs for ideas
17	break my program into multiple parts to carry out different actions
Note: All items used a 100-point scale where 0 = cannot do 50 = moderately I can do 100 = highly certain I can do	

The survey tool used by the researchers was designed for a mouse, and proved problematic when using the touch functionality of iPad and many participants reported issues with setting their response level. The researchers suspect this was the cause for much of the missing data – especially as it was concentrated in the pre-survey; as participants worked out how to correctly manipulate the interface they shared the techniques with their peers. Nonetheless, this pattern could also be due to participants being uncertain how to answer

TABLE IV. STATISTICAL ANALYSIS FOR THE SECT AND TSECT INSTRUMENTS

SECT Instrument			TSECT Instrument		
Item	P-Value	Cohen's Effect Size (d)	Item	P-Value	Cohen's Effect Size (d)
<i>Items Aligned with Intervention Activities</i>			<i>Items Aligned with CT Concepts</i>		
1	.001	1.65	1	.0001	2.42
2	.001	2.23	2	.00003	2.68
3	.01	1.57	3	.0002	2.32
4	.02	1.08	4	.0000008	4.17
5	.01	0.99	5	.0005	2.02
<i>Items Aligned with CT Concepts</i>			6	.0006	1.19
6	.02	1.09	7	.01	1.00
7	.001	1.81	8	.01	1.16
8	.01	0.79	<i>Items Adopted from earlier TSECT Instrument</i>		
9	.0004	1.59	9	.0001	2.09
10	.01	1.37	10	.00007	2.04
11	.009	0.78	11	.0002	1.82
12	.01	0.86	12	.0001	1.83
13	.02	0.78	13	.0001	1.98
<i>Items Aligned with CT Practices</i>			14	.002	1.80
14	.0005	1.79	15	.007	1.36
15	.001	1.59			
16	.00002	3.20			
17	.0001	2.08			

questions addressing specific CT constructs before encountering them in the intervention. Given this concern, along with the small sample size, the results of this analysis should be taken with a degree of caution.

After data cleaning as described above, responses of 11 students were analyzed. A one tailed, paired t-test was performed which revealed that the intervention had a statistically significant impact on both SECT and TSECT where $p < .05$, and a positive growth ranging from medium-to-large Cohen's effect size ($d > 0.75$). A Cronbach's Alpha of .96 indicates an internally consistent and reliable instrument.

The benefit of the re-worked instrument allows further investigation of how the students own understanding of computer programming and how they can integrate those computational concepts into their future classrooms.

As seen in Table IV, the intervention had considerable success in increasing pre-teacher computer science self-efficacy. Moreover, the re-worked instrument gives measures aligned to specific CT concepts, allowing specific intervention design questions to be addressed. For example, items 6, 7, 9, 10 show large effect sizes ($d > 10$) – an expected outcome of the intervention, as sequences, loops, parallelism, and conditionals were explicitly targeted in the intervention activities. Item 13, targeting the use of user input (ask and answer blocks in Scratch), had a much lower gain, even though it was a part of the generalized shape-drawing solution, suggesting this area may need more focus in future interventions.

While the CT constructs show to be meaningful in the SECT instrument, the TSECT instrument reveals a higher impact on the students' confidence in teaching CT in their future classrooms. This further suggests the accuracy of the instrument as the intervention emphasized on linking the computational thinking and programming concepts to potential integrations in the classroom. Another observation that leads to the students' confidence in teaching the CT constructs is their method of programming during the intervention. Students are able to employ computational thinking in a natural way, much like problem solving, while programming and the SECT items aligned with CT practices measures their confidence without directly asking them about programming practices, design, or principles.

VI. CONCLUSIONS

The intervention strategy of providing pre-service teachers with mastery experiences of using CT embedded within other subject areas was clearly successful in increasing their self-efficacy with CT. Both sets of evaluation data show a large effect. This was also reflected in students' end-of semester blog posts in comments like this one referencing the intervention:

I found a lot of value in learning about something that intimidated me, and learning to actually enjoy it. That feeling will be good to remember as I go into the classroom and teach students about things that they may be intimidated by.

Moreover, many students indicated their intent to use Scratch in their future teaching, recognizing that embedding Scratch programming into other areas can "[...] actually enhance lessons," and that "I really felt like I could apply this to my high school classroom which is something that I honestly did not feel for many of the other projects that we completed throughout the semester."

This growth is likely the result of directly confronting and breaking down students' preconceptions about programming – that it is difficult, only suited to a small portion of the population. Through mastery experiences, the students learn that they can indeed program, and may even enjoy it, even though they previously did not consider it a possibility. This

may trigger a similar shift in thinking about students' programming abilities. As one participant observes, "the students can create games, animations, art and anything they can think to make, all they have to do is drag and drop blocks."

VII. FUTURE WORK

While convenient for a pilot study, the limited duration of the intervention and tight bracketing of the pre- and post-instrument leaves long-term effects open to questions. A longer duration intervention, with repeated measures of instruments would give far richer data as well as support theory development about CT learning. Further, the authors believe that repeated use of CT throughout a pre-service teacher's training, especially integrated into their methods courses, will lead to both stronger self-efficacy and future adoption. Longitudinal studies to investigate this, along with the effect on those teachers' future pupils, are critically needed.

In considering the difficulty faced in carrying out the second intervention, and given the current penetration of the iPad platform into K-12 education, the authors have come to believe an iOS-friendly version of Scratch is necessary. The most attractive approach is to build a version of Scratch completely based on W3C standard technologies – i.e. HTML5, JavaScript, and Canvas or SVG – as this would ensure high cross-platform viability; as any platform equipped with a W3C compliant browser would be able to host it.

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GK-12 DISSECT: Incorporating Computational Thinking with K-12 Science without Computer Access

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Abstract—Computational Thinking (CT) introduces computing concepts and demonstrates their usefulness in many other disciplines. CT principles such as algorithmic problem solving, abstraction, modeling and simulation, are integrated into existing STEM (Science, Technology, Engineering, Mathematics) curricula by DISSECT (DIScover SciEnce through Computational Thinking). By pairing a local K-12 teacher with a graduate fellow, DISSECT provides instruction and resources as instruments that are pertinent to each specific discipline. These skills in problem-solving and abstract reasoning are necessary for students to be able to compete in the modern and future job markets.

DISSECT works to provide these skill-sets to students and classrooms that lack access to computers. The K-12 teachers and graduate fellows work together to develop modules that are capable of teaching CT concepts that are directly tied to their current curriculum while removing the need for access to computer systems. This paper will focus on the modules developed and executed in middle and high school classrooms, emphasizing the creative ways explored to operate in a computer-free environment discussing the strengths and weaknesses of different approaches, while qualitatively assessing student engagement, learning, and interaction which is gathered through teacher interviews, observations and informal talks with students.

Keywords—Computational Thinking, K-12, Graduate Fellows

I. INTRODUCTION

Computational technology is becoming more prevalent as the world evolves and its needs for technologically literate individuals increase. Computational thinking (CT) introduces concepts that are used in computing which are applicable in many other disciplines, especially scientific pursuits [1]. Individuals worldwide must have an understanding of these CT principles if they are to succeed in modern careers. According to the US Bureau of Labor Statistics careers in fields related to computer science are anticipated to grow between 15% [2] and 22% faster [3] than non-technical jobs through 2022 with an expected 4.2 million jobs available. Unfortunately as of 2010, there were 25 states that did not qualify CS courses as either a math or science course that a student could use towards their high school graduation. Furthermore there is a shortage of math and science instructors equipped with the experience and training necessary to teach these essential skills to students in K-12 education. This shortage of teachers is evident in the fact that there has been a 17% drop in computer science courses being offered in K-12 education since 2005 [4].

With the importance of CT skills in individuals it is critical that these skills be learned by students early in their education. The earlier these skills are taught, the stronger and more developed they will become as the student ages giving them an advantage in their future careers. Further, these skills are not only relevant to students practicing computer science but rather to any pursuit or area where critical thinking and problem solving abilities are required [5]. In contrast according to the Advanced Placement Data there were less than 30,000 students who attempted the AP CS test in 2013 [4]. Compound this with the declining interest in completing undergraduate degrees, especially among women and underrepresented minorities, in computer science and there is a responsibility to change these trends.

The DISSECT (DIScover SciEnce through Computational Thinking) program aims to combat these trends with an innovative technique of introducing CT into existing K-12 classroom courses. By integrating fundamental CT principles outside of traditional computer science courses, DISSECT is able to impact a much larger portion of students. DISSECT has chosen to focus on algorithmic thinking and problem solving abilities over the 2014-2015 school year which allows for easily combination with courses such as chemistry, biology, forensics, and literature. As only one course operating with DISSECT is a dedicated computer science course, this joint venture is enhancing far more students than traditional teaching methods would allow.

DISSECT operates by recruiting graduate fellows who are selected from graduate programs in the areas of Computer Science, Electrical & Computer Engineering, and applied computing such as Biology and partnering them to local K-12 instructors. The instructors are respected professionals working within the area who are selected by a panel of NMSU faculty and offer their expertise in the area of pedagogy to the fellows. In return the fellows bring their respective computing background to the table and together produce learning modules which introduce CT principles into the classrooms. Being a low-income area, though, many of the classrooms are unable to offer continued access to computer resources for these lessons and as such the fellows and teachers work together to ensure that their lesson plans are able to account for these limited resources and still provide an environment wherein learning ensues. DISSECT uses these limitations to investigate previously unexplored techniques in teaching CT. By approaching their current classroom curricula from

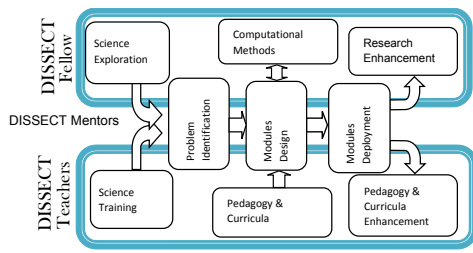


Fig. 1. Roles of Teachers and Fellows

a computing perspective, fellows and instructors are able to illuminate the underlying CT principles such as algorithms and problem solving that the students are already tasked to learn and provide them a fuller experience.

Throughout the remainder of this paper we will explain the approaches and methods that the graduate fellows and K-12 instructors are using to prepare their modules, their deployment, the techniques used to analyze their delivery, and an evaluation of the effectiveness thus far, placing particular emphasis on the pedagogical activities that expose CT skills with the use of actual computing technologies.

II. DISSECT

A. Concept and Design

Scientific computational thinking is the core concept in the DISSECT program. Even though computational thinking abilities are critical to all scientific pursuits ("All Science is Computer Science" [6]), the resources available in existing STEM courses and K-12 curricula are constrained and instructors have difficulties in providing the necessary environment for their students. DISSECT helps to provide these resources by recruiting graduate fellows with strong backgrounds in computational studies to be fellows in the program. This recruitment grants the fellows many opportunities they may not otherwise have including that of gaining an outside perspective towards their research area, training in pedagogy and communication of complex theories to people of limited experience and background, as well as leadership, team-building, and collaboration skills necessary to function in a group environment. The goals of the DISSECT program therefore are threefold, (i) to create more effective scientists in the recruited graduate fellows, (ii) to increase the levels of interest and future enrollment in STEM+C (science, technology, engineering, and math plus computer science) studies in future generations, and (iii) to help provide the recruited K-12 instructors with the necessary materials and background education to be able to continue creating CT enhanced modules and lesson plans in their classrooms.

By aiding the graduate fellows in becoming better scientists as a whole, the DISSECT program hopes to enhance the fields in which the fellows operate. As new discoveries and breakthroughs in computing have been forthcoming their applicability is not only to the domain of computer science but all sciences. By exposing the fellows to areas of research and topics outside of computer science, DISSECT hopes to inspire them to not limit their interests and efforts to this one domain but use this domain to further both computer science and other related areas as well. Furthermore, the training that the

fellows will receive in communication of advanced technical information to individuals of other backgrounds is vital in the workforce and academia where proposals and explanations must be given and understood by those around them.

The excitement that the graduate fellows have in their own areas of expertise is a factor that DISSECT leverages to inspire excitement in the fields of science and computing in the K-12 classrooms. As the fellows work with the instructors to create effective lesson plans and modules that introduce CT principles the students are able to experience these principles outside of the direct influence of computer science and apply them to many different areas of their academic pursuits. This direct application gives the students an understanding that areas of computing need not limit their options to working behind a desk always but instead can be combined with other interests they may have such as literature, forensics, biology, math, chemistry or physics.

B. Origins and History

The DISSECT program is funded by the National Science Foundation NSF under the Graduate STEM Fellows in K-12 Education (GK-12) program. One of the purposes of this program is for graduate fellows to integrate components of their research into K-12 classrooms. DISSECT believes that this is best accomplished by joining fellows with a K-12 instructor and having them collaborate to create modules that highlight CT concepts in their existing curriculum.

DISSECT utilizes the research and findings of both the Computer Science Teachers Association [7] and Computer Science Principles (CSPinciples) by CollegeBoard [8] in their efforts. The latter influence especially has served as an inspiration and guide to create modules that are completely integrated into the existing classroom curricula while exposing standardized CT principles in the K-12 classroom.

Since 2010, DISSECT has engaged 25 graduate fellows from the fields of Computer Science, Electrical & Computer Engineering, and applied computing (Biology, Psychology, Astronomy) and 16 middle school and high school instructors throughout the Gadsden Independent School District and the Las Cruces Public Schools District. The instructors have primarily been focused in science with a wide variety of subjects including middle school general science, forensics, zoology, biology, chemistry, as well as literature, history, and social studies.

C. Structure

The DISSECT program, as of the 2014-2015 school year, is comprised of 10 graduate fellows, 9 K-12 instructors from the Las Cruces Public School District, members of the New Mexico State University faculty from the departments of Computer Science and NMSU STEM Outreach Center, 1 program coordinator, and 1 external evaluator. The fellows work in conjunction with the instructors in classrooms around the Las Cruces, New Mexico, area to provide CT enriched lesson plans that are integrated directly into the existing curriculum. The fellows spend each week in the classroom presenting these lessons and directly communicating with and assessing the learning of the students with whom they are working. The instructors monitor and coach the fellows in the art of pedagogy

to help the fellows flourish as presenters and instructors under their tutelage. The fellows and instructors need to combine the existing K-12 curriculum, CT concepts, and the fellow's own research into the modules presented and are tasked with determining the appropriate blend of topics to be covered. The fellows as a whole meet regularly throughout the school year to brainstorm and devise techniques to better present the CT topics to their classrooms. Examples are detailed in Section V.

At the start of the academic school year DISSECT hosts an orientation meeting which allows all members of the program to be introduced to the goals and expectations of the current school year. Instructors and Fellows are required to meet at least an hour per week to plan for the classroom activities and module deployment. These meetings allow for cross-training between fellow and teacher in the arts of pedagogy and CT principles. K-12 instructors meet monthly with the program coordinator to discuss the status of the program, areas that need improvements, and ways to increase the benefits for their students. Graduate Fellows, the program coordinator, and NMSU faculty meet weekly to discuss modules that have been introduced or are in development, challenges encountered in the classroom and the ways to overcome them, and share their successes with each other.

All activities throughout the program are thoroughly documented so as to review and improve upon the success of the program. Weekly journals are required from the fellows and instructors that detail in length the preparation that went into the module presented this week, the activities undertaken in the classroom, and the evaluation of the benefits experienced by the students. Modules that are deemed extremely effective are documented in detail by the fellow and instructor so that all materials required are outlined and a step-by-step instruction for carrying out the module is presented. This is to give other instructors the opportunity to present the module in their own classroom without the benefit of the original fellow or original instructor being present. These modules are often repeated by the fellows in following semesters or the instructors in classrooms that the graduate fellow is unable to attend.

D. Components

The three components that comprise the DISSECT program are the graduate fellows from NMSU, the K-12 teachers in the schools, and the K-12 students who are affected by the CT instruction. The fellows benefit heavily from the program by becoming better researchers and educators. They learn how to communicate advanced technical information to a potentially non-technical audience in a way that is beneficial and relatable. The teachers benefit from the expertise of their graduate fellow and are able to learn how best to infuse their curricula with CT teachings. Finally the students benefit by being able to experience CT, even if they are unable to participate in a class that is dedicated to computing.

By participating in the GK-12 DISSECT program fellows obtain a deeper understanding of CT in order to demonstrate the underlying concepts present in the K-12 curricula and increase their presentation skills accordingly. Teachers discover that they need not disrupt their classroom or sacrifice valuable time in order to teach these skills to their students and as such are more likely to continue after their time with the fellow

is at an end. The students realize that CT is a concept that exists outside of computers and hopefully begin to understand the importance of learning these problem solving and critical thinking skills and begin to apply them throughout their lives.

III. CONTRIBUTION TO INOVATIVE PRACTICE

The work of DISSECT is innovative in that we are trying to find alternative methods to successfully teach CT to students without the use of computers. While many educators and researchers have already started integrating CT concepts into K-12 classrooms, most use programs such as Scratch [9] or App Inventor [10] or NetLogo [11] to facilitate teaching. For example, two schools in Connecticut investigated using App Inventor to introduce CT principles in the K-12 classroom for both students and teachers during a summer program. They created lesson plans that introduced App Inventor and gave activities for students and teachers to complete throughout the summer. At the end of the program they found that they were successful in promoting CT and STEM-C by using computer technology such as Android phones and tablets [12]. Other researchers from John Hopkins and Purdue focused their efforts on introducing CT principles to undergraduate students studying engineering. They found that by teaching these engineering students of all grade levels using Matlab that both the students' abilities in solving equations increased and their confidence in their abilities. Again, the influence of presenting computing in the engineering students' curricula provided positive results but relied on computer technologies to accomplish this [1].

A study from Purdue took an approach similar to what DISSECT has done to better prepare teachers and education majors with CT knowledge. For their study they created two 50 minute modules to be covered during one week which introduced CT in real-world applications in hopes of the educators being able to introduce this new knowledge to their own classrooms. After this week, participants were quizzed in their thoughts about CT and were able to distinguish CT from general computing activities versus the control group where most could not distinguish CT from computer related activities. Further, most of the participants saw the opportunity for integration and planned to implement it throughout their own curricula [13]. Using these results as a model, DISSECT has worked to integrate CT principles into K-12 classrooms by modeling the underlying algorithms that are present in the existing curriculum. This direct tie in allows students to gain an understanding of CT as well as a deeper understanding of the original curriculum.

IV. METHOD

As the goal of DISSECT is to incorporate CT into the teachers' current curricula, fellows and instructors work to showcase both the explicit and implicit ways CT is active in their daily lives. To accomplish the instructor-fellow team works together to create lesson plans for modules that integrate into the current curriculum. Modules are customized for a specific classroom subject, however, being that they are focused on the subject of algorithms most can be adapted to fit the requirements of other classrooms.

When creating modules, teachers and fellows utilize the inquiry based learning model [14] because it best captures

the computational thinking applications in the real world. The modules focus on asking students to develop their own methods for solving problems which implements the design-based learning aspect of the inquiry based learning model. For example, in the weather tool algorithm, students are asked to design an algorithm to create a weather tool such as a barometer. Having students create the algorithms themselves allows them to be innovative in their design while learning about the properties of temperature and weather.

When designing modules, fellows focused on the area of algorithms and the accompanying CT concepts. DISSECT has chosen algorithms as our key area for the 2014-2015 school year because algorithms are at the heart of CT concepts with every other concept stemming, either directly or indirectly, from them. The objective is for the fellows to demonstrate that algorithms are used, whether realized or not, in all subjects and that, when given thought, they can be optimized to produce more accurate or more efficient results. This is particularly easy in science classrooms where experiments are conducted and a specific algorithm must be followed.

Because DISSECT focuses its efforts in low-income areas [15], most of the schools the fellows and teachers are working in have neither immediate access nor continuous access to computers. This has proven to be a challenge for the graduate fellows and the teachers to teach computational thinking concepts to students in a straightforward manner. Rather, fellows are tasked to create modules that teach students these concepts without using computers or similar technological advances. A lot of the modules created focus on the design of the underlying algorithms. This is equivalent to the brainstorming a programmer does before starting to implement working code. For example, in the fingerprint search module discussed in detail in Section V, students are asked to write the steps needed to complete a fingerprint search. In this module, students write their answers in English, rather than a specific programming language or pseudocode, a theme that is prevalent in most of the modules used.

Algorithmic logic that are the focus of a couple of modules are abstraction and branching. Again, in these modules inquiry based learning is used but the implementation is through problem-based learning. Fellows design modules that have a problem statement or an article for students to read where students then have to extract the necessary information to answer questions and/or solve problems. This technique is demonstrated in the middle schools modules and again mimics real world environments in technical areas.

V. MODULES

The DISSECT fellows work with teachers in a variety of classrooms. The subjects that fellows are integrating CT modules that do not use computers in are Forensic Science, Computer Science, and 6th grade science. In the 6th grade classroom fellows integrate their modules in the areas of scientific practice, and meteorology. In the following section we will go over the vocabulary that DISSECT has deemed important for teaching CT and sample modules from the classrooms.

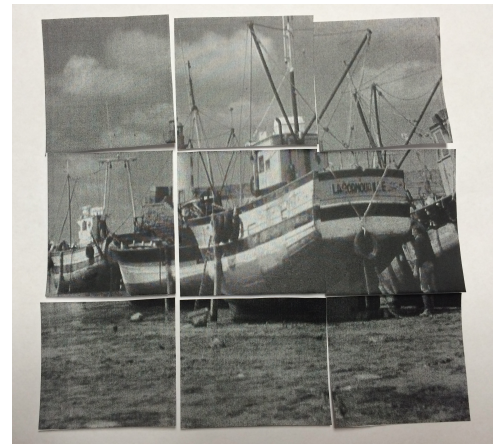


Fig. 2. Example of End Result of Image Reconstruction

A. CT Terms

The DISSECT fellows developed a set of 10 concepts that reflect our goal for teaching CT in the classrooms. *Computational Thinking* is a problem solving technique that uses methods from Computer Science. *Algorithm* is a step-by-step process for solving a problem. A *sequence of steps* is a list of steps to perform an action. *Branching* is making a choice that leads to different steps. *Iteration* is repeating steps until a condition holds. A *variable* is a named location that can hold a changeable value. *Abstraction* is a process of removing information from an idea in order to keep only the parts that are relevant to a problem. *Clarity* is a qualitative measurement of how easy an algorithm is to understand its function. *Correctness* is a measure of ability of an algorithm to solve the problem it is intended to. *Efficiency* is a measure of the resources an algorithm uses while solving a problem.

B. Example Modules

1) *Image Reconstruction Module*: This module is used in a forensic science class to show how the techniques are used in the real world. The students were engaged in a game to reconstruct images printed from USC image database [16]. Preparation for this activity includes selecting several images, mounting them on paperboard, and cutting each apart. The activity starts by distributing a piece of the image to each student. The students then need to ask other students questions to see if they have pieces of the same image. When a match is found the students form a group and continue looking for more pieces together. Example questions include asking about the color, shape or edges in the image. The students should gain an understanding of branching and iteration within an algorithm. An example image that is obtained after the activity is shown in Figure 2.

2) *Fingerprint Generation Algorithm Module*: This module is used in a forensic science class to teach students the importance of clarity in an algorithm. Students are expected to have experience in creating a 10-Print Fingerprint Card and are separated into groups of 2 or 3 and tasked with creating an algorithm that a person without any previous experience may follow to generate a successful 10-Print Fingerprint Card. The students must incorporate branching to determine if prints

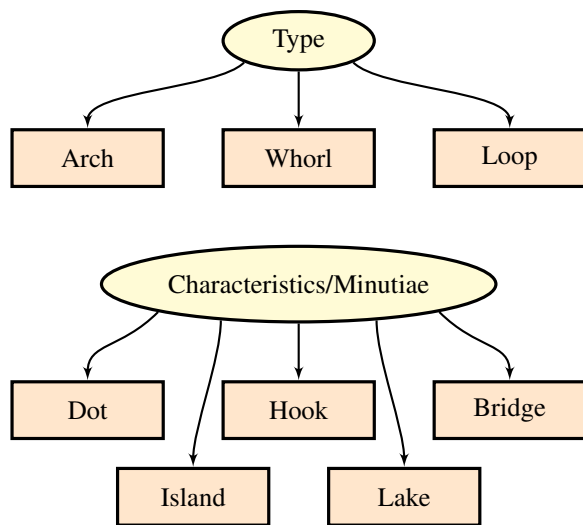


Fig. 3. Example of a Fingerprint Classification Algorithm

are successful and iteration to instruct the user in each finger. After the algorithms are generated they are collected and then administered to people outside the classroom to follow and the results are collected. At this point the results are returned to the students and a discussion ensues about why the results vary from what they expected. After this module, students have a better understanding of how to use iteration and branching to simplify a sequence of steps and a greater respect for the importance of clarity and correctness in an algorithm.

3) *Fingerprint Search Algorithm Module*: This module is designed to have the students create an algorithm to search fingerprints as well as review terms used in fingerprint identification. An example algorithm to search fingerprints is given in Figure 3. To prepare the module, a list of terms are written on index cards with a single term on each. The index cards are taped to the board in a random order. The students are instructed to create an algorithm to search for a fingerprint based on the characteristics listed, starting from most general to most specific. Students are called individually to select the next characteristic to search for. The CT concepts the students should learn about are algorithms and branching.

4) *Weather Tool Algorithm Module*: This module has the students building a weather measurement instrument and writing instructions for others to replicate their work. This module is divided into several days of instruction. On the first day the students are given a crossword puzzle with CT terms. This is followed by developing algorithms to draw shapes, first as an entire class then in smaller groups. On the second day, a warm-up involving writing an algorithm to draw a shape again is used. The class is divided into groups with two or three students. Each group designates a writer and supplier. The writers and suppliers are separated and given the supplies to build either a barometer or a weather vane as well as a picture of the completed tool. The students build and write instructions to build the pictured measurement instrument. On the final day, the groups are again split up and given instructions written by someone in the other group. This module is designed to introduce the ideas of clarity, correctness, and efficiency.

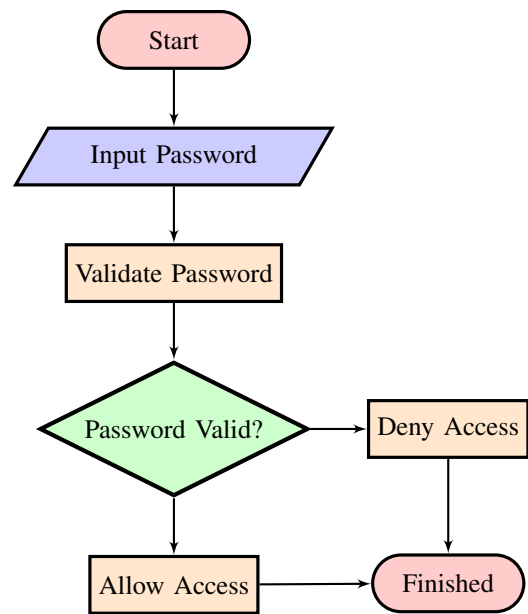


Fig. 4. Example of a Branching Diagram. The branch occurs at the green diagram, the 2 paths are represented by the "yes" and "no" arrows. Notice that both path lead to the finish.

5) *Rocket Branching Module*: This module introduces students to branching and abstraction by following true/false statements taken from an article about an event. In preparation for this module, an article on an event related to the subject in the class is obtained. Next, make a handout that contains true/false statements about the contents of the article. Based on the truth of the statement, there are directions given to move either North, South, East, or West a number of tiles. The students learn branching by following the true/false statements and ending up at the correct final location.

6) *Diagramming Modules*: This module teaches students how to plan out an algorithm through diagramming. Students work in groups to design a board game by diagramming out the rules. Students start by cutting out different shapes from colored construction paper. These shapes are labeled for different actions. Students then post the shapes in order on the wall to show a series of steps with arrows between shapes to show direction. A sample algorithm for checking a password is shown in Figure 4. This module introduces students to algorithm development and gives them a clear understanding of how branches and loops are used in algorithms.

7) *Binary Search Module*: This module has students writing instructions and following others on searching for an unknown page within a book. Students are grouped and given a large book and a secret page number for their group. Each group writes instructions that others can use to find a page within another book. The written instructions are shuffled between the groups and groups follow new instructions. After this an algorithm for searching the book based on a binary search is given to all groups. This module introduces students to algorithms and designing them. Also, clarity, correctness and efficiency are highlighted by discussing the instructions the students wrote and comparing the number of pages that need to be looked at.

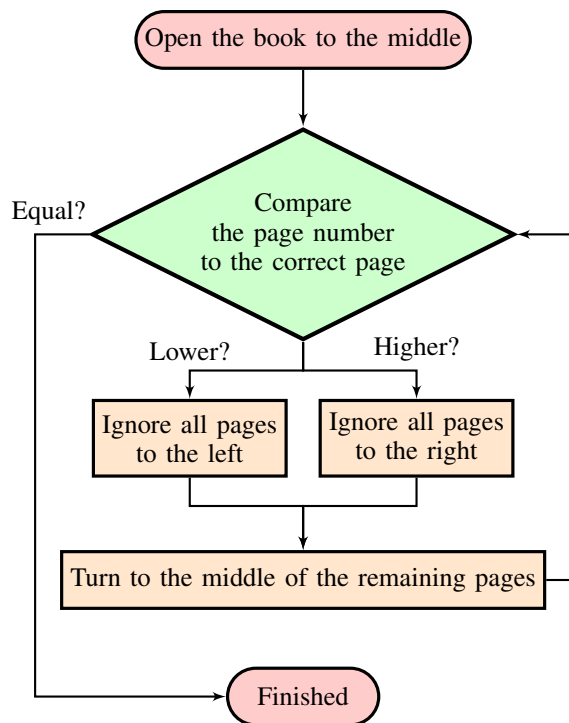


Fig. 5. A Binary Search Algorithm for a Book

TABLE I. RECOGNITION AND DEFINITIONS PAIRED T TEST RESULTS. THE T VALUE WAS TESTED FOR SIGNIFICANCE USING AN ALPHA OF 0.05. (* = $0.01 < p \leq 0.05$; ** = $0.001 < p \leq 0.01$; *** = $p \leq 0.001$).

Test	t Value	P Value	Significance
Recognition Fall	10.22	< 0.0001	***
Definitions Fall	9.02	< 0.0001	***
Recognition Spring	9.95	< 0.0001	***
Definitions Spring	12.28	< 0.0001	***

VI. EVALUATION AND RESULTS

A. Quantitative Evaluations

Students involved in the GK-12 DISSECT program were given a pre-test at the beginning of each semester and a post-test at the end of each semester. The students had continuous training in CT throughout the entirety of both semesters, consisting of a combination of modules taught with and without computers. The overall results can be seen in Table I. A combination of all of the classes showed a statistically significant increase in CT term definitions and recognition over the course of the semester.

More detailed module descriptions can be viewed at http://www.cs.nmsu.edu/gk-12/?page_id=460.

B. Individual Module Qualitative Evaluations

1) *Image Reconstruction Module*: Students seemed to understand what they needed to do to get a complete picture. The only challenge presented by this module was time; about 15 minutes were used to complete the module, and it most likely would be more successful if done in 20-25 minutes. Students liked moving around the classroom for the activity, and they were able to clearly see how iteration and branching

were used in the questions. Students appeared to enjoy the module, and they were quite vocal during the discussion of the concepts presented. This module successfully taught 11th and 12th grade forensic science students about how iteration and branching are used in image reconstruction without the use of computers.

2) *Fingerprint Generation Algorithm Module*: Students were initially surprised by the vast difference between what they believed their algorithm should generate and what the algorithm actually generated. As we discussed where deviations occurred, students were able to see how a lack of clarity and false assumptions led to incorrect results. After about 15-20 minutes of discussion the students then looked again at correcting their algorithms and were able to produce a clear and concise algorithm that generated the results they required.

Overall the students enjoyed this module and were amused by the results they received from their original algorithm and engaged in the process of improving the algorithm. This module successfully taught high school grade forensic science students about the importance of clarity and the use of iteration and branching used in algorithm creation.

3) *Fingerprint Search Algorithm Module*: In order to attempt to involve all of the students, the fellow and teacher tried to make enough terms on index cards so that each student could physically participate. For future modules of this sort, it may be more successful if students are put in groups. The module as a whole, however, was successful. Most students understood that they should look for general characteristics first, and follow with more specific characteristics. Students were able to understand how branching was incorporated in searching for a fingerprint. Students also learned what an algorithm is and how an algorithms can be depicted in psuedocode. Students were nervous at beginning of the module, but as it continued students became more confident in their choices and receptive to solving the problem of how to search for fingerprints based on characteristics. This module successfully introduced algorithms and branching as a method to search for fingerprints without the use of computers to an 11th and 12th grade forensic science class.

4) *Weather Tool Algorithm Module*: When rating each other's algorithms, the students often got confused between correctness and clarity; many gave a low correctness score because it was hard to understand. Also, they gave low efficiency scores because it took them a longer time to understand what they were supposed to do, which made the algorithm take longer, instead of evaluating the number of steps. There were no algorithms that were 100% correct, though some were close, while others were completely wrong. Most of the students were very confused by their partner's algorithms, which was the point of the module. This module demonstrated how in depth they had to go with their algorithms to make them clear, correct, and efficient. They really liked actually building something, and the kids who usually aren't engaged when doing writing exercises were very involved in the building process. This module successfully demonstrated how writing correct, clear, and efficient algorithms can be used to build weather tools in a sixth grade science class.

5) *Rocket Branching Module*: In this module, students had a lot of difficulty with remembering directions and abstracting

information. A lot of them had to do the activity multiple times before they got it right because they walked in the wrong direction, or didn't choose the correct answer. Students enjoyed physically exploring branching statements and getting out of the classroom. By the end of the module, students had a good foundation for understanding if/then branching statements. To improve this module, more time can be spent on practicing abstracting information after reading it. The module would be more successful and would take less time with older students. As a whole, this module successfully introduced branching statements and using abstraction to simplify a scientific article in a sixth grade science classroom.

6) *Diagramming Module*: Students were slow in understanding the concept of diagramming and its importance in problem solving. Because of this it is recommended that this module be presented over several class periods to give students the opportunity to better retain knowledge. Once students understood the idea and purpose of diagramming they greatly enjoyed working on this module and were proud of their work. They were able to create diagrams that were easily read and understood by others. This clearly demonstrates knowledge of clarity and correctness in algorithms. This module successfully introduced the idea of diagramming algorithms and using branching and iteration to problem solve in an 11/12th grade computer science classroom.

7) *Binary Search Module*: The students exclusively wrote a linear search for finding a page within a book. (e.g. "Look through the book, page by page, until you get to your page.") There was a wide range of success when the students followed directions provided by another student. Several students had incorrect instructions that stated to turn to the wrong page. Some of the instructions tried to make the search faster by opening the book to a random place to start as this would tend to be closer to the correct page. The algorithm given in Figure 5 checks few pages and doesn't rely on moving to the exact middle at each step.

VII. CONCLUSION

One of the goals of DISSECT is to teach CT principles to K-12 students while increasing interest in STEM+C. One of the obstacles of teaching CT in a traditional manner is the lack of continuous computer access in the classroom. This paper clearly demonstrates how DISSECT approached this problem and successfully incorporated algorithmic thinking and CT principles for problem solving into existing STEM classrooms. This success is demonstrated through both qualitative and quantitative analysis of the K-12 students by both the fellows and classroom instructor.

In order to develop modules fellows needed to pull out the underlying algorithms from classroom activities and curriculum lesson plans. Using this information the fellows, with instructor guidance, could then create modules to teach about developing algorithms and have students design their own algorithms, implementing the inquiry based learning module. Other times, the fellows focused on teaching individual portions of an algorithm such as branching, abstraction, and iteration, rather than a complete algorithm. Focusing specifically on a certain aspect of an algorithm has proven effective in helping students be able to better understand and apply the principle in other modules and classroom activities.

The modules developed by DISSECT were used in several disciplines from middle school general science through core and elective science classes taught throughout high school including graduating seniors and can easily be adapted for use in different settings. The modules are designed to be incorporated into the teacher's current curriculum, allowing them to supplement their current lesson plans in a way that allows them to achieve their goals while simultaneously incorporating CT principles. Algorithm design was the main concept focused upon in the modules because it is the center of most CT problem solving techniques. DISSECT felt that by teaching students the root of algorithm design the students would be able to have a strong foundation in applying these techniques to their future endeavors.

As seen in our results we had a statistical increase in CT knowledge after deploying these modules. The qualitative evaluation also shows that our modules were successful in the classroom. Most students understood the concepts we were trying to teach and had fun. This further engages students to participate in CT activities in the future.

In the future we would like to strengthen our methodology for creating modules for classrooms without computer use and better assess their effectiveness in the classroom.. Possibilities for better assessing CT knowledge is through the use of critical thinking questions. By adapting our pre- and post-test questionnaire to incorporate such questions we will be able to measure not only a taxonomic understanding of CT principles but also a conceptual and applied understanding. CT principles are applicable beyond the realm of computer science because they are skills that strengthen critical thinking, therefore by testing these skills directly DISSECT will be better able to assess the impact that the fellows and instructors are making in the classroom. Further, we will focus on ways to reach to students other environments than strictly those of a middle school and high school classroom. As the focus of DISSECT is to promote scientific computational thinking and we are innovating ways to achieve this goal without the use of computer technologies it is not necessary that we limit our reach to traditional areas of instruction.

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Computational Thinking and Impacts on K-12 Science Education

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Abstract — Jeannette Wing's seminal computational thinking (CT) paper, published in 2006, set forth CT as not just a way of looking at *computational* problems, but as an alternative approach to solving everyday problems. We strongly support Wing's assertion. Accordingly, we report the results of our meta-analysis of CT curricular implementations since 2006. Our principle interest is in CT framings and implementations for K-12 audiences in disciplines other than computer science, thus fulfilling the broad appeal and utility originally prescribed by Wing. We break CT down into its constituent characteristics, and split these characteristics into two principle groups: mechanistic (inextricably tied to and limited by computer science) and humanistic (separable from and adaptable beyond computer science). We use this conceptual bifurcation as a basis for selecting and analyzing implementations of CT for subsequent reporting. We summarize our CT meta-analytical results by distributional themes including grades, disciplinary foci, equity groups, and programming paradigms. In conclusion, we make recommendations for improving K-12 CT curricular implementations. Our hope is that utilization of CT characteristics and principles will become more commonplace in public education, be utilized more continuously through primary and secondary grades, and be inventively applied across a more inclusive range of academic disciplines.

Keywords — education, pedagogy, computational thinking, K-12, science education, computer science

I. INTRODUCTION

Jeannette Wing described computational thinking (CT) as "...solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science." (p. 33) [9]. The principle purpose of her seminal paper was to foster general application of thought processes and data/knowledge organizations that had been typically confined to computer science and computing technology. Wing supported broadening the applicability of CT in her statement, "One can major in computer science and do anything. One can major in English or mathematics and go on to a multitude of different careers. Ditto computer science." (p. 35) [9]. However, while Wing's paper has received significant attention from the computer science (CS) education community since its publication, we were aware of little application of CT beyond CS.

Therefore, in this paper we discuss our meta-analysis of the diversity and depth of academic studies related to CT *exclusive* of pure CS contexts. Our goal is to assess the extent to which

CT has been framed and implemented in K-12 and informal educational settings. To our knowledge, no one has published a similar meta-analysis of CT. A meta-analysis of this emerging field is warranted by virtue of its potential contributions to general education. The benefits include identification of characteristics of superior implementations, and illumination of pedagogical and developmental gaps among implementations. More broadly, this meta-analysis may contribute to increased discussions among CT stakeholders, which can do nothing but broaden and improve the state of CT research, and help to determine the limits of its efficacy.

II. COMPUTATIONAL THINKING DEFINED

A. Definition of CT from Wing (2006)

Given that our main purpose with this paper is to assess the evidence of CT in general K-12 education, it is essential that we settle on a definition of CT. Can we be sure that Wing [9] is the right starting point? Clearly, this is the case. Prior to Wing, Web of Science lists only four papers using the phrase, "computational thinking", in their topic descriptions. These papers, all of which precede Wing by at least seven years, are typically disjoint from her description of CT. From 2006 through 2014, Web of Science catalogs 167 papers that use the phrase in their topic descriptions. The vast majority of these papers clearly exhibit basic conceptual alignment with CT as described by Wing. In addition, 188 papers from Web of Science explicitly reference Wing. Among the combined pools of papers that use CT as a phrase in their description, and those that cite Wing, 115 of 240 papers (48%) do both.

Wing [9] frames CT by discussing aspects including who should use it ("...everyone, not just computer scientists". (p. 33) [9]), what kinds of problems are well suited to it (complex tasks or systems of tasks), the nature of answers it yields (degrees of precision), and how it consists of sub- and super-tasks (e.g. parallel processing, recursive routines, "...planning, learning, and scheduling in the presence of uncertainty" (p. 34) [9])

The characteristics of CT that Wing [9] discusses are presented in Table 1 in two categories. The white cells indicate *humanistic CT characteristics* that are related to thought processes such as formulating problems, weighing alternatives, and designing systems. The gray cells are *mechanistic CT characteristics* that are inextricably tied to computer science, traditional programming, and computer engineering. These

include operating system constraints, type checking, and aliasing. It is the set of eighteen humanistic characteristics that is the focus of this paper, as they embody the inclusivity for individuals and implementations that is a main thrust of Wing's paper. We decided to remove Wing's mechanistic characteristics from further consideration in the scope of this paper.

TABLE 1 - Elements of Computational Thinking from Wing (2006)

<i>Humanistic CT elements</i>	<i>Mechanistic CT elements</i>
problem solving	fundamental concepts of CS
designing systems	considering the OS
understanding human behavior	considering the machine's instruction set
considering resource constraints	interpreting data as code and code as data
reformulating problems by reduction, embedding, transformation, or simulation	generalization of dimensional analysis through type checking
thinking recursively	using aliasing appropriately
thinking in parallel	cost of indirect addressing or procedure call
decomposition and abstraction of large tasks	judging programs for aesthetics in addition to correctness and efficiency
suitable representations	suitable use of invariants
modularization	confidence of safe use of systems without intimate details
prefetching and caching	appropriate technical language
strategies for error correction and recovery	avoiding race conditions
heuristic reasoning	
planning, learning, and scheduling	
searching	
game theory	
using massive amounts of data	
choosing among tradeoffs	

B. Definition of CT from CSTA/ISTE

While the historical majority of CT research has been aligned with Wing's [9] articulation, we considered the possibility that Wing may no longer be considered the *de facto* definition. We found a couple additional definitions to consider in this regard. After analyzing these alternative definitions, we concluded that Wing's articulation should retain its status, but with a caveat, courtesy of several organizations involved in science and technical education.

From 2008 to 2010, the National Science Foundation's Directorate for Computer & Information Science & Engineering, then with Jeannette Wing as its assistant director, awarded three grants. The first was to the National Academy of Sciences to "...hold two workshops to explore the nature of computational thinking and its cognitive and educational dimensions." [6] This was followed by two grants to the International Society for Technology in Education (ISTE) and Computer Science Teachers Association (CSTA) to "...serv[e] as a national convener and consensus builder around defining a common language surrounding computational thinking..." and "...build [...] a shared understanding of computational thinking and prioritizing the strategies and resources that need to be developed to implement computational thinking in K-12 education.", respectively. [7] [8] The final product of these three grants was the Operational Definition of Computational Thinking for K-12 Education [2].

We note, and appreciate, that the Operational Definition [2] includes five habits of mind (such as tolerance for ambiguity) that are important for utilizing its six CT characteristics. These habits of mind are not mentioned in Wing's set of characteristics. While these habits of mind rationalize much about the design of the Operational Definition's set of characteristics, they did not factor into our meta-analysis.

C. Definition of CT from Google

Google's web sub-tree, called "Exploring Computational Thinking", is a component of Google for Education [4]. Google breaks down CT into four techniques: decomposition, pattern recognition, pattern generalization and abstraction, and algorithm design.

We found this articulation of CT problematic. For example, we consider pattern recognition to be a type of algorithm. Furthermore, we consider pattern generalization to be a product of the pattern recognition process...the ability to see commonality and generalize across sets of patterns *by virtue of* an abstraction of an algorithmic solution. In general, we consider the Google articulation of CT confusing because of hierarchical, cyclic, and overlapping constructs.

D. Choosing among the alternative definitions

Of the three CT alternative definitions, we viewed Wing's [9] and the Operational Definition's [2] articulations to be superior to Google's [4], so we proceeded to consider just the first two alternatives.

The Operational Definition [2] consists of six general characteristics compared to Wing's [9] eighteen more narrowly focused characteristics. In some cases, an Operational Definition characteristic is approximated only by aggregating several of Wing's characteristics. For example, automation of solutions through algorithmic thinking, combines several of Wing's characteristics including heuristic reasoning, planning, learning, and scheduling. Formulating problems in computational terms combines multiple characteristics from Wing including reduction, embedding, parallelism, recursion and modularization. The Operational Definition includes the important aspect of intelligent data organization, a characteristic notably absent from Wing (2006). Computer scientists often consider the various usage cases of data when

designing structures to contain them. Only one of the Operational Definition's CT characteristics specifically mentions computing ("Formulating problems in a way that enables us to use a computer and other tools to help solve them."). Even here, the characteristic is cast in terms that are not exclusively computational. All of the other Operational Definition characteristics are cast in terms that are agnostic with regard to computing.

We constructed a conceptual map relating Wing's [9] CT characteristics to those of the Operational Definition [2]. This exercise was instructive in that it illustrated the complexity of the interrelationships between the characteristics. In a number of cases, one author's characteristic was split into multiple characteristics by the other author. In other cases, separate characteristics from one author were combined by the other. Only three characteristics (consideration of resource constraints, decomposition and abstraction of large tasks, and modularization) were linked to a single characteristic from the other definition. At the other extreme, eleven of Wing's characteristics mapped to the tool-appropriate problem formulation characteristic of the Operational Definition, Eight of Wing's characteristics mapped to the automated algorithmic thinking characteristic from the Operational Definition.

Though the per-characteristic interrelationships between Wing [9] and the Operational Definition [2] were convoluted, the respective conceptual breadths of the sets of characteristics were very similar. This realization informed us to consider a superset of CT characteristics formed by combining Wing's articulation and that of the Operational Definition. From this superset, we eliminated three characteristics of Wing that, to us, seemed to be inapplicable based on their generality (solving problems, designing systems), or their inappropriateness for K-12 audiences (using massive quantities of data). However, aside of these exceptions, we considered Wing and the Operational Definition to be conceptually and functionally similar, though at two different levels of granularity.

III. METHODOLOGY

The purpose of this paper is not to expand the wealth of writing about computational thinking, but rather to attempt a meta-analysis of all writing on the topic and distill tangible evidence of educational impacts outside of computer science from the body of work. To our knowledge, a similarly focused meta-analysis has not previously been conducted.

Consistent with our purpose, we searched for CT-related academic writings using four sources: the Web of Science (WOS), the digital library of the Association for Computing Machinery (ACM), the digital library of the Institute for Electrical and Electronics Engineers (IEEE xPlore), and Wiley Online Library. The first and last sources are general repositories of academic writing. The second and third sources are, respectively, specific to computing, and generally focused on technology.

The first stage of searching sought to capture all writings that were possibly influenced by Wing [9]. As much as possible, we searched the four digital libraries similarly. We searched for "computational thinking" in the title, abstract, and topic text, except for the ACM digital library, which does not

offer topic metadata searching. An additional first round search of WOS was performed for all publications that referenced Wing.

TABLE 2 - Literature Search Stages by Source

Stage	Criteria for selection	Sources				
		WoS	IEEE	ACM	Wiley	total
1a	abstract contains topical word string	167	70	177	148	
1b	paper references Wing (2006)	188				750
2	paper is unique	240	67	177	148	632
3	title of paper indicates a plausible fit	230	65	174	52	521
4	abstract clearly meets topical criteria	45	9	47	1	102
5	full paper clearly meets topical criteria	17	4	20	0	41

The second stage of literature selection eliminated duplicates occurring between databases or between different searches of the same database. Duplicates were identified by matching title, author, and year of publication. As might be imagined, there was significant overlap between the two types of WOS searches (115 duplicates, Table 2). However, the degree of mutual exclusivity of the respective databases, with respect to CT, was surprising to us. Of the 395 non-WOS papers, only three were found in WOS. No papers whatsoever were found in common between the non-WOS databases.

The third stage of literature selection eliminated papers that seemed to only be related to traditional forms of programming (e.g. programming with the C language rather than assigned-function physical blocks). We also eliminated papers that were not related to education, learning, or cognitive processes. The vast majority of the Wiley writings were eliminated in this stage because they focused on professional biosciences where traditional computing was used as a simulation or analysis tool.

The fourth stage of literature selection involved reading the abstracts to explicitly evaluate the relevance of the related writings. Abstracts had to clearly meet the following criteria.

- Pedagogical or curricular implementations must have been completed. Implementations that were merely proposed, but not classroom tested, were eliminated.
- Implementations must have targeted a subset of grades K-16. Though this paper ultimately focuses on K-12, we thought that extending the literature search range into college would, potentially, identify implementations that could be *adapted* to high school or younger audiences.
- Implementations that abstracted programming functionality in non-traditional ways were accepted even if it was mixed with traditional programming.

- Implementations must have included non-CS majors and focused on disciplines and majors outside CS.

Table 2 shows that the fourth literature selection stage was the most discriminating, eliminating 80% of papers from further consideration. Web of Science papers were retained at a 20% rate, and IEEE xPlore papers were retained at a 14% rate. Only one Wiley paper was retained in this stage. By contrast, the ACM digital library papers had the best retention rate (27%).

The fifth and final literature selection stage involved full readings of the papers that passed stage four. Sixty percent of the remaining papers were culled out of this stage, with the principle reasons for rejection being...

- proposed or in-process implementations, rather than completed implementations
- reports on teacher workshops about CT implementations
- implementations for teachers only
- implementations for CS students only
- implementations based on conceptions of CT that did not fit the descriptions found in Wing [9] or the Operational Definition [2]

Forty-one (<6%) of the original set of 750 (632 unique) papers remained at the completion of our literature selection process. We then completely scanned (visually and electronically) for text strings or text string stubs (e.g. parallel*, abstract*, algorithm*) matching any of the characteristics of CT as articulated by either Wing [9] or the Operational Definition [2]. We reasoned that authentic implementations of CT were likely to mention the specific characteristics they utilized. We now present the results of our search for specific CT characteristics in the final group of CT candidate papers.

IV. IMPLEMENTATIONS USAGE OF CT CHARACTERISTICS

A. Wing's CT characteristics

Two concepts, decomposition of large tasks and abstraction of data representations, were used in sixteen and fifteen implementations, respectively. Beyond this, as can be readily seen in Table 3, the usage of Wing's [9] characteristics dropped precipitously. Eight of Wing's 15 characteristics were referenced by one or zero implementations. Modularization was mentioned only twice, which struck us as inconsistent with the frequent mentions of large task decomposition. Searching, one of the most basic and essential algorithm classes, was mentioned by only one implementation.

B. The Operational Definition's CT characteristics

Sixteen papers mentioned abstraction of methods or data representations from the Operational Definition [2] in their implementations. In four of the papers, this was the only CT characteristic they mentioned. Automation or algorithmic development was mentioned by nine of the implementations. Aspects of problem formulation were mentioned by six of the implementations. Only three (19%) implementations cited a majority of the characteristics identified in the Operational

Definition. Two of these implementations are discussed in more detail later in this paper.

TABLE 3 - Selected implementations' usage of Wing's CT characteristics

<i>Humanistic CT characteristics from Wing (2006)</i>	<i># of imps. using (max 41)</i>	<i>% of imps. using</i>
decomposition and abstraction of large tasks	16	39.0%
suitable representations	15	36.6%
planning, learning, and scheduling	5	12.2%
reformulating problems by reduction, embedding, transformation, or simulation	4	9.8%
thinking in parallel	4	9.8%
choosing among tradeoffs (optimization)	3	7.3%
modularization	2	4.9%
strategies for error correction and recovery	1	2.4%
heuristic reasoning	1	2.4%
searching	1	2.4%
understanding human behavior	0	0.0%
considering resource constraints	0	0.0%
thinking recursively	0	0.0%
prefetching and caching	0	0.0%
game theory	0	0.0%

TABLE 4 - Selected implementations' usage of Operational Definition's CT characteristics

<i>CT Characteristics from Operational Definition (2011)</i>	<i># of imps. using (max 41)</i>	<i>% of imps. using</i>
represent data (and methods) abstractly through models and simulations	16	39.0%
automate solutions through algorithmic thinking	9	22.0%
formulate problems that enables us to use a computer and other tools to help solve them	6	14.6%
logically organize and analyze data	4	9.8%
optimize a solution among competing solutions	4	9.8%
generalize and transfer problem solving process to other problems	1	2.4%

In the next section of our meta-analysis, we focus on identifying themes among the 41 implementation papers that passed all stages of our literature selection process.

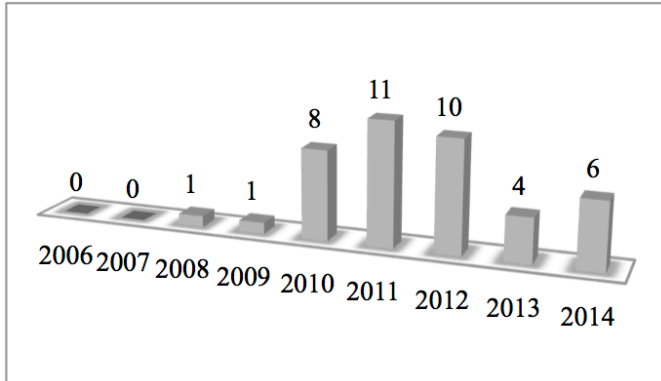
V. DISTRIBUTION THEMES IN CT IMPLEMENTATIONS

Here we present a few of the dimensions along which our select group of papers can be considered.

A. Distribution by publication year

Figure 1 shows the frequency of selected implementations by publication year. After several years of none to few papers that fulfilled our selection criteria, a significant increase started in 2010, proceeded into 2011, slightly declined in 2012, and finally declined significantly in 2013. There were somewhat more implementations in 2014.

FIGURE 1 - Selected Humanistic CT Implementations Per Year



B. Distribution by educational grade level

Table 5 shows the frequency of CT implementations per grade from kindergarten through senior year of college (note: two implementations did not clarify their grade applicability and were therefore eliminated from the table). Dark colors represent relatively small numbers, indicating a lack of implementations for some grade levels. Light colors represent relatively large numbers and an abundance of implementations for that grade. Very few implementations applied to elementary grades. Significantly more implementations applied to middle school grades. Fewer applied to high school, and college grades had another relative abundance of implementations. The reason college freshman had more implementations than either high school seniors or college sophomores, was two freshman-only implementations.

TABLE 5 - Computational Thinking Implementation Frequency by Grade (dark gray is least; white is most)

Primary					Middle			High				College				
K	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
4	3	4	5	5	4	14	14	14	9	8	8	8	17	15	13	13

While Table 5 is a summary by grade, Table 6 shows grade level details of the selected implementations. The shaded rows to the right of the publication year indicate the grade ranges for each implementation. The shading of the row is determined by the span of years (grade range) of the implementation. For example, some CT implementations spanned K-12, a range of 13 grades. This was the widest range and is colored dark gray. At the opposite extreme, single year implementations are shown in light gray. The vast majority of implementations were confined to only one school level (e.g. only to elementary school). However, Table 6 shows nine implementations spanned school levels. Three implementations spanned three

school levels. Twenty-seven implementations covered four or more grades. Of these, twelve implementations were restricted to the college level.

TABLE 6 - Computational Thinking Implementations by Author, Year, and Implementation Grade Range (light gray is most grade focused; dark gray is least grade focused)

Author	Year	Elementary					Middle			High				College				
		K	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
B. et al.	2014	■																
W.	2012	■	■	■	■	■												
G., et al.	2012	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
R., et al.	2010	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
W.	2010			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
S.	2011				■	■	■	■	■	■	■	■	■	■	■	■	■	■
B., et al.	2014							■	■	■	■	■	■	■	■	■	■	■
B., et al.	2013							■	■	■	■	■	■	■	■	■	■	■
B. & K.	2012							■	■	■	■	■	■	■	■	■	■	■
G. & K.	2011							■	■	■	■	■	■	■	■	■	■	■
W. & R.	2013							■	■	■	■	■	■	■	■	■	■	■
W., et al.	2012							■	■	■	■	■	■	■	■	■	■	■
W-J	2014							■	■	■	■	■	■	■	■	■	■	■
B., et al.	2011							■	■	■	■	■	■	■	■	■	■	■
T., et al.	2013							■	■	■	■	■	■	■	■	■	■	■
B., et al.	2010							■	■	■	■	■	■	■	■	■	■	■
W., et al.	2010							■	■	■	■	■	■	■	■	■	■	■
W., et al.	2011							■	■	■	■	■	■	■	■	■	■	■
Y.	2013								■	■	■	■	■	■	■	■	■	■
A., et al.	2012									■	■	■	■	■	■	■	■	■
F., et al.	2012									■	■	■	■	■	■	■	■	■
S.	2012									■	■	■	■	■	■	■	■	■
T. & P.	2011										■	■	■	■	■	■	■	■
F., et al.	2010											■	■	■	■	■	■	■
L. & W.	2012												■	■	■	■	■	■
B., et al.	2011													■	■	■	■	■
K., et al.	2014														■	■	■	■
A.	2010															■	■	■
C., et al.	2012															■	■	■
C. & J.	2011															■	■	■
D., et al.	2011															■	■	■
F., et al.	2010															■	■	■
H., et al.	2008															■	■	■
L. & H.	2010															■	■	■
M., et al.	2014															■	■	■
G., et al.	2014															■	■	■
Q.	2009															■	■	■
S.	2011															■	■	■
Y., et al.	2011															■	■	■

C. Distribution by disciplinary focus

Twenty-two (54%) of the selected implementations applied to general studies. Twelve (29%) were non-CS STEM oriented, and 7 (17%) were humanities focused.

D. Distribution by equity group

Thirteen implementations (32%) were designed with one or more equity groups in mind. Of these, girls were the most frequently targeted (six) equity group. Hispanic and Latino students were specifically mentioned in four implementations. African-American students were explicitly mentioned in three implementations. Other specifically mentioned equity groups were underachieving students (two), and students with disabilities (one).

E. Distribution by approach to programming

To reiterate, implementations that completely depended on traditional languages such as C, C++, and Python, were

dropped by our literature selection process. We considered these to be more typical of CS-specific implementations of CT and therefore outside the scope of this paper.

Thirteen (32%) implementations did not program at all, and instead used puzzles, creative writing, visualization, and interactive and online systems, as tools to teach characteristics of CT.

The remainder (68%) of the implementations used one or more game-development frameworks or visual language tools to teach CT skills. These tools included Alice, a program developed at Carnegie Mellon University for building virtual environment worlds; AgentSheets, a visual programming environment designed by researchers at the University of Colorado at Boulder; Scratch, a visual logic simulator from the Massachusetts Institute of Technology; VPython, a 3D graphics development system based on Python; Lego Mindstorms, for programming customized robot behaviors; and Kodu, a game development environment from Microsoft Research

VI. OBSERVATIONS ON META-ANALYTIC DATA

Here we list some observations regarding the data offered in the sections on literature selection, implementations' usage of CT characteristics, and distribution themes.

Only one paper from the Wiley database search made it through the fourth selection round. In fact, the titles of papers from the Wiley search indicated significantly less topical fit with our conception of computational thinking than other databases. Considering that the Wiley database encompasses a number of top education journals, this was very surprising to us. To corroborate this finding, we conducted several mini-searches of top education journals. These searches supported our initial interpretation of the Wiley database search result: educational research and computing-at-large seem to have little commonality in research literature.

The grade distribution of selected implementations from Table 5 was interesting in that there were fewer high school implementations than middle school. We expected either a more uniform distribution or gradual escalation of implementations from middle school, on to high school, and through to college.

Table 6 shows that nine implementations spanned multiple school levels (e.g. middle into high school) and six implementations spanned seven or more grade levels.

The extent to which our 41 selected implementations utilized CT characteristics in a piecemeal fashion surprised us. Not only were the majority of characteristics used little or not at all, a significant number of the authors cited CT characteristics which are not mentioned in either Wing or the Operational Definition.

VII. CONCLUSIONS

The Operational Definition's [2] CT characteristics provide a very useful adjunct to Wing [9]. Together, these two sets of characteristics provide different levels of detail yet have a high degree of conceptual overlap. Taken collectively, they help

explain CT more broadly and more effectively to a wider range of audiences than either does individually.

The degree to which Wing's [9] ideas about computational thinking have been implemented for disciplines other than computer science is small. Of 632 unique papers related to computational thinking, less than 7% met our selection criteria. This surprised us and led us to consider root causes for the lack of generalized application of CT.

Of papers implementing CT according to our selection guidelines, less than half utilized any characteristics of computational thinking as articulated by Wing [9] or the Operational Definition [2]. Further, among this subset of selected implementations, only one offered a complete set of CT characteristics. The typical implementation utilized three of fifteen characteristics from Wing, and two of six characteristics from the Operational Definition. As a result, we weighed the positive and negative impacts of less-than-complete CT implementations.

The distribution of the selected implementations, as a function of grade level, was uneven. The average number of implementations for elementary grades was four, while the average number for middle school grades was fourteen. High school grades averaged eight implementations. For several reasons, we considered this to be less than ideal for advancing students' use of CT as they progress from kindergarten through high school. We think the broad range of grades for some of the implementations may hinder their effectiveness by diluting their age-specific pedagogical criteria. In addition, the uneven distribution of implementations may mirror uneven scholarship connecting technical education to cognitive development. Finally, in terms of building academic momentum, especially for students interested in technical fields, we considered distributions that are flat or increasing over the grade range preferable to the low-high-low-high pattern we observed.

A couple excellent examples of CT implementations for non-CS students emerged from our selection process. Basawapatna et al.'s [1] implementation incorporates aspects of all Operational Definition characteristics. Using a game development and prototyping environment, 6th grade students associate agents with behaviors (an example of abstraction) that are simultaneously applicable to physical world phenomena (e.g. absorption) and games (e.g. predator/prey). Varying the parameters of the behaviors (an example of competing solutions), students pick the optimal parameter set for a given phenomenon, analogous to optimization for game play. Chaining outcomes of agents' behaviors fosters students' algorithmic thinking and planning.

Dierbach et al.'s [3] college-level implementation addressed four of the six Operational Definition characteristics. The authors initiated interest in computational thinking through a freshman seminar class and subsequently developed individual CT implementations for the humanities, music, kinesiology, and sociology departments. Common course goals included modeling, algorithm development, assessment of problem solvability and tool selection, and algorithm assessment. Additionally, faculty developed domain-specific CT-oriented goals for each of the implementations. For example, one of the goals for the CT music course was

“Demonstrate understanding of how sonic and visual information can be modeled through analysis, decomposition, abstraction, and alternate forms of representation in computational systems” (p. 260) [3]. Post implementation data indicated that more than 75% of students successfully applied CT characteristics within their respective domains. However, 45% of students reported having some confusion about CT. An overwhelming majority of administrators associated with the four implementations recommended using CT in diverse curricular settings beyond CS, math, and science.

We believe CT characteristics are confusing to educational researchers and educators alike, outside of CS circles, and our study identified a number of symptoms of this confusion. The symptoms included implementers citing CT characteristics that were not mentioned in Wing [9] or the Operational Definition [2], the dearth of non-CS implementations of CT, the lack of implementations’ use of CT characteristics excepting abstraction and algorithmic thinking, and students and teachers alike expressions of confusion about using CT in classroom implementations.

VIII. RECOMMENDATIONS

To answer the question begged by this paper’s title, “Does Computational Thinking impact K-12 science education?”, we respond, “No, but it could and should.”, and, to paraphrase Wing, “Ditto, non-science education, where it makes sense to do so.” At this point, not enough evidence exists to assess the limits of CT’s utility. Until this evidence exists, all efforts should be made to try CT in as diverse a collection of pedagogical circumstances as possible.

We recommend that educators wanting to incorporate CT into their teaching, and computer scientists wanting to get CT out of the computer lab, start talking and keep talking...together. Educators need to articulate what it is about CT that they don’t understand. Computer scientists, ironically, need to think abstractly (e.g. traditional programming is but *an instance of abstraction*) about elements of their craft and be ready to answer educators in non-CS terms. The bottom line is that conversations between computer scientists, educators, educational researchers, and non-CS scientists are invaluable, but happen all too infrequently. All of these groups were represented at the second NSF workshop on computational thinking. The report from that workshop contained significant contributions from educators and education researchers, and played no small role in the creation of the Operational Definition.

We also recommend that the Operational Definition for Computational Thinking [2] be considered as much a cornerstone document of CT as Wing’s 2006 paper [9]. Though the Operational Definition is more general than Wing, we judge it to be more readable by non-CS audiences. Furthermore, the section on dispositions and attitudes is wonderfully clear in depicting the right mindset for any application of CT, and the nature of the problems to which CT is best suited.

We recommend that classroom CT implementations be informed by educational psychology. Students’ cognitive abilities should determine the pedagogical CT mechanisms that are used to teach the topic at hand. Here again, more data from classroom CT implementations are needed to help determine what pedagogical CT mechanisms are effective for students at different levels of cognitive development. This is but one aspect of personalizing CT. As Roy Pea said in the first NSF workshop, “Connecting computational thinking in a personally meaningful way is at the heart of tackling the problem of how everyone can be brought into a pathway for developing and using computational thinking in their everyday lives.” (p. 6) [5]

Finally, once data of sufficient breadth and depth has been collected on CT implementations, educators and computer scientists should reconvene to discuss assessment. As it stands, the absence of a standardized assessment instrument to measure learning outcomes makes it harder for scholars to measure the effectiveness of current K-12 CT implementations. However, any effort to produce CT assessments at this point would be sorely under-informed by the present state (low volume and high variability) of CT classroom implementation data.

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DISSECT: An Experiment in Infusing Computational Thinking in a Sixth Grade Classroom

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Abstract—This paper summarizes the successes and challenges encountered during the incorporation of the New Mexico State University DISSECT (DIScovering SciEnce through Computational Thinking) Fellowship program into a 6th grade classroom. Graduate student fellows work with experienced K-12 teachers to create and deploy interactive computational thinking (CT) modules in middle and high school classrooms that promote active learning through the use of technology and cutting edge scientific research. One of the main objectives of the DISSECT program is to facilitate the professional development of graduate students in computing-rich fields, such as engineering, computer science, and biology, through leadership development, public speaking experience, and an enhanced vision of how CT is vital to in all scientific disciplines. The alliances formed between K-12 teachers and their fellows provide an opportunity for teachers to attain knowledge of CT principles and equips them with the ability to develop and continue their own future lesson plans integrating CT. This paper thoroughly describes specific modules that integrate CT concepts into the traditional 6th grade science curriculum, the statistical results of assessments gauging the development of CT skills and knowledge during the course of one academic year, and suggestions for improvements and incorporation into other curricula.

Keywords—Computational Thinking, K-12, Interdisciplinary, graduate fellows

I. INTRODUCTION

As is widely reported in the United States, economic recession has led to a rocky employment landscape over the past decade. Employment opportunities and salary rates have greatly expanded within the disciplines of Science, Technology, Engineering, Mathematics, and Computing (STEM+C) while growth has severely slowed or become stagnant within more traditional disciplines such as manufacturing, services, and sales [1]. In 2014, there were nearly 8.2 million Science, Technology, Engineering, and Mathematics and Computing (STEM+C) jobs, with computer occupations making 44% of those jobs [2]. In fact, the number of STEM+C careers are expected to rise by 17% by 2018, while non STEM+C careers are expected to increase by only 9.8% [3] while wages within these STEM+C careers are approaching nearly twice the US average [4].

Consequently, a strong background in scientific and computing principles is key to future financial success, especially for youth [5]. Instruction in computational thinking (CT), a pedagogy incorporating science and computing into classrooms, is becoming more prominent. Wing, 2006 defines computational thinking as "taking an approach to solving problems, designing systems and understanding human behaviour that

draws on concepts fundamental to computing". Through this teaching style, students are coached to think in an inductive, logical manner that strives for efficient solutions to challenging problems. Furthermore, through improved capacities for abstraction, students' ability to creatively solve problems grows as they are able to simplify complex problems into manageable components they can be addressed [6].

CT concepts and terminology was selected from CS Principles, the proposed AP Computer Science Curriculum Framework [7]. The CT terms used in module development were algorithm, clarity, correctness, efficiency, iteration, abstraction, branching, variable, and sequence of steps. The definitions given in the CS principles are described below, and they were simplified for optimal 6th grade understanding.

An algorithm is defined as precise sequences of instructions for processes that can be executed by a computer and are implemented using programming languages to solve a problem (simplified to a sequence of steps to solve a problem). Clarity is described as the language used to express an algorithm can affect characteristics such as clarity or readability but not whether an algorithmic solution exists (the readability of an algorithm). Correctness is described as the correctness, usability, functionality, and suitability of computational artifacts (how well the algorithm produce the desired outcome or answer). Efficiency is described as including both execution time and memory usage (the speed, or number of steps in an algorithm). Iteration is defined as the repetition of part of an algorithm until a condition is met or for a specified number of times (repeating a sequence of steps). Abstraction is described as reducing information and detail to facilitate focus on relevant concepts (simplifying information to solve a problem). Branching is defined as a decision point that affects the resulting steps of an algorithm (choosing a path). Variables are used in programs and initialized and updated, read, and written (a value that can change). Sequence of steps is a simple linear algorithm without a solution (a simple algorithm).

An education grounded in science augmented with CT introduces students to an essential body of knowledge and lays a solid foundation for future learning. Middle school is an appropriate age to introduce these computing concepts in order to facilitate their incorporation into the lives of these youth and form a foundation for their future careers. By being acquainted with CT, students can find the transition into STEM+C careers easier and more fulfilling. Furthermore, the underlying belief is that career choices are often formed during the transition of middle school, and the impact of early awareness to computing opportunities could influence students'

decision towards STEM+C careers [8]. Middle school students learn best when they are actively engaged, which is often a result of hands-on and inquiry based activities [9]. Studies in middle school classrooms have shown increased student engagement and enthusiasm when technology was used to implement lessons [9]. Implementing this new curriculum as a supplement to traditional science in order to improve subject comprehension and engagement is a primary objective of New Mexico State University's DISSECT program. To achieve this aim, graduate student fellows work in coordination with an experienced K-12 teacher to create and deploy interactive CT modules in middle and high school classrooms that promote active learning through the use of technology and cutting edge scientific research. Another main objective of the DISSECT program is to facilitate the professional development of university graduate students in computing-rich fields, such as engineering, biology, and computer science, through leadership development, public speaking experience, and an enhanced vision as to how CT is vital to in all scientific and social disciplines. The alliances formed between K-12 teachers and their fellows provide an opportunity for teachers to attain knowledge of CT principles and equips them with the ability to develop and continue their own future lesson plans integrating CT. The hypotheses underlying these objectives, and constituting DISSECT's philosophy are: (1) Several components of CT are already implicitly present and used in many traditional scientific disciplines (e.g., Physics, Biology) - thus, it is important to make them explicit and bring them forward to enable students to recognize them and reuse them across domains and disciplines; (2) CT provides principles, tools and models that can be effectively used to enhance the learning of traditional sciences, making the learning process more dynamic, interactive and engaging. The following sections of this paper describe methods for incorporating CT into the 6th grade science curriculum. The qualitative results for each developed CT module are reported, and suggestions for module improvement are discussed. The overall quantitative results based on pre and post-test evaluations are described and their implications discussed.

II. MODULES

Modules discussed in this paper were primarily created by Amanda Peel, a graduate fellow, with the guidance of Mrs. Kathleen Guitart, a Las Cruces Public Schools sixth grade science teacher, and were created to incorporate CT concepts into the existing curriculum. The sixth grade science curriculum consists of 7 concepts: scientific practice, matter, geology, meteorology, inventions, astronomy, and energy. The following modules have been selected to demonstrate CT concepts, algorithm skills (following and writing), branching, abstraction, visual programming, and iteration. Further details pertaining to the described modules, and other modules can be seen on the NMSU GK-12 DISSECT program website (<http://www.cs.nmsu.edu/gk-12/>).

A. CT Terms: Vocabulary Introduction Module

The learning goal of this module was to have students learn the definitions of the CT concepts, and how to identify examples of each. During the first and second class, students wrote the CT terms and their definitions with the assistance

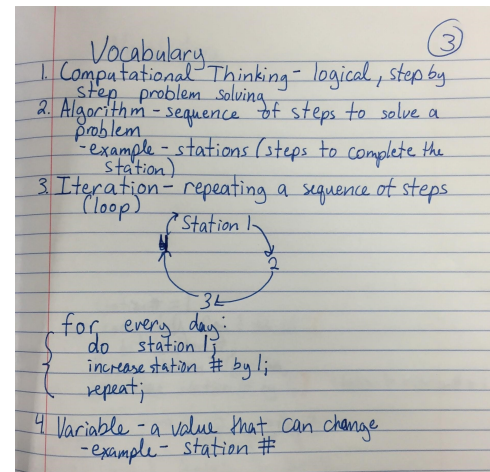


Fig. 1. CT Vocabulary Example

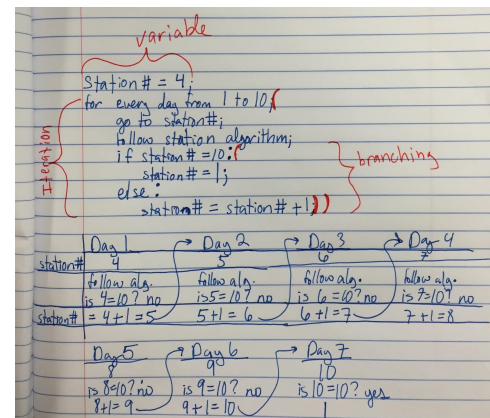


Fig. 2. Geologic Stations Algorithm

of the GK-12 fellow. After writing each definition, they talked about what each term meant and they were given real world examples of each (Fig. 1). At the end of defining all the words, the fellow and students wrote an algorithm together, describing how to go through their geologic stations (Fig. 2). In class, they were working on 10 stations, in which they would work in groups on one station per day learning about different geologic concepts. During the third class, students played CT Jeopardy (jeopardylabs.com/play/computational-thinking-vocabulary), which allowed the students to test their vocabulary understanding.

B. Metric Measurement: Following Algorithms Module

The learning goal of this module was to teach students how to measure in metric. Another goal was to introduce students to algorithms, and to evaluate how well they followed algorithms. Prior to module deployment, students should be taught how to measure in centimeters and millimeters. Students were given the handout with an algorithm of how to cover a composition notebook. The notebooks were called their computational thinking notebooks, and were used for the CT activities throughout the semester. They were instructed to follow the algorithm by themselves and only ask for help if they couldn't figure it out on their own. Once they finished covering their notebooks, they wrote down if they followed

the algorithm, didn't follow the algorithm, or had to ask for help. Next they were given a CT vocabulary words sheet, and they cut and glued them onto their notebooks.

C. Weather Tool Algorithm: Writing Algorithms Module

The purpose of this module was to get students comfortable with clarity, correctness, and efficiency of algorithms. They learned what the terms mean and how to score algorithms in each. Next, they practiced writing clear, correct, and efficient algorithms multiple times, which culminated in writing a weather tool algorithm. The fellow and teacher demonstrated the importance of correctness, clarity, and efficiency by writing an algorithm with the entire class on how to draw a chosen shape, or shapes. The fellow went in the hallway, while the class wrote the algorithm, and came back in when they were finished and followed their algorithm. The drawings were usually way off, so they saw how important these CT concepts were to algorithm development. Next, students paired up and they each chose a shape from an envelope and made their own algorithms to draw it. They switched notebooks with their partners and they followed each other's algorithms. They each rated the algorithms on a scale of 1 to 3 (3 being the best) for clarity, correctness, and efficiency. Next, students were split into groups of two or three. There were usually ten groups per class, so five groups went in the hallway and five groups stayed in the classroom. One student from each group got a brown paper bag with the materials needed for the project. The groups in the classroom got supplies to build a weather vane, and the groups in the hallway got supplies to make a barometer. Each group was given a picture of the final product, but no instructions. They had to build the tool based on the picture, and then write an algorithm for how to build it. In the next class period, they switched either to the hallway, or to the classroom from the last activity. As before, the groups in the classroom got supplies to build a weather vane, and the groups in the hallway got supplies to make a barometer. Each group was given an algorithm to make the product, which was written by a different group from the last class. They had to build the tool based on the algorithm. Once they were finished, they were shown the correct final products, and they rated the algorithms on correctness, efficiency, and clarity on a 1 to 3 scale, with 3 being the best score.

D. Rocket Branching Module

The learning goal of this module was to teach students how to use abstraction to solve a problem. Another learning goal was to have students learn how to execute if/then branching statements. Students read an article about a rocket launch at WSMR. Students all started by standing on a paper rocket we taped to the floor in the hallway. Next, they followed the branching statements the fellow and teacher wrote about the article. For example, "If the rocket took images of the sun, then move 4 squares west, else move 4 squares east." They had to abstract information from the article to decide if the statement was true or false, then move a certain amount of tiles N, E, S, or W. Once they completed the statements, they were given a key card with two more movements. If they chose the right paths for all four steps, they ended up on the rocket they started on after following the key card. To relate the module article to class content, after they were done with the branching exercise

they researched the different layers of the sun. This module can be adapted to any content, as long as there is an article or something to read with information to be abstracted.

E. The Case of the Bungled Bovine Bales: Abstraction Module

The purpose of this module was to get students comfortable with the measurement and calculation of density, which was the lesson unit for that week. This module also introduced the students to the world of genetically modified plants. Students were given an informative handout, density cubes, and measurement tools. The handout described a situation where a farmer was delivering four types of bales of hay, one made of organic alfalfa, and the other three made of different types of genetically modified alfalfa. On his way to deliver the bales, he hits something in the road, and the bales get mixed up. He knows that the densities of the bales are ranked in descending order, as follows: GS/SPS, SPS, GS, organic. In order to figure out which bales are which, students had to measure their densities and rank them. The handout was read together in class and students were told to highlight the important information needed to solve the problem of mixed up bales of hay. The fellow and teacher had to discuss the problem with the students in order to reinforce their understanding. Students measured and calculated the densities then solve the problem with the knowledge given in the handout.

F. Scratch Introduction: Visual Programming Module

The purpose of this module was to get students comfortable with the basics of Scratch, a visual programming language, while reinforcing the geologic Mesozoic Era, specifically the Jurassic Period, which was the lesson unit for that week. This module introduced the students to iteration, and using variables to make programs universal. The first class was used to introduce Scratch to the students. Students were given Scratch handouts with the element info program and the steps with formulas and vocabulary (Fig. 3). Students labeled the different parts of the program and filled out a worksheet with the sequence of steps of the element program. The computer screen was projected while building the program, so the students could see how to make an algorithm. To introduce iteration, the fellow built the Dancing Penguin algorithm in Scratch (Fig. 3). As each vocabulary word came up, students wrote it and its definition on their worksheet or in their journals. For the second class, students used Scratch on computers connected to the internet at www.scratch.mit.edu. Before this class, an account for each class was set up on the Scratch website. This allowed teachers and students to access their Scratch programs from any computer with internet connection. Students signed into the Scratch account, and began creating. The classes were studying the Mesozoic Era, they had to change the sprite to an organism from the Jurassic Period and change the backdrop to an accurate habitat for their Jurassic sprite. The subject matter can be adapted to the subject matter being studied. It is important to have students change the title to their name and the project title. For example, we used FirstLastJurassicPeriod. Once they finished the task, they explored Scratch by either adding to their program, or starting a new program.

G. Web Ad Iteration: Iteration module

The purpose of this module was to get students comfortable with iteration in algorithms using Scratch. Students had just

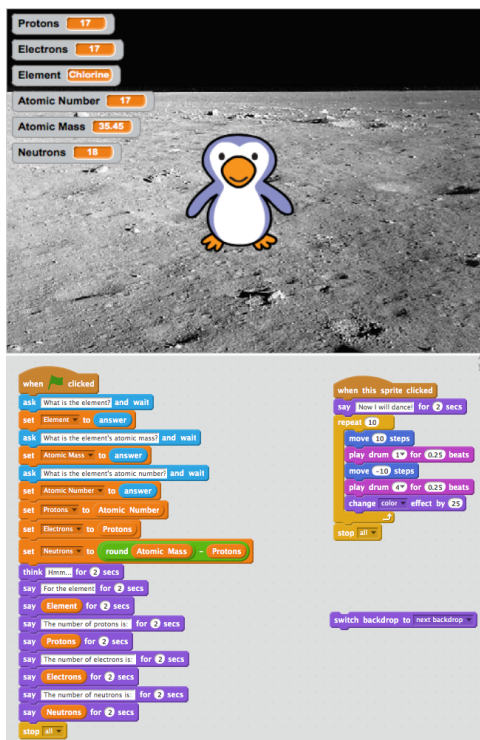


Fig. 3. Element Info Program with Dancing Penguin Iteration

made inventions for a class project, and were then learning how to make a webpage to advertise them. First, the fellow presented different examples of web ads made using Scratch and showed them how to use iterative structures in three different ways to catch people's attention (Fig. 4). Next, students wrote down the steps of one of the algorithms so they would have an example to base theirs on. Students then created their Scratch ads for their inventions using iteration. Screenshots were taken of their ads and glued to the poster of the web pages they designed for their inventions. This module took three class periods to complete.

III. RESULTS

A. CT Terms: Vocabulary Introduction Module

During this module, students were attentive and responsive while we went over the terms. Students enjoyed playing Jeopardy, however, they did not do very well the first time we played, but progressed as we played it through the semester. This module successfully introduced students to CT concepts.

B. Metric Measurement: Following Algorithms Module

This module helped the kids develop their measuring skills. By the end of the module most of them improved in measurement. They seemed to understand that an algorithm is a sequence of steps used to solve a problem and most of them tried to follow it. The students were engaged and excited to cover their notebooks. They were very excited to be given a notebook of their own and they were excited to decorate them. They were eager to measure and cut and glue things, but many of them became frustrated when they couldn't ask for help without trying it on their own first. Some were very slow

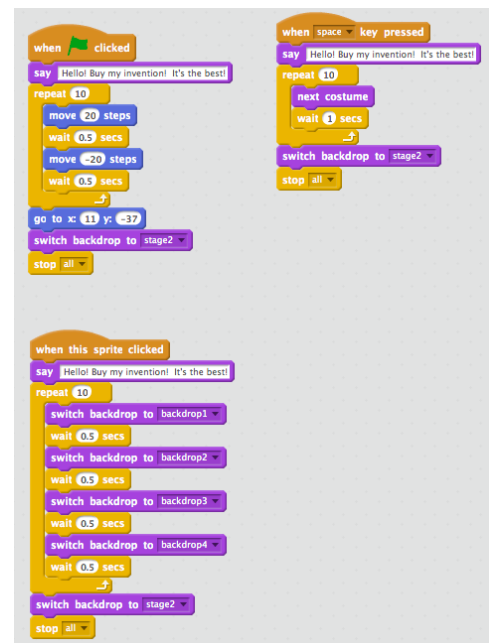


Fig. 4. Web Ad Iteration Examples

executing directions. A lot of the kids had to ask for help, but most could figure it out just by reading it together out loud. Almost all of the kids had difficulty measuring. Sometimes they would try and use inches and some kids didn't measure at all. They were not confident in their own problem solving skills; most kids were doing the right thing, but still asked for help with, and/or confirmation of what they were doing. This module successfully utilized algorithms and reinforced metric measurement.

C. Weather Tool Algorithm: Writing Algorithms Module

The students that did not look at their partner's shape were often very confused by their partner's algorithms, which was the point of the module. The kids were working on inventions for a multiple week project. In this project they had to write instructions on how to use and make their inventions. This module demonstrates how precise they had to be with their algorithms to make them clear, correct, and efficient. They really liked actually building something, and I noticed that the kids who usually aren't engaged when we do writing exercises were very involved in the building process. This gave opportunities to the students who like to write as well as the students who like to be more hands on. Scores were expected to be higher because they had practiced so much, but they still needed to work on their correctness and clarity. It was very challenging getting the kids not to show each other their shapes. One partner went outside and the other stayed in the classroom, but they still shared their shapes with the other students, which made it much easier for some of them to guess what their partner's algorithm was describing, rather than following the algorithm. When rating each other's algorithms, the kids often got confused between correctness and clarity; many gave a low correctness score because it was hard to understand. Also, they gave low efficiency scores because it took them a longer time to understand what they were supposed to do, which made the algorithm take longer,

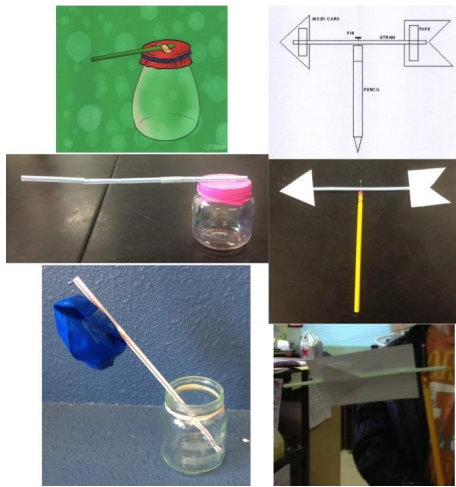


Fig. 5. Weather Tool Algorithm Module Results

instead of evaluating the number of steps. There were no weather tool algorithms that were 100% correct, though some were close (Fig. 5). Some were completely off, which was a little discouraging. The students really enjoyed this module because they were able to do more hands-on work and were able to work on their teamwork skills. Students really liked seeing how incorrect their algorithms were and many kids liked writing them. It was definitely challenging for them, but they enjoyed it. This module successfully demonstrated how important clarity, correctness, and efficiency are in algorithm writing. Students, however, did not completely grasp the individual concepts in terms of algorithms. This module can be improved by possibly splitting the three concepts into their own activities, and then combining them in this module.

D. Rocket Branching Module

During this module, students enjoyed getting up, and out of the classroom. They also began to understand if/then/else statements. They had a lot of difficulty with directions and abstracting information. A lot of them had to do the if/then/else activity multiple times before they got it right. The students enjoyed physically exploring branching statements. Although it took students longer than expected to complete the activity, this module successfully taught students about branching in the context of the classroom curriculum.

E. The Case of the Bungled Bovine Bales: Abstraction Module

The practice with density in this module was successful and really helped solidify their measuring skills. Most students were engaged and understood the concept of organic versus genetically modified alfalfa. They also understood that in order to be an organic dairy farmer the cows had to be fed organic hay. Some kids were still very slow executing directions. Almost all of the kids were comfortable with measuring mass, while most of them had difficulties with measuring volume. They thought that since the measurements for length, width, and height were the same that they could just multiply that value by three when it should have been raised to the third power. Some kids had trouble making the connection between density and bale identity even though it was clearly stated in

the introductory paragraph. Most students did not effectively abstract the data; they either highlighted way too much, or not enough information. There was an error in the handout because we did not specify the difference in densities between GS and GS-SPS hay bales. We accepted correct answers as long as the highest density and lowest density were correct. Most students assumed GS-SPS was more dense than GS alone, which is a correct assumption, indicating their comprehension of the subject. The students were engaged and excited to figure out the identity of the hay bales in order to deliver the correct bales to the correct farmers. They were very excited when they identified them correctly. This module was successful in teaching students about density, and although students seemed interested in abstraction they did not fully grasp the concept; more practice was needed.

F. Scratch Introduction: Visual Programming Module

The students were very excited to see programming, and they understood the CT concepts introduced and reviewed. The students were very enthusiastic about using computers and Scratch. All of the kids finished their assignment and many went on to explore more in depth Scratch concepts. Most students were very creative and liked making their sprites move and talk. During the first class, we really didn't have any challenges with the students, but we did run out of time trying to get through the programs and vocabulary thoroughly. This module can be challenging if the internet connection is bad, or if the computers are slow. The students loved this module; the next time I went into the classroom, they were asking me if we were going to do more Scratch. Some students even told me that they went home and used Scratch on their own time. This module successfully introduced the students to visual programming.

G. Web Ad Iteration: Iteration module

At the completion of this modules, there was significant improvement on the understanding of CT vocabulary words. The kids loved working with Scratch and some kids really got into it and understood iteration. The kids' projects that had both iteration and advertising were very impressive. The biggest challenge was getting the computers set up. Another challenge was getting all the students to change the name of their projects. Even after four weeks, there were still untitled projects. I noticed that the projects were mostly either very good with iteration or very good with advertising; it was rare to find a project with both iteration and advertising (Fig. 6). Providing more time may improve student incorporation of both iteration and advertising. The students seemed to enjoy working with Scratch and I noticed that the kids who are usually not engaged were enthusiastic and working hard when using Scratch. This module successfully allowed students to use visual programming to demonstrate their knowledge of iteration and advertising.

H. Statistical Results Fall 2014 Semester

Pre-tests were given to students before any CT instruction was given, and post-tests were given at the end of the semester. Assessments of the tests were split into two categories: CT term recognition, and CT term definitions. The data shown in this section was collected during the Fall 2014 semester.

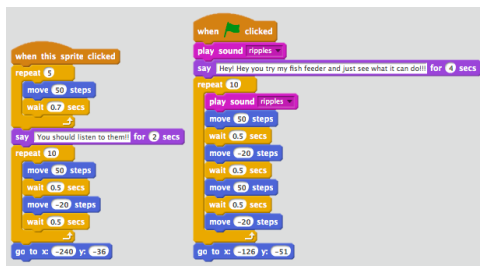


Fig. 6. A Student Example of a Scratch Web Ad Iteration Program

TABLE I. FALL 2014 RECOGNITION DIFFERENCES PAIRED T TEST. THE T VALUE WAS TESTED FOR SIGNIFICANCE USING AN ALPHA OF 0.05. (* = $0.01 < p \leq 0.05$; ** = $0.001 < p \leq 0.01$; *** = $p \leq 0.001$).

Mean	Std Dev	t Value	p Value	Significance
3.1582278	2.2681523	12.38	< 0.0001	***

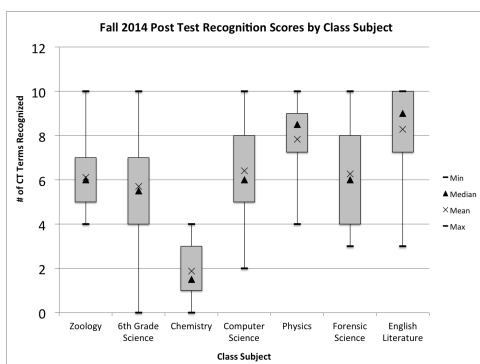


Fig. 7. Number of CT Terms Recognized. All class subjects, with the exception of 6th Grade Science, were high school classes.

The number of words recognized in the pre-test was subtracted from the number of words recognized in the post-test, and a paired t test was done using Statistical Analysis System (SAS) software (Table I). The amount of CT terms the students recognized significantly increased at the end of the semester, indicating that the modules successfully introduced the students to the CT terms. When compared to the high school students scores, Fig. 7, the mean recognition was comparable in the 6th grade students. This suggests that 6th grade students had a relatively equal recognition of CT terms to high school students at the end of the semester.

The pre-test definition score was subtracted from the post-test definition score, and a paired t test was done (Table II). The amount of CT terms correctly defined significantly increased at the end of the semester, indicating that the modules successfully taught the students how to define the CT terms. When compared to the high school students scores, Fig. 8, the mean correct definitions was comparable in the 6th grade students. The max score was highest in the 6th grade class, which suggests that 6th grade students have the same capacity to learn complex concepts, such as computational thinking, as high school students at the basic definition level.

I. Statistical Results Spring 2015 Semester

Pre-tests were given to students again in January, and post-tests were given at the end of the semester. Assessments of

TABLE II. FALL 2014 DEFINITIONS DIFFERENCES PAIRED T TEST. THE T VALUE WAS TESTED FOR SIGNIFICANCE USING AN ALPHA OF 0.05. (* = $0.01 < p \leq 0.05$; ** = $0.001 < p \leq 0.01$; *** = $p \leq 0.001$).

Mean	Std Dev	t Value	p Value	Significance
1.47468354	1.16821893	11.22	< 0.0001	***

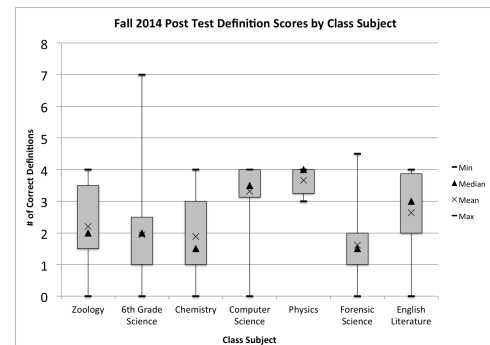


Fig. 8. Number of CT Terms Correctly Defined. All class subjects, with the exception of 6th Grade Science, were high school classes.

the tests were split into two categories: CT term recognition, and CT term definitions. The data shown in this section was collected during the Spring 2015 semester.

The number of words recognized in the pre-test was subtracted from the number of words recognized in the post-test, and a paired t test was done using Statistical Analysis System (SAS) software (Table III). As seen in the fall semester, the amount of CT terms the students recognized significantly increased at the end of the spring semester, indicating that the modules successfully further introduced the students to CT terms. When compared to the high school students' average scores, Fig. 9, the mean recognition difference was significantly higher in the 6th grade students. This suggests that 6th grade students had a higher recognition of CT terms than high school students over the course of both semesters.

TABLE III. SPRING 2015 RECOGNITION DIFFERENCES PAIRED T TEST. THE T VALUE WAS TESTED FOR SIGNIFICANCE USING AN ALPHA OF 0.05. (* = $0.01 < p \leq 0.05$; ** = $0.001 < p \leq 0.01$; *** = $p \leq 0.001$).

Mean	Std Dev	t Value	p Value	Significance
3.84507042	2.31546285	13.99	< 0.0001	***

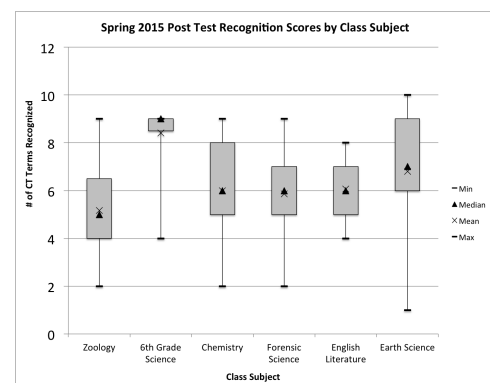


Fig. 9. Number of CT Terms Recognized. All class subjects, with the exception of 6th Grade Science, were high school classes.

TABLE IV. SPRING 2015 DEFINITIONS DIFFERENCES PAIRED T TEST. THE T VALUE WAS TESTED FOR SIGNIFICANCE USING AN ALPHA OF 0.05. (* = $0.01 < p \leq 0.05$; ** = $0.001 < p \leq 0.01$; *** = $p \leq 0.001$).

Mean	Std Dev	t Value	p Value	Significance
3.88571429	2.18554445	14.88	< 0.0001	***

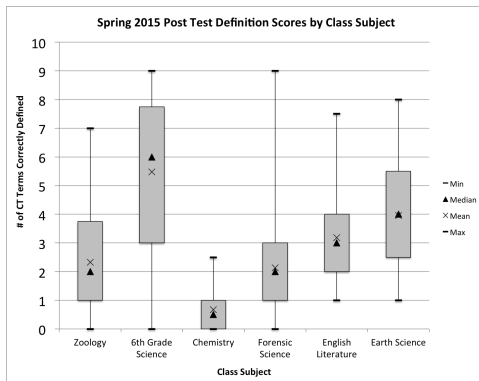


Fig. 10. Number of CT Terms Correctly Defined. All class subjects, with the exception of 6th Grade Science, were high school classes.

The spring 2015 pre-test definition score was subtracted from the post-test definition score, and a paired t test was done (Table IV). The amount of CT terms correctly defined significantly increased at the end of the semester, indicating that the modules continued to successfully teach the students how to define the CT terms. When compared to the high school students' scores, Fig. 10, the mean correct definitions was significantly higher in the 6th grade students. This suggests that 6th grade students have the capacity to learn complex concepts, such as computational thinking, at a the foundational level, which could supplement further in depth CT learning in their educational futures.

IV. CONCLUSION AND FUTURE WORK

Taken together, the qualitative and quantitative results indicate that the developed modules successfully increased CT term recognition and meanings over the course of one semester. The qualitative results and module development have confirmed DISSECT's hypotheses: (1) Several components of CT are already implicitly present and used in many traditional scientific disciplines (e.g., Physics, Biology) thus, it is important to make them explicit and bring them forward to enable students to recognize them and reuse them across domains and disciplines; (2) CT provides principles, tools and models that can be effectively used to enhance the learning of traditional sciences, making the learning process more dynamic, interactive and engaging. Quantitative analyses showed that students significantly increased in their level of CT term recognition, suggesting that they should be able to recognize these terms in other contexts. The increase in correct CT term definitions indicates that students understand complex CT concepts at a foundational level, which should provide adequate framework for future encounters with these concepts. Qualitative assessments indicate a more thorough understanding of the concepts that surpasses the foundational definition in some students, suggesting that these students may be able to not only recognize CT concepts, but also reuse CT concepts across subjects and disciplines. Although these results

are positive indicators that the modules work in achieving the desired goals, future modules should be geared towards creating specific challenges requiring algorithmic and parallel processing thought processes [10]. Qualitative analyses indicate that the level of engagement and learning in the 6th grade science curriculum concepts incorporated in the CT modules was higher. The use of CT concept modules provided hands-on and inquiry-based learning environments that could have contributed to increased student interaction and engagement. The developed modules successfully used CT concepts to enhance the learning of traditional 6th science, resulting in more student interaction and engagement. The comparison of the mean scores seen at the end of the fall 2014 semester between high school classes and the 6th grade class showed that the 6th grade students had similar scores to the high school students. Before data collection began, there was concern that younger students would have difficulty understanding the concepts, but the fall 2014 results indicate that 6th grade students have the capacity to learn complex concepts, such as computational thinking, at a the basic definition level. Some students demonstrated the ability to recognize and create their own examples of the CT terms, which suggests a much more thorough understanding of the concepts that surpasses that of simple definitions. As seen in the fall 2014 data, the sixth grade students scored significantly higher than the high school students. This indicates that the continued participation over the course of a second semester resulted in more CT term recognition and correct CT definitions in 6th grade students than high school students. It is important to note that this was the only fellow/teacher combination working with 6th grade students, so the success of the modules could be due to other contributing factors, such as teacher and fellow teaching styles, and school and classroom atmosphere. Regardless, the data presented suggests that middle school students can benefit more from CT modules than high school students. In conclusion, the results clearly indicate that the created CT modules are effective in increasing the interest, motivation, and knowledge of computer science in 6th grade middle school students. It is, however, important that future studies be directed towards exploration of concept mastery. Future research will indicate whether students are developing concept mastery beyond foundational understanding and recognition of covered topics.

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DISSECT: Analysis of Pedagogical Techniques to Integrate Computational Thinking into K-12 Curricula

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Abstract—This paper analyzes the efforts of DISSECT (DIScover SciEnce through Computational Thinking) to introduce computer science theories into K-12 Curricula. This is accomplished by teaching computational thinking (CT) problem solving techniques in existing STEM+C courses in select middle and high school classrooms in Las Cruces, New Mexico, USA. Data collected over the course of the fall 2014 and spring 2015 semesters involving 10 graduate fellows, 9 teachers, and over 200 K-12 students has been analyzed. A single assessment was issued at the beginning and end of each semester in order to track metrics about fellow-teacher pairings, student understanding of CT concepts, and student interest in STEM+C areas. Using statistical analysis software to evaluate the data, we were able to determine the efficacy of the DISSECT program. In particular, we use descriptive statistics to evaluate the trends in CT vocabulary recognition and overall interest in computing, and we compare trends across courses and grade levels.

Index Terms—Computer science, computational thinking, K-12, graduate fellows, statistical analysis, stem+c.

I. INTRODUCTION

Integrating computational thinking into the K-12 curriculum has been a long standing goal of the New Mexico State University DISSECT (DIScover SciEnce through Computational Thinking) program. Computational Thinking (CT) is an important component of all STEM+C activities, but CT is traditionally underrepresented in the K-12 curricula. CT is not to be confused with computer programming but is instead the art of thinking in a similar manner to a computer scientist. Before being able to program a solution, a computer scientist must conceptualize the problem and abstract the required information before crafting the appropriate algorithm with which to solve the problem. These problem solving abilities are what Wing originally referred to as CT and is one of the cornerstones of the research that DISSECT performs [1]. This is especially important as computer science becomes more important in the workforce. In fact, the number of careers in fields related to computer science are expected to grow by as much as 22% faster than non-technical careers [2]. We also believe that fields that do not directly apply computer science can benefit from training in CT. Consequently, one of DISSECT's objectives is to infuse CT into standard K-12 curricula and how to leverage CT in a variety of subjects ranging from chemistry to literature.

The DISSECT program operates out of New Mexico State University's Computer Science Department and pairs graduate students in Computer Science or applied computing fields such as Electrical and Computer Engineering and Biology with K-12 teachers around Las Cruces, New Mexico. The graduate students (fellows) offer expert knowledge in CT while the teachers provide their skills in pedagogy.

Together, the fellow-teacher pair create modules that integrate the teacher's current curriculum and important CT concepts. The fellows do not create these modules in a vacuum - modules are designed to teach CT concepts while directly tying them to the current coursework. By keeping the modules closely tied to what the students are learning, any disruption to the teacher's schedule is minimized while maximizing instruction in CT principles. DISSECT's aim is to illustrate that CT is inherent in the subjects the students are learning, rather than an extracurricular activity or supplement. Furthermore, by illuminating that CT concepts form the foundations for the subjects currently being taught in the classroom, students will be able to apply their skills in CT across all disciplines.

In the 2014-2015 school year, DISSECT had ten fellows in nine classrooms, and we focused instruction on the process of algorithmic thinking. To assess our effectiveness analytically, we have designed an assessment to be administered as a pre-test at the beginning of DISSECT's instruction in the classroom and after the winter holiday for single semester courses. This same assessment was used as a post-test at the conclusion of the calendar year (December 2014) for single semester courses and the academic year (May 2015) for year-long and single semester courses. The test assesses students on their ability to recognize and define CT concepts, and further includes a section of Likert questions to assess students' attitude towards CT and computer science. We have performed statistical analysis on the data collected for the fall 2014 and spring 2015 semesters and present our findings in this paper. In particular, we directly compared pre- and post-test scores within the same class, between a control Computer Science course without a fellow (only for the fall semester) and courses including fellows, and we compared post-test scores between semester-long and year-long courses. We also describe DISSECT's general techniques in the classroom and explain in detail how we collected our data. Finally, we

interpret our results, describe our findings, and discuss our plans for future research.

II. EXISTING RESEARCH

Several researchers have been working to develop methods to integrate CT into K-12 education. Several visual programming environments have been developed that are useful in this regard such as Scratch [3], App Inventor for Android [4], and NetLogo [5]. For example, in Connecticut, the Computer Science Department of Trinity College developed a summer program where they first began investigating the effectiveness of App Inventor as a teaching method to instill CT principles in K-12 education [6]. By working with college students with varying backgrounds in computing and K-12 teachers with a background in computer science instruction, the team worked to develop a curriculum that would impart CT knowledge by developing applications for Android smartphones. The rapid development cycle offered by App Inventor allowed students to quickly learn the techniques needed to create apps that could be shown to friends and colleagues. This led to an enthusiastic learning environment that helped the students improve their abilities to solve problems and overcome new challenges.

Purdue used another approach to prepare K-12 teachers and college students majoring in education to be able to infuse CT principles into their curricula [7]. Purdue researchers introduced CT into the existing topics involving critical thinking and problem solving in an educational psychology course. Their program was deployed during one week of instruction and was comprised of two 50 minute sessions. During this week long module, the researchers introduced one group of the class to a CT infused curriculum while the curriculum of the other group remained unaltered. The first session involved defining the chosen CT concepts and illustrating how these concepts are integral to their daily lives and exploring their applicability to problem solving and strengthening critical thinking. The second session involved applying these principles in solving problems that were not well defined or required convoluted solutions. By using CT concepts, the students were better equipped to solve these challenging problems. The researchers demonstrated how CT could be infused in other curriculum areas with concrete examples in science and social science scenarios.

During the 2013-2014 school year, DISSECT worked with students from 6th grade and 9th grade through 12 grade in subjects including general science, biology, and forensics to investigate the integration of CT into K-12 science curricula [9]. This involved pairing graduate fellows from New Mexico State University (NMSU) with K-12 teachers around Las Cruces, NM. The pairs would then work together to create modules that infused the teacher's current curriculum with CT concepts that were derived from the fellows CT background and current research topics. These modules followed an inquiry-based learning style and often incorporated a hands-on approach to illustrate the underlying CT concepts in the science and forensics classes. The modules that were created covered a broad variety of CT concepts spanning the use of programs

for animating subject matter to developing algorithms to solve problems in the given classroom subject. These modules also included various programming environments including the MIT Scratch environment and Python programming language to model and demonstrate levels of understanding of both CT concepts and classroom material [10]. When qualitatively evaluated by their paired teachers, the fellows were acclaimed for challenging the students' critical thinking in the subject matter of their assigned class, relating CT principles to the students' daily lives, and successfully infusing CT concepts into their respective classroom's curriculum.

III. DISSECT METHODS AND ASSESSMENT

Continuing the strides made last academic year (2013-2014), DISSECT again paired graduate fellows with K-12 teachers to work to integrate CT into the teacher's current curriculum by demonstrating its presence in the students daily lives. Receiving invaluable instruction in pedagogy from the teachers, the fellows developed their modules following the inquiry-based learning model. Fellows focused the modules on the theme of algorithms and all the CT concepts that tie into it such as branching, iteration, clarity, and sequence-of-steps. Fellows were encouraged to be creative in their module development because resources, especially computational technology, are limited due to the low-income areas in which DISSECT operates [9]. Due to this, the fellows investigated numerous ways to incorporate CT in their lesson plans utilizing both the use of computer technology and a lack of access to advanced technology. For classrooms with access to computer technologies, several fellows decided to incorporate the MIT Scratch environment as an instruction tool, using it in a variety of ways to demonstrate materials from the curricula. For example, in a forensic science class one fellow teacher pair had the students develop a program that modeled a crime scene from one of three vantage points: criminal, victim, or investigator. Another fellow used ToonDoo [12] in a high school English class to have the students plan and implement a scene from the story Macbeth. For classes without access to computers fellows looked towards the classroom curricula and sought to illuminate the underlying algorithms that were being taught. In one class the fellow developed a module that covered image reconstruction in which case different groups of students were issued a part of different images that had been cut up. The student groups would then attempt to find the other pieces of their images by inquiring among the other groups for characteristics similar to their own image. The goal of this module was to demonstrate iteration in going from group to group making the same inquiries each time and branching by determining from the answers obtained what their next course of action should be. To accurately assess the efficacy of the DISSECT program, the fellows issued a pre and post test to measure the change in understanding over the course of the semester. The test was composed of one page of CT concepts and two pages of Likert questions which focused on the students feelings concerning a job in computing and their general interest in computing. The assessment asks for

recognition, definition, and usage of ten concepts which are tightly integrated into the modules and applicable to each of the curricula that the fellows are integrating CT into. DISSECT defined the given terms as such.

- *Computational Thinking* is defined as using methods from Computer Science as a technique for problem solving.
- A *variable* is a piece of data that is assigned a name and has a specific value that can be changed.
- An *algorithm* is a step-by-step process that, when followed from start to finish, will result in a solution.
- A *sequence of steps* is merely a list of steps that must be followed.
- *Branching* is defined as the need to make a choice where each decision will have unique outcomes.
- *Iteration* is repeating a set of instructions until a certain condition is met; one common condition is a predetermined number of times.
- Simplifying the problem with *abstraction* is to remove information from the idea until the only parts left are those that are relevant and necessary to the problem.
- *Clarity* is a qualitative measurement of how easy the program or algorithm is to understand.
- A measure of the ability of the program or algorithm to correctly solve the intended problem is defined as *correctness*.
- *Efficiency* measures the resources used by the program or algorithm to solve a given problem with respect to energy exerted, be it time, space, and power.

IV. DATA COLLECTION TECHNIQUES

The data collection performed by DISSECT was based upon the assessment form outlined in Section III which was approved according to NMSU IRB-11201. This IRB allows us to collect data centered around a specific pre- and post-assessment created by DISSECT to be used in the classroom. This IRB does not allow collecting data outside of this assessment which includes a student's course grades, performance from other courses, or external opportunities that may influence a student's learning of CT principals. Around the city of Las Cruces, NM, there are many opportunities to indirectly learn various CT principals including MESA, Project GUTS, and YWIC, but our program does not track if any students are involved in these programs. DISSECT does not track this data because these programs teach CT principals in a computer science aspect while DISSECT teaches CT as a discipline that can be tightly integrated into any K-12 curricula as a problem solving method. Tracking this information is an area that is being considered for future research.

The fellows were to issue the assessment as a pre-test at the beginning of the fall 2014 semester before beginning instruction in CT principles had begun. The pre-tests were to be labeled with a unique identification number to each student and not include a name or other method of identification in order to respect the student's privacy. The fellows would then collect the test and keep them through the remainder of the semester. Prior to the pre-test being administered the only

contact with the students had with the fellows was to be an introductory period in which the fellow would introduce herself or himself as well as the GK-12 DISSECT program to their respective classrooms. After a semester of instruction in which the fellows had been actively attending the classroom between 5 and 8 hours a week teaching CT concepts, the fellows would issue a post-test. This post-test was to be given during the final or penultimate week of instruction and was identical to the pre-test given at the beginning of the semester.

The students would identify themselves on the post-test using the same unique identification number they had used on their pre-test. The fellows then used the statistical analysis techniques which will be outlined in Section V to evaluate the differences between the pre- and post-tests. Unfortunately, some of the data was collected outside of the methods outlined and the exemptions are stated as follows. One fellow was unable to collect the pre-tests personally which meant the teacher paired with the fellow collected the tests for the fellow. The fellow received the tests from the teacher at a later date and retained them throughout the semester. One fellow was unable to administer the post-test and had their teacher administer it. However, no identifying number was present on the test and the data had to be discarded and the results are not present in this paper. Several of the fellows gave either pre- or post-tests that were missing one or both pages with the Likert questions. In these cases, DISSECT ignored the direct comparison of missing datasets between the students. DISSECT did however incorporate the remaining data that contained successful pre- and post-test pairs. Two fellows that shared a classroom administered one set of pre- and post-tests to the students in the classroom instead of a set per fellow. Two fellows instructing at the same school administered the pre- and post-tests via Google Forms. The students were assigned a random identification number which they used to enter their answers. There were cases of missing data, be it pre- or post-test, due to student absences when the tests were administered. In these cases, the students collected data is used but no direct comparisons are made when one set of data is not available.

Despite the anomalies in data collection outlined above, DISSECT has maintained student confidentiality and have used data only where it is both permissible and applicable. Our analysis of the data indicates that these issues had no effect upon our results.

V. RESULTS - FALL 2014

The results of the pre and post-tests were categorized into four assessments: (1) CT term recognition, (2) CT term definitions, (3) Likert job questions: Getting a job in computing would allow me to..., (4) Likert interest questions: How much interest do you have in the following? The difference between pre and post-test values were subjected to paired t tests using the Statistical Analysis System (SAS) [13]. Table I describes information collected in addition to the pre and post-test data for each fellow/teacher combination.

As seen in Table I, the change in CT term recognition and the number of correct CT term definitions were statis-

TABLE I
INFORMATION ABOUT FELLOW/TEACHER (FT) COMBINATIONS.

FT	Fall 14 # of Students Observed	Spring 15 # of Students Observed	Subject Matter	Grade Level	Class Length	Core or Elective
1	22	20	Zoology	10, 11, 12	Year	Elective
2	79	71	6thGradeScience	6	Year	Core
3	N/A	18	6thGradeScience	6	Year	Core
4	17	N/A	CSandPhysics	9, 10, 11, 12	Year	Elective
5	28	34	ForensicScience	11, 12	Year	Elective
6	14	13	EnglishLiterature	12	Semester	Core
7	24	25	ForensicScience	9, 10, 11, 12	Semester	Elective
8	N/A	29	EarthScience	9	Semester	Core
9	15	N/A	Chemistry	9	Year	Elective
10	31	N/A	CSw/oFellow	9, 10, 11, 12	Year	Elective

The number of students observed, class subject matter, and student grade levels vary between the FT combinations. Note: # of students observed varies slightly between the four assessments. CS (Computer Science)

TABLE II
RECOGNITION AND DEFINITIONS PAIRED T TEST RESULTS.

Test	t Value	p Value	Significance
Recognition	10.22	< 0.0001	***
Definitions	9.02	< 0.0001	***

The t value was tested for significance using an alpha of 0.05.

* = $0.01 \leq p \leq 0.05$

** = $0.001 \leq p < 0.01$

*** = $p < 0.001$

TABLE III
DIFFERENCE OF CT RELATED LIKERT QUESTIONS OVER THE COURSE OF ONE SEMESTER.

Test	t Value	p Value	Significance
Job	4.03	< 0.0001	***
Interest	3.90	< 0.0001	***

TABLE IV
COMPARISONS OF PRE VS. POST-TEST DIFFERENCES OF A COMPUTER SCIENCE COURSE WITH CT MODULES TAUGHT BY THE FELLOW AND TEACHER (4) AND MODULES TAUGHT WITHOUT THE FELLOW (10).

Comparisons significant at the 0.05 level are indicated by ***.

Test	FT Comparison	Difference Between Means	Significance
Recognition	4 – 10	1.0740	
Definitions	4 – 10	0.2391	
Job	4 – 10	-0.1344	
Interest	4 – 10	0.1667	

The F value was tested for significance using an alpha of 0.05.

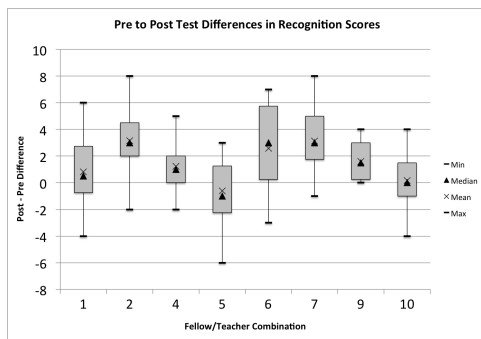


Fig. 1. Difference of CT Term Recognition Over the Course of One Semester.

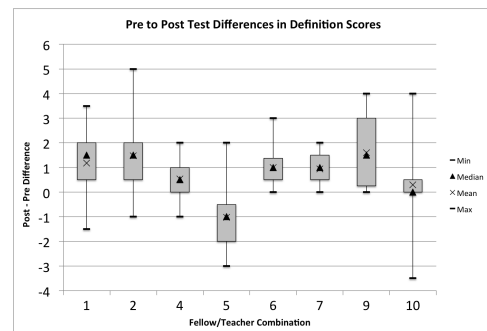


Fig. 2. Difference of CT Term Correct Definitions Over the Course of One Semester.

tically significant, indicating that the modules developed and deployed to students were successful in increasing basic CT knowledge. Figures 1 and 2 depict the differences in CT term

recognition and definitions over the course of the semester. Due to the differences in class size and other factors, such as

TABLE V
NUMBER OF STUDENTS OBSERVED FOR EACH FACTOR.

Factor	Zoology	General Science	Chemistry	CS	Physics	Forensic Science
# of Obs	25	82	17	42	6	55
Factor	<i>English Literature</i>	<i>Core</i>	<i>Elective</i>	<i>Year</i>	<i>Semester</i>	
# of Obs	14	96	145	203	38	

TABLE VI
COMPARISON OF CLASS SUBJECTS FOR CT TERM RECOGNITION, CT TERM DEFINITIONS, AND LIKERT QUESTIONS.

Test	F Value	p Value	Significance
Recognition	4.25	0.2026	
Definitions	2.98	0.2728	
Job	19.92	0.0485	*
Interest	21.48	0.0450	*

The F values were tested using the Type III MS for FT(Subject) as an error term. The F values were tested for significance using an alpha of 0.05.

TABLE VII
FALL RECOGNITION AND DEFINITIONS PAIRED T TEST RESULTS.

Test	t Value	p Value	Significance
Recognition	9.95	< 0.0001	***
Definitions	12.28	< 0.0001	***

The t value was tested for significance using an alpha of 0.05.

* = $0.01 \leq p \leq 0.05$

** = $0.001 \leq p < 0.01$

*** = $p < 0.001$

TABLE VIII
DIFFERENCE OF CT RELATED LIKERT QUESTIONS OVER THE COURSE OF ONE SEMESTER.

Test	t Value	p Value	Significance
Job	2.50	0.0138	*
Interest	-1.44	0.1517	

The t value was tested for significance using an alpha of 0.05.

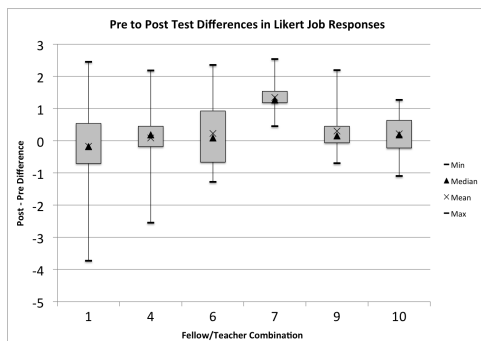


Fig. 3. Differences of Likert Job Questions Over the Course of One Semester.

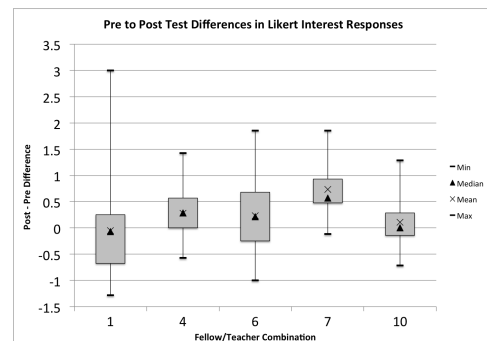


Fig. 4. Differences of Likert Interest Questions Over the Course of One Semester.

teaching style, class dynamics, and class time, there is large variability between fellow/teacher combinations. The mean difference of CT terms recognized increased, or was greater than zero, for every fellow/teacher combination (FT) except FT 5, suggesting that the modules successfully introduced students to CT terms, and they were able to recognize more terms at a basic level at the end of the fall semester. The average difference of CT terms correctly defined increased, or was greater than zero, in all fellow/teacher combinations except FT 5 and FT 10, indicating that, in most cases, students increased in their foundational knowledge of CT concepts after

one semester of participating in CT learning modules.

For each Likert subject areas, each of the student's answers were averaged first by individual student then by pre and post-test, and the difference between pre and post-tests were tested for statistical significance (Table III). The increase in differences was statistically significant for both sections of Likert response questions, indicating that students' views about computing jobs and their interest in computing increased over the course of one semester. As depicted in Figures 3 and 4, the mean differences in both Likert subject areas

TABLE IX
NUMBER OF STUDENTS OBSERVED FOR EACH FACTOR.

Factor	Zoology	General Science	Chemistry	Forensic Science	
# of Obs	23	79	27	66	
Factor	<i>English Literature</i>	<i>Core</i>	<i>Elective</i>	<i>Year</i>	<i>Semester</i>
# of Obs	14	140	116	129	127

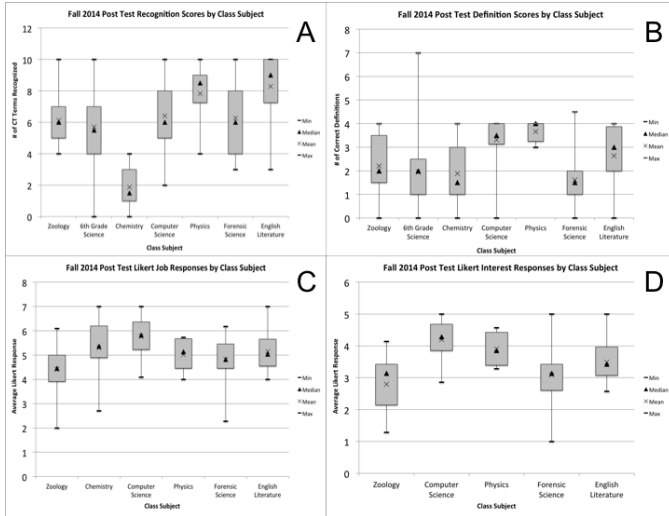


Fig. 5. Class Subject Comparisons for CT Term Recognition, CT Term Definitions, and Likert Questions.

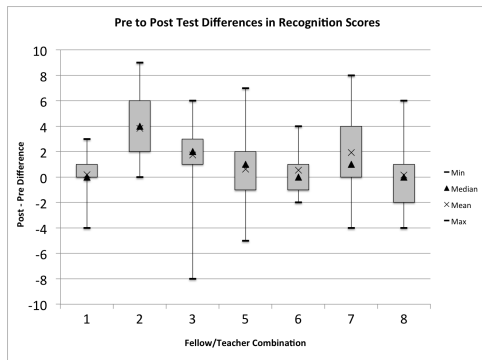


Fig. 6. Difference of CT Term Recognition Over the Course of One Semester.

increased over the course of the semester, with the exception of FT 1. These results demonstrate that high school students who participated in DISSECT modules for one semester were more interested in computing and had higher expectations for computing jobs.

For the fellow/teacher combination in the computer science classes, the same teacher taught another section of the same computer science class and deployed the same modules without the fellow. This class acted as a control so that the effectiveness of the teachers CT training and their ability to teach CT concepts without the fellow could be evaluated. As seen in Table IV, there were no significant differences in the averages of the pre to post-test differences, which indicates that the computer science teacher successfully de-

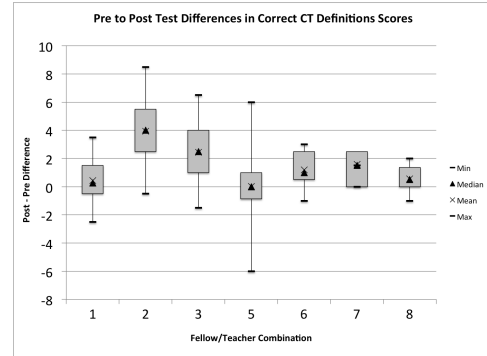


Fig. 7. Difference of CT Term Correct Definitions Over the Course of One Semester.

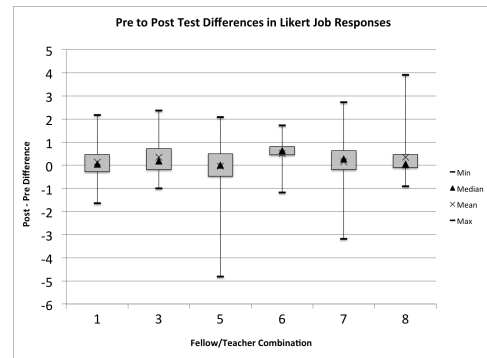


Fig. 8. Differences of Likert Job Questions Over the Course of One Semester.

ployed the CT modules without the fellow. This solidifies one of the primary goals of the DISSECT program to train teachers to effectively deploy CT modules on their own. This teacher was already trained in computer science, so it would be more informative to deploy this evaluation with teachers of different subject matters. The modules that were developed through the DISSECT program available for use at http://www.cs.nmsu.edu/gk-12/?page_id=460.

To further explore students CT learning, the differences between class subject, core class versus elective class, and yearlong class versus semester class were examined using the post-test averages for all four categories. There were no significant differences in the means for class subject in CT term recognition, or CT term definitions (Table V). This indicates that over the course of one semester, the class subject that CT was incorporated into did not influence the students' ability to recognize or define CT concepts. There were significant differences between class subject area in both Likert questions (Table V). A similar trend in means is seen in each category

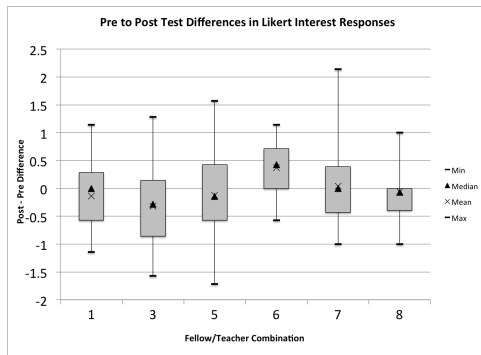


Fig. 9. Differences of Likert Interest Questions Over the Course of One Semester.

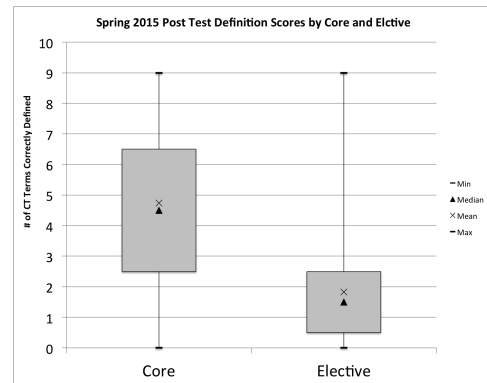


Fig. 11. Comparison of Number of Correct CT Definitions in Core and Elective Classes.

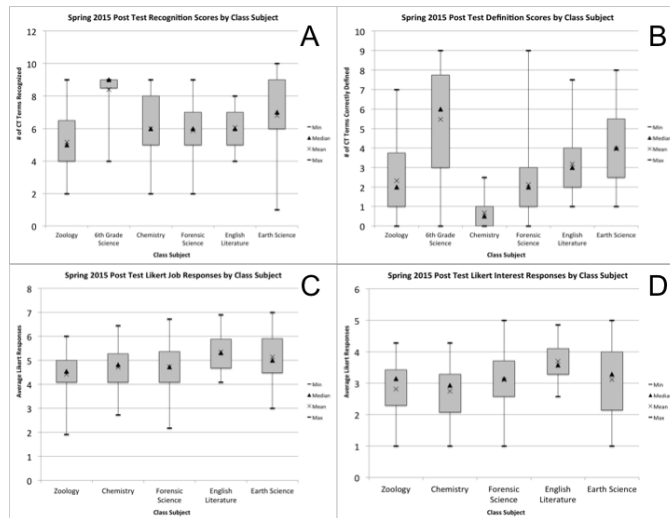


Fig. 10. Class Subject Comparisons for CT Term Recognition, CT Term Definitions, and Likert Questions.

(Figure 5). The computer science classes means were the highest in correct definitions and both likert questions (Figure 5B,C,D). This trend is expected because computer science is an elective course, and its curriculum already includes CT concepts. The students in those classes chose to take the class, which may suggest that their scores were higher because they were already interested in computing, and they learned CT concepts as part of their curriculum for the course. The sample sizes were small in the chemistry, physics, and english literature subjects, which contributes to the smaller variation seen in these subjects compared to others (Table V). The small sample sizes also make it difficult to make statistical conclusions on the comparison of class subjects. The overall trends show that CT term recognition was high in all subjects except for chemistry, and the number of correct CT term definitions was highest in computer science and physics and all other subjects had similar means (Figure 5). It is important to note that, in most cases, the class subject is confounded with fellow/teacher combination, so the differences described could be attributed to the differences in fellow/teacher combination teaching styles rather than subject. For future studies, efforts

will be made to have multiple fellows within a class subject.

When comparing core classes to elective classes, there was no significant difference in the post-test means for CT term recognition, CT term definitions, or Likert questions. From this, it can be concluded that the modules being taught in both types of classes are successful in teaching students fundamental CT concepts. When comparing yearlong classes versus semester classes, there was no significant difference in the post-test means for CT term recognition, CT term definitions, or Likert questions. A difference at this stage in data was not collection was not expected because fellows had only been deploying modules for one semester. It is important to note that there were not enough data combinations to test interactions between class subject, core, elective, year long, and semester long classes. Fellow/teacher combination and class subject may influence the data compared at the core vs elective and year vs semester levels.

VI. RESULTS - SPRING 2015

Spring 2015 data was collected and analyzed in the same manner as the fall 2014 data. Table I shows the information collected for each fellow/teacher pair. The post minus pre-test difference significantly increased over the course of the spring 2015 semester for CT term recognition and CT concept definitions (Table VII), indicating that students were able to recognize more CT concepts and correctly define more CT concepts at the end of the semester than at the beginning of the semester. This also implies that the fellows in the year long courses continued to increase knowledge over the course of the second semester. As seen in Figures 6 and 7, there is a large amount of variability between fellow/teacher combinations, which can be attributed to outside factors, such as teaching method, class time of day, and number of students. Overall, the mean differences for CT term recognition and correct definitions were greater than zero, indicating that students increased in their foundational CT knowledge with every fellow/teacher combination, especially in combinations 2, 3, and 7. This data enforces the DISSECT goal of successful CT incorporation into K-12 curricula.

The difference of Likert responses for computing interest and jobs were also investigated for the spring 2015 semester. The average responses were subjected to a paired t test to detect significant changes over the course of the semester (Table VIII). The responses for computing jobs showed a significant increase, while the responses for CT interest did not show a significant difference. This illustrates that the CT modules increased students' understanding of computing jobs, but did not change their interest in computing in general. This is in contrast to the results from the fall semester, which could be due to the year long courses. The students in the year long courses already displayed an increase in interest in the fall semester, so it is possible that their spring pre-test average was high to begin with, which would result in a small or undetectable difference over the course of the spring semester. Figures 8 and 9 depict the differences of the Likert responses, showing that the fellow/teacher combination 6, which was a semester long course, had the highest difference in both Likert responses.

The differences between class subject, core class versus elective class, and yearlong class versus semester class were examined using the spring post-test averages for all four categories (Table IX). The fellow/teacher combinations were used to account for the variability of the model. There were no significant changes in CT term recognition, correct CT definitions, or Likert responses (Figure 10). This demonstrates that subject matter does not influence the students' ability to learn CT or their interest in and understanding of computing, which correlates with the fall semester data.

There were also no significant changes in recognition, definitions, or Likert responses when comparing year long classes to semester long classes. This was unexpected because it was assumed that the more time students had with CT modules, the more they would learn, and thus, they would have had increased in CT term recognition and correct CT definitions. This data demonstrates that CT incorporation was equally effective in year long and semester long courses.

There was, however, a significant increase in the number of correct CT definitions in the core classes when compared to the elective classes (Figure 11), which resulted in a p value of 0.0296. This indicates that the CT modules delivered in the English literature, 6th grade science, and earth science courses resulted in higher CT term recognition and number of correct CT definitions. As with the fall semester data, it is important to note that there were not enough data combinations to test interactions between class subject, core, elective, year long, and semester long classes. Fellow/teacher combinations and class subject may influence the data compared at the core vs elective and year vs semester levels.

VII. CONCLUSION AND FUTURE WORK

This paper discussed the intentions of the DISSECT program and the efforts to equip the students with essential skills in CT and increase their abilities in problem solving and critical thinking. The fellows imparted these skills by creating

and deploying modules in the classroom with the students on average between 5 and 8 hours a week for two semesters.

The modules were evaluated by issuing an assessment before instruction in CT begins and issuing the same assessment at the end of the semester. The results of the assessments were compared and analyzed to determine the differences between their before and after scores. The intention was that the efforts of DISSECT and the graduate fellows working in the classrooms had a positive impact on the students recognition and integration of CT principles in their daily lives. In addition to increasing the students' CT knowledge, DISSECT intended to increase their interest in pursuing a career in computing or involving computing and their interest in computing in general.

According to our generalized method of assessment, the results clearly indicate that the modules developed and used by DISSECT fellows were effective in increasing the interest, motivation, and knowledge of computer science in secondary education students. The analysis was robust in its ability to assess improvements in knowledge of, attitude towards, and interest in computer science and computing in general, with the results being favorable in this regard. It is important, however, that future studies be directed towards finer exploration of concept mastery.

Future research will need to indicate whether students are developing concept mastery beyond rote memorization and recognition of covered topics. It is essential that students not only recognize examples of the terms and concepts discussed, but also show a creative process of concept use. DISSECT's ultimate goal is the improvement of analytical thinking, strategic organization, and planning. The program aims to test the organization's underlying hypothesis that participation in DISSECT modules will improve these intellectual qualities beyond those of nonparticipants.

In future semesters, DISSECT fellows plan to extend and expand assessment to include questions that test the critical thinking skills of the students. It is the goal of the DISSECT program to characterize the improvements made by students in their understanding of CT concepts and their ability to apply those concepts to both real-world and computer science problems. By providing students with several thought provoking challenges fellows aim to show a marked improvement in students' analytical abilities. As the program progresses it evolves and data collection techniques are refined. There are many uncontrollable variables when collecting data across many schools, grades, subjects, teachers, and fellows. Then NMSU DISSECT team held one summer camp in 2014 and plans to continue camps in the future since they provide an opportunity to evaluate the productiveness of CT modules in a more controlled environment. Additionally, expanding the assessments to include more questions will provide more insight into each student's depth of understanding of specific CT concepts and effectiveness between individual modules.

ACKNOWLEDGMENT

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Young Women in Computing: Creating a Successful and Sustainable Pipeline

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Abstract—Young Women in Computing (YWiC) is an outreach initiative housed in the Department of Computer Science at New Mexico State University (NMSU). The program is designed to increase the number of women introduced to computer science; promote the role and presence of women in the field of computing; improve the retention of female students in computing programs; establish a permanent infrastructure (i.e., pipeline) to promote the participation of women, especially of Hispanic heritage, in computing activities; and, serve as a model of effective computer science outreach practices to reach young women. Since 2006, YWiC programming has reached over 10,200 students. By enhancing interest in computing among student populations, YWiC has successfully created a pipeline into Computer Science and Science, Technology, Engineering, and Mathematics (STEM-C) undergraduate programs, particularly at NMSU; among the 366 non-repeated summer campers, 99% of the 98 high school graduates attended college in the fall term immediately following their graduation, with 61% declaring a major in a STEM-C field. This paper will present quality practices and lessons that YWiC has learned in order to become a successful and sustainable outreach program in southern New Mexico.

Keywords— *Computer science; Computer science education; Outreach; K-12; Curriculum development*

I. INTRODUCTION

Female presence in the field of computer science (CS) is dramatically underrepresented; the problem is compounded when observing the presence of Hispanic females. Research suggests that the gender gap and lack of interest in CS among female students can be traced to high school [1, 2]. College Board's 10th Annual AP Report to the Nation analyzes each state's effort to "provide opportunities to demonstrate college-level skills and knowledge in high school" for low-income and traditionally underserved minority students [3]. At 46.7%, New Mexico (NM) was the state with the highest number of Hispanic Advanced Placement (AP) test-takers. However, Hispanic students only made up 18.8% of the entire pool of test-takers [4]. The supplemental report for the AP CS exam [5] stated that out of the 22,273 AP CS test-takers in 2013, women made up 19%, and Hispanic students made up only 9%; the report did not include the percentage of test-takers that were both female and Hispanic.

This has a direct impact on CS degrees awarded to women in general, and, more specifically, Hispanic women. Several studies conducted to track the graduation rates of women show that the number of women graduating with CS degrees, while slowly increasing, is not on track to fill the Department of Labor's projected 15% growth in Computer and Information Research Scientist jobs by 2022 [6]. The 2011-12 CRA Taulbee Survey reported the fraction of women awarded bachelor degrees in CS increased to 12.9%, compared to 11.7% in the previous year [7]. An infographic compiled by the National Center for Women and Information Technology (NCWIT) explores the disparity of women in tech in 2013: women earned 57% of undergraduate degrees in the US, while 18% of undergraduate computer information and sciences degrees [8]. The increase from 12.9% to 18% may be attributed to the increase in diversity recruitment efforts to hire and retain women and Hispanics in computing. Yet, in 2013 women still made up only 26% of the computing workforce, 2% of which were both female and Hispanic [9].

The Southern Education Foundation has published a Research Bulletin that detailed the nation's poverty rates in 2013 [10]. The bulletin explained that 51% of students were living in poverty or near-poverty, qualifying for free or reduced-price lunches; NM is ranked second in the nation with a 67.7% poverty rate. Additionally, NM holds a 50.4% female and 22% Hispanic female population, on trend with projections for the United States female population (50.2%) and Hispanic population (28%) in 2060 [11-13]. The increase in demand for computing services and the diverse and representative population within NM establishes a prime environment for bringing CS to one of the most underrepresented and underserved populations within the industry, who can potentially have a tremendous long-term impact. This problem has prompted the creation of numerous K-12 outreach initiatives (e.g., [14-21]) that aim to introduce female and other underserved student groups to CS and other STEM disciplines (STEM-C) earlier in their academic careers in NM. The Young Women in Computing (YWiC) program is one such initiative that was created in 2006 under a National Science Foundation's Broadening Participation in Computing grant [22].

YWiC, in partnership with the Department of Computer Science at New Mexico State University (NMSU), is committed to promoting the role and presence of women in computing at all levels across the educational pipeline, with particular focus on girls and Hispanic students from the south-central region of NM. Specific goals and objectives of YWiC are to:

- 1) Increase the number of girls being exposed to CS through initiatives geared towards introducing computing in fun and interactive ways.
- 2) Increase the presence of women in college CS programs.
- 3) Improve the retention of female CS students, and ultimately improve female CS graduation rates.
- 4) Provide a space to develop mentor-mentee relationships to support women in their work.
- 5) Establish a permanent infrastructure (i.e., pipeline) that unites regional school systems with NMSU to promote the participation of women, especially of Hispanic heritage, in a 4-year CS program.
- 6) Create a base of expertise to train K-12 instructors in computing and in best practices to motivate young women to study CS.
- 7) Serve as a model of effective computer science outreach practices to reach young women.

II. PROGRAM DESIGN

A. Program Overview

Established in 2006, YWiC has become a multi-faceted and sustainable outreach program, reaching over 10,200 students through outreach initiatives across southern NM. YWiC initiatives are implemented year-round and strategically occur at key points to efficiently introduce CS to the most female students; outreach initiatives, which are designed to build upon one another, include competitions, clubs, conferences, classroom workshops (roadshows), and summer camps. Figure 1 provides an overview of YWiC's outreach components throughout the school year. YWiC is designed to introduce students to CS via roadshows, give students a deeper understanding of CS with after-school programming clubs and competitions, and give students a broader perspective of CS through conferences. The goal is for the more committed students who participated in YWiC activities during the school year to attend YWiC summer camps, where students have the opportunity to learn and apply more advanced CS skills through project-, problem-, and inquiry-based curriculum.

B. Curriculum Design

Acknowledging that the current challenge is to continuously engage female students in CS activities as they progress through their education, YWiC offers extensive interdisciplinary year-round opportunities for elementary, middle, and high school girls in computing. The structure of YWiC's curricula is a series of integrated modules that span across all outreach initiatives and multiple stages of the pipeline to generate an interest in CS for all students. Each unique module offers opportunities for students to learn

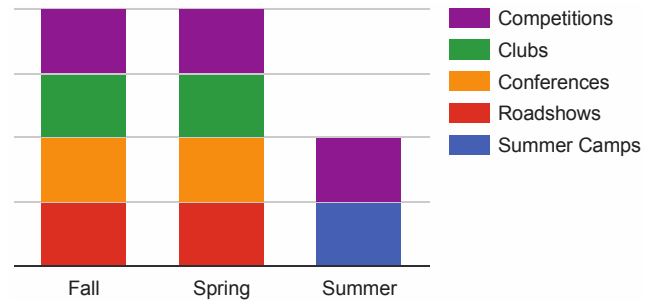


Fig. 1. Annual Outreach Timeline

computing and algorithmic thinking concepts through either a programming language, programming platform, or an interdisciplinary context. Overall, YWiC modules are taught with three pedagogical approaches: 1) project-based; 2) problem-based modules present students with a problem that can be solved after acquiring knowledge; and, 3) inquiry-based modules provide an active questioning, critical thinking, and problem-solving approach. These modules are designed to encourage continued learning after a module is complete by utilizing platforms and languages that are open-source, address student needs and interests by covering a wide range of interdisciplinary content, and meet student programming experience level by offering instruction with both visual and textual programming platforms. Note, visual programming platforms implement a simple drag-and-drop programming interface (e.g., Scratch [23]), while textual programming platforms represent traditional programming languages (e.g., Python, HTML).

It is vital to find a proper balance between challenging and overwhelming students [24]. Each cohort of students brings a unique set of skills, so the difficulty of material and the style of the presentation is dynamically adjusted to meet the needs of students. Unchallenged students tend to quickly lose interest, while presenting too many concepts leads to frustration. Another important component is to ensure that the material is always presented in a way that puts "computing in context", in order to make the subject matter relevant to the students' interests.

C. Personnel

YWiC currently staffs one full-time coordinator and five part-time Undergraduate Research Assistants (URA); in the past, YWiC has employed up to seven URAs. The choice of instructors and team members is critical for success. They not only have to be prepared and skilled, but they should also demonstrate enthusiasm and a willingness to establish a bond with the student participants. YWiC experience has demonstrated that students engage more with instructors from similar backgrounds; the URAs are highly motivated female undergraduate students majoring and/or minoring in STEM-C fields at NMSU and are the technical experts associated with each element of YWiC's outreach initiatives. Integral to the success and sustainability of the program, the URAs are responsible for the implementation, from idea to instruction, of innovative platforms and projects that enhance YWiC summer camps, roadshows, and competition curricula.

III. PIPELINE STRUCTURE

Multidimensional program components such as classroom workshops, summer programs, conferences, after-school clubs, and competitions graft together to facilitate the pipeline: elementary school, middle school, high school, and college. An overarching goal of YWiC is to create a structure that successfully integrates the five program components to retain female CS students from elementary school through college graduation. Figure 2 depicts the structure of YWiC's pipeline by illustrating the outreach avenues implemented at each level of the pipeline. YWiC collaborates with the Las Cruces Public Schools (LCPS) District and surrounding districts for all outreach practices. Due to the scope of this paper, the following sections expand on only the most successful and effective outreach activities conducted to each group of students.

A. Elementary School

The elementary school phase of the pipeline was first implemented in 2011, and was a strategic move in an attempt to increase the number of students continuing the pipeline in middle school. Effectively put by the J.B. School of Engineering, adding elementary students to the pipeline serves to "enlarge the funnel" of interested and prepared students that pursue STEM studies later in their education [25]. Other research [26] shows that such pursuits are worthwhile, as "STEM initiatives and activities positively impact elementary students' perceptions and dispositions", and may better motivate and prepare students to undertake STEM-C careers.

Roadshows (i.e., informal hands-on classroom-style workshops) range in duration from 45 minutes to 1.5 hours and are the foundation for elementary outreach. At the elementary school level, roadshow curriculum is designed to introduce students to CS through a short discussion followed by an engaging project. The discussion is a 10-minute interactive presentation focused on the definition of CS and the well-known exciting job opportunities (i.e., game programming, industry software engineering at Google, Apple, Facebook, etc., and government jobs with NASA and White Sands Missile Range). Students are encouraged to take active roles in the discussion; small prizes are awarded to provide an incentive for shy students. To retain interest, YWiC instructors complete the presentation as quickly as possible; students are usually more excited to play with robots or make their own computer games.

The emphasis of these roadshows is the hands-on project component, where students are led through an example program and are tasked with modifying the sample program or creating one of their own. Because roadshows vary in structure (duration, number of students, student age, location, and resources), YWiC has utilized a range of platforms as the basis for roadshow projects. Each platform determines the student project to be completed and has its own limitations.

B. Middle School

Middle school outreach began in 2009. Early on, YWiC understood the phenomena that elementary school girls and boys show equal interest in STEM until middle school and

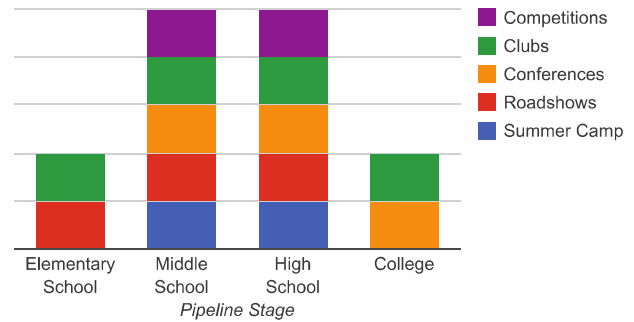


Fig. 2. Pipeline Structure

recognized that if girls do not develop the correct perceptions of their strengths and weaknesses in specific subjects during this crucial time, their interest in STEM begins to fade [27, 28]. YWiC has continued to introduce young students to technical fields and provide encouragement at the middle school level to make it more likely for students to pursue STEM-C fields in their post-secondary education. It should be acknowledged and celebrated that the LCPS system has invested significant effort in the creation of programs to train and motivate all students; at the middle school level, three schools offer magnet programs to attract students to specific areas of interest (i.e., media, science, music technology, and engineering). However, although most programs include a technology component, they do not specifically teach students CS or its relation to the program content. YWiC works to address this problem by providing these students, and all other students who do not attend magnet schools, CS learning opportunities to supplement the curricula they are taught in school. Specific CS learning opportunities for middle school students include summer camps, roadshows, conferences, clubs, and competitions.

In response to the increased interest of the students who participated in YWiC's first after-school club, middle school summer camps were created in 2010. The majority of the 2010 "campers" were club members, and, therefore, the curriculum was designed to build upon their existing knowledge. Since the pilot year, the summer program has evolved significantly: the length of camp has increased from one week to two; recruitment is open to all area students; and, the curriculum provided is more extensive. Each summer YWiC instructors guide campers through an action-packed curriculum that is designed to show students that CS is a rewarding field. The camps are designed to achieve three major goals: 1) generate and sustain girls' knowledge and interest in CS; 2) drastically increase students' confidence in CS and CS-related disciplines; and, 3) build a community among camp participants. Each goal is achieved through specific sets of activities implemented in the summer camp.

CS Knowledge and Interest: The central focus of each summer camp is the instruction of the underlying computational thinking skills and CS concepts needed to succeed in CS courses. Each Spring, YWiC chooses the summer camp curricula by determining the best combination of modules that are interactive, hands-on, exploratory, and relevant for 10- to 13-year-old girls. Figure 3 depicts the history of YWiC's middle school summer camp modules

integrated into the curriculum. In particular, it portrays YWiC's increased flexibility and wide range of module instruction.

The majority of the summer camp modules are project-based and challenge campers to implement a solution to a problem through the use of interactive software platforms; many modules implement visual programming platforms to meet the needs and experience-level of middle school students. YWiC research has shown that visual programming platforms are more enticing to the middle school population.

Confidence: The second objective of the summer camp is to build the students' confidence in CS endeavors. This is done through a variety of methods. First, the curriculum is taught in a fun, engaging atmosphere, where successful outcomes are frequent and celebrated. Second, self-efficacy is developed by challenging students to step out of their comfort zone in a non-threatening environment to solve a problem, interact with their peers, and present their project. Finally, YWiC instructors pose discussions that aim to break down the stereotypes and perceptions students have about CS.

Community: Not only do the students learn technical CS skills, but YWiC also emphasizes soft skills – such as leadership, teamwork, and communication. Campers should experience CS as a social and collaborative profession. Thus, every summer camp is composed of community building components that aim to reduce any sense of isolation. Campers use pair-programming to complete projects; participate in daily ice breakers and small team-building activities; and are invited to weekly social events including game nights and movie nights.

C. High School

High school is when students spend the majority of their time determining what they want to study in college. Most often, students will choose careers that they are familiar with (e.g., careers held by family members, related to elective courses, etc.). However, the rigidity of curricula in school systems does not easily allow the introduction of new courses, such as CS courses. This presents a problem because high school course selection is one of the factors that contributes to the lack of female interest in information technology (IT), as noted by Bartol and Aspray [29]. According to their research on the underrepresentation of women in IT, other contributing factors include confidence with computers, female role models, perceptions of IT careers, and knowledge about career options. Thus, if students are not presented with the opportunity to take a CS class in high school, the chances of them pursuing a CS career are low. On the other hand, when CS courses are offered, the majority of students do not have any incentive to take them; only 25 states offer graduation credit for CS classes [30], and many female students perceive CS as a man's pursuit [31]. Hence, it is critical for YWiC to reach out to the high school students who are interested and have the potential to do well in CS, but are either intimidated by CS, can't fit it in their schedule, or do not have access to CS courses. YWiC first addressed this problem in 2006 by offering a summer camp for female students. The program has now expanded to provide additional year-round CS learning opportunities such as roadshows, conference opportunities, competitions, and clubs.

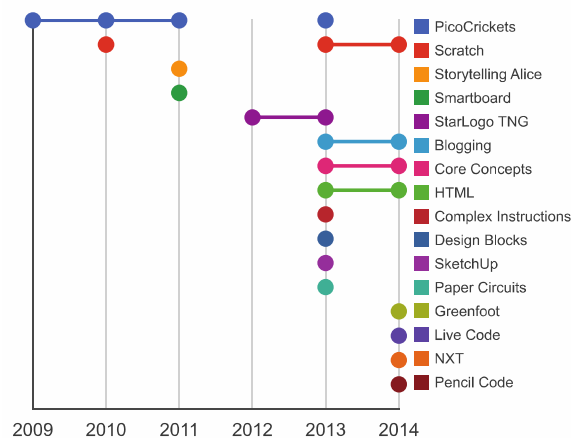


Fig. 3. Middle School Summer Camp Module Instruction

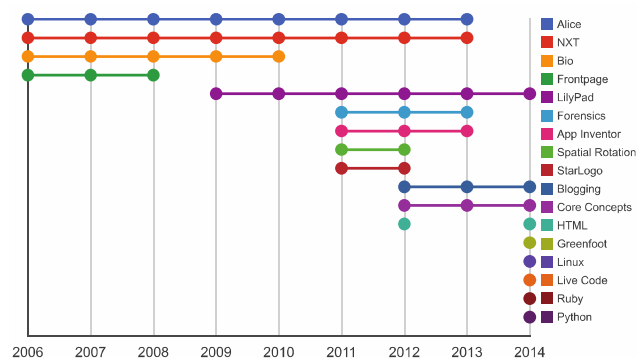


Fig. 4. High School Summer Camp Module Instruction

Summer camps have been the cornerstone of YWiC's outreach initiatives to generate interest in CS among young women. The nine years of summer camp have reached 438 aggregate participants. A net total of 232 high school females have participated: single year students amount 115, two-year attendees total 42, and the number of campers who participated in three or more camps is 11. The goals of the high school camps encompass those of the middle school camp with one additional goal: 1) generate and sustain girls' knowledge and interest in CS; 2) drastically increase students' confidence in CS and CS-related disciplines; 3) build a community among camp participants; and, 4) introduce students to the plentiful, diverse, and multidisciplinary nature of CS career opportunities.

CS Knowledge and Interest: At the high school level, the camp curricula focuses on building competency in CS concepts to prepare students to excel in introductory-level CS courses in college, should they decide to study CS. Figure 4 represents the progression of YWiC's high school summer camp module instruction.

Specifically, YWiC's camp curriculum has evolved to include more modules that feature textual programming platforms, as opposed to visual programming platforms. Again, this tactical decision was to ready high school students for the CS concepts and programming style they would face in college; the AP CS exam also requires knowledge of the Java programming language, so test-takers would benefit from being

comfortable with textual programming platforms. Furthermore, students leave camp with a comprehensive understanding of CS topics including, but not limited to, animation, robotics, and mobile development.

Confidence & Community: The methods to increase student confidence in CS and to build a community among campers in high school are similar to those in middle school. Please reference section 3B for explanation.

CS Career Opportunities: To some high school students, the concept of going to college can be intimidating; it is difficult for these students to picture themselves getting a degree, and even more difficult to see themselves pursuing a tough technical degree like CS. To remedy this, students are given three presentations: the college admissions process, financial aid options, and benefits of a CS career. The general feedback from campers about the presentations has been consistently positive. Campers report that they were previously unaware of the many scholarship opportunities available, and would be less intimidated to meet with an NMSU Advisor after the presentation. Students are also surprised to learn that they could potentially contribute to products that billions of people use every day (e.g., Facebook, Google, etc.), or even invent the next new tech fad themselves.

D. College

The college stage of the pipeline exists to retain the female students that have matriculated from high school into college. YWiC gives female college students the chance to travel to conferences, join the YWiC team as URAs and conduct research, and be a part of a friendly undergraduate community within the CS department at NMSU.

Beginning in 2009, in conjunction with NMSU, the CS Department, and other partners, YWiC began to offer support for the URAs and other undergraduate students to attend local, regional, and national conferences. YWiC encourages the URAs and all conference attendees to take full advantage of the conference experience by actively participating in conference activities. The URAs have not only attended conferences, but have served as student panelists, keynote speakers, poster presenters, and career fair interviewees. Notable accomplishments include the 2010 New Mexico Celebration of Women in Computing Undergraduate Student Poster Award, 85 industry-sponsored conference scholarships, and 7 internship/job securements as a direct result of conference attendance. In total, YWiC has assisted 162 students to attend 23 conferences.

IV. PROGRAM EVALUATION

The ultimate goal of YWiC is to create a pipeline structure that: increases exposure to and interest of young women in CS; attracts them to four-year CS programs; and, effectively prepares them for academic success. These goals are broad and general, and address the problem with a long-term solution. This section presents metrics that measure the short-term and estimated long-term effectiveness of YWiC, including program growth, curricula impact, and college success.

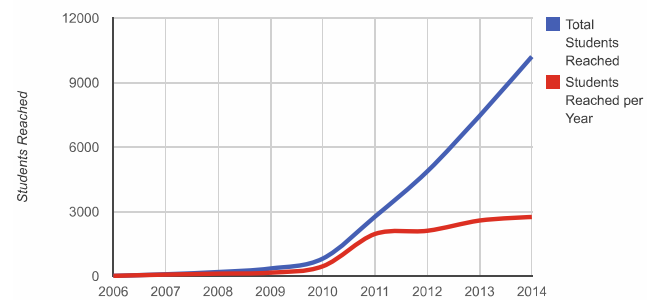


Fig. 5. Program Growth

A. Program Growth

In an effort to increase the number of women being introduced to CS, YWiC has provided a plethora of CS learning opportunities for the students of southern NM, and has experienced considerable growth in the process. Figure 5 depicts the number of students reached per year via outreach initiatives and the cumulative total of students reached. Overall, YWiC's outreach trend has been positive, as the program has continued to engage an increasing number of students every year. YWiC reached the following number of students each year from 2006 - 2014, respectively: 12; 71; 113; 160; 456; 1,956; 2,108; 2,583; and 2,756.

As of January 2015, the organization has reached over 10,200 students through: 53 weeks of summer camps, 315 roadshows, 15 teams mentored in competitions, hosting 5 conferences, and sponsoring 45 women to professional conferences. It is important to note that the 10,200+ students were not all female; the nature of roadshows and competitions provide opportunities for both female and male students to engage in a supportive introductory CS learning experience. Although gender-specific data was not collected from each outreach avenue, YWiC has reached female students at all levels of the pipeline, successfully meeting its goal to introduce female students to computer science.

B. Curricula Impact

In large part, YWiC research has been centered on evaluating the effectiveness of interdisciplinary modules to teach CS concepts and encourage students to pursue STEM-C degrees. YWiC roadshows and summer camps have yielded quantitative and qualitative data via student questionnaires and interviews, which have attempted to: 1) gauge student perceptions of and interest in STEM-C, and 2) provide feedback to evaluate the effectiveness of summer camp and roadshow modules across the curriculum. The research objectives for each year directly affect the questions that students are asked in the pre- and post-camp questionnaires and interviews. Likert-scale questions allow students to respond to questions on a scale from 1-5 (e.g., 1: Strongly Disagree through 5: Strongly Agree); open-ended questions allow students to elaborate on their camp experiences.

One question that has remained consistent across the nine years of camp is: "I have basic knowledge of computer science". Figure 6 presents data for the high school students who selected a 4 or a 5 on a scale from 1-5 to this question

from 2006 – 2014. As expected, pre- to post-camp knowledge of CS increased substantially each year of camp. The largest increase observed was in 2009; 46% of campers reported previous knowledge of CS, while 93% of the campers reported knowledge of CS after the completion of camp. The smallest increase occurred in 2008 when the pre- to post-responses were 71% and 100%, respectively. There were no pre-surveys administered in 2006, but the 100% post-camp responses showed that all campers acquired knowledge of CS during camp. Data from 2011 is missing.

Figure 7 displays the most recent data available for student responses to the questions: 1) “I want to major in Computer Science”; 2) “I would like a job that uses Computer Science”; and, 3) “I want to be a Computer Scientist”. The chart represents those students who selected a 4 or 5 on a scale from 1-5. Interestingly, the 2013 middle school group reported the largest percentage of students most interested in majoring in CS, and the 2013 high school group contained the highest percentage of students that wanted a job utilizing CS, and, specifically, wanted to be a computer scientist.

At the conclusion of the 2014 middle school summer camp, after being exposed to visual and textual programming environments, students were surveyed to determine what was their favorite programming style and which programming style they felt taught them more about CS. Figure 8 shows that the students’ favorite programming styles correlated with their perceptions of the programming style they felt taught them the most about CS. From this study, YWiC concluded that middle school students are more comfortable with visual programming platforms.

In 2013, YWiC conducted a two-week study during the high school summer camp to determine which module, LilyPad Arduino [32], a textual programming platform, or App Inventor [33], a visual programming platform, was most effective at teaching students programming skills. Students were asked to indicate which software approach best instructed them in the fundamental concepts of CS; Figure 9 shows the percentage of students that indicated which modules successfully taught them each CS concept. The results were as follows: compared to App Inventor, LilyPad was more effective in teaching variables (75%), loops (69%), functions (81%), and properties (63%). Conversely, App Inventor was more effective than LilyPad Arduino at instructing if-else statements (81%), input/output (81%), and events (69%). Both tools were equally successful in teaching the concepts of objects (81%) and parameters (56%). The study concluded that if time permitted, a combination of both platform types (textual and visual) is ideal to teach the specified CS concepts.

The study also measured student interest in a number of STEM-C-related domains. Figure 10 presents the percentage of students that became interested (or more interested) in mobile applications, electronics, math, CS, programming, and technology as a result of learning LilyPad and App Inventor. Students reported an overall increase of interest in all categories as a result of their work with LilyPad and App Inventor: App Inventor was most successful in increasing student interest in mobile applications (86%); LilyPad was most successful in increasing student interest in technology



Fig. 6. High School Summer Camp Understanding of CS

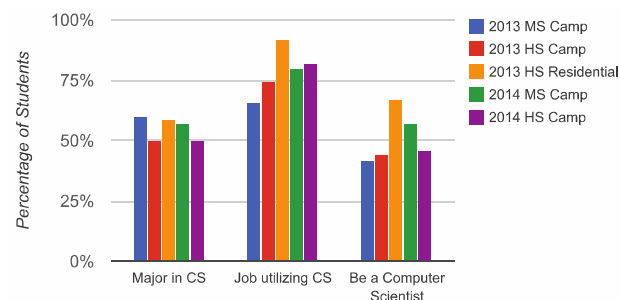


Fig. 7. Middle School and High School Post-Camp CS Aspirations

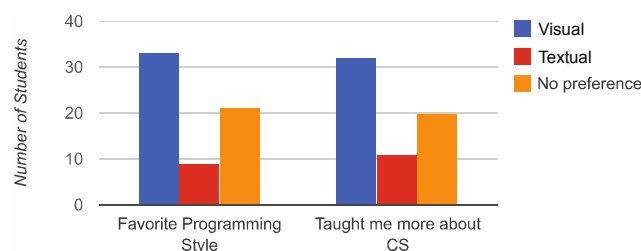


Fig. 8. 2014 Middle School Summer Camp Programming Preferences

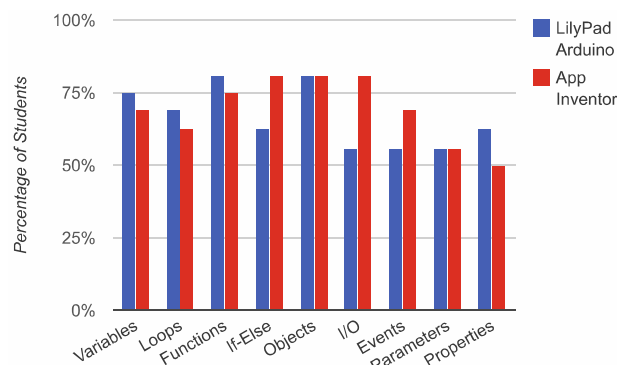


Fig. 9. Concepts Learned Through LilyPad Arduino and App Inventor

(85%). In particular, reported interest in CS reached 76% and 52% as a result of working with LilyPad Arduino and App Inventor, respectively. YWiC hypothesizes that LilyPad Arduino generated more interest in CS, programming, and technology than App Inventor because of the textual-based programming environment that gives students a more intimate and challenging programming experience; LilyPad Arduino also has a hardware component to the module, which creates a tangible connection to CS.

In 2013, YWiC also initiated a survey study to see the factors impacting student interest in CS during roadshows. The modules used for these roadshows were PicoCricket [34] and Storytelling Alice [35]. Over a four-month period, 18 sets of pre- and post-surveys were administered to students during roadshows. Due to roadshow time constraints, it was impractical to administer both pre- and post-surveys to all students; 9 groups received pre-surveys and 9 groups received post-surveys. A total of 295 responses were recorded: 157 (53%) were pre-survey responses and 138 (47%) were post-survey responses. Figure 11 shows the responses to the question: “How interested are you in Computer Science?” Between the pre- and post-survey groups there was a 4%, 19%, and 9% decrease in the not interested, a little interested, and pretty interested responses, respectively; there was a 66% percent increase in the number of students that reported being super interested in CS. The significant increase in “Super Interested” responses justifies that roadshows are effective tools for increasing student interest in CS.

C. College Success

The obvious metric to measure the increase of presence and retention of female students in CS is the number of women in the NMSU CS program and other STEM-C programs. Because this is a long-term metric, data in this section is only available for the 98 summer camp alumnae that have graduated high school since their participation in YWiC camp in 2006, and the student-base in the CS program at NMSU. It is important to note that many of the students in YWiC’s pipeline are currently in the elementary and middle school stages, far from graduation. Further, at this time it is infeasible to track every student that YWiC reaches through various outreach activities.

YWiC encourages every student to pursue a college degree, and has seen a high matriculation rate for high school summer camp students. Of the 98 high school graduates, 97 chose to attend college the semester immediately following graduation. Among them, 63.2% are STEM-C majors, and 76.5% chose to attend NMSU. Figure 12 shows the distribution of majors that were chosen by the 97 students upon entry into college. Although only 16% of camp alumni chose to pursue a CS degree, YWiC deems the fact that 63.2% of students selected STEM-C majors a success. CS is interdisciplinary in nature, and many recent advances have been motivated and guided by the interaction between CS and other scientific domains. Various research suggests that women do not perceive CS as a self-sustaining discipline, but as a tool to serve the needs of other disciplines, (e.g., education, medicine, etc.) and recognize its potential to address societal needs. This allows young women to pursue CS careers where they feel like an active part of the solution; this interdisciplinary perspective also stresses the role of collaboration, teamwork, and communication, factors that have been recognized to be of great importance to enhance success of Hispanic students.

D. Lessons Learned

YWiC has encountered many challenges and successes throughout its nine years of outreach. Post-experience reflection and analyses have yielded interesting insights, with many valuable lessons learned.

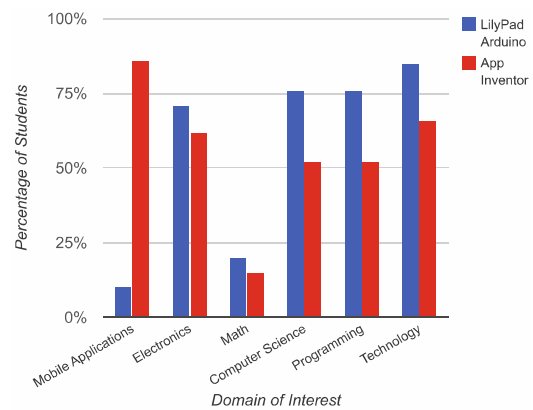


Fig. 10. Interest Generated by LilyPad Arduino and App Inventor

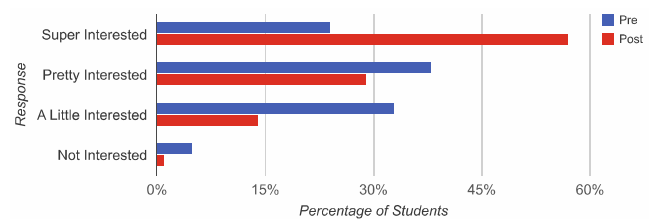


Fig. 11. Roadshows Survey Question: “How interested are you in CS?”

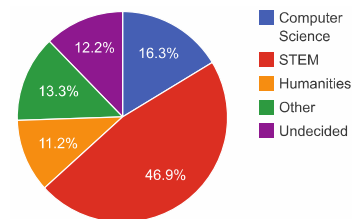


Fig. 12. Chosen College Major

Curriculum Design: The retention of student interest in CS relies on the relevance, engagement, and uniqueness of the YWiC curriculum. The curriculum has been effective at generating interest in CS among students at all stages of the pipeline; the challenge that remains is keeping repeat students interested. Many students participate in more than one YWiC program, and so it is imperative to continuously update and redesign curricula with both challenging and engaging content. This includes the creation of new modules when cutting-edge programming platforms are introduced.

Data Collection: Collecting data regarding student experiences with CS in YWiC-sponsored events is essential to the development of relevant and successful program curricula. YWiC has found it challenging to keep questionnaires consistent. The fluctuations in management and URA positions have complicated data collection at times, specifically in relation to the consistency of the types of questions and methods for student questionnaires and interviews. Survey questions reflect the different research initiatives, innovative modules and platforms, outreach avenues, YWiC staff, etc.

Instructors and Student Assistants: Camp instructors and student assistants are critical to the success of all outreach practices. Each activity offered by YWiC is taught by

undergraduate and/or graduate students and staffed by student assistants. Hiring student assistants promotes the continued engagement of past students who have participated in YWiC programming; they engage in mentor-mentee relationships with camp instructors and help teach material to students in ways that are applicable, meaningful, and relevant to their own age group. It is important to train all instructors and student assistants in topic and substance, and also in the overall goals and mission of the program for maximum student participation, engagement, and retention. With community outreach, the desired effects include recruiting students for future participation in outreach initiatives through activities that promote confidence, positive self-image, and create bridges for building communities and social networking.

Leveraging Partnerships: Expanding the collaborations with school districts, as well as with local, state-wide, and national girl-serving programs helps to ensure a larger pool of talented students from the under-served areas of NM and the survivability of the program. Specific to summer camps, YWiC has partnered with organizations including, but not limited to: GUTS y Girls, AAUW, DataOne, and NCWIT.

Parental Involvement: Direct communication with parents/guardians via phone calls, emails, Facebook, website postings, text messages, and informational sessions assists YWiC in reaching out and communicating about upcoming opportunities. Parents learn they have a direct link with the university, the department, and the programming available for their children. This increases response rates, participation rates, and interest for new, upcoming activities. In addition, as families become more familiar with the campus community, they become less intimidated by the transition between secondary and postsecondary education and more vocal when questions and/or concerns arise.

Student Involvement With Other Programs: YWiC's outreach initiatives are limited to the students who are able to participate in them. This is challenging because many students participate in additional extra-curricular activities that conflict with YWiC programs and opportunities. To overcome this challenge, YWiC has learned to promote opportunities in advance to allow interested students to plan accordingly. YWiC has also learned that to retain interested students it is important to be flexible and, if possible, adapt to student schedules as best as possible.

Target Schools: Expanding collaborations with local schools is crucial to the expansion and success of the program. YWiC began targeting three local public schools, and later expanded to local private high schools, home schools, and other school districts. Targeting a wider range of schools has led to greater diversity of students from the under-served areas of NM.

Team Building: YWiC has learned that it is essential to provide exciting team building exercises for students in order to foster a successful cohort. Students increase satisfaction and connection with instruction sessions as their cohort generates greater familiarity and comfort with one another. This also raises creativity levels and overall design output for each participant.

V. CONCLUSION AND FUTURE WORK

To address the underrepresentation of women and minorities in computing fields, YWiC has created a permanent infrastructure (i.e., pipeline) that ensures the participation of girls and women in CS. YWiC's broad student base, engaging curricula, unique pedagogical approaches, and ability to learn from and adapt to a changing landscape of technology and student abilities have enabled the program to be successful in recruiting and retaining females in STEM-C post-secondary programs at NMSU and other universities. Specifically, YWiC research initiatives show that summer camp and roadshow curricula have a positive effect on student perceptions and abilities in CS, with 63.2% of YWiC summer camp alumnae having selected STEM-C majors. Additionally, since the introduction of YWiC in 2006, the NMSU CS Department has seen an increase from 8% to 23% of female undergraduate students, and YWiC experiences have been instrumental in the design and addition of a Bachelor of Arts degree in CS, which facilitates the interdisciplinary study of CS.

YWiC has reached a level of reputation and maturity to fill a bigger role within NM by coordinating state-wide initiatives and acting as an entity that will lead to integration and growth for existing programs. Looking to the future, YWiC aspires to fully develop each stage of the pipeline (i.e., conduct more outreach for elementary and college students) and expand its role to serve as an information and outreach portal for other similar STEM-C outreach programs on a regional scale. YWiC will continue to connect organizations, individuals, universities, and industries, both public and private, to further engage students in their STEM-C journeys.

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A Community of Practice to Develop, Teach, and Disseminate Learning in Engineering Design

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Abstract—This work-in-progress paper describes the initial efforts and findings from the development of a pedagogical approach to prepare pre-service teachers for teaching engineering and engaging with the community mediated through an online portal. This project incorporates the latest research on inverted classrooms and best practices for online learning in an effort to build the VILLA Community of Practice. VILLA has been designed in a manner that makes it unique in the area of instructional technology and web-based learning. This project recognizes the importance of engaging community in the teaching and learning of engineering-based content. Where VILLA is able to distinguish itself from other service-learning projects is the use of an inverted classroom format to facilitate instruction and the emphasis on modeling artifacts as a representation of student learning.

Keywords—communities of practice, design education, pre-service teachers, teaching

I. INTRODUCTION

This work-in-progress paper describes the initial efforts of VILLA, a Community of Design and Creation, in preparing pre-service teachers for teaching engineering and engaging in and with the community mediated by an online portal. Education is constantly debated and evolving as it relates to technology. With the printing press, the computer, the world-wide-web, and social media educators and students have questioned how technology might best be employed for learning. Technology not only influences how curriculum is developed and delivered, but also impacts nearly every aspect of teaching and learning.

II. MAKERS IN A FLIPPED CLASSROOM

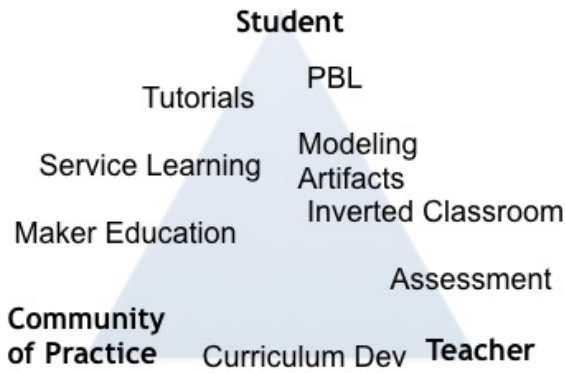
A mismatch between teacher's pedagogies and students' learning preferences has precipitated the need for introducing technologies to improve students' opportunities to learn. One such approach is "inverting" the classroom where traditional instruction and lecture that normally occur inside the classroom are flipped and these events occur outside of the classroom [1]. In inverted classroom settings teachers focus mainly on student outcomes whereby the student is expected to take more responsibility for deciding the best method to reach said outcome [1]. One drawback is the amount of time and commitment needed from the instructor on the front end to facilitate this kind of instruction. Inverted classrooms also require students to take more responsibility for their learning

and the delivery of course content. In the inverted classroom lectures and similar content are not covered in class, instead students are expected to review tutorials and other pre-packaged content and class time is used to do get students involved in active work [2].

In order to build effective online learning environments there needs to be consideration for the necessary elements needed to develop a learner-focused, active-learning community. Pallof and Pratt [3] developed a framework for the development of effective learning communities that include: *people, purpose, policies, computer systems, collaborative learning and reflective practice*. This model evolved into three categories: *people, purpose, and processes* wherein the outcomes of an effective online learning environment would be *reflective/ transformative learning*.

This project incorporates the latest research on inverted classrooms and best practices for online learning in an effort to build the VILLA Community of Practice. VILLA has been designed in a manner that makes it unique in the area of instructional technology and web-based learning. This project recognizes the importance of engaging community in the teaching and learning of engineering-based content. Service learning projects provide students, in this case pre-service teachers, with authentic real-world experiences which helps secure buy in from the student, teacher, and community of practice [4]. Where VILLA is able to distinguish itself from other service-learning projects is the use of an inverted classroom format to facilitate instruction and the emphasis on modeling artifacts as a representation of student learning [5]. Furthermore, the students not only publish what they have made and learned, but also are able to receive feedback from the community of practice as well. Students learn from resources on the web and in turn develop their own resources and share them as tutorials and videos. The learning then is truly student driven, Figure 1.

FIG. I. THE COMPONENTS OF VILLA.



III. GETTING OFF THE GROUND

The majority of teachers create activities that are either deskwork or have a singular focus on a certain tool. Most educators are accustomed to being the single source of information in the class and control the flow of learning. The more advanced students typically wait for other students to finish or be remediated. This creates a pause in learning for the students who want to learn more and delve deeper into the activity.

In this project the research-practitioners had to look at making the class more student-driven and inclusive to a majority of learning preferences. Realizing that technology is rapidly changing, the research-practitioners had to assume the role of co-learners in the classroom. There are times when a student knows more about subject than the instructor. Some students have a parent that work with them on a home project that is above and beyond what is being covered in the classroom. Having a student-driven classroom allows motivated and advanced learners continue to progress at their pace.

It can be a little disconcerting to the students and instructor to walk into a classroom and say, “Let’s explore.” Even though there was a class learning management space to guide the students, the primary medium for student work and interaction with the community was a wiki. The students typically published tutorials from the projects they developed on the wiki. Other students, teachers, and anyone from the community were able to leave comments on the tutorials.

In order to help students become familiar with online successful tutorial authoring, they were to find existing tutorials on mechatronic systems, critique them, and eventually make them better. From there, the students were to begin their own projects. The students documented their process with multi media, photos, videos, slides shows, etc. Now it was the students’ turn to create a new tutorial and publish them. As the students were encouraged to reflect and justify their designs, they shared not only what they had done but also why they were doing it.

IV. COMMUNITY AND PARTNERS PERSPECTIVE

The maker and open source movements have always focused on developing knowledge bases that help others learn. Some examples of these knowledge bases are Instructables, various

company websites, Youtube channels, and personal websites of individuals. Quality can sometimes vary. For educators who need to know what items are needed to complete a project or judging how long it will take students to complete, community knowledge bases need to be developed with pedagogy in mind.

Several educators have been developing lesson plans and posting them online. Few of these postings have become vetted tutorials. College faculty create excellent tutorials on innovative ideas, yet these pages are usually hidden behind a learning management system. This model does not help the student as they progress through their programs. It also does not help the current educators to know what other tools are available to improve their student’s learning. Institutions of higher learning are starting to use public platforms to share work to interested parties. These platforms allow for others in the community to add to the posts.

A. Lessons Learned

As educators we want to ultimately impact student learning. Having students publish what they did and why they did it compels them to reflect on their designs and furthermore provides an outlet for dissemination. The students were instructed to write to a middle school audience, thus ensuring the students understood what they were doing.

B. Modeling

The students posted what they did and why they did it, engaging in reflective practice. The modeling artifacts produced were conceptual, graphical, mathematical, and working models. Figures II and III are screenshots of the recycled robot tutorial with graphical (code) and working models.

FIG. II SCREENSHOT OF CODE DEVELOPED FOR ROBODOG

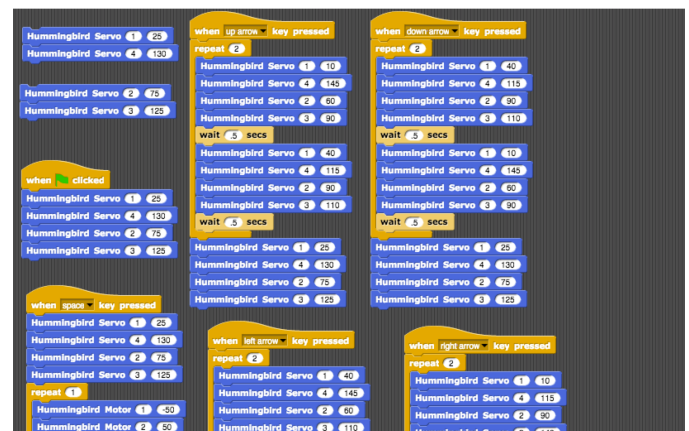
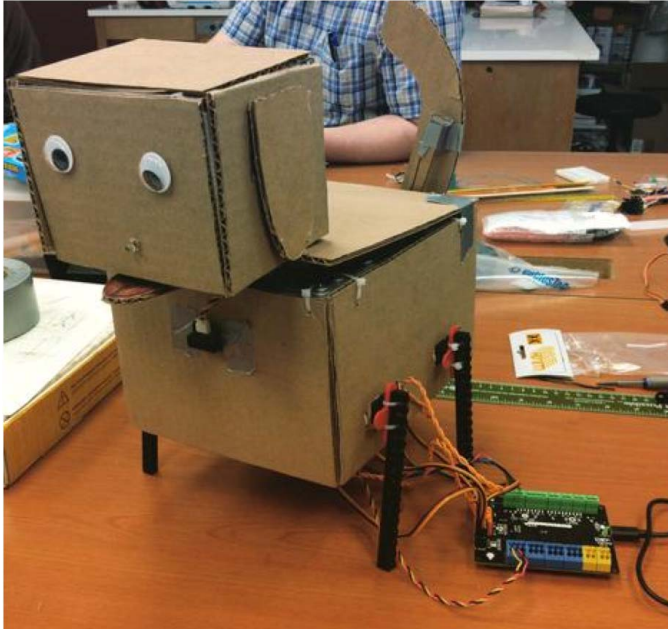


FIG. III PHOTO OF WORKING MODEL OF ROBODOG



C. Format

Although a wiki was chosen as the medium for sharing tutorials, the format is still a challenge. As of now, there has to be restrictions on who can post and edit on the wiki. The students typically needed feedback to improve the tutorial so that it was actually helpful and informative. Copyright and privacy issues are continual concerns. From their experiences, the students did come up with a list of “best practices” for developing a successful tutorial, Table 1. This also served as a standard for the students’ work.

TABLE 1. ELEMENTS OF A SUCCESSFUL TUTORIAL

- Written like they were speaking to you
- Shows how to put project together with steps that are detailed and readable
- Explain why it works or what the different parts do
- Provide an overview and explanation and then provide details
- Know why your are doing the steps
- Inspires you to create
- Quality multimedia
- No fluff
- Shows finished product
- Clear formatting, spelling, and grammar
- Links to resources, both needed and supplementary

D. Assessment

The modeling artifacts not only served as a medium for communication to the community of practices, but also facilitated assessment, formatively and summatively. However, there is a learning curve for using a technology to disseminate tutorials. For some students the learning curve was steeper than others. Students come in at different levels of

publishing on the web. It is not certain how novice students would participate, especially at the k-5 levels. Furthermore, it was easier to assess the teams’ work, but not as simple to assess an individual’s work. One clear advantage was the opportunity for feedback from the community. They are the real users and want vetted resources for themselves and their students.

V. MOVING FORWARD

The overarching goal of VILLA is to provide a central space for creating, editing, and accessing vetted learning resources. Additionally, it aids in collaborative development (professional development) for learners and co-learners (practitioners, instructors, teachers, parents, administrators, mentors, et.c). It is hoped that this resource will help bridge formal STEM learning through informal activities. It is anticipated that the results from this study will lead to pedagogical improvements in teaching engineering design, community engagement, and innovative ways of developing curriculum.

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TIES to STEM: University Outreach Model for Teachers in K-12 STEM Schools to be Trained in Engineering Skills

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Abstract - This paper discusses plans to establish the 'TIES to STEM' outreach program for K-12 STEM school teachers at our University. TIES denotes Training in Engineering Skills and comprises the engineering education program, the pre-engineering curriculum, and the cyber-instructional networks to integrate the K-12 STEM education programs with the engineering disciplines at institutes of higher education. The engineering education program creates the opportunity for K-12 school teachers to learn and apply the engineering design process, engineering technology, and skills in the products approved and used by the engineering industry. The teachers will be better prepared to (a) teach STEM concepts to the K-12 students (b) revise the content and delivery of the K-12 STEM curriculum (c) advance their STEM careers in engineering and engineering technology. The pre-engineering curriculum for the middle school and high school students (a) improves the STEM preparation of the students (b) motivates and encourages the students to pursue degree programs in engineering and/or engineering technology at institutes of higher education. The networks based on cyber-instruction facilitate the widespread dissemination of course content, involve the teachers from widespread K-12 schools and school districts, and promote cohort identification and professional collaboration among the educators.

Keywords – STEM engineering education, cyber-instruction

INTRODUCTION

The 'TIES to STEM' outreach program for K-12 STEM teachers is viewed as the partnership between the engineering departments at the University and the K-12 schools with science, technology, engineering, and mathematics (STEM) curricula to enhance the content and improve the delivery of critical teaching and learning components of K-12 STEM education. Unfortunately, factors that contribute to the high drop-out rates of students from the STEM school systems and the low enrollment of school graduates in the STEM colleges and universities across the U.S. include (a) inadequate preparation and the lack of technological resources available to the K-12 STEM teachers to effectively deliver STEM teaching (b) STEM curricula which fail to inspire the students to develop a life-

long passion for STEM learning (c) lack of awareness of the promising careers after the successful completion of STEM-based school and college education. The partnership between K-12 schools with STEM curricula and the engineering departments at the University which offers the ABET-accredited baccalaureate degrees in engineering disciplines [1], [2] can address the critical issues facing STEM learning and teaching in the following areas.

(1) Introduce revisions to K-12 STEM courses and curricula

The K-12 curriculum will include new and revised STEM courses which introduce the engineering design process and teach students how to use engineering technology to solve engineering problems with design and cost constraints. These courses will incorporate project-based and goal-oriented STEM learning experiences to supplement the traditional STEM curriculum.

(2) Raise student motivation and desire to learn STEM

The engineering education program and the pre-engineering curriculum integrate the teaching of concepts with hands-on project activities to train the K-12 teachers. This approach will equip the teachers with the knowledge and skills required to sustain the STEM learning experience for the students. The adoption of the pre-engineering curriculum by the teachers will motivate the students to advance their understanding of basic and advanced STEM concepts.

(3) Improve the retention of STEM concepts by the students

The training of K-12 STEM teachers in the engineering education program will lead to revised K-12 STEM courses across the K-12 curriculum. The pre-engineering curriculum for the K-12 students will deliver critical STEM learning competencies and improve the retention of STEM concepts by the students.

(4) ACT-48 compliant course work

ACT-48 is the statewide recognized pathway for educators in our state to earn course credit toward professional growth. The courses offered by the 'TIES to STEM' program will allow the teachers to gain or sustain continuous professional development through ACT-48 compliant credit hours assigned to each course. This will serve as the incentive to motivate K-12 STEM teachers across a wide range of schools and school districts to enroll.

This paper reports work-in-progress to create the ‘TIES to STEM’ program comprising (a) the engineering education program for high school teachers (b) the pre-engineering curriculum for middle and high school students (c) the dissemination of educational content through networks based on cyber-instruction (d) the teacher induction, teacher residency, and cohort identification criteria. Section 2 discusses the engineering education program. Section 3 outlines the pre-engineering curriculum. Section 4 documents the set up of cyber-instruction. Section 5 identifies the evaluation and dissemination plan for the program. Conclusions and future work are in Section 6.

SECTION 2: ENGINEERING EDUCATION PROGRAM

The engineering education program will comprise engineering courses offered to STEM-based K-12 high school teachers. These courses will be written to conform to the EC2000 guidelines of the accreditation board for engineering education (ABET). The courses will focus on solutions to engineering problems with products and tools approved by the engineering industry and will be offered through training institutes and professional development workshops.

The proposed initiative adopts the model displayed in Figure 1. In this model, centralized engineering projects whose scope and breadth encompass most engineering disciplines and STEM teaching/learning are identified. For example, the solar-powered home and the electric car are engineering projects with broad engineering coverage and significant STEM components related to engineering design and validation. Each project is a complex engineering system made up of subsystems with engineering design specifications and requirements, and capable of reliable operation upon integration. The assembly, test, and validation require the understanding of engineering concepts and their applications from several engineering disciplines.

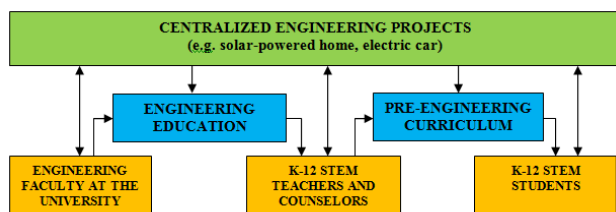


Figure 1. Model for STEM teaching and learning.

The centralized engineering projects create the environment for active engagement in real-world engineering design. Thus, the participants gain measurable knowledge and the tangible sense of accomplishment. In addition, the projects help structure the content of the STEM-based courses offered in both the engineering education program and the pre-engineering curriculum through course objectives which are measured by hands-on STEM project activities related to the subsystems of the project. Each course has clearly defined STEM goals which

relate the STEM teaching and learning to engineering design and practice in the context of the chosen projects.

The engineering education program will comprise course work which emphasizes the application of fundamental and advanced concepts to the engineering projects. The courses will comprise modules whose focus will be to understand and implement the design of subsystems required by each project. The modules will be either discipline-specific (i.e. ECE, ENV-SE) or cross-discipline integrative (i.e. EEE) in nature. The broad topical areas covered in each module are shown in Table I.

TABLE I
COURSE MODULES

Category	Module #	Theme of Module
ECE	1	Electronic Circuits and Electromagnetic Fields
	2	Microprocessors and Embedded Systems
	3	Signal Analysis and Communications
ENV-SE	1	Fundamentals of Environmental Science & Engineering
	2	Emissions Control and Environmental Regulations
EEE	1	Smart Sensors and Actuators
	2	Alternate and Renewable Energy
	3	Climate Control and Prediction

The courses will be offered to K-12 teachers as workshops and seminars during the three months of the summer session (June to August). Each course module will run for four weeks (one month). For each course module, there will be three sessions each week. The duration of each session will be three hours. The total contact time for each course module will be 36 hours over 12 sessions. Table II displays the schedule for the course modules.

TABLE II
SCHEDULE FOR COURSE MODULES

Month	Course module
June	ECE #1, ENV-SE #1, EEE #1
July	ECE #2, ENV-SE #2, EEE #2
August	ECE #3, EEE #3

The K-12 teachers will pay a nominal tuition fee per course module. They will receive a stipend to cover the expenses (e.g. board and lodge, course supplies) incurred as part of their enrollment in the course modules of the program. They will receive a certificate upon successful completion of the course modules in the program.

The goals of the engineering education program are to create the environment for STEM-based K-12 high school teachers to (a) understand the application of engineering concepts to solving problems at the component, subsystem and system level as related to the chosen engineering projects (b) gain proficiency with the engineering products and tools necessary to solve the engineering problems associated with the projects (c) develop the infrastructure to design and offer new courses to K-12 students through the pre-engineering curriculum (d) apply the learning and

training to incorporate revisions to their K-12 STEM curriculum.

SECTION 3: PRE-ENGINEERING CURRICULUM

The pre-engineering curriculum comprises STEM-based engineering courses for the K-12 teachers to adopt at the middle school (grades six through eight) and high school (grades nine through twelve) level. These courses use the platform of the centralized engineering projects to emphasize the critical aspects, issues, and constraints to be understood for successful engineering design and practice.

The K-12 teachers who have successfully completed course credits from the engineering education program are qualified to choose courses from the pre-engineering curriculum as part of their K-12 STEM teaching. These qualified teachers in turn engage their K-12 STEM students as active participants in the centralized engineering projects. The knowledge gained by these teachers through the course modules of the engineering education program will prepare them to deliver the critical STEM learning to the K-12 students.

The courses for the middle school students will focus on engineering technology and the understanding of engineering principles through laboratory activities. The laboratory activities will consist of experiments which stimulate the interest, enthusiasm, and energy of the students to tackle the engineering design issues as they relate to subsystems of the centralized engineering projects.

The activities are categorized into three levels (1) basic (2) intermediate (3) advanced. For middle school students (grades six to eight), the K-12 teachers can introduce the applications of STEM concepts to solve problems related to the centralized engineering projects. Each course focuses on the development of the solution to simple and complex engineering problems through hands-on experiments and laboratory activities. The course activities will take place over 9 weeks during the summer months from June through August. Table III displays the duration of each course, the course activity level and the theme of the course activity as it relates to the centralized engineering project.

In each session, the students will apply the principles of engineering design and the concepts of STEM to build and test simple and complex engineering systems. The students will also become familiar with industry standards and practices, as well as gain proficiency in the use of engineering tools.

The courses for the high school students are identified in three categories - *core/fundamental*, *elective/specialized*, and *capstone/design*. The *core/fundamental* courses will teach the engineering design process, the principles of engineering, and the design of engineering systems.

TABLE III
CONTENT AND SCHEDULE - PRE-ENGINEERING, MIDDLE SCHOOL

Course Activity Level (Duration)	Theme of Course Activity	
	Centralized Project: Electric car	Centralized Project: Solar-powered home
Basic (Two weeks)	Battery charging & test	Energy sources
	DC signals & circuits	Energy conversion
	AC signals & circuits	Solar cell test
Intermediate (Three weeks)	Sensor design	Solar cell design
	Sensor calibration	Solar cell calibration
	Energy & Power	Solar water heater
Advanced (Four weeks)	DC motor test	Solar panel test
	AC motor test	Solar pump design
	Smart sensor design	Solar pump test

The *elective/specialized* courses will focus on strengthening the mathematics and science required by the students to understand and interpret the subsystems of the centralized engineering projects. The *capstone/design* course will comprise integrated design, development, and implementation of one or more subsystems of the centralized engineering projects.

The pre-engineering courses for the high school students (grades nine to twelve) are project-driven activities taught at three levels as shown in Table IV. At the *Core or Fundamental level*, the students are first introduced to the principles and practices of engineering system design. Thereafter, case studies are used to illustrate the components of a project: specifications, requirements, preliminary design, schedule, and the steps leading to the final design, test, validation, and technical documentation.

TABLE IV
CONTENT AND SCHEDULE - PRE-ENGINEERING, HIGH SCHOOL

Course Level (Duration)	Theme of Course Work	
	Centralized Project: Electric car	Centralized Project: Solar-powered home
Core/Fundamental (Two weeks)	Engineering Project Design Principles	Engineering Project Design Principles
	Case study: Project Specifications & Requirements	Case study: Project Specifications & Requirements
	Case study: Preliminary Design & Schedule	Case study: Preliminary Design & Schedule
Elective/Specialized (Three weeks)	Motor Subsystem	Inverter Subsystem
	Hydrogen Fuel Cell	Solar-powered Laptop
	Smart Sensor System	Off-grid Solar System
Capstone/Design (Four weeks)	Project Identification: Scope, Prelim. Design	Project Identification: Scope, Prelim. Design
	Build & Test Prototype	Build & Test Prototype
	Technical Documentation	Technical Documentation

The proposed pre-engineering curriculum will (a) improve the STEM preparation of the students by

introducing and re-enforcing the importance of STEM learning in engineering project design and practice (b) create more options for the students to pursue degree programs in the fields of engineering and engineering technology at colleges and universities across the country.

The course work at each level will take place over nine weeks during the summer months from June through August. The total contact time for the entire schedule is 81 hours across 27 sessions with three sessions per week and three hours per session.

SECTION 4: CYBER-INSTRUCTION

Cyber-instruction is an effective means to deliver the STEM teaching and learning for the model described in Figure 1. This creates the *virtual* classroom experience to complement the hands-on training and leads to curriculum development and integration with positive impacts on (a) program and course enrollment (b) digital storage of and access to teaching and learning materials (c) dissemination of learning outcomes. Figure 2 illustrates the set up for cyber instruction. The content of each course is accessible to K-12 teachers and students on secure internet sites. The K-12 teachers and students can obtain instructional material or engage in interactive sessions with the engineering faculty responsible for the course content.

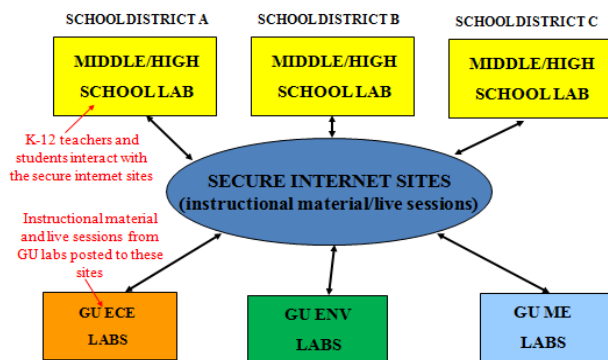


Figure 2. Cyber-instruction

Cyber-instruction offers the following benefits to K-12 teachers across schools and school districts (a) opportunity to interact with the engineering faculty to enhance the STEM teaching and learning experiences (b) engage in discussion and curriculum development with the K-12 teachers and students from remote school districts (c) reduce or eliminate scheduling conflicts within the regular day by organizing the laboratory session(s) after school hours.

SECTION 5: PROGRAM EVALUATION AND DISSEMINATION

Program evaluation will consist of the following components:

(a) *Project, course, and instructor evaluation*

This component of the project evaluation relates to the assessment of the chosen project platform, course

curriculum, and course instruction by the engineering faculty teaching in the engineering education program. The external evaluator will be identified from the list of nationally recognized STEM program evaluators. The external evaluator will employ surveys as well as other indicators of program success. The assessment of the course content and delivery will be separately conducted by (a) the external evaluator, and (b) the course attendees i.e. the high school teachers enrolled in the course.

(b) *K-12 STEM course and instructor evaluation*

This component comprises evaluation of course instruction by the high school teacher or counselor trained through the engineering education program. This evaluation will determine methods to improve their ability to effectively use the material learned from courses of the engineering education program in their K-12 curriculum and classrooms. This evaluation is separately conducted by (a) the external evaluator, and (b) the K-12 students attending the pre-engineering courses taught by the teachers who have been trained through the engineering education program.

(c) *Pre-engineering course-level learning outcomes*

This component comprises assessment of the learning outcomes of the K-12 students enrolled in the pre-engineering courses taught by the high school teachers trained through the engineering education program. This evaluation will have formative and summative assessment techniques to measure the student learning of the course outcomes for each pre-engineering course [3] based on surveys created for each course.

SECTION 6: CONCLUSIONS AND FUTURE WORK

The 'TIES to STEM' program delivered through the engineering education program for K-12 teachers, the pre-engineering curriculum for K-12 students, and the networks for cyber-instruction will exploit the synergy between the K-12 environment and baccalaureate engineering degree institutions to develop new or revised course material and instructional practices to reinforce the learning of K-12 STEM concepts through the application of mathematics and science in engineering design and practice. In the future, the program will be expanded to incorporate teacher residency, cohort identification, and professional collaboration.

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Comparing Students' Mathematics Achievement by Their School Types

Inclusive STEM Schools that implemented PLTW curriculum with Inclusive STEM Schools that did not Implement PLTW

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Abstract— Inclusive STEM high schools (ISHSs) are increasingly emerging in the research literature and have yielded promising effects on students' science and mathematics achievement [1; 2; 3]. ISHSs emphasized STEM preparation for underrepresented subpopulations and offered open enrollment. In the present study, we selected 17 ISHSs in Texas and divided those schools into two groups. Of these schools, seven ($n=1,682$) implemented Project Lead the Way (PLTW) curriculum and 10 ($n=3,070$) did not implement the PLTW curriculum. PLTW was an engineering curriculum and professional development program intended to increase K-12 students' interest in the fields of science and engineering [4]. Results from the present study showed that students who attended ISHSs increased their mathematics score regardless of the curriculum used. Results also showed that the mathematics achievement of students over time did not differ ($p>.05$) between STEM schools that implemented PLTW and those that did not. In fact, given the effect sizes, it is arguable that schools in which PLTW was not implemented had greater gains in mathematics.

Keywords—STEM schools, and PLTW.

I. LITERATURE REVIEW

The United States was a global leader in science and technology, but the present trends among students do not look promising [5]. International comparisons in mathematics and science performance ranked U.S. school students below students from many other industrializing and industrialized countries [6; 7]. The National Assessment of Educational Progress (NAEP) has also stated that the proficiency of students in mathematics and science was inadequate. One result of the poor performance in mathematics and science by young people in the United States has been the decline in the number of science, technology, engineering, and mathematics (STEM) graduates, creating a shortage of skilled domestic workers [8]. This shortage has forced employers to rely heavily on a foreign workforce to meet labor demands [9]. In a world dominated by technology, employers need people with basic

STEM knowledge and problem-solving skills even for non-STEM related jobs [10], making the existence of a domestic STEM proficient workforce even more critical. In order to retain a position of technological and innovative leadership, the United States must improve the domestic labor force by emphasizing STEM subjects in K-12 education [11]. The shortage of a domestic STEM workforce was attributed to a lack of interest in STEM among K-12 students and a low retention rate of students majoring in STEM fields in college [12]. Increasing student exposure to STEM concepts and practical applications at the K-12 level may help engage more students in STEM pursuits. Historically, this has been attempted in many ways as a response to international labor and innovative competition.

Though the distinctive term STEM emerged in the 21st century, the concept of schools dedicated to supporting student interest in STEM is not recent [13]. Specialized STEM schools first appeared in the early 1900s with the purpose of catering to the needs of gifted or talented students in addition to developing a technically skilled workforce for the nation [14]. As the launch of the Soviet Union's Sputnik threatened the scientific superiority of the United States, the government emphasized improving mathematics and science achievement among students [15]. This STEM emphasis resulted in initiatives that were the forerunner to modern STEM programs. Students were encouraged to participate in programs such as early college entrance, STEM summer camps, STEM schools, after school STEM activities, internships, and mentorship programs [16]. Specialized STEM schools were considered one of the most effective ways to prepare and motivate students in STEM fields as they provide adequate time, guidance, and authentic learning environments for students [17].

STEM schools were classified into three categories: (1) selective STEM schools, (2) inclusive STEM schools, and (3) schools with STEM-focused career and technical education [18]. Reference [18] pointed out key differences between the types of STEM schools. Selective STEM schools admitted

students who meet certain criteria, such as achievement on standardized tests or interviews. Inclusive STEM schools admitted students regardless of academic ability but required at least 50% of the student body to consist of student subpopulations that were underrepresented in STEM fields. Schools with a STEM-focused career and technical education emphasis offered programs and classes within a traditional school format to engage students in STEM related learning activities. Even though the three types of STEM schools had differences, they served the common goal of introducing students to STEM subjects and motivating them to pursue STEM related careers.

STEM schools, in their various forms, were developed to address national achievement issues and have done so with success. STEM schools were successful at a) narrowing the achievement gap between students of different socioeconomic statuses [19], ethnicities, and genders; and b) motivating students to pursue STEM disciplines [1; 20]. Students of subpopulations who were underrepresented in STEM fields, such as Hispanics, saw improvements in their performance when they were enrolled in a STEM school [21; 22]. A consistent aspect of STEM schools was an emphasis on STEM throughout a child's academic career. Research has shown that students who have positive experiences with STEM subjects early in their education are more likely to choose a STEM major [23]. Students exposed to STEM content in traditional high schools were not as motivated as the students from STEM high schools to take up a STEM related career [24; 25]. A notable improvement in student mathematics performance was shown when a non-STEM school transitioned into a STEM school [22]. STEM schools differ from traditional schools in their teaching methods and curriculum. STEM schools generally employ a student centered and inquiry-based instructional approach to actively involve students in the learning process. Problem-based, project-based, and activity based learning were some inquiry-based teaching strategies used in STEM classrooms. Project-based learning allowed the student to learn the subject while producing a well-defined end product [26]. Students developed the ability to conduct research, think critically, and apply their knowledge practically [27]. Project-based learning allowed students to learn while solving multiple problems in context [28]. Additionally, it helps students to understand the subject and recall information better than students taught using traditional methods [29]. Activity based learning allows groups of students to work together on various activities to gain knowledge [30]. Inquiry-based instructional strategies were found to be effective in improving students' content knowledge and their ability to actively think to arrive at solutions [31]. There have been several different curriculums that utilize these teaching strategies at STEM schools, but one in particular is the focus of investigation for the current study.

Project Lead the Way (PLTW) was a STEM curriculum that was implemented extensively in STEM programs in elementary, middle, and high schools across the United States [32]. The PLTW program was first established in 1986 by a high school teacher named Richard Blais. The program grew out of his efforts to teach basic engineering skills to his students. The Charitable Leadership Foundation in 1997

financially supported the expansion and development of his teaching method into a more rigorous engineering curriculum. It was designed to allow high school students to explore technology related career options in New York State [33]. The program grew and offered various curricular options for different grade levels, involving subjects such as mathematics, science, biology, robotics, health, and computer science. PLTW incorporated activity, problem-based learning, and project-based learning into classrooms along with professional development and support for teachers [32]. Teacher training and professional development were an integral part of the PLTW program. Teachers received constant support from master teachers and university professors either through online sources or through meetings and workshops. Due to the flexibility of PLTW courses, many schools had incorporated PLTW courses either to complement the existing courses or as the core curriculum.

PLTW was shown to be effective at increasing student performance in STEM subjects as well as increasing interest in STEM pursuits. It was claimed that students who learned using the PLTW curriculum could efficiently understand, analyze, and solve problems under time-constraints, similarly to an engineer's approach to problem solving [34]. Proper implementation of the PLTW curriculum was successful in improving students' academic performance, critical thinking, and problem solving skills, and it narrowed the performance gap between students from different sections of the population [32]. Students in PLTW courses a) were exposed to more rigorous and engaging science and mathematics classes, b) had richer experiences in engineering and technology subjects, and c) were more likely to take up and complete four-year university courses [35]. PLTW had a positive impact on students' self-efficacy and interest in an engineering career [36]. These positive gains made PLTW appear to be a viable solution for addressing many of the problems in the United States and specifically in STEM schools.

II. RESEARCH QUESTIONS

- 1) Is there a statistically significant change in the mathematics TAKS test scores from 10th grade to 11th grade of all the students who attended T-STEM academies?
- 2) Is there a statistically significant change between students who attended STEM schools with PLTW and students who attended STEM schools without PLTW on their mathematics TAKS test scores?

III. METHODOLOGY

A. Project Lead the Way (PLTW) Curriculum as an Intervention

Project Lead The Way (PLTW) was a STEM-focused engineering curriculum and professional development program aimed to increase middle and high school students' mathematics and science competencies [4]. Reference [37] also described PLTW as "an instructional project designed to prepare students to be successful in post secondary engineering and engineering technology programs" (p. 15). The PLTW program was multifaceted and included curriculum,

professional development, and innovative instructional practices [32].

One of the goals of the PLTW curriculum was to strengthen the problem solving, critical thinking, and innovation skills of all students who took the courses, meeting the need of the United States for a more STEM proficient population. Another long-term goal was to inspire K-12 students to specifically follow an engineering related career pathway in college, thus increasing the domestic STEM workforce. PLTW was later implemented by several STEM schools, and was of specific interest to inclusive STEM high schools. As of this writing, PLTW was the largest nonprofit provider of STEM programs, providing 6,000 PLTW programs to more than 5,000 K-12 teachers in all 50 states and the District of Colombia [32].

B. Data Sources

In this quantitative study, student and school-level data of students who attended inclusive stand-alone Texas STEM (T-STEM) academies were obtained from the Texas Education Agency (TEA). This study was based upon 17 selected T-STEM academies out of a possible 75. These 17 were comprised of seven that implemented the PLTW engineering curriculum in conjunction with their regular STEM school curriculum and 10 that implemented the mainstream STEM school curriculum.

The sample consisted of two years of the Texas Assessment of Knowledge and Skills (TAKS) test data for a total of 4,752 students. These students either attended a T-STEM academy that utilized the PLTW curriculum (n=1,682) or a T-STEM academy that implemented a typical, non-PLTW curriculum (n=3,070). The participants took the first TAKS examination in 2010 at the end of 10th grade and took the second examination at the end of 11th grade in 2011.

In the present study, only ISHSs that started implementing STEM or PLTW curriculum before 2009 were selected. This was done to ensure that these schools and teachers had fully adopted the new curriculum and instructional approaches associated with ISHSs. Also, selecting schools that had already implemented these programs for consecutive years ensured that the student population had received at least three years of STEM school curriculum. We examined all students' mathematics growth from 2010 to 2011. We also observed how students' mathematics scores changed by their school types (STEM high schools with PLTW and STEM high schools without PLTW).

Students were excluded from the study if they did not take the TAKS test in 2010. Students were also excluded if they (1) left a T-STEM school with PLTW and transferred to a T-STEM school without PLTW, (2) left a T-STEM school without PLTW and transferred to a T-STEM school with PLTW, or (3) transferred to a T-STEM school from a non-STEM school. These exclusions ensured that the students who attended T-STEM academies could accurately display the impact of attending STEM schools with and without the PLTW curriculum.

C. Analysis

In order to understand how students' mathematics scores changed overall and by their school types, repeated measures ANOVA was employed. Hierarchical Linear Model would be an appropriate analytic method if the number of schools was larger. Due to a limited number of schools in this study, repeated measures ANOVA was the preferred analytic method. Eta-squared effect sizes and confidence intervals (See Figure 1), along with descriptive statistics (See Table 1), were provided.

TABLE I. DESCRIPTIVE STATISTICS

Grade	School Type	Mean	SD	N	d
10 th	nonPLTW	2240.47	194.479	3070	
	PLTW	2228.32	181.532	1682	
	Total	2236.17	190.067	4752	-.064 ^a
11 th	nonPLTW	2300.36	183.630	3070	.316 ^b
	PLTW	2290.16	199.614	1682	.253 ^c
	Total	2296.75	189.484	4752	-.052 ^d

^a. Note. a= The effect for 10th grade with PLTW as the treatment group; b= The effect for nonPLTW comparing from 11th grade to 10th grade; c=The effect for PLTW comparing from 11th grade to 10th grade; and d= The effect for 11th grade with PLTW as the treatment and nonPLTW as control.

Fig. 1. 95% Confidence intervals for all students in the current study.

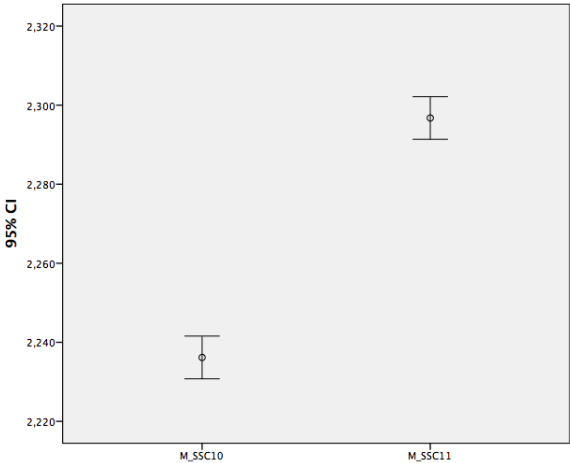
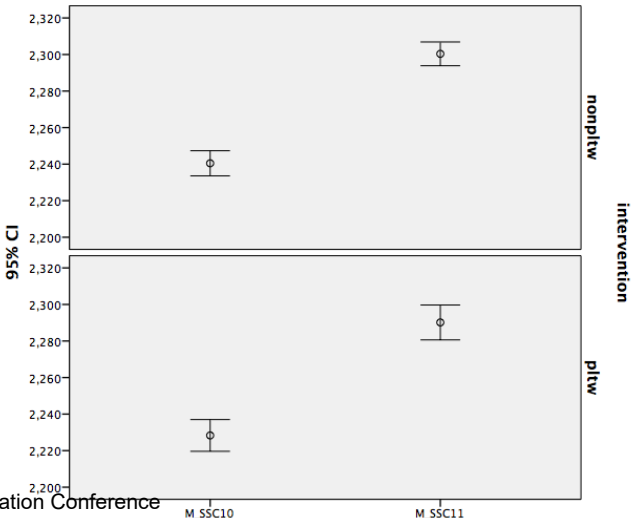


Fig. 2. 95% Confidence Intervals for both STEM high schools with PLTW and without PLTW.



IV. RESULTS

Before investigating results, five assumptions were checked to make sure the results were accurate and differences were not due to violation of statistical assumptions. First, the dependent variable was continuous. Second, the independent variable was nominal with at least two categories (STEM with PLTW and STEM without PLTW). Third and fourth, there were no outliers in the data, as assessed by the inspection of a boxplot, and the data was normally distributed. Fifth, the sphericity assumption was not violated because the variances of the differences of each pair of groups were not statistically significantly different from one another ($p > .05$). Descriptive statistics (see Table 1) and 95% confidence intervals (see Figure 1 & Figure 2) were provided.

Repeated measures ANOVA was used to answer the first question concerning the possible existence of a statistically significant change in students' mathematics scores from 10th to 11th grade. The results from the present study yielded that regardless of school types, students who attended STEM high schools statistically significantly ($p < .05$) increased their mathematics scores with an eta-squared effect size of ($\eta^2 = .137$).

To answer the second question concerning whether the change in students' mathematics scores was statistically significantly different based on the use of PLTW curriculum or a typical STEM school curriculum, the interaction effect of time and school type (math X PLTW curriculum) was also added into the model as a between factor. The results from this step showed that the improvement in student scores was not statistically significantly different ($p > .05$) from 10th to 11th grade by their school types as STEM schools with PLTW and STEM schools without PLTW. The eta-squared effect size was calculated to be 0.0004, which was negligible. This effect size implies that the implementation of PLTW curriculum in STEM schools was not an effective means of improving students' mathematics scores.

V. DISCUSSION

There is a great deal of interest in STEM, so much so that schools search for innovative solutions whether or not there is a sufficient research base underlying those innovations. In this study a curriculum, Project Lead the Way, was examined. This curriculum requires a heavy school commitment in budget allocation and a huge time commitment from teachers [32]. This sizeable commitment can create a psychological dependence on the part of teachers and school administrators. It is reasonable to believe that when anyone commits a sizeable portion of school funds and teacher time during the summer for training, decision makers do not want to be wrong. This psychological dependence can yield to persistence with a program even though the obtained results are no better than the results obtained through traditional methods. It is important to note that this is a limited study with a relatively small sample of schools. Additionally, there was no check on fidelity of implementation, so it is not known how well PLTW was implemented in the schools. We do hope that given the time required by the teacher to invest in the summer before implementation and the schools' financial commitment, that

the enactment would be typical of PLTW implemented anywhere. One has to wonder what the economic effect size would be for any STEM centric program. Unfortunately, schools are reluctant to reveal how much they spend on PLTW so it is difficult to determine the gain students realize per dollar spent, which is needed to understand if the money is being spent wisely.

There are many challenges facing STEM education and its successful implementation, none of which is greater than the ill-informed and self-proclaimed STEM curriculum by STEM enthusiasts. When the National Science Foundation transformed the arrangement of the starting letters for mathematics, engineering, technology, and science into the ubiquitous STEM – it created a void. What we know from science is that nature abhors a void. That void created by the NSF became the destination into which many sprinted. Some transformed from business, some from law, and some from various education disciplines. All these are potentially damaging to the education mission. There was no credential to proclaim one's expertise in STEM curriculum design or implementation than to add four simple letters arranged into a now meaningful and pronounceable acronym, "STEM" to their business card. While the void metaphor works, consider evolution and the work of Darwin – species voids are filled. But not always as elegantly as the one who vacated it.

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On the Development and Implementation of a Project-Based Learning Curriculum for Air Quality in K-12 Schools

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Abstract—The availability of low-cost sensors and environmental monitoring technologies is growing rapidly. While researchers are making use of these technologies and validating their results, there is also enormous potential for their use in education and outreach. Through the North Fork Valley (NFV) Project, we are bringing next-generation air quality monitors into the classroom and developing necessary resources to support student-driven research projects. This project is a collaboration between the University of Colorado at Boulder, community partners, and educational partners (Delta County School District 50, and St Vrain Valley School District) and is funded by the NSF-funded AirWaterGas (AWG) Sustainability Research Network Education and Outreach (E&O) efforts. During year two, we are formalizing the curriculum, implementing it in multiple school districts, and conducting assessment activities. This paper will discuss the curriculum, the results of our assessments thus far, and our vision for the project. The work completed during year two will help ensure we are building a sustainable project. Additionally, we intend to make the curriculum public with hopes that other research groups working with low-cost air quality sensors can utilize our materials and possibly our model for their own education and outreach.

Keywords—project-based learning; low-cost sensors; air quality education and research

I. INTRODUCTION

For the past two years our team has implemented a project that brings together innovative research and K-12 education. The North Fork Valley (NFV) Air Monitoring Project takes a low-cost, next-generation air quality monitoring instrument, still undergoing the research and development process, and explores its place in education and outreach. Partnerships like these provide a unique opportunity beneficial to both researchers and K-12 students. Researchers are able to learn about their work from a different perspective; in our case how the public would like to use our technology, and how well it can be adapted for this purpose. Students in these K-12/university partnerships are able to work in a hands-on way with a technology that is not a black-box and learn about university-level research and the possibility of pursuing a

degree or career in STEM. This program provides students with an introduction to disciplines like environmental and mechanical engineering, as well as the problem-solving that goes into investigating complex questions. Teaching students about air quality is not our final goal, but rather we hope to use air quality research as the vehicle by which students can learn more about the skills specific to STEM fields, both technical and professional. This paper will describe the project's evolution, the technology that makes this project possible, and our efforts to build a sustainable outreach program.

A. The Communities

Our initial school district partner was Delta County School District 50 (DCSD) located on the Western Slope of Colorado in the North Fork Valley. During the second year we have expanded to the St Vrain Valley School District (SVVSD) on Colorado's Front Range. Delta County is a rural and primarily agricultural community with several coal mines that have been in operation for over 30 years. However, the recent collapse of the local coal industry [1] and the continual loss of jobs due to mechanization in agriculture is putting stress on the local economy. During the 2013-2014 school year, 50.1% of the students were eligible for free or reduced lunch [2]. In terms of the perceived value of higher education, 10%-20% of residents have a college degree [3]. DCSD is also more than a four hour drive from Colorado's large state schools located on the Front Range, which makes K-12/university partnerships difficult to initiate and sustain.

By contrast, SVVSD is a mixture of rural and suburban. This part of Colorado has experienced significant growth over the past few years due to the expansion of the oil and gas industry [4]. During the 2013-2014 school year, 37.4% of the students in SVVSD were eligible for free or reduced lunch [2]. Additionally, the area is well served with university outreach programs as the schools in this district are less than an hour drive from the Denver Metro area and several major Colorado universities. The districts also differ demographically, with DCSD made up of a 10-20% minority population and SVVSD made up of 20-40% minority population [3]. Working with these two districts during year two of the project is helping our team to build a program that meets the needs of a variety of

groups, especially underserved rural communities. We hope to build a curriculum both accessible to and suitable for the diverse geography and socio-economic demographics of Colorado.

B. NFV Project, Year 1

The North Fork Valley Air Monitoring Project began as a collaboration between the Western Slope Conservation Center (WSCC) in Paonia, CO, the University of Colorado, Boulder's Office of Outreach and Engagement, and the Hannigan Air Quality Research Lab (Mechanical Engineering, CU Boulder). Delta County lacks detailed historic air quality data, and the WSCC was interested in understanding current air quality in the area in light of proposed increased oil and gas development in the NFV. The original objectives of the project were to pilot low-cost tools for baseline air quality data collection and engage the community in citizen science.

During year one we engaged local high school students in assisting with the project, but found that they were more interested in asking their own questions than helping with the collection of baseline data. The project naturally grew into two parts: (1) the long-term, continuous collection of air quality data using a stationary network of monitors, and (2) student-driven air quality research projects. After seeing the benefits of this experience to students, particularly in a rural and underserved community [5], we decided to continue for a second year in an attempt to build a sustainable outreach program.

C. NFV Project, Year 2

During year two, the project is continuing through the NSF funded AirWaterGas (AWG) Sustainability Research Network, specifically with the help of the AWG Education and Outreach (E&O) team [6]. AWG is a large-scale interdisciplinary research project including teams studying air quality, water quality, water treatment, water quantity, natural gas infrastructure, social-economic systems, health effects, practices and policies, and E&O. Together all of these teams are examining the benefits, risks, and challenges associated with unconventional oil and gas development. Year two activities for the NFV Project included continued data collection in the NFV, curriculum development, implementation in multiple school districts, and overall project/curriculum assessment. Although the title of the program has not changed, we have expanded to an additional school district in an area of Colorado outside of the North Fork Valley.

Working with school districts affected by current and proposed oil and gas development helps us build bridges to facilitate the sharing of results from the larger AWG Project. For example, these communities may have specific questions regarding risks to local air/water quality, and because we have built trust between the community and our University, they may feel comfortable coming to us for information. Using this program to build relationships has the potential to help us get up-to-date, relevant research to these communities to inform decision making on the local level. Finally, air quality serves as a vehicle to initiate conversations on complex issues surrounding energy development and use.

II. THE TECHNOLOGY: U-PODS

Developments in sensor technology are making environmental monitoring tools more accessible, and ideal for supporting STEM learning opportunities. Researchers at the University of Maine demonstrated through the GK-12 Sensors! Program that using sensors in secondary schools is beneficial to students, teachers, and graduate teaching fellows [7]. For several years, our research group has been developing and using an air quality monitor that utilizes low-cost sensors for our own research. Our monitor (the U-Pod, shown in Fig. 1) is an open-source design and can be constructed for under \$1000 per monitor [8]. The U-Pod is capable of measuring multiple pollutants (e.g., carbon dioxide, carbon monoxide, volatile organic compounds, ozone, and nitrogen dioxide) continuously; data is then recorded to an on-board memory card. Although the sensors used in the U-Pod are less accurate than the more costly instruments used for regulatory purposes, if we leverage both the low-cost and high quality instruments, there is the potential to collect far more detailed information regarding our air quality than currently exists.

New technologies such as this one are extremely valuable for STEM education not only because of their increasing affordability, but also because students can take an inside look at something they could build themselves. These tools are not the traditional "black box" instrument because they utilize a relatively simple design and 'off-the-shelf' sensors. Students can open up the U-Pods and understand how they function, making the technology is ideal for hands-on learning. Using the monitors also provides students with exposure to the various fields of study that went into making it: electrical engineering, computer science, and mechanical engineering in addition to the environmental engineering involved in air quality research. Citizen science is another area where technologies like the U-Pod could have a large impact. Citizen science "refers to the engagement of non-professionals in scientific investigations – asking questions, collecting data, or interpreting results" [9]. Citizen science can range from contributory (where participants collect data as part of a larger, researcher led project) to collaborative and co-created (where scientists and participants work together with both groups engaged in defining the question, collecting the data, and interpreting results) [9]. Our research group sees using the U-Pods for educational applications as a way to move toward



Figure 1: Image of the U-Pod, interior (top left) and exterior

this vision of using low-cost technologies to support collaborative and co-created citizen science.

III. A PROJECT-BASED LEARNING CURRICULUM

A. Project-based Learning

In addition to hands-on learning, we have found that the U-Pods are an ideal way to support project-based learning (PBL) driven by student-generated research questions. Project-based learning is a method of teaching in which students work for an extended period of time on a complex problem, question or challenge, and thereby gain knowledge and skills. [10]. In engineering education, projects better equip students to apply their knowledge in practice, as well as providing a better understanding of the complexities involved in professional practice [11]. Similar outcomes have been observed in K-12 education where research indicates that PBL leads to an increased level of student engagement, higher interest in content, and better problem-solving skills, and an increased depth of learning and ability to transfer skills to new situations [12]. During year one of the project, teachers anecdotally reported similar outcomes including increased engagement and greater depth of learning. For this reason, we chose to build a program and curriculum supporting the PBL teaching method.

PBL challenges students to apply their existing knowledge in new ways and acquire new knowledge to solve novel real-world problems. As students progress with their project, they stumble upon “need-to-knows;” in this case, questions about atmospheric chemistry and pollution that they need to answer in order to progress in their investigation. Additionally, since projects are conducted over a long period of time, students must manage working with a team, adhering to a schedule, and monitoring progress. We currently cover the bulk of the content (discussed in the following section) during the first semester and leaving the second semester for projects. The curriculum introduces students to the U-Pods, and helps them build useful skills with all of the pieces supporting the PBL model [5].

B. Curriculum Development

During the first year, it was interesting to observe the synergism between the continuous data collected through the stationary network and the student-driven projects. For example, we were able to use the baseline data to support student learning about air quality concepts in the classroom. Alternatively, student-led investigations provided our group with information on potential local air quality issues (e.g., agricultural practices like ditch burning). In addition to local knowledge, students use of U-Pods clarified what skills and background knowledge users need. This also led to the idea of developing a curriculum to support U-Pod use.

During year two, the curriculum used in the classroom is being reviewed and polished for public distribution. Five modules are currently under development. These modules provide students with background knowledge and an introduction to the skills necessary for successful projects including data analysis and how to present scientific results. The curriculum will empower students to ask complex and informed questions about local air quality issues. Each module

(summarized in Table 1) includes guidance for teachers, presentations, worksheets, data sets, templates, links to more information, and suggested assessment as necessary. Together the five modules cover skills useful for this project and beyond it (e.g., working with large data sets in Excel, making a poster in PowerPoint, etc...). The series of modules culminates in a ‘Science Symposium’ or poster session, open to other students, teachers, parents, and the community. In line with the goals of PBL, the poster session challenges students to interpret and communicate their research to an authentic audience.

C. Curriculum Implementation

Lack of resources, knowledge, and skills is often as a barrier to technology integration in K-12 settings [13]. To address these barriers, we are creating a U-Pod ‘check-out program’. Given that the U-Pod is a developing technology – a rental program will likely be more successful than selling the U-Pods because this type of program will allow the researchers to maintain the technology. This type of program will provide teachers with access to resources while facilitating technical support and providing our group with a way to maintain and strengthen relationships with districts using the U-Pods. We feel this is a promising model, and plan to make our curriculum publically available in Fall 2015 in the hopes that other groups working with low-cost sensors will replicate this model.

Table 1: Air Quality Curriculum Overview

	Module Description	Skills
1	Introduction to air quality research and the U-Pod (lecture and demo)	Background knowledge and vocabulary for air quality and engineering and concepts
2	Data collection (activity)	Using the U-Pod Critical thinking regarding sources of error and results
3	Data analysis (activity)	Basic statistics and data visualization information Using Excel for calculations and graphing Interpreting results using background knowledge
4	The Project (planning, data collection, data processing and analysis)	Planning and carrying out a research project (scheduling, logistics, designing data collection, etc...) Processing raw instrument data Analyzing data in Excel
5	Interpreting data and presenting results	Data interpretation Communicating results Making a scientific poster or presentation

IV. PROJECT ASSESSMENT

A. Overview

Informal and anecdotal assessment data were collected at the end of year one. Assessment for the second year is more rigorous; formal assessment matrices have been developed for both the NFV Project and the AWG E&O team [5]. The NFV Project goals include developing/finalizing curriculum and conducting formal assessment of both the curriculum and the program. The goals for AWG E&O are broader in scope, for example one of the goals listed in the AWG E&O Assessment matrix is to ‘Integrate AWG SRN Research, Education & Outreach Activities’. We are successfully reaching an underserved rural Colorado community (Delta County

students) by facilitating the use of the U-Pod for E&O in addition to the research it is being used for internally. Year two data will allow us to better determine which goals we are addressing and where we can improve.

Summative assessment data will assist in evaluating the project upon the completion of year two; this data will focus on student skills/attitudes, the project's impact, and opinions regarding the project. Our methods are typical of those used to assess similar K-12 outreach projects [14]. We are also engaging in formative assessment throughout the year, as we work with teachers one-on-one to ensure we are meeting the needs of their class and implementation is running smoothly. Summative assessment activities and our progress are presented in Table 2. Student surveys (4 total) include attitude questions and confidence questions intended to assess whether students are developing the skills intended with each module. Multiple student surveys with repeated questions will allow for pre vs post analysis to provide insight into the impact of the program over the course of the year. Surveys and interviews from teachers will ask whether they would continue participating in this program, what benefits to their students they observe, if they received enough support, and their overall reflections. Input from other stakeholders will allow us to consider whether or not we are meeting the needs of the community. The external review team assessing the curriculum includes an air quality expert and a teaching expert. The criteria this team is using was derived from guidelines developed by Cooperative Institute for Research in Environmental Sciences (CIRES) to assess proposed curriculum for Climate Literacy and Energy Awareness Network (CLEAN) [15]. In all surveys where we have requested that participants rate an opinion or experience, a score of 4.00/5.00 (80%) is our target. Together all of this data will be used to not only evaluate year two, but also inform future implementations of the project, the overall structure of the program, and revisions to the curriculum before it is made publically available.

B. Preliminary Results

Table 3 provides an indication of the scope of the project during years one and two. Following the completion of year one, all three of the teachers were interviewed and a simple student survey was distributed. The teachers shared the following observations regarding their students:

- Increased engagement in science classes
- Student ownership of their projects
- A better understanding of the scientific process (particularly the iterative nature of data collection and analysis that is not typically demonstrated in high school science classes)
- Students strengthened skills likely to help increase their success in higher education (e.g., problem-solving and analysis skills)

Teachers also mentioned that students benefited from working with a graduate student mentor, access to new classroom resources, and hands-on use of technology (both the U-Pod and tools such as Microsoft Excel, and the Google Drive platform to facilitate collaborative work). Finally, all three teachers expressed interest in continued participation in this program.

Table 3: Project Scope

	Year 1	Year 2
Number of Districts	1	2
Number of Teachers/Schools	3	5
Number of Students	40	81

Complete assessment data from year two will help us to evaluate whether or not outcomes and benefits we observed during year one are occurring repeatedly. In the meantime, we can provide a discussion of preliminary results. The Module 1 and 2 Survey results are available in Tables 4 and 5 respectively. The Module 1 Survey was distributed to the high school students following our first classroom visit. This survey sought feedback on students' attitudes regarding engineering and air quality and their reactions to the module. The results suggest that the presentation offered a valuable learning experience as students from District 1 (Delta County) rated their understanding of the impact of air quality research as a 4.60/5.00 and the amount they learned highly as 4.50/5.00, both meeting the goal of a minimum score of 4.00/5.00. District 2 (SVVSD) shared similar results with a rating of 4.31/5.00 for their understanding of the impact of air quality research and 4.60/5.00 for the amount they learned. Mean scores below 4.00 for both school districts are reflected for questions 1, 2, and 5, which indicates that these are areas

Table 2: Assessment Overview

Stakeholder	Type of Assessment	Progress
Students	Surveys (4 total, all students)	1 st & 2 nd complete (results available) 3 rd & 4 th incomplete (mid-may)
Teachers	Survey (1, all teachers) Interview (1, 2 teachers)	Both incomplete (mid-may)
Community (e.g., partner with Public Health Dept.)	Interview (1, 2 stakeholders)	To be given (mid-may)
Curriculum	Survey for external review team (1 per module)	1 st & 2 nd complete 3 rd , 4 th , & 5 th in progress (may)

Table 4: Module 1 Survey Results

Question	Mean		P-value
	District 1 ^a (n = 20)	District 2 ^b (n = 35)	Two Sample T-Test
1. I am interested in learning more about air quality.	3.50	3.69	0.399
2. I want to know more about what an environmental engineer does.	3.35	3.40	0.868
3. I feel that engineers have made major accomplishments and advancements.	4.85	4.60	0.126
4. I would have a difficult time explaining these topics to another person.	3.10	3.09	0.965
5. I know where to go to find out more about these topics.	3.45	3.57	0.732
6. I understand the impact of air quality research on the community.	4.60	4.31	0.190
7. I learned a lot in this presentation.	4.50	4.60	0.570

Table 5: Module 2 Survey Results

Question	Mean		P-value
	District 1 ^a (n = 15)	District 2 ^b (n = 30)	Two Sample T-Test
1. After doing this activity, I feel more confident that I could use this technology to collect air quality data	4.27	4.30	0.887
2. I learned something new about the process of data collection and experimental design in a complex environment.	4.33	4.43	0.743
3. This activity led me to think about scientific investigations I might conduct, either for this air quality project or in another context.	3.67	4.27	0.047

^aDistrict 1 is Delta County School District 50, ^bDistrict 2 is St. Vrain Valley School District

where we may be able to improve students' attitudes over the course of the project. Responses to similar questions in the final student survey will help us understand if the project may have positively impacted students' attitudes toward air quality, attitudes toward environmental engineering, or their knowledge of sources for information on air quality and other STEM

related questions. Lower scores were also observed for question 4, but this question is a reflection of students' comprehension of the material, and a lower score indicates comprehension. Additional open-ended questions in the Module 1 survey revealed that students responded most positively to the hands-on demonstration of the technology

The Module 2 Survey (Table 5) was distributed to students after they participated in an activity to measure car emissions during which they were able to practice using the U-Pods. The data indicates that the desired mean score of 4.00/5.00 or higher mean was met for every question and for both districts (with the exception of one score for question 3 and District 1). The qualitative feedback indicated that students enjoyed the hands-on aspect and the opportunity to do the experiment themselves. One student commented, "I liked how we got involved in the activity" and another noted the change in teaching style was valuable and that "it was nice to get out of the classroom and learn a different way.

C. Discussion

Engineering outreach programs "introduce students to the joys and frustrations of engineering" [16]; this type of

experience can have a multitude of benefits. Some students may be inspired to pursue a degree in engineering or STEM, while others (who may go on to work in entirely different fields) gain an increased understanding of STEM and its role in our society enhancing their multidisciplinary education. We believe that using the U-Pods for E&O has the potential to provide this type of experience. Comparing our preliminary data to results of the evaluation of four outreach projects at the Colorado School of Mines indicates that we are building a promising outreach program [17]. Among the observed benefits to middle school students (the target audience) Mines researchers listed:

- Increased use of technology
- Increased classroom resources
- Availability of college role models
- Increased interest in science mathematics, and computer science
- Increased exposure to and interest in college
- Successful participation in academic competitions, including several awards [17]

Many of the benefits listed above match or are similar to benefits our teachers observed during year one (mentioned in the Preliminary Results section).

Year two is providing more quantitative information regarding our project's impact and thus far the indication is that the modules are serving their intended purpose. Students responses resulted in mean scores of over 4.00/5.00 for

questions 6 and 7 (Table 4), these questions cover the primary purpose of Module 1 – introducing students to air quality research and communicating why it is important. Lower scores (below 4.00/5.00) for interest/opinion questions regarding engineering and air quality are not uncommon and have been found in other studies where high school students were surveyed [18]. It is possible that 80% is an unrealistic expected score for questions such as these, or that a lack of exposure to engineering in traditional curricula results in lower scores. We plan to compare these initial scores to the scores of similar questions in the final survey; however, this may be an area where more research is necessary.

Module 2 is intended to prepare students for data collection. As indicated by the scores, students came away from the activity feeling more comfortable with the technology, and thinking about study design. The one exception is the low score from District 1 for question 3 (Table 5) regarding whether the activity led them to consider project ideas. This may be an indication that the module was implemented differently, and it would be worthwhile to add suggested discussion questions into the curriculum to address this need. Additionally, this mean score is significantly different from District 2. All other mean scores were not significantly different (p -values $> .05$) between districts, which indicates that students in both locations are reacting to the curriculum and project similarly. We will continue to observe the differences and similarities between the school districts throughout the remaining surveys, as it will inform our program design, and specifically designing to meet the needs of a variety of school types.

V. LIMITATIONS AND FUTURE PLANS

The primary limitations of our assessment data are the lack of a control group and small sample size. These are limitations we will address in future iterations of the program. We already have plans for implementation in new districts during year three, which will provide a larger population. We would also like to refine our assessment tools and implement established tools developed by external groups, as well as examining how we can incorporate more established outreach frameworks into the program. Year three of the project will include the above, as well as implementation of the final version of curriculum, continued assessment, and building the U-Pod ‘check-out’ program. In the long-term, we are interested in working with school districts to track the long-term progress of students and their degree choices in college.

In addition to planning for future iterations of the project, we are considering program viability. One key to ensuring our program is sustainable is to refine our ideal role as a university partner. Although the relationships built between high schools students and the graduate student mentors are an integral piece of the project, currently a graduate student mentor leads or co-teaches each module. Ideally, we would like graduate student mentors to support rather than lead, which in turn gives teachers more independence and flexibility in implementation and promotes program sustainability. To facilitate this transition, we will add teacher training sessions providing hands-on experience prior to their using U-Pods in the classroom. This model will result in a more resilient program

and allow our team to take a facilitator/resource role and reach a greater number of students and classes across Colorado.

We are also aware that sustainability beyond the AWG grant period is another challenge to consider. Karp and Gale report in their paper on long-term program sustainability that a means for continuing beyond the initial grant was forming partnerships with established organizations [19]. These partners were then able to assist the program in continuing after it had been built through the initial grant. This may be a model that would work for our project as well, and we will continue to explore our options.

We see this program as having the potential to benefit participants in a lasting way. This program provides students with a window into engineering, academic research, and even public and environmental health. For example, a group of students from one of the high schools in Delta County incorporated a U-Pod into their science fair project. They used the U-Pod to compare by-products from the combustion of homemade biodiesel to the combustion of regular diesel fuel. This group was subsequently invited to the state science fair at Colorado State University (Ft. Collins, CO). At the state level they were awarded an honorable mention and scholarship money for college. Their teacher also reported that visiting CSU increased their interest in higher education. While in Ft Collins, the students were able to participate in a state-wide academic competition, attend classes, and tour the campus. With support from our team and access to resources like the U-Pod, the students were able to go from making biodiesel to assessing the impacts of using biodiesel – moving toward an understanding of the entire lifecycle of the fuel. This provided these students with experiences similar to those of environmental engineers, and also an idea of the supporting disciplines (e.g., mechanical engineering and computer science). Utilizing the program for a science fair project provide an example of a group taking the U-Pod further than the intended PBL curriculum, which is something we hope to see more of and support in the future. We hope that through opportunities such as this, increased access to university resources, or even simply by connecting them with researchers we can inspire students to consider the wide variety of options available post high school.

VI. CONCLUSION

The NFV Project is the beginning of a promising K-12 outreach program. The project has evolved from a grassroots effort to work with rural Colorado students into a systematic project undergoing implementation in multiple school districts, funded by the National Science Foundation, and aiming for sustainability and longevity. We believe our unique model of a U-Pod ‘check-out’ program will ensure teachers are provided with access to resources and the necessary technological support and facilitate building partnerships that may lead to future collaborations and opportunities for our University. This program has the potential to build and sustain a community of learners using the U-Pods and inspire students to consider careers in science, engineering, and public and environmental health.

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Measuring Undergraduate Students' Self-Efficacy in Engineering Design in a Project-Based Design Course

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Abstract— Engineering design pedagogy coupled with strategic problem-solving activities can foster real-world skills in students, and measuring students' confidence in executing the activities can help understand the effectiveness of the pedagogy better. However there is little understanding of how strongly students' confidence in problem-solving activities is related to students' confidence in conducting engineering design. In this study, the students' self-efficacy in engineering design and problem-solving activities was studied in three rounds (N = 67, 55, and 92 students). Data was analyzed to assess the students' self-efficacy and to study how closely the efficacies in problem-solving and engineering design were related. Results showed an increase in students' self-efficacy in areas related to engineering design. Regression and correlation analysis showed strong relationships between students' self-efficacy in engineering design and other problem-solving activities.

Keywords— design engineering; engineering education; engineering students; problem-solving; product design

I. INTRODUCTION

Engineering design, taught in the form of a structured problem-solving process, can foster real-world problem-solving skills in students [1] - [3]. In addition to providing strong analytical skills, undergraduate engineering education needs to strengthen skills that prepare graduates to work within rapidly diversifying and innovative fields [4]. Future innovators need to be prepared to adapt to changing technology, collaborate with people from outside their discipline, and be able to apply their skills to solve new problems. Anderson *et al.* cite attributes such as problem-solving, team work, clear communication, and effectively working within time and budget constraints as some of the crucial skills that engineers must possess to be successful in the workforce [5]. In recent years, engineering design has gained significant attention as a way to incorporate these skills into engineering education to better prepare graduates to succeed in the workforce [1] - [3]. Project-based engineering design courses, coupled with a real-world application, can help strengthen these skills in students.

Though capstone design courses have been adopted by universities throughout the country [1], [6], many courses continue to use traditional teaching methods instead of project-based courses. Due to the traditional teaching methods

involving textbook questions, written exams and limited hands-on work, students often underestimate the importance of creative-thinking, problem-solving, communication, and team work skills in the engineering education. Students often relate good mathematical and analytical skills to being good engineers; but overlook the problem-solving and creative skills which are also important to succeed post-graduation [5], [7]. They sometimes think about design and manufacturing in a way that is isolated from cross-disciplinary communication, teamwork and problem-solving skills. Though researchers have looked at students' perception of engineering and design [8] - [11]; little is known about the extent to which students relate various creative-thinking and problem-solving skills to conducting engineering design.

One way to tackle this disconnect is to study how students' confidence in engineering design compares to their confidence in various creative-thinking [12], [13] and problem-solving skills [14] - [16]. Self-efficacy is the measurement of a person's confidence in carrying out an activity. Educational research has shown that motivation, self-efficacy, and value-expectancy influence students' academic behavior [17] - [21]. Further, it has been shown that the students consider various aspects of performance to report their efficacies and the self-efficacy varies during a learning period. This variation in self-efficacy during learning influences the students' self-regulated learning processes and outcomes [22]. Therefore a self-efficacy instrument was developed and administered three times during a project-based design course taught in the Mechanical Engineering and Mechanics (MEM) department at Drexel University. The self-efficacy instrument asked students to rate their confidence in carrying out 19 activities related to creativity and problem-solving skills. In addition to the 19 activities, students also rated their confidence in conducting engineering design. This was done so we can make compare efficacies in problem-solving to efficacy in engineering design. The reader is referred to [23] for details on the course.

Several self-efficacy instruments have been created to measure students' confidence in carrying out learning activities. In particular, Carberry *et al.* developed an instrument identifying individuals' self-concepts specific to engineering design [24]. This instrument has been adopted by groups (example: [25]) to monitor self-efficacy in engineering

students during design courses. Though the instrument serves as a great tool for educators to collect data on students' design self-efficacy, it lacks information about activities that are important in creative thinking and problem-solving. Therefore the instrument is not able to map self-efficacy in engineering design to that in creative thinking and problem-solving skills. Problem-based learning and creative thinking skills have proven to foster the necessary skills in students to become successful engineers [1], [3], [5], [7], [26] - [29]. These skills have also been emphasized by the United States Accreditation Board for Engineering and Technology (ABET) [15]. Further it has been shown that students need to have the will and skill to succeed in school [30]. Therefore in addition to seeing how self-efficacy changes over the course, it is also important to study the relationships between students' self-efficacy in engineering design and students' self-efficacy in problem-solving and creative-thinking.

The purpose of this study was to monitor changes in self-efficacy during the design course and to investigate relationships between efficacies in creativity and problem-solving skills and efficacy in engineering design. To that end, the following research questions were addressed:

- (a) Did the students report changes in self-efficacies related to conducting engineering design and various creativity and problem-solving skills?
- (b) What creativity and problem-solving skills had self-efficacies that were strongly related to those in engineering design?
- (c) How did the relationships between efficacies in creativity and problem-solving skills and efficacy in engineering design change over the ten week course?

II. BACKGROUND

Engineering design and its assessment can benefit a great deal from the work conducted by Woods *et al.* [14], the model established by the Partnership for 21st century skills [12], and Sternberg's theory of creativity [13] in conjunction with the skills listed by ABET [15].

By combining the ABET criteria and the work done by Woods *et al.*, problem-solving can be defined as a decision-making process to find solutions to a problem subject to needs and constraints. In addition to being good "problem-solvers" it is desirable that engineering students also possess creative thinking and communication skills [2], [4], [5], [28]. Similarly, inspired by Sternberg's theory of creativity [13], we can define creativity to include the ability of a student to combine and process different kinds of intelligence and personality traits within themselves, their team members and others such as their customers.

In order to do become creative problems-solvers, engineering students must possess the ability to do the following:

- (a) gather information to formulate design and engineering problem statements
- (b) listen effectively to extract the meaning, knowledge, and intentions of their customer
- (c) design solutions to meet desired needs and constraints
- (d) draw on self-knowledge and objectively assess quality and accuracy of work
- (e) evaluate solutions based on accuracy
- (f) use a structured process when identifying solutions and troubleshooting problems
- (g) self-monitor skills and reflect upon self-progress
- (h) be flexible and adaptable to changes and challenges
- (i) communicate effectively and systematically in a team and with a multi-disciplinary audience
- (j) articulate thoughts and ideas effectively using oral, written and nonverbal communication skills
- (k) work effectively and respectfully in teams
- (l) share responsibility for collaborative work, and value the individual contributions made by each team member.

These 12 attributes were extracted by referring to [12] - [15].

III. METHODS

A. Sample

The sample of the study consisted of undergraduate students in the Mechanical Engineering and Mechanics department of Drexel University. The study was conducted with students enrolled in a ten-week design course. A total of 118 students were registered for the course (100 male students, and 18 female students), out of which 37 students were juniors and 81 students were seniors (i.e. in their final year).

B. Course and setting

A ten-week design course is developed and taught to undergraduate mechanical engineering students at Drexel University. The objective of the course is to teach students a formalized product development method [31]. During the course, students develop concepts, and design for an educational device to be used by K-12 Science, Technology, Engineering, and Mathematics (STEM) educators to teach STEM topics. The students also build a prototype to prove the crucial functionality of the proposed device. The course is divided into three phases that were slightly modified from those described in [31]. The course uses a problem-based learning (PBL) approach in which the students work in teams, interact with real-world users of the device and build the device to address the needs of these stakeholders [23], [32].

C. Self-efficacy instrument

The instrument was developed to record students' self-efficacies in design tasks during a design course in which they learned a formal product development methodology [31]. The instrument criteria were developed by observing activities performed by students during past iterations of the course and by incorporating the creativity and problem-solving skills described in the previous section.

The instrument asked the students to rate their confidence in 19 activities related to the engineering design process, creative thinking, problem-solving, and communication skills. In addition to those 19 activities, the students were asked to rate their confidence in conducting engineering design. This was done so the response to the 20th activity could be compared to the response to the other 19 activities.

The students were asked the following: "Rate your current degree of confidence (i.e. belief in your current ability) to perform the following activities by marking a number from 0 to 10, 10 being extreme confidence and 0 being no confidence". Table I lists the activities provided during three rounds of survey during the 10-week course. Some activities were omitted from the survey during different rounds. This was done based on the relevance of the activity in the specific phase of the course. For example, the students were not asked to rate their confidence in their ability to "refine concepts based on feedback" in week 10, because they only had that opportunity during and before week 5. Similarly, the students were only asked to "justify design solutions" in week 10, because they developed designs and got opportunities to defend design solutions between week 6 and 10. Some activities, such as forming problem statement, developing design specification, integrating multiple subjects, communicating designs in different ways were an integral part of problem-solving and creative thinking skills, and therefore were included in all three surveys. This facilitated the monitoring of these crucial skills over the entire course. The column on the far right in Table I notes the problem-solving skills from section II that are related to the activities in the instrument.

D. Data collection

The instrument was administered online three times during the 10-week course; during week 1, week 5 and week 10. The forms were created and shared, and data was collected using Google forms. Out of the 118 students in the course, 67, 55 and 92 students submitted their responses in week 1, 5 and 10 respectively.

E. Data analysis

The self-efficacy of the student population related to each activity was compared with the self-efficacy of the student population in "conducting engineering design". The average efficacy numbers were plotted with standard errors (standard deviation/ $n^{1/2}$) while monitoring changes in the efficacy over the 10-week course.

Linear regression analysis was conducted to investigate the extent to which self-efficacy in each activity was related to the self-efficacy in conducting engineering design. The efficacies in the problem-solving activities were considered to be

TABLE I. 20-POINT SELF-EFFICACY ASSESSMENT CRITERIA INCLUDED IN THE INSTRUMENT

Activity	Included in			Creativity and problem-solving skills (a) – (l) from section II.
	Week 1	Week 5	Week 10	
0. Conduct engineering design	X	X	X	
1. Form a problem statement	X	X	X	(a)
2. Develop design/product specifications	X	X	X	(b), (c)
3. Develop design/product solutions	X	X	X	(c), (f)
4. Objectively select best design solution/concept	X	X	X	(b), (c), (f)
5. Evaluate a concept		X		(e)
6. Revise concept based on feedback		X		(e), (f), (h)
7. Use computer simulation and analysis to analyze a design	X		X	(e)
8. Communicate design details through CAD	X		X	(i), (j)
9. Justify design decisions and solutions			X	(d), (e), (f), (i), (j)
10. Evaluate and test a design	X		X	(d), (e)
11. Re-design based on feedback from customer	X		X	(h)
12. Understand manufacturing constraints and incorporate those in making design decisions			X	(c), (h)
13. Make and justify trade-offs in design (i.e. compromising one design feature for another)			X	(c), (f), (h), (i), (j)
14. Integrate information from a non-engineering field/subject with engineering while developing product solutions	X	X	X	(d), (f)
15. Explain designs to non-engineers	X	X	X	(i), (j)
16. Work effectively in a team	X	X	X	(i), (k), (l)
17. Communicate project details orally	X	X	X	(i), (j)
18. Communicate project details in writing	X		X	(i), (j)
19. Manage my time efficiently to accomplish activities			X	(g)

"predictors" of students' efficacy in engineering design. The objective of the linear regression analysis was the following:

(a) To examine if the relationship between the efficacies in problem-solving activities and engineering design was significant. In other words, did the efficacies in problem-solving activities predict the students' efficacy in engineering design?

(b) To determine the estimates of the linear regression model parameters. These values of the estimates represent the strength and the sign of the estimates represent the proportionality of the relation. For example a high strength for activity 14 would imply that the students' efficacy in activity 14 is strongly related to efficacy in engineering design. Further a positive estimate would imply that a direct relationship between the efficacy in activity 14 and engineering design. In other words, an increase in students' efficacy in activity 14

would be accompanied by an increased in students' efficacy in conducting engineering design.

We used nine out of the nineteen self-efficacy activities (shown in Table II) as the predictor variables for the self-efficacy in conducting engineering design, which was the predicted variable. The nine self-efficacy activity variables were chosen because they were included in each of the three rounds the instrument was administered.

IV. RESULTS

A. Gains in self-efficacy

Students reported an increased self-efficacy in all 20 activities listed in the instrument over the 10 weeks of the course (Fig. 1). The largest increase was seen in students' ability to use computer simulations and analysis to analyze a design. The smallest increase was seen in students' ability to work effectively in a team, i.e. activity 16. Though the increases over the course of 10 weeks in activity 16 were the smallest, students' confidence in the activity had the largest average score among all activities. Similarly, though there were increases in students' efficacies related to integrating multiple subjects to design solutions (activity 14); the average values related to this activity remained within the bottom two spots among all activities. Students' self-efficacy related to communicating project details orally (activity 17) and explaining design to non-engineers (activity 15) showed no significant changes from week 1 to week 5, but showed a significant increase from week 1 to week 10 and week 5 to week 10 (p-test with 95% confidence interval). For all other activities, students showed an increase as the course progressed.

B. Relating self-efficacies in engineering design to other activities

The linear regression analysis showed a significant relationship between the self-efficacy in the nine activities and in conducting engineering design. Table II illustrates the significance of relations, the coefficients of the linear regression, and the coefficients of determination (r^2) values. The significance is denoted by an asterisk in Table II. The coefficients of the linear regression show the strength of the relation between the efficacy in the activity and engineering design. The r^2 values indicate how much variability in the "dependent variable" (self-efficacy in engineering design) is accounted for by each "independent variable" (self-efficacy in the nine activities).

The following can be summarized from the regression analysis:

- Self-efficacies in all the nine activities were significantly related to the overall self-efficacy in conducting engineering design, except for activities 14 (integrating information from a non-engineering field with engineering to develop solutions) and 17 (communicating project details orally) for the first round of administering the instrument (in week 1). This implied that students' efficacy in integrating information and oral communication did not predict

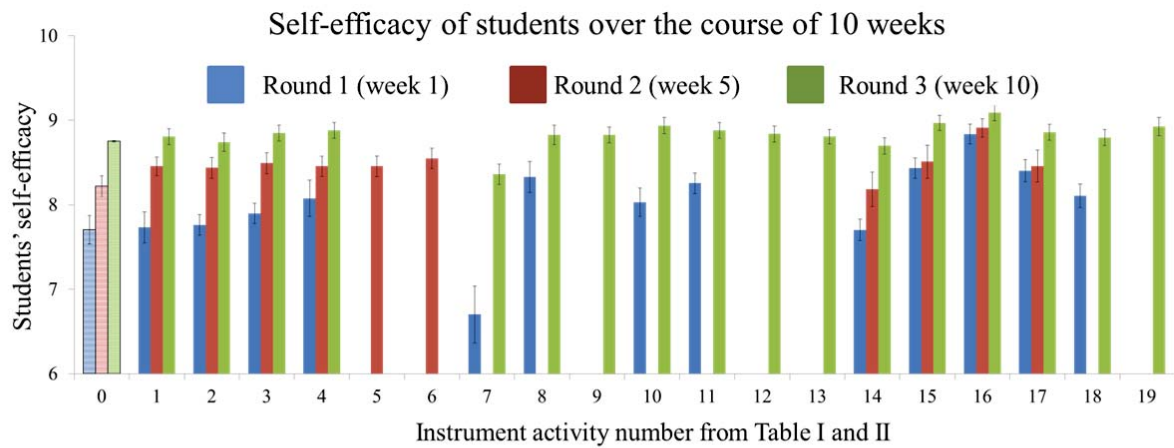
their efficacy in engineering design in the first week of the course.

- All the regression coefficient values were positive, indicating a direct relationship between efficacies in all nine activities and engineering design. In other words, an increase (or decrease) in efficacy in any of the nine activities was likely to be accompanied by an increase (or decrease) in efficacy in engineering design. The highest regression coefficient value was seen for activity 3: developing design solutions (0.978), and the lowest coefficient was seen was activity 17: communicating project details orally (0.066). This implied that efficacy in developing design solutions was the strongest predictor of efficacy in engineering design, and efficacy in oral communication of designs was the weakest predictor of efficacy in engineering design.
- Between the three rounds of administering the instrument, the coefficient values increased for activity 10, 14, and 17, decreased for activity 2 and 15, and were a mixture of increases and decreased for activity 1, 3, 4, and 11 (Table II), (Fig. 2). This implied that the efficacy in evaluating and testing a design (activity 10) became a stronger predictor of efficacy in engineering design as the course progressed. On the other hand, the efficacy in developing measurable specifications (activity 2) weakened in predicting efficacy in engineering design as the course progressed.
- The amount of variability accounted for in the dependent variable (self-efficacy in conducting engineering design) by each of the nine-predictor variables changed throughout the three points of administering the instrument (Fig. 3). The data were inconclusive but will be examined more carefully in the future.

V. DISCUSSION

Students showed gains in self-efficacy related to engineering design and problem-solving activities, indicating a good execution of the course. It can be hypothesized that these gains are a result of: (a) the increase in student knowledge and learning as the course progressed, and (b) the increase in hands-on engagement of the students with their projects and real-world customers. As the course progressed, students developed a greater understanding of the engineering design process and realized the importance of several problem-solving activities in developing good designs. Students also showed appreciation towards working on an application that integrated engineering with non-engineering principles. Readers are referred to [23] and [32] for details on the course, the project, and quotes from students.

The correlations between the self-efficacy in the nine problem-solving activities (listed in Table II) and the self-efficacy in conducting engineering design (activity 0 on the instrument in Table I), showed some interesting trends. It is



0. conduct engineering design
1. Form a problem statement
2. Develop design/product specifications
3. Develop design/product solutions
4. Objectively select best design solution/concept
5. Evaluate a concept
6. Revise concept based on feedback
7. Use computer simulation and analysis to analyze a design
8. Communicate design details through CAD
9. Justify design decisions and solutions
10. Evaluate and test a design
11. Re-design based on feedback from customer
12. Understand manufacturing constraints and incorporate those in making design decisions
13. Make and justify trade-offs in design (i.e. compromising one design feature for another)
14. Integrate information from a non-engineering field/subject with engineering while developing product solutions
15. Explain designs to non-engineers
16. Work effectively in a team
17. Communicate project details orally
18. Communicate project details in writing
19. Manage my time efficiently to accomplish tasks

Fig. 1. Self-efficacy in all 20 activities in the instrument, recorded three times during the 10 week project-based design course. The average values of the class are plotted with standard error bars.

TABLE II. COEFFICIENTS OF THE LINEAR REGRESSION AND DETERMINATION VALUES FOR NINE OUT OF NINETEEN ACTIVITIES IN THE INSTRUMENT

Activity	Round 1 (n=65)	Round 2 (n=55)	Round 3(n=92)
1. Form a problem statement	.716* ($r^2 = .613$)	.773* ($r^2 = .469$)	.347* ($r^2 = .105$)
2. Develop measurable design specifications	.895* ($r^2 = .414$)	.610* ($r^2 = .373$)	.361* ($r^2 = .149$)
3. Develop design solutions	.978* ($r^2 = .465$)	.724* ($r^2 = .528$)	.809* ($r^2 = .524$)
4. Objectively select best design solution/concept	.550* ($r^2 = .479$)	.469* ($r^2 = .202$)	.614* ($r^2 = .319$)
10. Evaluate and test a design	.505* ($r^2 = .251$)	.516* ($r^2 = .268$)	.664* ($r^2 = .392$)
11. Re-design and refine based on feedback from customer outside of engineering	.627* ($r^2 = .211$)	.629* ($r^2 = .381$)	.546* ($r^2 = .252$)
14. Integrate information from a non-engineering field/subject with engineering to develop solutions	.278 ($r^2 = .044$)	.350* ($r^2 = .331$)	.490* ($r^2 = .208$)
15. Explain and communicate designs to non-engineers	.411* ($r^2 = .082$)	.254* ($r^2 = .162$)	.105* ($r^2 = .009$)
17. Communicate project details orally	.066 ($r^2 = .003$)	.318* ($r^2 = .235$)	.379* ($r^2 = .121$)

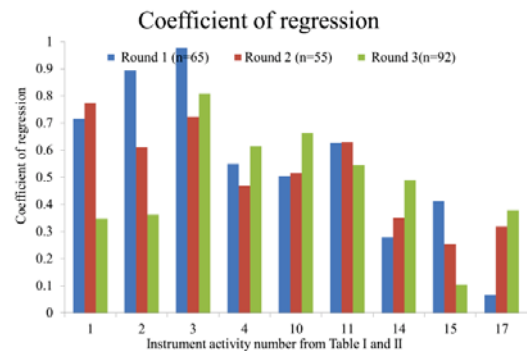


Fig. 2. Changes in coefficient of linear regression for the nine activities

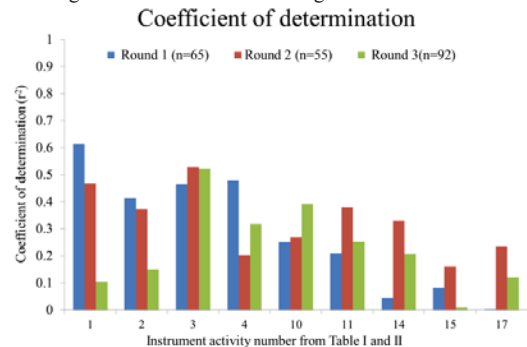


Fig. 3. Changes in coefficient of determination for the nine activities

important to note that the regression and correlation analyses only indicated how and to what extent the nine problem-solving activities were related to conducting engineering design. The analysis does not decipher any causal relationships. Also, recall that the correlations are between students' self-rated confidence in the activities and in conducting engineering design. Hence, the low coefficients of regression for a certain activity could potentially imply that students' confidence in conducting engineering design did not depend on the students' confidence in that certain activity. We will now discuss some examples.

The largest increase in efficacy, from week 1 to week 10, was seen in the students' ability to use computer simulation and analysis to analyze a design (activity 7). The efficacy in activity 7 increased by 25% from week 1 to week 10. We believe this was primarily because the students were given an assignment that required them to work in teams and use several tools to analyze their designs. The tools included CREO Mechanisms, MATLAB, Ansys, Excel etc. Though these junior and senior engineering students were knowledgeable about the analysis and simulation tools (example: mechanics, controls, dynamics, statics, heat transfer etc.), the course gave them the opportunity to apply the knowledge through a hands-on project.

The students' self-efficacy in integrating information from non-engineering fields with engineering (activity 14) received consistently low scores. The students did not feel very confident in being able to integrate topics from biology, chemistry, business etc. with engineering. The course required the students to develop a product that can teach biology and engineering to K-12 students; therefore it was fundamental for the students to understand biological principles. The instructor and teaching assistants of the course often found students struggling with this integration. The challenge of integrating these subjects was also expressed by students through course evaluations and comments on surveys. Students in college, rarely get the opportunity to work on an assignment that pushes them out of their comfort zone and encourages them to bring in information from fields outside of engineering. In addition to receiving low efficacy scores, activity 14 also had low values for coefficient of regression. In other words, the efficacy of students to integrate information from different fields was not a strong predictor of their efficacy in conducting engineering design. Though the strength of this relationship between the activity and engineering design increased from week 1 to week 10, its value remained low (0.278, 0.350, and 0.490). It can be concluded that students' self-assessed ability to integrate information from multiple fields did not adversely affect their self-assessed ability to conduct engineering design.

Similar to activity 14, the low regression coefficients values for oral communication (activity 17) for all three round of surveys illustrates that students' confidence in oral communication did not have a strong relationship with the students' confidence in conducting engineering design. One way to explain that behavior is that students who do not feel confident in communicating project details orally may still feel confident in conducting engineering design. Further, the low coefficient of determination (r^2) implied that the regression coefficient does not explain the variability in the data well (Fig.

3). A larger sample of data may assist in understanding this correlation better.

Students' confidence in "forming a problem statement" had a strong correlation with their confidence in "conducting engineering design" for the first two rounds. However, that strength decreased in round 3 (Fig. 2). This may be explained by considering that the students worked iteratively in constructing a good problem statement for their products up till week 6 of the course. After week 6, students were more involved in designing their products, manufacturing prototypes, testing prototypes, modifying designs based on customer feedback etc. Hence, we see strong relations between activity 3, 4, 10 and 11 in week 10; activities that were more representative of what the students were actually engaged in before taking the survey.

Students' efficacy in their ability to re-design and refine based on feedback (activity 11) was strongly correlated to their ability to conduct engineering design in the first two rounds, but that correlation got weaker in round 3 (Fig. 2). This was particularly interesting because the self-efficacy of the students related to this activity increased from week 1 to week 10 (Fig. 1). The students gained more confidence in being flexible and adaptable to making changes but the regression analysis did not show a strong correlation of that with conducting engineering design.

Students' efficacy in their ability to explain design to non-engineers (activity 15) did not show a significant increase from week 1 to week 5, but showed a significant increase from week 1 to week 10 and week 5 to week 10. It is important to note here that from week 1 to week 5, the students mainly communicated their ideas with customers through text, flow charts, sketches, and 3D solid models (made through CREO Parametric). In week 10, when the students responded to the third round of survey, they had communicated their ideas through a physical prototype (built by the students), along with analysis of the prototype. We believe that having hands-on experimentation time with their prototype and having a physical device to explain ideas, made the students feel more confident in their ability to carry out the communication.

Based on the trends seen in students' self-efficacy in problem-solving activities and the relations between efficacy in the problem-solving activities and engineering design, we can make some suggestions to improve engineering design education.

- More courses, even during the first two years of college, should be constructed to provide students with added hands-on work with a real application. Applying physics and engineering principles to a real design or product can help improve students' knowledge of analysis and simulation tools, and can increase students' awareness of the importance of simulation and analysis in conducting engineering design.
- More project-based courses should be developed where students get a chance to interact with customers from non-engineering fields (example: non-engineering teachers, nurses, artists, business analysts

etc.). Learning how to gather and interpret information from non-engineers is crucial for engineers. It is equally essential for engineers to learn how to use different modes of communication (written, oral, or non-verbal such as virtual 3D models and drawings) to convey ideas to non-engineers.

- Project-based courses should also enable students to step outside their engineering coursework (which often includes math-heavy course work) and encourage them to spend time researching and gathering information about a non-engineering topic. It is important for engineering students to be comfortable and confident to study a new topic and be able to integrate information from the new field with engineering to design a solution to a problem.
- Project-based design courses should facilitate prototyping activities so that the students can develop physical devices to experiment with, understand its use, and use the physical prototype to communicate their ideas to peers and customers.
- Project-based design courses should facilitate repeated feedback from peers and customers, refinement of problems statement, and objective evaluation of ideas. These were some of the activities that were strong predictors of engineering design when students were actively involved in executing them. (For example, forming problem statements in week 1 and week 6). These activities weaken as predictors of engineering design when the students are not involved in the activities. Therefore, it may be beneficial to develop design courses where students are performing various problem-solving activities in iteration. This will also reinforce the relation between being flexible and adaptable, and engineering design.

These suggestions can help improve the engineering students' abilities and perception of engineering, to address the creativity, teamwork, communication and problem-solving skills discussed in section I and II.

VI. CONCLUSION

Overall, the students reported an increase in their ability to carry out the problem-solving activities on the instruments and ability to conduct engineering design. Self-efficacy is a useful measure to monitor students' self-assessed growth in conducting engineering design. The activities on the instrument proved to be good predictors of efficacy in engineering design. Though, the correlation and regression analysis does not give any causal relationships, the information helps identify strong and weak correlations between problem-solving activities and engineering design. This can further help in developing the pedagogy that can adequately foster essential creative problem-solving skills in engineering students. In other words, can weak correlations between creative problem-solving activities and engineering design be improved by incorporating those activities in engineering pedagogy? If students conducting engineering

design regularly communicated with non-engineers, conducted rigorous analysis of designs, formed problem statements, evaluated and tested designs, and re-designed based on feedback from customers, will these problem-solving activities become stronger predictors of engineering design among students?

VII. FUTURE WORK

Future work involves, further investigating the gains in self-efficacy and correlations between efficacies in the problem-solving activities and engineering design. Data will be collected from a larger student population in various project-based settings. We will also gather a more controlled data set by assigning identities to each response, so that individual growth can be monitored over the 10 week course. The instrument will be used in additional institutions to see how well the existing results hold, and to see the influence of real customer on the self-efficacies of the students.

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There's More Than One Way to Analyze Feedback on Design

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Abstract — Most studies on feedback and design use thematic analysis. In this paper, we apply three text analysis methods that are not commonly used in feedback and design studies to encourage researchers to think outside of the box and try different methods. We show how word cloud representation, word frequency, and reading ease and grade level tests can be applied to a feedback on design dataset in order to highlight the strengths and limitations of each approach. In general, findings of these three methods are aligned with those from our previous thematic analysis and provide new insights about the feedback. We recommend that these methods be used in addition to thematic analysis in analyzing feedback on design research.

Keywords— *Design Education, Information Visualization, First-Year Engineering, Feedback on Design*

I. INTRODUCTION

Engineering educators are encouraged to provide students with authentic learning experiences that reflect aspects of engineering practice. This can be accomplished through the integration of real world design problems. As design is seen as a central [1] and defining [2, 3] aspect of engineering practice, it is essential that engineering students develop design skills, and become more like experienced engineering practitioners [4]. One way of developing design skills is to provide feedback on students' design work. Feedback is a key catalyst for learning [5] and is positively related to improvements in engineering design skills and professional skills such as communication, teamwork, and critical thinking [6].

One of the most utilized frameworks in studying design and feedback is the expert-novice framework [7]. We used this framework to analyse feedback on design [8]. Based on this framework, design work or feedback of individuals who are identified as experts (typically based on greater experience and higher education) is compared to individuals who are identified as novices. The goal of this comparison is highlighting the differences between experts and novices in order to encourage novices to become more like experts. Methodologies used in most of these studies are thematic analysis and case study. In thematic analysis, common themes are identified and coded based on a coding scheme that characterizes the design work or feedback [9]. In a case study, one or a few individuals are selected and their work is reported in detail to provide insight about their design or feedback [10].

In our previous studies, we developed a coding scheme for written feedback on design including two domains Substance (Communication, Design Concept, Design Idea) and Focus of feedback (Direct Recommendation, Investigation / Brainstorming, Expression of Confusion, Negative Assessment, Positive Assessment, Details/Example) [11]. We coded and analyzed the feedback of students and educators in a first-year engineering course based on this coding scheme [8, 12]. In summary, students provided more feedback related to the communication aspects of design work (e.g., grammar, quality of images) and educators provided more feedback on the design ideas specific to a design problem. Both groups gave feedback on design concepts related to the design process (e.g., identifying users, defining criteria and goals). In addition, students gave mostly negative feedback (i.e., pinpointing the weaknesses of the work) and direct recommendations on how to improve the design work. In contrast, educators provided more detailed comments with examples and asked thought-provoking and brainstorming questions to guide the students to think about their design work more deeply and correct their own mistakes [8].

In addition to thematic analysis and case study, there are a number of different ways to analyze written text that may be useful for analyzing written feedback on design. Visualization techniques, calculating word frequencies, and text readability tests are some of these methods. In summary, the goal of information visualization is to summarize data that can be understood easily by humans [13]. Word frequency techniques calculate the number of time each word has been used in the text to draw attention to the most frequently used words. Text reading ease tests (e.g., Flesch-Kincaid test [14]) indicate how difficult it is to read a text and can assign the grade-level education necessary to read the text.

The aim of this paper is to explore some of the text analysis methods that are not commonly used in analyzing feedback on design in order to show their strengths and limitations for this purpose. Some of these methods can be used in addition to thematic analysis to contextualize students' and engineering educators' written feedback on engineering design work and highlight the differences between the students' and educators' feedback across different stages of design project work. This comparison could enable more effective development of pedagogies for instructing students on how to provide feedback on design work and how to design professional development for educators.

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II. RESEARCH QUESTIONS

In this paper, to understand the strengths and limitations of different methods for analyzing written feedback on design, we investigate the following research question: *What are strengths and limitations of using word cloud representation, word frequency, and a reading ease test for characterizing and comparing students and educators written feedback on design?*

III. METHODS

A. Participants and Settings

Instructors and GTAs of a required first-year engineering course were invited to participate in this study as part of their weekly instructors' meeting during the Fall 2013 semester. Before the instructors began to review their own students' design work, they were asked to give written feedback on a sample piece of student team design work. In total, instructors and GTAs gave feedback on four milestones of a design project over the course of four different meetings. The milestones focused on Problem Scoping (Milestone 1), Concept Generation (Milestone 2), Concept Reduction (Milestone 3), and Concept Detailing (Milestone 4). Each milestone was a 2-4 page long document describing the team's progress on a particular aspect of the design project. Nineteen people (instructors and GTAs) provided feedback on Milestone 1, and 14 provided feedback on Milestones 2-4.

In the first-year engineering course, students work together in teams of four to develop solutions to open-ended mathematical modeling problems during the first half of the semester. During this time, the students begin to develop their feedback skills through in-class activities and homework assignments and then provide feedback on their peers' work. During the second half of the semester, students continue to work in their teams on a design project. Approximately 120 students were asked to provide feedback on the four milestones of the same sample student team's design work on which educators provided feedback. The feedback from 30 students was selected for this study.

B. Design Problem

In the design problem, "aliens" are coming to campus to study! Student teams are asked to prepare the campus for the extraterrestrials' drinking water needs [15]. For example, one possible solution could be re-designing the water fountains according to the extraterrestrials' physical abilities.

C. Analysis

1) Word Cloud Representation

To provide a visual representation of the feedback comments provided by educators and students on each milestone, word cloud images of the comments were created using Wordle [16]. In a word cloud representation, after removing common two letter words (e.g., is) and some other common English words (e.g., the), more frequently used words are demonstrated with bigger size fonts. Size is one of the visual features that can be perceived quickly and without much attention by humans [17]. Word cloud representations of comments can highlight similarities and differences between students' and educators' feedback. It can also reveal if students or educators use similar words among themselves or not.

2) Word Frequencies

Another way to analyze written feedback on design is to count and compare the frequency of words used by students and educators. For each milestone, the most frequent words in students' and educators' comments were calculated to characterize the feedback. First the top 100 most frequent words used by educators were selected; then the word frequency divided by the number of educators reviewing that milestone to calculate the average frequency of the words per educator for each milestone. Following the same process, the average frequency of the words per student for each milestone was calculated for students. Then the words that were used by both educators and students were selected and a frequency ratio was calculated by dividing the average frequency for the educators by the average frequency for the students as in (1).

$$Freq. Ratio (word) = \frac{Educators Avg. Freq. (word)}{Students Avg. Freq. (word)} \quad (1)$$

In addition, the words (out of the top 100 words) that were used by only one of the two groups (i.e., only by students or only by educators) were extracted to further highlight the differences between the students' and the educators' feedback.

3) Reading ease and grade level test

Another way to analyze a written text document is by calculating its readability based on the words and sentences in the text. Flesch-Kincaid reading ease and grade level tests [14] were conducted to quantify the differences in students' and educators' writing level. The reading ease score is between 0 (very difficult) and 100 (very easy) and is based on the number of words in the sentences and the number of syllables in the words in the text; the "plain English" score (with about five words per sentence and 1.6 syllables per word) is between 60-70. The reading ease score can also be converted into a grade level. The lower the score, the higher the level of education needed to read the text. The lowest grade level, 5th grade, is equivalent to a reading ease score of 90-100. Reading ease scores of less than 50 will be assigned a grade level higher than 12, meaning the text is at a collegiate level.

IV. RESULTS AND DISCUSSION

A. Word Clouds

Table I shows the word clouds created based on students' and educators' feedback. In addition to participants' word choice, these images show the level of homogeneity among each group. For Milestone 1, the educators' word cloud shows words with a bigger font size compared to that of the students' word cloud. This is an indication that educators used similar words among themselves, and students used a greater variety of words. Since most of the instructional team have been working at Purdue University together for a number of years, it seems they have adapted a similar language and formed a community that can be seen as a community of practice [18]. Similar training, interactions among educators, exchange of knowledge, and similar experiences may be some of the reasons that educators used similar words in their feedback. For Milestone 1, students used longer words, such as stakeholders and constraints – words they learned in the course. Educators' chose simpler and shorter words.

Educators used words such as water, aliens, problem, ideas, schedule, etc. in their feedback more often than students. This can be an indication of providing feedback on design ideas specific to the design problem, which confirms our previous findings [8]. While word cloud representations provide a visual summary of feedback, the images are not always easy to use to make fine-grained comparisons among groups' feedback characteristics.

B. Word Counts

Table II shows the common words used by educators and students at least twice as many times by one group as compared to the other group. This ratio indicates how many

times educators used a word compared to students. For example, the word "list" in Milestone 1 was used 10 times more by the educators than the students. Words with a ratio of greater than 2 were used at least twice as often by educators than students and words with a ratio of less than 0.5 were used by students at least twice as often as by educators. As can be seen in Table II, most of the common words are used more frequently by educators. Only a few words (shown at the bottom of the table for each milestone), and sometime no words, were used more frequently by the students. This confirms the word cloud representation results - educators used similar words and students used a greater variety of words.

TABLE I. WORD CLOUD REPRESENTATION OF STUDENTS' AND EDUCATORS' FEEDBACK ON DESIGN.

Milestone	Students	Educators
M1		
M2		
M3		
M4		

TABLE II. COMMON WORDS FOUND IN EDUCATORS' AND STUDENTS' FEEDBACK ON DESIGN WITH RATIOS OF MORE THAN 2 OR LESS THAN 0.5.
A RATIO GREATER THAN 2 INDICATES EDUCATORS ON AVERAGE USED THE WORD MORE THAN STUDENTS.
A RATIO LESS THAN 0.5 INDICATES STUDENTS USED THE WORD MORE OFTEN THAN EDUCATORS.

Milestone 1		Milestone 2		Milestone 3		Milestone 4	
Word	Ratio	Word	Ratio	Word	Ratio	Word	Ratio
list	10.26	figures	5.36	wdm	8.57	installation	6.43
measurable	7.11	criteria	5.00	water	7.14	time	5.36
purdue	4.74	clean	5.00	table	4.82	team	5.36
cost	4.34	ideas	3.75	ideas	4.29	need	4.29
problem	4.21	did	3.57	cost	4.29	water	3.21
needs	4.21	prior	3.37	weights	4.29	figures	3.21
clean	4.06	art	3.37	clean	3.75	done	3.21
ph	3.95	aliens	3.21	double	3.21	volunteers	2.86
need	3.83	generation	3.21	aspirator	3.21	solution	2.86
data	3.68	solution	3.10	seems	2.86	description	2.68
water	3.49	include	2.50	final	2.86	feedback	2.68
how	3.30	used	2.14	how	2.57	how	2.64
different	2.63	different	2.14	criteria	2.45	did	2.41
identify	2.63	idea	2.14	explanation	2.14	prototype	2.14
does	2.48	provide	2.14	convenience	2.14	schedule	2.14
criteria	2.37	in-text	2.14	hose	2.14	images	2.14
fountain	2.37	direct	0.47	much	2.14	costs	2.14
time	2.37			models	2.14	professional	2.14
drink	2.37			because	2.14	questions	2.14
define	2.11			does	2.14	plan	2.14
				energy	2.14	criteria	2.14
				rationale	0.48	very	0.39
				matrix	0.41		
				cons	0.37		
				pros	0.34		

In the list of common words used more frequently by educators, design problem specific words such as Purdue, water, aliens, and installation indicate that educators focused more on design ideas specific to the design problem than students. Also some words such as how and does, which are commonly used to start sentences in the form of questions, indicate that educators asked more questions than students. This aligns with our previous finding that educators asked thought-provoking questions [8].

Table III lists words commonly used by both educators and students. Words such as stakeholders, rational, constraints, and goal indicate that both groups emphasized design concepts.

Table IV shows the words (from the top 100 words) that were used by students and not educators and the words that were used by educators but not students as well as the words average frequency per person. Use of words such as bullet, points (typically used together), pictures (in three of the milestones), and sketch by students shows that they focused on the communication aspect of the design.

TABLE III. COMMON WORDS FOUND IN STUDENTS' AND EDUCATORS' FEEDBACK ON DESIGN WITH RATIOS OF BETWEEN 0.5 AND 2. THESE ARE WORDS USED SIMILARLY BY BOTH GROUPS.

Milestone 1		Milestone 2		Milestone 3		Milestone 4
provide	physical	need	know	top	did	problem
effective	just	how	better	provide	team	captions
good	goals	means	well	use	design	provide
stakeholders	specific	chart	good	make	based	enough
aliens	many	use	problem	designs	chose	sketchup
constraints	use	water	citations	metrics	good	labels
goal	one	short	sketches	rating	decision	materials
rationale	well	captions	morphological	solution		picture
fountains		see	get	need		good
make		solutions	stories	used		google
able		labeled	put	time		grammar
		way	table	units		iteration

TABLE IV. FEEDBACK ON DESIGN WORDS USED ONLY BY STUDENTS' OR EDUCATORS' BUT NOT BOTH GROUPS WITH AVERAGE FREQUENCY PER PERSON.

Milestone 1				Milestone 2			
Students (n=30)		Educators (n=19)		Students (n=30)		Educators (n=14)	
Word	Frequency	Word	Frequency	Word	Frequency	Word	Frequency
points	0.40	solution	0.74	pictures	0.77	design	0.64
explain	0.37	design	0.74	team	0.47	sub-functions	0.57
bullet	0.37	clear	0.42	include	0.30	clear	0.50
user	0.33	know	0.42	statement	0.20	morph	0.50
cheeks	0.30	way	0.37	chemicals	0.20	function	0.50
team	0.30	example	0.37	ethical	0.20	strategies	0.43
pictures	0.30	project	0.32	seem	0.17	overall	0.43
very	0.23	might	0.32	hard	0.17	functions	0.36
intake	0.23	seem	0.32	confusing	0.13	example	0.36
without	0.23	alien	0.32	missing	0.13	work	0.29

Milestone 3				Milestone 4			
Students (30)		Educators (14)		Students (30)		Educators (14)	
Word	Frequency	Word	Frequency	Word	Frequency	Word	Frequency
weighted	0.43	data	0.71	pictures	0.40	design	0.71
chart	0.33	pros/cons	0.64	list	0.23	cost	0.64
read	0.27	options	0.50	page	0.23	project	0.57
solutions	0.27	clear	0.43	label	0.23	procedure	0.43
statement	0.20	model	0.36	sketch	0.20	sketch-up	0.36
needs	0.20	benchmarking	0.36	get	0.17	work	0.36
problem	0.17	evidence	0.36	well	0.17	does	0.36
list	0.17	measurable	0.29	statement	0.13	missing	0.36
errors	0.17	scale	0.29	specific	0.13	see	0.29
best	0.17	humans	0.29	blank	0.13	price	0.29

While calculating word frequencies can be an effective way to summarize and get an insight about the context and choice of words, it may be better to use these methods in combination with other methods, as it is not easy to look through a list of words and get a sense of the feedback. One suggestion is to code the most frequent words based on a previously develop coding scheme instead of coding the whole text. If the results are similar, coding only the most frequent words is less time consuming than coding the whole text.

C. Readability and Grade Level Tests

Table V provides results of the Flesch-Kincaid reading ease and grade level tests. Educators' reading ease score is consistent across milestones and is in the 60s, which is consistent with the plain English score. In contrast, students' reading ease varies greatly from the first milestone, 43.7, to the last milestone, 69.6. As can be seen from the word cloud representations, the low reading ease score for Milestone 1 may be based on the choice of long words (with more syllables) that students adapted from the course. In contrast, educators avoided using "jargon" and provided their comments in plain English. As students progressed in the design milestones, it seems they started to use simpler words in their feedback.

TABLE V. FLESCH-KINCAID READING EASE AND GARDE LVEL TEST.

Milestone	Flesch-Kincaid	Students	Educators
M1	Reading Ease	43.7	63.8
	Grade Level	14.5	6.8
M2	Reading Ease	60.4	61.4
	Grade Level	8.7	7.8
M3	Reading Ease	64.6	68.4
	Grade Level	8.1	6.4
M4	Reading Ease	69.6	66.5
	Grade Level	5.6	6.3

Reading ease and grade level tests are a great way to quantify feedback for comparison purposes, but they are better used in combination with other methods that can provide deeper insight about the feedback. In addition, because the test scores are calculated based on the number of words in the sentences, texts that are not properly punctuated (such as feedback in bullet lists) may lead to erroneous results.

V. LIMITATIONS AND FUTURE WORK

In addition to the limitations discussed earlier for each method, one common limitation of the presented work results from combining everyone's feedback for each milestone. If one person overuses a specific word, that word may show up as frequent but only has been used by very few people. To avoid this problem it is possible to count the number of participants that used a specific word instead of word frequency in general.

Another suggestion is to combine each of these methods with thematic analysis. For example, it is possible to create a separate word cloud for different substance of feedback (i.e., Communication, Design Concept, Design Idea) for each milestone. This can make a more detailed visual representation of the choice of words not only for each milestone, but also based on different substances of feedback.

VI. CONCLUSION

In this paper, we briefly reviewed three different and unconventional approaches to analyzing feedback on design. We applied them on a feedback dataset to highlight the strengths and limitations of these methods. In summary, while all three methods provide good insight about written feedback on design, we recommend that these methods be used to complement more conventional methods in analyzing feedback such as thematic analysis. Since the methods discussed in this

paper are efficient in analyzing large text datasets, this can be a first step to analyze a large amount of feedback automatically. For example, it may be possible to use a combination of these methods (e.g., word counts) with a developed coding scheme to monitor changes in feedback over time.

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Evaluating capstone project through flexible and collaborative use of Scrum framework

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Abstract—Scrum framework disseminates principles that guarantee a dynamic and adaptable Software development process. Supporting the software engineering teaching using agile methodologies and Scrum framework with some proper adaptations is the challenge of Federal University of São Carlos in the Software Engineering specialization course for graduated students. The article presents an evaluation of Scrum adaptations performed to evaluate the capstone project. In this case study, the adoption of Scrum to manage the capstone project represents a direct and objective approach in order to have an environment similar to the real one. Moreover, the inexperience of the teams, the partial dedication in the projects and the distributed teams showed the necessity of self-management of the teams among other lessons learned to teach Software Engineering in this setting. Finally, evaluating a capstone project using Scrum framework in a flexible and collaborative way made it possible to realize the difficulties faced by the teams and the need for technical improvements, thanks to Scrum framework functions.

Keywords — agile methodologies, software engineering, higher education, SCRUM

I. INTRODUCTION

Software Engineering teaching needs to follow the industry demands when the purpose is to improve the skills of graduated students who seek better placements in industry or want to update knowledge to complement the graduation learning.

Developers in Software industry complain about the constant changes in software requirements. In traditional methods, the clear requirements are prerequisites to the next level. Currently, developers need to transform the constant chaos of Software development industry in advantage and find a way of better assisting the client [1]. Due to fast changes in this industry, traditional approaches are not very practical to some professionals [2].

The Software development in the industry is fast and offers our students an unstable environment in relation to the aspect of technology, requirements management and team management. The industry needs a professional who is flexible to manage all the chaos in an unstable environment and able to deliver a functional product in a short period. It is possible to conclude that there is the necessity of an approach closer to the real environment, in which theories and practices can be

applied allowing the student to have a further learning using agile methodologies of Software development [2].

In face of this setting, the Federal University of São Carlos/Brazil offers a Software Engineering specialization course for web development for graduated students based on agile methodology principles. For this to be achieved, Scrum framework was chosen and the course was adapted so that the students were able to learn and, at the same time, apply Scrum principles.

Since the first group in 2003, the traditional methodology was adopted in the capstone project. However, some problems were faced during this period such as partial delivery of the project, because the complete project was developed in a single cycle and the traditional methodology was used [2]. Some studies discuss that this is an ideal methodology for inexperienced students [3]. However, the analysis of the course reality showed that some variables needed to be included such as time dedicated, experience, talent for programming and auto-management. Some of these variables were only realized in the end and reflected on the capstone project.

Agile methodologies and Scrum framework principles, mainly the iterative aspect of the production cycle for a delivery in each Sprint, were adapted in the course. All the subjects were enrolled, allowing the student to learn new programming techniques and to deliver a part of the capstone project following the Backlog, Sprint and stories.

In a general view, Scrum has some important meetings that guide the team so that the members can understand what is necessary to deliver. For example the Sprint Planning, the Daily Scrum, the Sprint Review and the Sprint Retrospective [1,8].

In Scrum, the Product Owner prioritizes and inserts in a list called Product Backlog the functionalities expected for the Software. The functionalities are presented to the team in order to have an assessment and the Sprint Planning establishes what the team will assume. During the period of stories performance, named Sprint, the teams perform the daily meeting for a daily follow-up of tasks and difficulties. In the end of the Sprint, the Sprint Review is performed, considering the delivery of what was performed during the period and after that, the Sprint Retrospective aims at identifying positive and negative points, and what can be improved [1,8,5].

During Software process development using Scrum, some artifacts are generated to give an idea of what the team needs to do. These artifacts are the following: the Sprint Backlog showing the stories contemplating desired functionalities to be implemented in the product; the Burndown charts showing the performance relation versus the stories assumed by the team; and the Backlog release that relates everything that will be delivered, which might comprise one or more Sprints. All these meetings and artifacts are inserted in the Software development process and they will guide the work [1,8].

The entire course syllabus was divided in phases that allow the students to learn gradually and release a compatible part of the capstone project based on subjects studied during the classes [2]. In order to make the academic environment closer to the real world, the students were grouped in teams of 6 to 7 people, a Technical Product Owner was named to help all the teams, and a Product Owner was chosen for each team in order to create a reality and have an impact in the learning setting.

Organizing a course with such a structure has an impact in the student's learning process. This way, the purpose of this paper is to determine, discuss and quantify how Scrum became flexible and collaborative when teaching Software Engineering. Adaptation and other aspects of development were evaluated with a questionnaire applied in about 34 students who were concluding the specialization course in 2013.

The paper is organized as follow: Section II shows how teams were organized during the course so that Scrum methodology could have a real application. Section III shows the outcomes and discussion about the questionnaire applied to students in the end of the last year of the course. Section IV presents the related works; Section V presents the lessons learned for this kind of application according to the student's point-of-view. Finally, Section VI presents the conclusion of the research.

II. ADAPTING SCRUM FOR THE SPECIALIZATION COURSE

In general, there are 30 to 40 students attending the Software Engineering specialization course per year. The course lasts 444 hours distributed over two years [2], the classes are offered twice a week and most people in the teams live in different cities, making it difficult to manage the capstone team.

During this period, since the beginning the students are grouped in small teams. According to the Scrum philosophy, small teams, not exceeding 10 people, are easier to manage [1]. Therefore, in this course, the teams are organized in 6 to 7 students who have to develop a web project based on a real problem presented by the professor responsible for the Software agile development subject.

The course coordinator and the professor look for a Product Owner that will offer a problem for each group. This action creates a solution based on real requirements raised by the teams to an alleged real client. From this moment, the teams effectively start using Scrum.

Scrum framework is transmitted to students in the first day of class and in the course of two years, the topics highlighted in

the course such as Sprint Planning, Daily Scrum, Sprint Review and Sprint Retrospective are reviewed. Often, these topics are reviewed before students start using Scrum to develop the project.

The class that finished the course in the end of 2013 had 34 students grouped in five teams. Each team was responsible for a project that became a software solution for the Product Owner. The systems created during two years of course are briefly described as follow:

- a) SICOM: SICOM offers control and management of properties and residents in the campus of the Federal University of São Carlos, such as identification and location for the people who live there.
- b) University Restaurant System: the university restaurant system automates the stock control process reducing the time of this operation and making it easier to raise administrative and financial information.
- c) Student assistance system: The student assistance system offers computational support for requests and management of scholarships handled by the University social assistance department.
- d) IIS: The institutional identification system is responsible for managing the individual's identity in the Federal University of São Carlos.
- e) Property management system: the property management system aims at managing the life cycle of Federal University of São Carlos properties.

By analyzing Scrum adaptation under a general view, it is possible to report some changes in the quantity of days for a Sprint. According to the official version of Scrum, a Sprint must take 2 to 4 weeks and in the academic setting, a Sprint took about 41-84 days. This modification was an explicit order given by the course coordination because the quantity of days each Sprint must have is defined by the coordination.

Another adaptation is the definition of Scrum Master role turnover. This role turnover has allowed each student to understand the idea behind the daily meeting management, remove obstacles, protect the team from external problems and make things easier. The addition of the Scrum Master role turnover in the course promotes its use in a collaborative way.

Another challenge originated from the application of Scrum in the course is that most students have full-time jobs, and they dedicate time to the project only on weekends and free time during the week. Thus, in this course, teams reported the necessity of appealing to instant communicators such as messengers to deal with distance issues.

In the official version of Scrum, in-person daily meetings are necessary. Later on, in the academic adaption, the daily meetings were replaced by one meeting with all members through online communicators as a solution. Another resource used by students was emailing during the project. Most communication was performed through email among all the members and the Product Owner.

Another adaption was the replacement of Kanban used to present task lists through an electronic worksheet. Therefore, all artifacts necessary to manage the capstone project migrated to an online version. All the documents such as backlog, sprint backlog and burndown charts were shared by the members of the teams to promote interaction and follow-up.

The team starts applying Scrum since the first contact with the Product Owner. After the first meeting with the Product Owner, the groups raise the requirements. So, the members of the team discuss to start the creation of the Backlog. During the capstone project, the professor responsible for the agile development subject and a tutor support the team. Both have technical expertise to guide the teams in technical issues and in the Scrum.

Leite and Lucrédio's work [5] reported the adaptation of the Scrum in the team that developed the University Restaurant System. And we verified that the same adaption was applied in other groups in the same specialization course concluded in 2013. In the article [4], Prado and Ferrari report that the distributed teams appeal to the online communicators and email. But there is a difference realized by the teams mentioned in Prado and Lucrédio works, the need of meeting in person in the end of classes to clarify some doubts concerning the development. Other topics mentioned concern the use of SVN to centralize the code and keep the files updated for all the members in all the teams.

All adaptations made by the teams helped to develop the capstone project during the two years available to define the scope, the interviews with the Product Owner and the implementation. Thus, in the end of each Sprint, the Sprint Review is performed in the presence of the professor responsible for the agile development subject and the tutor. The Product Owner is not present in all Sprint Reviews, being invited only to some of them. In this case, another adaption to the academic setting is characterized. During the Sprint Review, it was possible to control the evolution based on the implementation according to the level of difficulty of the subjects already studied. The idea is that the students deliver parts of the project based on the subjects learned.

In the beginning, as reported by Leite and Lucrédio in [5], the team faced some difficulties. In the first Sprint, the professor helped the students to define the stories to be implemented. After defining each story, students played the Planning Poker in order to determine the points of each story. Each story has a level that defines its complexity. In this phase, students felt the necessity of further knowledge about the technology to be used in order to improve the outcome of the first Sprint.

Leite and Lucrédio [5] reported all the regressions in their work. A summarized version of what is faced during the period can be seen in Table 1 with the implementation of the "Federal University of São Carlos Restaurant Management System" project. The table shows the main obstacles identified by this group, but in general, it can be extended to others.

The Sprint analyses of all teams showed all the challenges faced in this process using Scrum in a flexible and collaborative way. Reviewing the Burndown chart of each

Sprint developed by all the teams, it is possible to realize the evolution during these two years studying new technologies and working on the the capstone project. The idea of using the Burndown chart for follow-up is because the chart shows how many tasks are performed by a team during a period. In this case, the period reported in the chart is the time of each Sprint.

TABLE I. GENERAL VIEW OF SPRINT – TABLE ADAPTED FROM [5]

<i>Sprint</i>	<i>Days</i>	<i>Stories</i>	<i>Obstacles</i>
1	41	4	Project Scope.
2	71	8	Lack of planning in the meetings.
3	56	4	Complications in the self-managing model.
4	84	4	Technical issues.
5	63	5	Outdated documentation.
6	63	10	Lack of dedication from the member of the project.
7	55	12	Overload of programming activities.

It is possible to highlight a team among the followed-up teams, for example, the team reported by Leite and Lucrédio. Figure 1 shows the main point of the team evolution. In the first and fourth Sprint, this team suffered some regressions causing delays in the tasks. In the fourth Sprint, a lack of commitment with Scrum practices was reported due to the amount of overwork. This episode generated a lack of trust in the real situation of the project in the Sprint causing a delay in the activities; and it was reported that some tasks were not accomplished [5].

However, the team showed a significant improvement in Sprint 7 thanks to an experienced Scrum Master that is always vehemently following the framework principles and characteristics according to Leite and Lucrédio[5]. In the last Sprint, the team showed more maturity in the development process and dealt better with the regressions. This was verified in all the other teams too. Thus, the outcome of Sprint 7 in Leite and Lucrédio's team showed that all tasks were performed, except one that was not concluded because there was a disagreement concerning the operation flow.

In general, in the end of the project, the teams realized that if everybody dedicated more and lined up with the goals, the outcome of each Sprint could be much better, as mentioned in work [5].

The flexible and collaborative use of Scrum applied in the capstone project provoked some changes in the learning process of these students. Students worked on the capstone project during the two years and delivered it in parts due to the Sprints. An important aspect using an approach based on Scrum is how much it helped the students in the learning process and what were the lessons learned with this experience from the students' point of view. The experience reported by Leite and Lucrédio can similarly describe other teams' behavior. However, in order to obtain an opinion and evaluate the approach, a questionnaire was applied for each student

based on his or her own experience developing the capstone project.

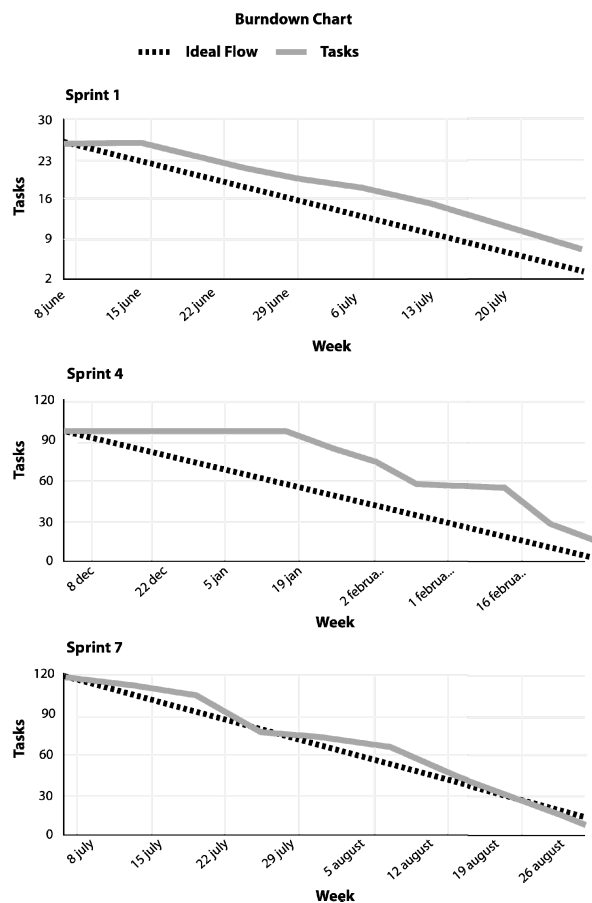


Fig. 1. Active flow – Adapted [5]

III. EVALUATING THE ADOPTION OF SCRUM

In order to evaluate the impact of the Scrum-based approach in the class of 34 students who concluded the specialization course in 2013, a questionnaire was sent by email to all the students. After the end of the period of collection, all the answers were summarized and analyzed. The questionnaire considered a view of students' profile, how the team used Scrum, the positive and negative aspects when using Scrum and if the student knew the Scrum

The questionnaire was composed of nine questions, with five objective questions and four open-response questions. In all objective questions it was possible to define a percentage and assess the maximum and minimum value. In the open-response questions it was necessary to summarize the main ideas in the answers and group them to have a better analysis. Therefore, it was possible to quantify more precisely the students' opinion about the use of Scrum adaptations in the capstone project.

The questionnaire sent to the students was composed of the following questions:

- Do the members of the team have any knowledge about Scrum?
- Are the members of the team from the same city?
- How often does the Sprint Planning happen?
- How was the Sprint Planning performed?
- How did the team adapt the Scrum for the capstone project?
- What are the positive points of Scrum in the project?
- What are the negative points of Scrum adaptations in the Project during the course?
- Did the previous knowledge contribute for the project?
- Do you use Scrum in other settings besides the Software development one?

The answers from each student were summarized and discussed. In the following summary, the students' profile, the Scrum adaptations by the team, the positive aspects using Scrum and the negative aspects using Scrum adaptations are initially related.

A. Student's Profile

The specialization course is offered twice a week and most students are from cities near São Carlos, which is located in the countryside of São Paulo state in Brazil, or from the capital. Therefore, 100% of the students do not live in the same city where the members of the team live, and the teams were composed of members from different cities characterizing distributed teams without full dedication to the project.

Another point observed with the questionnaire is that not all the students know Scrum framework. In total, only 29% of the members knew it. This contributed to create a setting where the students had no knowledge about agile methodologies, generating new challenges for the course.

As the questionnaire was applied in the end of the specialization course, it was possible to quantify if the previous knowledge in programming or any other technical knowledge helped the user in the project. In general, 94% of the students reported that the previous knowledge contributed to the capstone project. This result might be related to the type of course. With regard to a specialization course, some prerequisites are demanded before the student gets in. Thus, the more the student is prepared, the more it will help him during the activities, even in the capstone project.

Other issues define if the student uses Scrum in other setting besides the Software development one. It can sound conflicting, because only 47% claim that use Scrum in different settings and 71% claim that they do not know Scrum.

It is possible to relate the 47% of students to the setting where they work. In some reports, they mention that they use Scrum in the bank office, in the production process control, in the development of games and even in the Software development setting. Maybe the 71% is related to the further knowledge of Scrum, because living the routine where the

Scrum is applied is different from having a further understanding about the framework.

The profile of students were mapped using questions (a), (b), (h) and (i). All results showed that the 34 students came from different cities, only 29% of the students knew Scrum and 71% of the students did not know Scrum. Most students (94%) mentioned that the previous knowledge in programming language and Scrum contributed to the project and 41% of the students used Scrum in another setting.

B. Scrum adaptations

Adaptations were necessary because the teams need to develop the capstone project in a distributed way and the responsibility for the Project needs to be shared. However, the use of Scrum demands intensive contact among the teams. Thus, it was necessary to adapt mainly the Kanban and the meetings that provide a closer follow-up. In order to apply Scrum in an academic version, students had to take some actions such as replacing the board containing the stories and tasks of a Sprint by digital resources and using the online communication to keep the Sprints in progress.

In general, all the students combined the online communication, email exchange and in-person meetings to perform the Sprint Planning. Therefore, in 65% of times, the use of instant communicators and e-mails were more frequent than the in-person meetings. Only 26% used all the options to perform the Sprint Planning, as presented in Figure 2.

For a better understanding, the Sprint Planning is a meeting in the Scrum that defines what is necessary to do in that Sprint based on what is available on the top of the Product Backlog. In the official version, the Sprint Planning is performed with the Product Owner. In this case, it was not possible to have the Product Owner always available, so the meetings were organized online most of the time, as presented in Figure 2. The outcome of this meeting is that the students need to implement during the Sprint. In general, the Sprint Planning is performed in the beginning of a Sprint to define and understand the tasks.

Sprint Planning frequency varies from team to team. The rule is that the team has a date to initiate a Sprint and a deadline to deliver a functional part in the same Sprint. The Sprint planning time increased twice a month (18% of the team), weekly (41% of the team) or monthly (38% of the team). Only 3% of the students did not know how to answer this question, as presented in Figure 2.

The Sprint Planning do not replace daily meetings, aims at planning the Sprint and must be performed primarily always in the beginning of a Sprint. However, the distance and the lack of time make the students create a strategy that allows a closer follow-up with monthly, weekly or bimonthly meetings. In order to complete the Scrum adaptation in the capstone project, the answer to question (e) was analyzed. Therefore, a brief description of the students' answers is shown as follow.

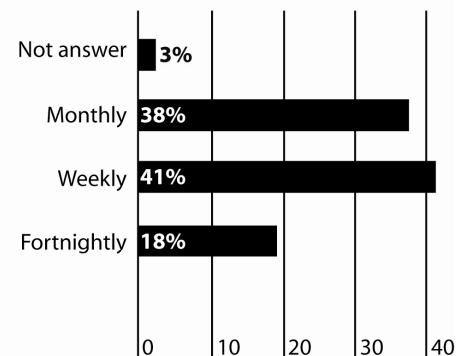
It was interesting to analyze the students' answers because it was possible to note the Scrum potential. As a framework, Scrum provides an idea of how it can be used. Therefore, the main concern of students was keeping the communication to

guarantee a good project. Some students, almost 32%, reported that used the online communicators to have a daily meeting; and to reduce their distance; they also exchanged emails. In general, the students told that they arranged weekly meetings with online communicators to have information about the Project development.

Almost 18% of the students reported that they inserted the Product Backlog, Sprint Backlog and Burndown in web tools to share the content with some members, allowing the online follow-up. Some students told that the in-person meetings were held mainly in the retrospectives and in planning meetings. Other students commented that in the end of the classes they used to meet to discuss the evolution of the project. Other students reported the creation of long-term Sprints, and other students addressed the tasks according to the technical ability of each member. Eventually, other students told that when they finished the task, they used to help others who had not finished yet.

By analyzing question (e), some students, about 24%, did not give an opinion about Scrum adaptation performed in their teams. Almost 12% of the students told that using Scrum was difficult in the beginning and two students from this group reported that the problem was in the difficulty of communication.

What is the frequency of the sprint planning?



How were the sprint plannings executed?

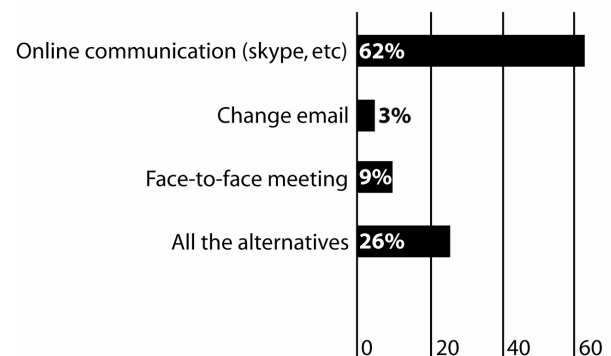


Fig. 2. Graphics to understand Scrum adaptations

C. Negative aspects of using Scrum adaption.

Students are free to adapt some framework points such as communication and follow-up. All the changes can have a negative impact based on the options defined by each team. To have a better understanding about the impact of adaptations, the answers to question (g) were analyzed. All the answers were analyzed and the main idea was summarized and grouped for a complete understanding of the impact. A brief description is presented as follow.

By analyzing the questionnaire, it was possible to conclude that the flexibility and collaborative use of Scrum represents a challenge of 41% of the student in the agile methodology learning process. Although the flexible use guaranteed the adoption of the framework by the course and by the teams, the mapping shows some negative aspects in Scrum adaptation.

About 6% of the students considered that replacing the in-person meetings by virtual meetings contributed to the negligence on the part of some members in the team; 6% of the students considered that learning with the project management was more demanding; 6% of the students considered the lack of dedication from the members a problem; 12% of the students faced difficulties in following Scrum in a distributed format and 9% of the students considered that the lack of experience with the Scrum caused some regression.

The remaining 18% of the students did not comment on the negative aspect of adaptation and only 3% did not identified problems with the respective teams using Scrum adaptations.

Considering all the percentages, it is possible to infer that the use of Scrum in the capstone project caused a change of attitude from the students. The use of this framework clearly showed the members that really participated and others that did not show interest. Therefore, in the end, a member draws the attention of other uninterested members to be more participative, or in some situations, this members give up.

The capstone project became demanding for only 6%, but the advantages of living in an academic area similar to the professional area is reassuring. On the other hand, the capstone project is made in parts, making it easier to follow the evolution of the project.

D. Positive Aspects of using Scrum.

Besides the negative aspects raised in this questionnaire, the positive aspects of using Scrum were identified. The good news is that the positive aspect of this approach justifies the management of the capstone project development using Scrum. In order to analyze the positive aspects of adopting Scrum, the answers for question (f) were summarized and a brief description is presented as follow.

In the evaluation, all the students who answered the question reported that the use of Scrum stimulates the participation of all the members of the team and helps to release functional products in a faster way, adding more agility to the team. This agility provides a continuous improvement in Software delivery, because at the end of each Sprint it is possible to receive a feedback, make more changes and understand better the product.

The students appreciated this approach because with a minimum view of project it is possible to start the implementation and gradually understand the new requirements. In addition, the flexibility in using the framework provides a different way of working, for example: working remotely. The students say that the use of online spreadsheets makes it easier to understand the status of the Project and defines the user who is performing the task.

A student said that using Scrum in this format provides a more real framework setting, which is truly used in the industry. Another student reported that it is possible to use all the twelve principles of the agile methodology with this approach.

In a general view, the students told that the use of Scrum provides an agile setting, continuous feedback, frequent deliveries, less bugs, more motivated team, improvements in organization, clear delegation of tasks, the possibility of focusing on a product functionality, a better view of the Project development and improvement in the communication. These improvements increase the interaction and participation of the members in the team.

According to the percentage summary, around 18% of the students told that this approach increases the speed in delivery of some functional parts of the project; 18% of the students agree that it increases the participation of the members; 15% of the students told that it is easier to manage the project when they face adversities; 3% of the students told that it is possible to use a framework used in the market in practice; 6% of the students told that the use of Scrum allows a continuous improvement; 29% of the students told that it is easier to manage the project using Scrum; and 3% of the students told that it is possible to use principles of agile methods.

IV. RELATED WORKS

The review of some works related to the evaluation of the impact of Scrum identified this impact on the area of industry development versus academic area [6,10]; Scrum application in capstone projects [7] and Scrum applied in the academic area approaching the Software project to reality [9].

In work [6], Vicentin applied a questionnaire in two parts to evaluate the impact of a possible use of Scrum on a Software House. Based on the answers, Vicentin concluded that the use of Scrum could be a good tool to manage the teams. However, the problem starts with the change, where the laziness of some friends will have an impact on the use of Scrum. The author realized that when he applied the same questionnaire to his own team that was making the capstone project managed by Scrum, the opposite happened. The use of Scrum was well accepted. In addition, this kind of use helps to bring the members closer to develop the work.

In another work [7], Carnevali and Lucrédio reported that when Scrum was applied in a Software House to improve the requirement engineering, it showed improvement in communication and in the roles in the Software House. In general, it is clear that the individuals' commitment is necessary when the Scrum is adopted.

In Wagh's work [9], Scrum application is performed to provide the students with a practical view of the Software development industry, getting closer to the reality in the profession. The Scrum application evaluation in a class project proposed by Wagh was performed through a questionnaire answered anonymously by the students. The aim was to understand how much the students learnt with this approach and its efficacy. As result, most students saw improvements in how the project was managed and in the teamwork with the use of Scrum. The questions that evaluated the use of artifacts and Scrum meetings showed that the daily meeting is the most popular technique among this group, followed by the follow-up chart, sprint planning, user's stories and assessment.

Finally, in work [10], Mahnic and Rozanc discuss the use of Scrum in a capstone project and ask for the students' point-of-view based on the use Scrum. The result is compared to other research carried out with professional developers. In short, two important factors were realized: the first is the teamwork and communication among the members of the team and with the Product Owner. However, other points present different points-of-view such as clarity in the specification of requirements, daily meetings and sprint planning.

In works [6,7,9,10] it is possible to realize that Scrum helps in the organization, teamwork and commitment of the members in the team. These points can be seen in the evaluation performed with the teams that concluded the capstone project in the end of 2013.

V. LESSONS LEARNED

The evaluation showed that the approach is valid when analyzing the positive aspects in relation to the negative aspects. According to the students' point-of-view, the flexible and collaborative use of Scrum increases the communication, feedback, continuous improvement and provide faster deliveries compared to the traditional model. In other words, students see the outcomes from their work in a faster and gradually way when compared to the traditional models to perform the capstone project.

According to Leite and Lucrédio [5], it is understandable that the adoption of a framework like Scrum will provide the self-management of the members. The students need to take responsibility for what they need to deliver. This practice is sometimes different from what the students face in some organizations, when they receive a work and are constantly charged for faster deliveries. In Scrum, the team needs to work together and cooperate to reach a goal. In their work [5], Leite and Lucrédio report this kind of experience, and they add that it is important to define clear purposes, the roles and the tools.

Other lessons learned in Leite and Lucrédio's work [5], and which can be extended to the teams that concluded the capstone project in the end of 2013 are the following: the communication is an essential tool; defining points to be discussed in meetings is a good methodology to improve the efficiency; identifying the limitation and trying a solution for the next iteration are great techniques; sharing knowledge among the members and tutors; omitting the use of Scrum in

some period of the project can cause delays; and the commitment and shared knowledge provide positive outcomes.

VI. CONCLUSION

The article proposes to determine, discuss and quantify how Scrum becomes flexible and collaborative in Software Engineering teaching. It presents a general view of the specialization course offered in São Carlos, in the state of São Paulo/Brazil focused on web development. Next, the way the course allows the flexible and collaborative use of Scrum to teach Software engineering is presented. In order to evaluate the impact of this approach, a questionnaire was sent to the students who finished the course in the end of 2013.

Considering the students' point-of-view, the approach allows to improve the experience in the capstone project development. Adaptations performed by students taking into account the flexibility, communication and releasing of functional parts of the system are important points.

Finally, using Scrum during the capstone project helps the professor to see the difficulty, guide the student as best as they can and provide assistance to the team with big difficulties during the project development. With this approach, it is possible to create points of action to try to reduce problems related to delivery.

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A Self-Assessment Instrument to Assess Engineering Students' Self-Directedness in Information Literacy

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Abstract—Information literacy, the ability and processes of information gathering and application, is of paramount importance to engineers, engineering design, and engineering decision-making. Building on prior qualitative research, this paper presents the development and initial validation study of a self-directed information literacy assessment for engineering and technology students ($n = 366$). Internal consistency was found to be high, ($\alpha = 0.895$). Exploratory factor analysis results provide evidence of structural aspects of validity and support for scoring structure. In addition, areas were identified for future development of the items and instrument.

Keywords—Instrument Development, Information Literacy, Exploratory Factor Analysis (EFA)

I. INTRODUCTION

Engineers must gather, evaluate, and make use of information as they go about their work. This information provides engineers a basis on which to make decisions, evaluate concepts and ideas, and meet clients' needs. The way that engineers use information derives from a set of personal beliefs, habits, and knowledge. Known generally as information literacy, those components of engineering behavior are vitally important to professional success [1], [2]. The goal of the paper is to present the initial development and psychometric studies of a measure of engineering and technology students' self-directed learning in information literacy. Specifically, we are examining structural aspects of validity.

This study performs initial development work on an assessment instrument designed to measure self-directed learning in information literacy for engineering and technology students. The 69 item instrument, known as the evidence-based self-assessment of problem solving skills (E-SAPSS), was developed from prior qualitative work [3], with data collected from students in the engineering program of a large Midwestern research university. The study identifies items whose removal increases measures of reliability and proposes a modified factor structure that captures the behavior of E-SAPSS items on the population studied. This work serves as an initial step in constructing an argument for the instrument's use on undergraduate populations.

II. RESEARCH QUESTIONS

This study addresses one overarching and two specific research questions. Overall, this study addresses (RQ0) what

items can be scored together as a measure of students' self-directed information literacy in a design problem. More specifically, it answers; (RQ1) Do items conceptually written to explore stages of the information literacy process in undergraduates factor together? (RQ2) do those items show evidence of unidimensionality on theorized factors?

III. THEORETICAL FRAMEWORK

A. Definitions and Components of Information Literacy

The exact definition of information literacy has been parsed and argued at length. In a 2005 study, Owusu-Ansah performed a review and historical description of the development of both the term information literacy and the myriad of closely linked concepts that exist [4]. He identified 15 general concepts at the core of information literacy and also notes the migration of information literacy work from library centric domains to domains more situated in discipline specific work. He concluded that the ALA definition of information literacy, the ability to "recognize when information is needed and have the ability to locate, evaluate, and use effectively the needed information" [5, p. 2] sufficiently documents the core principles of information literacy and suggested a shift in focus from field definition to educational development.

Kuhlthau developed a conceptual framework known as the Information Search Process (ISP) [6]. The framework defines six stages of the information process beginning with task initiation and ending with presentation. The framework was built from interviews of students in various disciplines. The ISP framework has been adjusted for this study to more closely meet the needs of engineering education researchers and the engineering design process. Work by Fosmire and Radcliffe [7] identified overlaps between information literacy, the ISP framework, and engineering design processes. They proposed a use of the overlap with information literacy and develop interventions that increase students' abilities. As part of their work, Fosmire and Radcliffe [7] proposed a revision of the information literacy stages to form and measure the behaviors in engineering design.

Theories and research in information literacy also have significant ties to a broader discussion of self-directed learning in engineering students [8], [9]. These lifelong learning skills are called out in ABET program evaluation and accreditation

as fundamental skills that engineering programs must develop [1]. There is a strong interdependency of information skills and information literacy [9]. Strong information literacy skills give students tools with which to effectively pursue the growth of their own knowledge in the engineering discipline. This correlation is vital to the instrument developed here, and the self-directed learning work is used as the underlying theory.

B. Measurement of Information Literacy Skills

A difficulty present in the field’s prior work is the measurement of information literacy skill and knowledge in students. Different approaches have included test assessment, skill inventories, or self-assessment. Oakleaf [10] reviewed scored assessment approaches for information literacy. She identified three general categories of information literacy assessments: fixed-choice tests, performance assessments, and rubrics. She suggested that the choice between these summative assessment methods largely speak to the abilities of students to either apply the information literacy concepts in their work, identify information literacy skills being applied, or identify knowledge gaps in a scored way. An instrument by Wertz et al. [11] is an alpha version example which takes the form of eight multiple choice questions requiring students to use information literacy concepts when evaluating a technical memo. This approach is representative of the fixed-choice test category from Oakleaf [10].

Denick et al [12] considered student citations in engineering reports as an indicator of information literacy ability and performance. She argued that the structure of educational interventions by libraries in engineering classes, often a single class period, tend to over focus the field on a singular direct assessment. Other assessment approaches include skill inventories, or allow students an opportunity to self-assess their information literacy skills encouraging self-monitoring and self-efficacy. Monoi et al. [13] developed validity evidence for an instrument that assesses students’ self-efficacy using their online searching behaviors. The resulting instrument includes items such as “I can construct a search using Boolean operators” [13, p. 103]. While constructed in a true/false style, the focus of the questions on modern manifestations of information literacy skills in students is important to effective assessment of the construct through modern manifestations and reappears in this study’s instrument.

Collectively, these approaches measure students’ abilities to recognize, identify, and implement information literacy strategies in structured classroom assessment or through student artifacts via a single dimension. However, they do little to drive an understanding of students’ beliefs, habits, or abstracted knowledge in terms of information literacy, especially in the more holistic view of information literacy presented in the ISP framework. The assessment methods largely lack a tie to the stages defined in Kuhlthau [6], and do

not consider students’ beliefs about their information skills to make informed design decisions.

IV. METHODS

A. Instrument Development and Prior Work

The development of E-SAPPS was guided by the recommendations for scale development from Netemeyer and colleagues [14]. Netemeyer and colleagues recommend beginning by identifying what will be measured through construct definition and domain. For this initial step, we consulted existing literature on information literacy, including assessment designed to measure students self-reports. In addition, we built from previous work [3] detailing semi-structured interviews into the actual strategies used by students in design situations using a protocol informed by the Kuhlthau ISP framework [6]. This served as the first stage, reducing the interviews to a set of theorized factors, detailed in Table IVV-1, that represent the stages in information literacy apparent in students’ progression through an engineering design project.

After the completion of the interview analysis, the development process moved to the generation of specific measures in the form of individual items. The individual items were written to fit the factors created through the interview process. When possible, the items were grounded in specific good and bad example behaviors identified in the qualitative interviews. In total, 69 items were written for a 5 point, strongly disagree to strongly agree, Likert-type scale. Both forward and reverse scaled items were written for each theorized factor, as recommended by Spector [15]. Example items for each theorized factor are shown in

Table IV-2.

Table IVV-1 Theorized factors, definitions, and items in instrument

Factor	Definition (Students...)	Items
Recognize	identify what information they have and what information they must gather.	19
Locate	gather information via appropriate search methods, using appropriate search terms, and correctly identifying or employing different types of information.	16
Evaluate	assess the credibility and accuracy of information that they find based on the source, the age, and the purpose	7
Apply	make use of information that they gather to improve designs or make decisions not just confirm their beliefs.	7
Document	appropriately document, keep, acknowledge, and cite sources.	12
Reflect	intentionally engage in a process of evaluating and improving their	8

	information literacy behaviors after completing a design project.	
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Table IV-2 Example items for theorized factors

Factor	Example Item
Recognize	"It is my responsibility to identify what I need to learn in order to complete the design problem."
Locate	"I use the general information I find to help focus my search for more information."
Evaluate	"When I gather information, I consider the trustworthiness of the source."
Apply	"While reading an information source, I take notes of all my ideas of potential applications to the design problem."
Document	"As I find information, I keep track of where it came from."
Reflect	"I consider how I could synthesize information more efficiently."

After we wrote the base items, they were tested using a think-aloud activity of 10 undergraduate engineering students. Using a protocol derived from Czaja and Blair [16], students were asked to 'think-aloud' as they answered the questions. This process allowed for the identification of items that students had to reread, paused on, or did not understand. Items that were identified were revised prior to the third stage of work presented in this study which comprises a first quantitative test of the instrument structure.

B. Data Collection

The survey was distributed through two courses at a large Midwestern research institution during the fall semester of 2014 (2014-2015 Academic Year). The first course was a single section of a required first semester first year engineering class 'ENG'. The second course presented with the survey was 'TECH' the equivalent class in the College of Technology. All students in the 16 sections of the TECH course were given the opportunity to complete the survey. The potential sample size was 119 and approximately 600 for the ENG and TECH courses respectively.

In the ENG course, students completed the survey during class time while the TECH population completed the survey outside of class for a small amount of extra credit. Respondents completed the survey electronically. Instructions were presented to respondents once, at the beginning of the instrument. Demographics information was gathered after completion of the E-SAPPS component of instrument. Of the potential respondents, 525 completed the instrument.

1) Participants

The responding participants were generally representative of the overall potential population at the study institution. Of the 410 TECH respondents, 331 (81%) were male while 77 (19%) of respondents were female. Within the ENG population, the respondents were 26% female. Ethnically, the ENG data set

saw 75% of respondents self-identified as White, 18% as Asian, and 5% identified as underrepresented minorities. In the TECH data set, 70% of students self-identified as White, 16% as Asian, and 9% as underrepresented minorities. Finally, 84% of ENG respondents and 89% of TECH respondents reported English as their first language.

2) Data Cleaning

The responses and associated data were cleaned based on a modified versions of the LongString procedure described by Meade and Craig [17] and the time based criteria proposed by Wise and Kong [18]. Individual responses were flagged and removed from later analysis for failing one of two criteria: (1) All answers on a single page being identical (i.e. all of the first page responses are 2's), or (2) a response time of less than 4 minutes (e.g. shorter than feasible for valid individual responses). The cleaning was performed prior to correction of items designed as reverse scored. Overall, 159 responses were removed for the two noted reasons with 108 based on the response time criteria and 51 from the answer variance criteria.

The 366 responses remaining after cleaning are the data used for analysis in the remainder of the study. The responses contain 100 ENG and 266 TECH data points.

C. Methods of Analysis

This paper focuses on the second foundational aspect of assessment instruments, observation, as articulated by Netemeyer [14]. The prior qualitative work to develop theorized factors serves as the basis for the assessments. As noted in Douglas and Purzer [19], the use of the term cognition is not exactly appropriate for the case at hand, but the theorized factors and qualitative factors serve as effective analogues for our understanding of the underlying cognition or behavior that is being assessed. This paper's focus on the observation component makes it an appropriate place to apply methods that gather psychometric evidence on the instrument. Initial data processing and analysis were performed with Microsoft Excel while IBM JMP was used to calculate coefficient alpha, calculate bivariate correlations, and perform exploratory factor analysis (EFA)

Four methods of analysis were used to answer the research questions noted above. The first three methods serve as prerequisite work to prepare the instrument for EFA analysis as suggested by Fabrigar [20]. This preparatory work focused on improving the unidimensionality of the scale through removal of items that perform poorly. This unidimensionality refers to the underlying construct and focuses on ensuring that all items focus on a cohesive measurement of information literacy based on the underlying self-directed learning theory.

Within the focus on overarching unidimensionality of the *complete scale*, we also expect to see a multidimensional measurement of the information search process' *different stages*. The performance of individual items was assessed using three approaches. Descriptive statistics including the mean, standard deviation, minimum, and maximum, were

used to examine the general behavior of individual items including their center and response patterns. We examined descriptive statistics to ensure that items generally fell within an expected pattern of means and standard deviations and that no items established clear correct/incorrect answers. Second, the impact of individual items on the instrument's internal reliability was assessed using coefficient alpha. The E-SAPSS instrument presents an appropriate use of the coefficient alpha as detailed by Douglas and Purzer [19]. The coefficient alpha is a calculation of the degree of consistency between individual items within the instrument [21], [22]. An item whose inclusion lowers the alpha of the overall instrument may potentially be measuring something other than the main construct. Items whose inclusion lowers the overall alpha were removed from further analysis as suggested by [22]. The final technique applied prior to EFA was the assessment of inter-item correlations. A linear bivariate correlation was calculated for all individual item pairs. Using the theorized factors, items were grouped and compared to other items of the same theorized factor and direction. Items that did not correlate above a threshold (>0.30) with at least one other item within the theorized factor were removed [23]. Together, these techniques align with RQ2 and assess evidence of scale unidimensionality.

After the prerequisite work on individual items was performed, EFA techniques were applied to answer RQ1. EFA is a data-driven approach to examine the underlying factors represented in learners' responses. The main goal of factor analysis is to summarize the interrelationship among variables in a concise and accurate manner, for the purpose of aiding in conceptualization [24]. EFA was used to examine whether the data set supports the characterization of the items as members of the theorized factors. EFA provides evidence by which items that do not function *as intended* may be identified.

For this study, EFA was performed using best practices suggested by Fabrigar [23]. An oblique rotation method (Promax) was used to allow factors to be correlated. Oblique factor rotations are generally considered more appropriate for data in the psychological or educational realm [23, p. 281]. Scree plots were generated for all runs. Decisions on the appropriate number of factors were based on a combination of Scree plots for each analysis and the Eigen value greater than 1 (K1) rule. The maximum likelihood item fitting procedures was used for all runs because of its ability to provide significance testing of factor loading. The analysis was rerun after every change in the items included, details of which are documented in the results section

V. RESULTS

The results section presents the analysis of the instrument using the techniques detailed in the previous section. The analysis makes use of the 366 responses that remained after the data cleaning process discussed in section IV.B.2. Throughout, we will refer back to the theorized factors and their respective definitions that were noted in Table IVV-1.

A. Descriptive Statistics

We calculated descriptive statistics after the scoring of reverse written items was inverted to standardize the entire instrument. The mean score of responses to items ranged from 2.68 (item 59) to 4.18 (item 12) with the mean of all responses at 3.62 on the zero to five point Likert-like scale.

The descriptive statistics differed between items written as forward ($M=3.83$, $SD=0.76$) and reversed ($M=2.88$, $SD=0.98$) scored items, even after standardizing item scoring. The difference was highly statistically significant ($t(21.7)=8.86$, $p<.0001$) suggesting that respondents displayed a tendency to agree with items, a phenomenon commonly noted in psychometrics research [25]. The standard deviation of the forward items was also significantly lower ($t(39.3)=9.80$, $p<.0001$) than the standard deviation for reverse scored items. The highest item mean was found on item 12 ($M=4.26$, $SD=0.77$). No items were removed at this stage as all items were behaving within the expected range.

B. Coefficient Alpha

The value of Cronbach's Alpha for the entire instrument was 0.8950. A value for Cronbach's Alpha was then calculated that excluded each item. Alphas between 0.7 and 0.9 are considered good, while value above 0.9 considered excellent [26]. Two items were found to be decreasing the overall instrument reliability. We excluded those items, number 34 (excluded $\alpha=0.8957$) and 41 (excluded $\alpha=0.8954$), from further analysis. With the removal of those items, the data provides evidence that the instrument as a whole is functioning in a sufficiently unidimensional for continued analysis.

C. Bivariate Correlations

The items remaining after the Cronbach's Alpha analysis were used in an inter-item correlation test to gather evidence of unidimensional behavior within each of the theorized factors. The factors used for grouping were the same as those reported in Table IVV-1. Forward and reverse scored items were assessed separately. Four items were removed because they did not significantly correlate with other items in the same theorized factors.

After removing the four items, the remaining correlations between items in the different factors used for item construction was generally high. The average correlation between items of the same theorized factor ranged from 0.44 in the 'locate' factor to 0.59 in both the 'evaluate' and 'reflect' factor. A full cross tabulation of average correlations between items in theorized factors appears in Table V-1.

Table V-1 Avg. of Item Correlations Between Factors

Original Factor	Apply	Document	Evaluate	Locate	Recognize	Reflect
Apply	0.52	0.39	0.39	0.35	0.28	0.37
Document	0.39	0.55	0.39	0.33	0.29	0.36
Evaluate	0.39	0.39	0.59	0.38	0.30	0.37

Locate	0.35	0.33	0.38	0.44	0.31	0.34
Recognize	0.28	0.29	0.30	0.31	0.49	0.28
Reflect	0.37	0.36	0.37	0.34	0.28	0.59

D. Exploratory Factor Analysis

After the preparatory work described above, 63 items remained. This item set was used to perform an EFA analysis addressing RQ1. The EFA runs were performed iteratively with a single change made between runs to isolate individual impacts.

The initial EFA run was performed with the remaining 63 items included. This run identified a strong grouping of the reverse scored items to the same factor. This phenomenon mirrors the separation seen in the descriptive statistics and inter-item correlations between the forward and reverse scored items and has been noted in other psychometric research [27]. Based on this result, the reverse items were removed from subsequent EFA runs for separate treatment.

In the first runs, the nine factors had an Eigenvalue of greater than one (satisfying the K1 rule). However, a clear final drop, using the Scree plot rule, was seen after the fifth factor. Based on that information, a six-factor model was used. The resulting best-fit factor structure had multiple cross-loaded and non-loaded items. Those are items that loaded on more than one factor at a value greater than 0.3 or failed to load on any factor above 0.3 respectively. The EFA analysis was then repeated iteratively removing a single item at a time. The cross loaded items were removed first, followed by the no-loading items. The number of factors suggested by the K1 rule began to converge to that supported by the Scree method as the poorly performing items and single item factors disappeared. Overall, 10 EFA runs were performed.

The results of the final EFA analysis run on forward scored items only appears in

Table VI-1 on the following page. Most of the theorized factors, such as 'recognize' and 'reflect', clearly establish on single, isolated factors. All items from those two scales that were not removed during the EFA runs grouped together on a single factor, and no items from other factors loaded with them. Further, the loading of those items on the factor was quite strong ranging from 0.51-0.69 for the recognize items and 0.49-0.74 for the items on the reflect factor. The final EFA run maintained 38 items in a 6 factor model with no cross loading or unloaded items. This structure explains 77.53% of the overall variance in the data.

The final run items and loading were used to assess the naming and definition of the theorized factors. Generally, the theorized factors were appropriate. Of the 38 remaining items, 2 were realigned from one theorized factor to another final factor. Because EFA does not assert and test a hypothesis (as confirmatory factor analysis does), items are allowed to shift to the best fit factor. In this case, 2 items which were originally written as locate items factored with the application

items. The wording of the items, which suggests the application of prior knowledge to the process of locating information, presents a fine-grained understanding of the application of information to the information process. Based on their wording and EFA results, the 2 items were moved from the theorized to the EFA derived factor.

As a final check, Cronbach's alpha was calculated for the overall and each subscale using the remaining items. The Cronbach's alpha for complete set of remaining items was 0.9250, which is excellent [26]. Further, none of the remaining 38 items decreased the reliability of the scale. The Cronbach's alpha for the factors was 0.88 for Recognize, 0.87 for Reflect, 0.76 for Apply, 0.76 for Document, 0.66 for Seek, and 0.77 for Evaluation. While these are lower than the overall scale, they are sufficient for the subscales given the low number of observations on several of the factors.

VI. CONCLUSIONS AND DISCUSSION

The initial presentation of validity evidence for the E-SAPSS instrument was focused on testing the items and structure developed from qualitative interviews presented in prior work [3]. This study focused on the third step of scale development proposed by Netemeyer [14], conducting studies that aid in developing and refining the scale.

The items that were retained in this study represent a set of items from which future validity evidence can be built. Fabrigar [23] suggests four to five items per factor represent an appropriate number of items. Three of the theorized factors contain at least that many remaining items. In the case of the 'reflect' and 'recognize' scales those numbers are considerably higher (8 and 13 respectively). On other factors, notably 'Evaluate' and 'Locate' the number of items remaining from the original development pool is not sufficient to ensure reliability and representation of the factors and require development of further items to ensure appropriate redundancy.

Where a large number of items do exist, the 'best performing' items from the EFA procedure will be maintained as the representative variables that best measure unidimensional factors or substages of information literacy behavior in respondents as suggested by Fabrigar [20] and Netemeyer [14].

For the factors that did behave well, namely the recognize and reflect stages, evidence exists that these items can begin to be used as a measure of student's self-directed information search process. Other factors require caution and some revision or addition of items to ensure reliability of those components of the instrument. Work will also focus on validation of the reverse scored items that were removed from the EFA analysis. These steps represent the later, stage 4, components of the process for scale development suggested by Netemeyer [14].

The process of information literacy continues to be vitally important to the practice of engineering. The developments presented here continue the process of developing measures of student's self-directed processes. This improved measure is important to allow for educational interventions to effectively increase students' abilities in these areas.

A. Pedagogical Implications

We encourage readers to contact us for access to the improved instrument for use in their own information literacy educational efforts. The construction of instruments with documented evidence of validity and reliability is useful for helping instructors understand their students. This instrument presents a method of understanding students' personal views on their information literacy practices. Combined with other

methods of information literacy assessment (e.g., those presented by Oakleaf [10]) allow faculty to more deeply understand their students abilities to gather and use information, a skill critical lifelong learning and design.

This instrument may be used to explore what modern and classical components of effective information literacy students do or do not perform. Such understanding has the potential to allow more targeted educational interventions that, for example, target the ways in which students gather information in the age of google or document information in the age of Twitter. The stages and specific behaviors represent specific behaviors that manifest in student work, which can be tracked to understand the efficacy of such interventions for the improvement of classrooms and programs.

Table VI-1 Resulting forward item details and structure after EFA

Item #	Item Text	Recognize	Reflect	Apply	Document	Seek	Evaluation
5	I take time to think about what I need to learn in order to address the design problem.	0.50					
9	I seek feedback on my understanding of the design problem's constraints from an instructor or TA.	0.50					
7	I create a list of information I will need in order to address the design problem.	0.52					
14	It is my responsibility to identify what I need to learn in order to complete the design problem.	0.57					
15	I ask for feedback on my list of design criteria and constraints.	0.57					
12	I participate in group discussions to plan out project completion.	0.58					
3	I seek clarification of the design expectations.	0.59					
6	I collect information to become familiar with the concepts needed to carry out the task.	0.59					
4	I create an action plan for completing the design problem.	0.61					
8	I brainstorm information needed to complete the design problem.	0.63					
11	I talk with others to gather a variety of perspectives about the design problem.	0.64					
2	I identify constraints of the design problem.	0.66					
1	I identify what needs to be done to complete the design problem.	0.70					
63	I consider whether I utilized information appropriately.		0.52				
62	After I finished a design, I reflect on whether I found enough information.		0.57				
68	I consider how I could synthesize information more efficiently.		0.60				
69	I reflect on how to more effectively determine an information source's credibility.		0.62				
67	I consider how I could better organize information.		0.67				
64	I reflect on how I could improve my information search strategy.		0.73				
66	I consider what I could do to improve gathering information.		0.73				
65	I reflect on whether I understood what information was needed.		0.74				
43	I am open to changing my idea based on information found.			0.36			
47	When I read information related to my design project, I generate ideas.			0.45			
23	I use the general information I find to help focus my search for more information.			0.51			
48	I make design decisions based on the information I find.			0.52			
21	I relate information I find to my pre-existing knowledge.			0.55			
49	When I find new information, I incorporate it into my design.			0.62			
60	I am comfortable determining what information needs a citation from information that is common knowledge				0.32		
33	When presented with conflicting information, I critically review the evidence for each stance.				0.33		
50	When I give an oral presentation of the information, I acknowledge the source either verbally or in my slides				0.55		
54	I have a method of organizing my references.				0.56		
52	As I find information, I keep track of where it came from.				0.58		
51	When presenting information from a source, I use correct and complete citations.				0.75		
25	Once I find a reputable article that is relevant to my design, I look at the					0.41	

	reference list for more potential sources						
27	I compare information from different sources in an organized way.					0.44	
24	I know when to use different kinds of information (e.g. patents, standards, handbooks).					0.69	
36	When gathering information, I assess the accuracy of the information I find.						0.40
37	When I gather information, I consider the trustworthiness of the source.						0.96

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Implications of Anonymous Assessment

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Abstract—The role of anonymous assessment in ensuring fair and equitable outcomes for students has been one of the major tenets of educational reform over the last few decades [1]. One of the major goals of these efforts is to reduce the impact of subconscious discriminatory behaviour in assigning grades based on perceptions of ability of gender or minority groups by the examiner. Recently however research has been emerging which challenges the widespread assumptions about the benefits of anonymity drawn from Newstead's work. Contrary results include the work of Dorsey and Colliver, 1995, in medical education, and Batten et al. 2013, who explore the impact of student reputation on assessment. These and many other studies conclude that anonymous assessment resulted in no apparent changes in assessment outcomes. In this paper we explore the implications of anonymity taking examples from educational settings where student anonymity is already an adopted practice. We discuss the positive and negative implications of student anonymity, and identify areas for future research.

I. BACKGROUND

In many countries quality assurance processes place emphasis on the role of anonymous assessment in ensuring fair and equitable outcomes for students. The goal is to eliminate discrimination and other types of bias from the process of assessing or evaluating student knowledge and ability. Student anonymity has been identified in some contexts as an important mechanism for reducing systematic discrimination in assessment. The most influential study, resulting in widespread adoption of anonymous grading, is that of Dennis and Newstead, 1990 [1].

Following the introduction of anonymous written examinations, another body of research emerges which challenges the widespread assumptions about the benefits of anonymity resulting from Newstead's work. Results which challenge the impact of anonymity include the work of Dorsey and Colliver, 1995, in medical education, and Batten et al. 2013, who explore the impact of student reputation on assessment. These and many other studies [2] conclude that anonymous assessment resulted in no apparent changes in assessment outcomes.

The anonymous assessment movement is also in apparent conflict with simultaneous movements in pedagogy and didactics resulting from the trend towards student-centric learning, and continuous assessment. This trend emphasises (see for instance the work of Gibbs) the importance of seeing the

individual student, and providing multiple contexts for student-teacher interaction and dialogue. This appears to be in direct conflict with providing increased anonymity in assessment situations.

Anonymous assessment also results in a concomitantly increased administrative overhead, as has been observed in our own context (a Swedish Research 1 University), and has also been discussed by Gledhill in Higher Education Management (David Warner and David Palfreyman editors) as early as 1996. These overheads need to be weighed in terms of the cost/benefit proposition that introducing anonymous assessment represents.

In this paper we explore the implications of anonymity taking examples from an educational setting where nearly absolute student and teacher anonymity is already required as a result of cultural norms, for a significant proportion of students. Even though the degree of anonymity in this environment surpasses that which is usually discussed in relation to fair and equitable assessment in a Western context, we believe that these examples expose other implications of anonymity that should be considered in the current debate.

Drawing on interviews with teachers, and observational data gathered in anonymous teaching and learning situations by the authors, we build up a "thick description" through which to explore the range of positive and negative impacts that anonymity can have for both educational quality and student learning.

II. THE STUDY

This study explores some of the implications of student anonymity in higher education using qualitative data collected in an environment where student anonymity is nearly absolute. The environment has not been designed to achieve anonymity, but to fulfill other cultural and legal requirements. However, the resulting educational environment does provide almost complete student anonymity. The paper draws on the authors' personal observations and experiences, in the form of field notes, as well as interview data from two academic colleagues who spent approximately three weeks teaching in an environment where more than half the student cohort were completely anonymous.

The study uses the "thick description" technique to build up a nuanced picture of the anonymised character of the teaching

and learning situation. Using this as a background we draw on data collected in our discussions with teaching staff and students who are working in this environment to explore the impact of anonymity on the learning process and the attitudes of the participants.

“Thick description” is discussed by Ponterotto, 2006 [3] as a means to provide a rich context for the interpretation of actions and events.

“As emphasized by all the authors heretofore referenced in this Brief Note, a central component of “thick description” is the interpretation of what is being observed or witnessed. Denzin (1989) has made a major contribution to qualitative research by carefully showing the sequential link of “thick description” to “thick interpretation.” It is the qualitative researcher’s task to thickly describe social action, so that thick interpretations of the actions can be made, presented in written form, and made available to a wide audience of readers. Without “thick description,” “thick interpretation” is not possible. Without “thick interpretation,” written reports of research will lack credibility and resonance with the research community, the research participants themselves, and with the wider audience of readers for whom the report is intended (Ponterotto and Grieger, in press). It is the thick interpretive work of researchers that brings readers to an understanding of the social actions being reported upon.”

To provide the necessary context we first describe the teaching and learning situation in detail in the next section. In the subsequent discussion we use quotes from discussions and personal observations in a “thick interpretation” of the implications that anonymity can have for teachers and students.

III. TEACHING IN A GENDER SEPARATED ENVIRONMENT

The authors are teachers at a Swedish research university who have had the opportunity to visit a university in a Middle Eastern country frequently over a period of several years. The country is Islamic, and, in comparison to Sweden, religion plays an important role in the local culture and in peoples’ everyday lives. In the education, as well as in many other situations, the genders are separated. On the few occasions where men and women are at the same place, women wear black clothing that cover their entire body, including the face, so called abaya and niqab. When only women are present, however, they wear whatever they like. Since one of the authors is female, she has had the unique opportunity of being able to visit both male and female campuses and take part in activities both among men and women.

In the following discussion we present our observations and information gathered by talking to teachers and students working in the environment. We stress the fact that these observations are subject to our interpretation and therefore, necessarily, coloured by our own cultural background and experiences.

What might be the implications of teaching and learning in an environment where anonymity is enforced in the educational setting? In much of the Islamic world gender separation throughout higher education is the norm. In addition, due

to shortages of qualified female staff, a consequence of the gender separation is that female students are anonymous to male teachers in the regular classroom situation.

Male and female students are taught separately, in different campuses. The students that we have met have only encountered male lecturers. There are teaching assistants (TAs) of both genders, male students meet only male TAs and female students meet only female TAs. No men are allowed to enter the female campus, which is surrounded by a wall and the entrance is guarded to make sure that only women enter.

Male teachers teaching female classes lecture from a studio in a building outside the campus. Computers in the studio are connected to screens in the classroom and there are cameras in the studio, one directed toward the desk, used to display anything the teacher writes during the lecture, and one directed towards the teacher. The teachers that we have met choose not to use the second camera. One teacher explains this by saying that he perceives that he will be at a disadvantage if the students can recognize him if they should meet outside the teaching situation while he cannot recognize them.

Oral communication is possible, the teacher has a microphone on his desk and there is a microphone for the students in the classroom. Teachers tell us that it is hard to hear the students and that they have no idea about which student they are talking to. Most of the time, they either hear nothing from the class and wonder if there are any students present, or they hear a mumbling and wonder whether the students are paying attention to the lecture or discussing something else. Our observations inside the classroom reveal that classroom microphone is attached to the wall on one side of the room. This means that most of the students are sitting too far from the microphone to be heard clearly by the teacher.

A female member of staff accompanies the female students in the classroom. Her main responsibility is to make sure that the students are in the right room and that audio and video works. If teaching is not done in the students’ native language, the staff member sometimes translates words that the students struggle with or the students sometimes help each other with translations. This is one explanation for the mumbling that the teachers can hear. Another explanation is that keeping the students’ full attention for an entire lecture is a challenge even when you are in the room with them. When voice and slides are the teachers only tools, it is likely that the students do lose focus and talk about other things every once in a while.

In rare cases, when courses are given to a small class consisting of both male and female students, both genders are taught simultaneously with the male students in the studio with the male teacher. With that setting, it is easy for the men to get caught up in discussions where the invisible female students are forgotten.

IV. INTERVIEW

Two lecturers from our own university spent three weeks teaching in the environment. After their return we performed a semi-structured interview with them to find out how they had perceived teaching in the environment and in particular

how they perceived teaching anonymous and invisible students. They had taught a group of Master-level students in mathematics. The group consisted of 4 male and 8 female students. Teaching was in English, which is not the most common for the students, but passing a TOEFL-test was a requirement for admission. For the first course meeting, they were able to meet the students outside the campus, in the same room with only a screen separating the genders. That gave the teachers an opportunity to see the female students once, which is not common in the environment. The rest of the course was given at the female campus with the male students present in the studio. To communicate with the female students they used voice communication and a camera directed at the teachers desk, showing his hand, writing on paper. The notes were then made available to the students. The teachers describe that it felt bizarre to not see the students, but only know that they were there from the constant mumbling that he could hear. They told us that the female students differed from the male students in that they did not ask any questions.

V. DISCUSSION

Why is anonymity prized? Anonymity has been seen as a way to ameliorate the subjective nature of assessment. In essence, however, all assessment is through its very nature a judgement of how well a person performs in relation to defined criteria. The nature of these criteria vary significantly as a function of the complexity of the outcome under consideration.

Ways of viewing and valuing learning outcomes has been in reference to taxonomies. A number of taxonomies have been proposed as a means to reason about learning and learner development. Perhaps the best known of these is the Bloom taxonomy [4], which hypothesises an hierarchical structure of learner sophistication in relation to ability and learning outcomes. Another approach can be found in the SOLO taxonomy [5], which emphasises the interconnected nature of knowing, and relates learner processes and reasoning to the ability to contextualise and interrelate items in the conceptual ecology of the individual. Entwistle takes a third approach in his work on learning objects and conceptual change [6], where he distinguishes between learner's conceptions of knowledge, and approaches to knowledge acquisition. Figure 1 summarises Entwistle's model. Drawing on a large body of prior work, Entwistle theorises that conceptions of knowledge and strategies for learning are related, and form two dimensions of learner development. Learners progress from an initial understanding of knowledge as ability to recall facts, to a perception of knowledge as a philosophical position, that must be supported by argument and logic. Congruently, learning strategies develop from pure memorisation to encompass ability to reason about alternative solutions, and the realisation that the definition of an optimal solution depends on the context of the problem posed.

Regardless of the model chosen, it is clear that the complexity of making a judgement in relation to a type of learning increases as the learner develops, and as learning outcomes include higher order cognitive processes such as evaluation,

and synthesis. What observable phenomena provide assessors with evidence that a learner is performing high cognitive order activities? Inevitably questions of subjective judgement and interpretation arise in the dialogue between teachers, and also between teachers and students in the context of associating grades with learning processes and outcomes.

This type of argument leads often to a discussion of the subjective nature of assessment. A particularly sensitive topic is subjective judgement, which we define to mean judgements made on grounds other than those which can be associated with aspects of academic performance, and which can therefore be judged to be inappropriate and inequitable.

In many legal systems discrimination on the basis of ethnic background, race, religion, gender, and a range of other grounds has been specifically identified as unacceptable. This protection from discriminatory behaviour naturally also extends to professional judgement in the workplace, employment situations, and education, as well as a range of other areas, such as health care, legal systems. In Sweden this has become a part of the higher education dialogue, in particular a question for student associations.

What goals are identified by student groups? The major areas identified in recent publications aim to avoid bias based on the individual knowledge of the student, as well as eliminating systematic discrimination and protect examiners from accusations of favouritism and bullying. This approach allows students to challenge lecturers' opinions and give critical feedback without risking a negative impact on their final grade.

One reason for making assessment anonymous from the student union perspective is based on assumptions regarding the areas we identified above, in particular student groups identify a need to

allow students to challenge lecturers' opinions without risking effects on marking ¹. In this reasoning, there is an implicit assumption that the lecturer might be expected to disapprove of being challenged, or be threatened in their professional role, rather than appreciate the fact that a student might challenge the lecturer, giving strong arguments in doing so, thus providing evidence of high order cognitive order skills. In a setting where the lecturer is trusted to make a professional judgement, and continuous assessment is used, this evidence could be included as a positive element in the student's final grade.

In our example setting, however, the anonymous students rarely, if ever, participate in classroom discussions, and if they do, the lecturer is highly unlikely to know which student is making an argument, or if it is one student or many that are taking part in a discussion. The student's achievement is most likely lost in such a situation.

In our example setting, discrimination on the basis of gender is not avoided. In fact, all teachers we have talked to tell us that the (anonymous) female students are better than the male students, despite having never interacted with them in person.

¹One website that is relevant in this context is <http://services.su.nu/galway.ie/site/view/2545/>

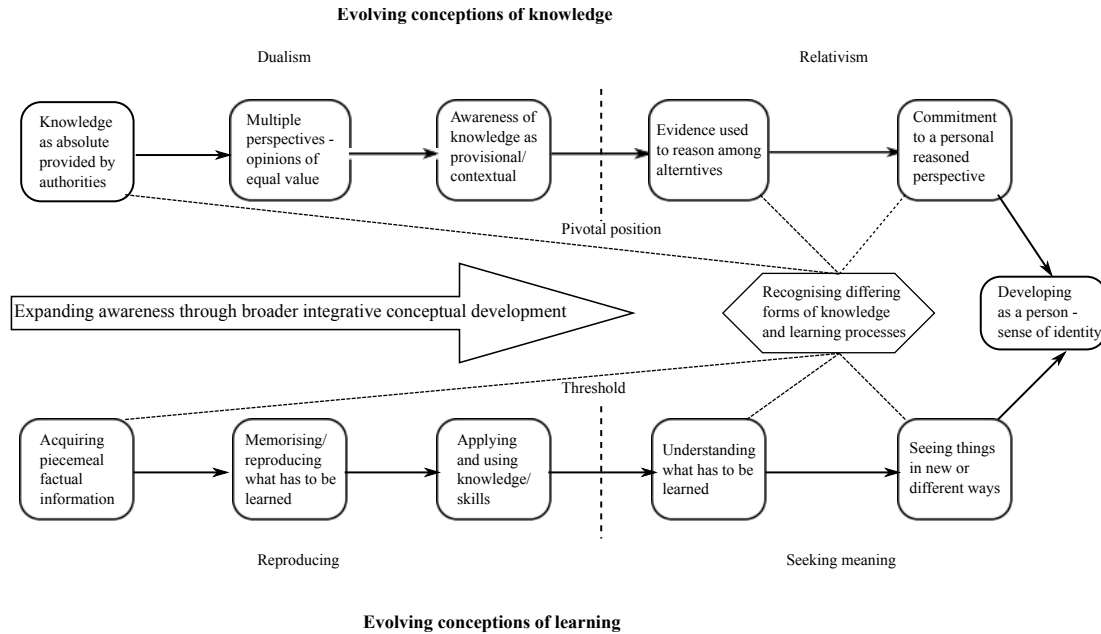


Fig. 1. Entwistle's integrative model of learner development

This suggests that in the anonymous setting, there may still be gender, or some other type of observational bias in the assessment process.

A difference between the male and female students that is reported by (especially among Swedish) teachers, is that female students don't ask as many questions and do not interact with the teacher as much as male students. An important part of engineering education is to achieve competencies necessary for professional engineers such as the ability to apply content knowledge in projects working with others, and presenting and discussing the topic of study [7], [8]. These competencies need to be practiced in the educational setting, but in our example setting, the anonymous students are separated both from discussions with teachers and with other student groups.

In conversations with the female students, they reveal that they do know what their male teachers look like on Facebook, but despite this, that they have a strong wish to see them in real life. They also express a desire to have female teachers, or to be able to interact with the teacher directly. In our interpretation, these students lack contact with a role model. Separation of student groups also entails that the students lack insight into what other students do and learn. We were able to let some female students see male students present course work and they expressed that they were surprised to see that the male students learned the same content as they did, even though the students were studying in the same year in the same study program.

One can argue that some of the problems we have high-

lighted above stem from other characteristics of the study context, and are not associated directly with anonymity. For example, that gender bias exists only because of the gender separation, even though the students are anonymous, the teacher knows their gender. However, it is easy for a teacher to get an idea (correct or not) regarding a student's gender by e.g., looking at their handwriting. Some of the problems related to isolation of the student group can be avoided in other cultural settings but achieving student anonymity in a teaching situation without separating the students from the teacher is not easily accomplished. Consequently, we believe that it is worthwhile considering these implications in any cultural setting.

VI. SUMMARY

The negative impact of large scale classes, and impersonal learning environments on the student learning experience has been well documented [9]. What is less broadly discussed is the tension between tailoring the learning experience to the individual, and constructively aligned student-centric learning and assessment, and an increasing pressure on universities to offer anonymous assessment, especially in relation to written examinations, but even in the context of essay marking in the humanities.

The experiences of learners and teachers in a nearly completely anonymous educational environment has been explored in the thick description which forms the core of this paper. Even though the degree of anonymity in the environment

surpasses that which is usually discussed in relation to fair and equitable assessment, the implications of anonymity revealed by these experiences are important to consider in the current debate. It is clear in the experience of teachers and learners as related there, that anonymity also presents many challenges. Interaction is reduced, ability to communicate is curtailed by the paucity of the facilitating technologies, and the considerable negative impact on the social dimensions of learning reduce student motivation and engagement.

We conclude that anonymity in assessment is difficult to reconcile with other student-centric, and continuous examination strategies. Naive approaches to achieving anonymity, such as separating teachers from students, clearly do not result in a system desirable to either teachers or students.

Trust and transparency lie at the core of the issue. The university teaching profession must reclaim its professionalism and reputation of impartiality. To do so we must strive to elucidate our learning goals, and assessment criteria in a manner that rebuilds student trust in the manner in which we judge and assess learning. Through such a strategy universities can circumvent the shortsighted attraction of anonymous assessment.

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Case for Reflection in Engineering Education--and an Alternative

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Abstract— This paper examines the use of reflections in engineering education. The paper provides a review of practices in engineering education, especially during the last century. It starts by reviewing the research and pedagogical approaches in utilization of reflections and various reflective activities in engineering education. Then the authors provide various perspectives regarding reflective activities. The first part of the paper establishes the case for featuring reflective activity in engineering education. The writers were a pairing of a committed reflective practitioner and a staunch disciple of Dewey. An alternative commentary is given by the third author.

Keywords—Reflections, Engineering Education, self-assessment, intramental

I. INTRODUCTION

Recently engineering researchers and educators have expressed renewed interest regarding the affordances of reflective activities and the role of reflections in engineering education. Since reflections have for some time been an established and practiced methodology for on-going professional development in many discipline areas, the current interest regarding engineering education is worthy of careful consideration. As engineering educators, it thus behoves us to carefully review current reflective practices in engineering and elsewhere in both higher education and continuing professional development.

Our paper opens by the first two authors' review of basic pedagogical writings about the role and potential of reflections and various reflective activities in tertiary education in general, and engineering education in particular. It points briefly to some of the noteworthy developments in various professional areas that, in our judgement, have been successfully using reflections as learning/evaluation/development tools in continuing professional development. The third author then provides an alternative perspective regarding reflective activities in general, with an examination of reflections and reflective activities and their validity in assessment/evaluation of student growth, education, critical thinking, and becoming lifelong learners.

II. REFLECTION AS THE ESSENCE OF HUMAN THINKING

The term and concept of "thinking" has a wide embrace. In the cognitive domain alone, thinking covers such mental

activities as analysis, problem-solving, the formulation of judgements, what is commonly called critical thinking, but might more helpfully be renamed reasoned thinking - and reflection. All of these, and more, are sub-sets of the overall sphere of "thinking" or cognition - as is metacognition, which is thinking about our thinking. [Cowan, 2006) [1]

Before discussing the role of reflections in engineering education, we should briefly define and describe cognitive reflection and what it entails, according to current usage. This meaning of the concept is of course far removed from the Internet dictionary definition of reflection, which can centre upon something that is bounced back at us, as is an image from a mirror. In contrast, Moon writes helpfully of reflection as "a common idea that has a variety of connotations"[2]. Drawing on the work of Dewey and of King and Kitchener (Dewey; King & Kitchener)[3-5], she proposes that cognitive reflection is:

"A form of mental processing with a purpose and/or an anticipated outcome that is applied to a relatively complicated or unstructured idea for which there is not an obvious solution."(Moon, 1999: p4) [2]

Moon echoes the words of John Dewey (almost a century earlier),

"one reflects in order to know whatever one wants to know, wherever a state of perplexity arises. The method of reflection is a three step process including problem definition, means-ends analysis, and generalization that are carried out with attitudes of open mindedness, responsibility and whole heartedness"

Cowan (2006)[1] has expressed this to his students in simplified terms by telling them that they will be reflecting when they pose a question whose answer, as yet unknown to them, should be useful to them - and when they immediately seek that answer. It is this sub-set of thinking with which our paper is concerned. This echoes the seminal writings of Dewey (1910, 1933) [3-4] who stressed a century ago that exemplary reflective thought distinctively originates in doubt, hesitation, perplexity or mental difficulty. It will then lead into searching, hunting, inquiring, and above all self-questioning to resolve doubt and dispose of perplexity. This will then be accompanied by motivation to apply the consequent learning to the enhancement of that practice (Hughes, 2009)[6]. Reflection

should thus first entail a searching interrogation of one's own experiences, to identify and resolving issues worthy of attention (Bourner, 2003)[7].

III. RECENT DEVELOPMENTS IN THE USE OF REFLECTION IN LEARNING

Reflection is nowadays well established as valued component of education and lifelong learning (Atman, and Turns, 2003[8], 2015[9], Jay and Johnson, 2002[10]; Davis[11], 2003; Cowan and Westwood, 2006[12]; Findlay et al.,[13] 2010; Moon, 2004[14]). Recently, University of Washington established the Consortium to Promote Reflection in Engineering Education (CPREE) that is led by Atman and Turns. The center is focusing on studying reflective practices in engineering education with the premise that reflection accelerates the learning that happens through experience, and so it is critical for preparing the next generation of engineers (Atman 2011)[9].

Thus the widely acclaimed suggestions in the keynote texts on reflection for learning (Schön, 1983[15]; Kolb, 1984[16]; Boud et al.,1985[17]) have been taken up for some time in educational programmes and schemes for professional development (Bourner, 2003[7]); Williams and Grudnoff, 2011[18]). Generally learners are encouraged to consider both past and impending actions, with a view to effecting future enhancement (Hatton and Smith, 1995[19]). The reflective process can commonly take place within a written, keyed or narrated reflective journal or blog within which writers engage with their learning experiences, and unearth their tacit knowing (Bickford and van Vleck, 1997 [20]) thus leading them to new insights, understandings and appreciation (Boud et al., 1985 [17]).

Many justifications for such practices have been advanced (McGarr and Moody, 2010[21]). Anecdotal claims of the benefits, issues and challenges associated with this aspect of self-directed learning have proliferated (O'Connell and Dymont, 2011[22]). Journal writing is said to increase the sense of ownership of learning, to acknowledge the role of emotion in learning and above all to encourage metacognition (Moon, 2004[14]; Samuels and Betts, 2007[23]; O'Connell and Dymont, 2011[22]). Journaling has been described as a bridge across which learners can move from the specific to the general, through developing a habit of reflection (Griffin, 2003)[24].

However it must be acknowledged that presentation of data-based evaluations of reflecting is sparse. Recent criticism of critical reflection has been helpfully summarized by Hickson (2011)[25]. Such critics have cautioned against the wave of euphoria, commending reflecting on experiences as a valuable component of constructivist learning through which learners construct understanding. Many publications virtually presume the effectiveness of reflective practice in developing meta-cognition (thinking about thinking), in promoting self-directed development, and in nurturing valuable abilities used in professional life (Moon,1999)[26]. Yet there are few rigorous evaluations of the effectiveness of reflective writing in achieving valued learning outcomes (White et al., 2006)[27], which omission does not of course necessarily imply that the

enthusiasts are deluded in what they believe reflection is achieving for their learners.

IV. THE POTENTIAL OF REFLECTIVE PRACTICE FOR ENGINEERING EDUCATION

Half a century ago, the principal demands that the world of employment made of engineering graduates were a knowledge and understanding of the properties and use of materials in an engineering context, together with ability to use certain fairly common methods of calculation to support the processes of analysis and design. The situation has changed. The on-going explosion of knowledge is such that the half-life of a curriculum in electronic engineering education has been put at two years. Additionally, the Internet, through effective use of search engines, can readily provide more information and advice than any single graduate mind could hope to store and recall. Sophisticated programs and apps carry out calculations whose basis would be beyond the grasp of the graduates who comfortably employ them. Hence the principal demands on the graduates of today and tomorrow are to develop and exercise higher-level abilities - in conceiving designs and solutions to problems, in exercising oversight over computerised data and productions, in relating to customers, clients and colleagues in hectic workaday situations, and above all in exercising informed self-evaluation leading into further professional development.

We therefore make an important distinction here between learning and development. We take learning to describe the grasp and mastery of concepts and subject matter, such that, in respect of the certain "learning", when an acceptable cognitive outcome that is provided in assessment by one individual, it will be similar to that from another. For example, explaining the meaning and relevance of "entropy" will cover common ground for most competent learners. In contrast we take development to describe improvement in an ability, which may be cognitive, interpersonal or affective. The ability can be applied in situations where assessors may agree on the nature of the demand and the outcomes of a successful performance; but how that performance is successfully achieved through exercise of the ability in question is likely to be highly personalised. An example is problem-solving, where assessors may agree that a problem has been adequately solved by someone, but will generally only have a vague notion of the intermental and intramental thought processes that led to that outcome - a distinction which it may now help to clarify.

V. INTERMENTAL AND INTRAMENTAL THINKING IN DEVELOPMENT

Vygotsky[28] saw learning as a social process in which communication between people is essential. He maintained that productive thinking has its beginnings in the social plane (*between* people engaged together in activity), and is later internalised *within* the learner, on their individual plane. Hence it progresses through an 'intermental' activity to 'intramental' consolidation. The ultimate internalisation depends upon reflection in personal terms. For intramental thinking, by definition and in practice, occurs within an individual's mind. While interaction with others contributes to our mental processes, our eventual generation of an innovative solution to a problem, our noticing of a weakness in a reasoned argument,

our empathy for the declared difficulties of another, our discernment of the attitude behind a particular comment and way of speaking, and above all our development of an ability, all entail much which is essentially intramental in nature. This is prompted by reflective and formative self-evaluation and forward planning, embodying Dewey's frequently neglected principle of the active experimentation that further refines our generalised and still speculative thinking (Cowan 2012)[29].

VI. FACILITATING REFLECTIVE DEVELOPMENT

At times, the vagueness and strangeness of what reflection is creates problems for engineering educators. Typically engineering faculty are used to making judgements of learning based on tests, quizzes, laboratory reports, different forms of examination and formal report writings. These call for a range of responses, from direct return of learnt knowledge and understanding, to the open-ended use of understanding in response to creative challenges. Nurturing and judging learners' competence becomes more and more difficult. As the hoped-for learning outcomes progress to higher taxonomic levels, featuring demanding mental abilities, then nurturing and judging learners' competence becomes more and more difficult. This is understandable. For reflection in particular, it is no easy task to develop or assess the vital (self-) questioning ability.

Postman and Weingartner (1971)[30], echoed Dewey (1910)[4] in maintaining that the most important intellectual ability for humans to develop is the art and science of asking questions. They valued those who perceived and posed searching questions, much more than they venerated those with a rich store of book knowledge. For

'Here is the point; once you have learnt how to ask questions – relevant and appropriate and substantial questions – you have learned how to learn and no one can keep you from learning what you want and need to know' (Postman and Weingartner, 1971: p34)[30].

Furthermore, reflection in particular can come in many ways, and can feature as parts of tests, quizzes and all student activities. Historically, however, reflective practices have been popular in many circles of thoughts, educations (learning and teaching) and even faith based practices. [31]

Reflections probe the ways we think, imagine, verbalize, and depict "what is going in our thoughts!" They are connected to our cognitive process, value systems, thinking circles, imagination, experience, verbal abilities, memory management, and all cognitive connectivity that defines us. When a scientist conducts an experiment or when an engineer tests something, they take "notes" on the data, their thoughts, their observations, and even at times on "what and how they felt". Those are true observations. However, even the best scientific notebooks and observations can be considered biased by our knowledge and belief structure. These notes can feed our reflections, which should be (are) a part of organized process of our engaging and visualizing our critical thinking capabilities. They are the cyclic process of inquiries that develop our "holistic self". However, even the best scientific notebooks and observations can be considered biased by our knowledge and belief structure. At times they can also

be tainted with our feelings and emotional context. They reveal how we develop ideas, how we interact, think, and perceive the world. Reflections, consequently, can be valid avenues into the status and level of maturity of our critical thinking capabilities.

From our pragmatic approaches and experience, we have seen how the utilization of reflection can help engineering students focus more critically on probing what they know, what they think, what they feel and what they can do. Consequently, reflecting can help them explore their holistic approach to the subject at hand. Experience and research shows that when students practice personal as well as group reflections, they critically examine their thoughts, their beliefs, and disbeliefs and they re-examine their approach to problems.

VII. REFLECTION AS A VEHICLE OF SELF-EXPLORATION AND EXPRESSION

There are two interesting practices that have appeared in engineering and sciences. In these fields many concepts are represented in equations. Good examples include Maxwell's equation for Electromagnetism, Bernoulli's equation, the continuity equation that appears with slightly different forms in different engineering fields. These equations are pictorial symbols of many connected and complicated concepts. One of the interesting reflective practices (that frequently features in PhD oral examinations) is to ask a person to describe, in their own words: "What does this equation mean?" Answering such questions helps the student to examine his or her understanding of major concepts and connections, as well as his or her technical and active vocabulary and communication capabilities. The words, the verbalization, expression, and description bring about a more in-depth critical connections in their mind.

A second useful practice is the process that every educator has experienced for themselves when the process of teaching, explaining and presenting make them question more, think deeper into something, and examine the subject and all connections more critically. That is why we all believe "the best way to know something in depth is to teach it." We always encourage students to create their own lecture summaries of the main concepts of each section and each class. That process helps them carefully examine their knowledge, related to the meaning and connections of the equations and subject interconnections of the field.

VIII. REFLECTION LEADING THROUGH SELF-ASSESSMENT TO IMPROVEMENT

When reflecting, and examining our knowledge, our inner belief systems and the interconnections of our thoughts, basics, applications and facts, we have an opportunity to reflectively seek answers to such questions as:

1. How fluent are we with the basic terminology and assumptions?
2. How well do we know the subject as a whole?
3. How well do we know the connections of the subject to other fields?

4. How well do we know the ways to apply ideas based on the subject?
5. How capable are we to synthesise our knowledge, and created designs and focus on the practical aspects of the knowledge?

The process of inquiry (into our own knowledge), and verbalization (constituting the ease and fluency in a subject) help us know what we need to work on, what we need to connect, and what we need to change. When such self-evaluative reflection is done honestly, openly, realistically, bravely and clearly, it can accelerate one's self-assessment and help one design ways for improvement, growth, and meaningful change.

IX. INTEGRATING REFLECTIVE ACTIVITY INTO AN ENGINEERING CURRICULUM

Over 35 years have elapsed since student centred learning with a concentration on individual ability development was first established on a significant scale in engineering - in Canada by Woods [32] and in Scotland by Cowan. Since it is our view that the development of reflection and metacognition are facilitated and not taught, the distinction between directive teaching and facilitative tutoring is thought important for the subject matter of this paper. Cowan's innovations, even or especially at first year level, emphasised metacognition - thinking about thinking - as well as self-assessment and the facilitation of reflective practice centred on the development of abilities of professional relevance. He promoted a regular discipline of facilitated weekly reflection-on-action in relation to the development of abilities, as the means of nurturing the intramental heart of the exercise of constructive self-assessment and insightful metacognition. At the close of each academic term, learners critically reviewed the evidence of their journaling, and formulated a self-assessed claim of their professional development. At the end of the first academic year, one student (of average ability) wrote when introducing his claim for substantial development through reflection:

"Now, when I'm working at home at my desk, it's maybe fanciful, but I often feel as if a ghost has come out of me, and is looking over my shoulder at what I'm doing, offering useful comments and suggestions."

He was describing how he thought usefully about his thinking - even if he did not know he was engaging in metacognition. He went on:

"And, even more weird, sometimes it's as if another ghost has come out of the first ghost, and is offering comments and suggestions to the first ghost about how to advise me."

This first year student had discovered and practiced meta-meta-cognition - in his own words! He had never heard of the concept, nor had he encountered Pask's thinking on this topic [33]. His claim for development epitomised the potential of reflection for development of abilities, and its relationship to intramental metacognition.

We were heartened recently to encounter an independent initiative in engineering education in an Irish university, where reflection-on-learning informs the preparation and presentation

of evidence-based reflective self-assessment claims in regard to development and use of what learners had identified as key abilities. In the same setting, students are to be encouraged to engage in reflection-for-action as they prepare to engage in the next problem solving to be featured in their undergraduate project work. It is these innovators' hope that their increasingly metacognitive students may constructively contribute to the action researching and formative evaluation of these developments. This example indicates for us one way ahead that is currently being purposefully explored in engineering education west of the Atlantic.

We consequently see development of key professional abilities as even more important today and for the future than fifty years ago. In the interim, however, reflective practice has progressed in many professional areas. Hence any question asking what an engineering educator should be doing now in regard to promoting and using reflection should have a revised and enhanced focus, appropriate to this decade of this century.

X. IS REFLECTION EFFECTIVE AS A COMPONENT OF AN ENGINEERING PROGRAM?

While this paper was being finalised, Cowan found himself drawn into communication with a pair of Irish academics who were teaching undergraduate engineers and architects, and trying to put into practice some of the notions in *On Becoming an Innovative University Teacher* (Cowan, 2006). At that point in their program, the students had been asked to draw together their reflective reviews on the various elements in the program. Cowan volunteered himself into position as a supportive online tutor, to assist students (if they so wished) to refine their draft claims for the learning and development which featured for them in their program experience.

In the exchanges which ensued, Cowan noted:

- The commendable and almost universal concentration on generic and transferable abilities, rather than the (common in other engineering programs) focus on very specific learning;
- The tendency to simply state claims for learning and development, rather than to set out data or reasoning in support of such claims;
- The responses, when this weakness was pointed out, in the form of amplification in which the key role of metacognitive and hence transferable thinking and analysis had often prevailed in the students' reflections and in their self-directed pursuit of enhancement;
- The interest of a few of these students, during communication which overlapped with preparation for examinations, to engage in reflective pursuit of issues arising for them from the messaging.

Cowan formed a strong and somewhat informed impression of a cohort of engineers and architects on whom a program

featuring reflective review had had a strong impact in terms of effectiveness in developing generic abilities.

XI. PERSPECTIVES ON REFLECTION: A COMMENT BY JOHN HEYWOOD

Reflection is a term that is a terminological inexactitude. While the development of skill in reflection is advocated as a goal of higher education, it is not always clear what teachers understand by the concept. It takes its meaning from the person using it and is, therefore, context dependent. For some it is used in the sense of “review” that is a formal or informal review of the past in some context or another. In engineering it is sometimes caused by a review of something that has failed, particularly when numbers of individuals have been killed. At other times it is used by designers evaluatively of machines when they ask- “what could I have done to improve its performance?” Or, “Given the same opportunity would I approach the design differently?” Those who write about reflection often fail to mention the context of the “self” yet we spend much time thinking about ourselves and what we would have done differently about large and small things. Reflection, or *thinking* as I would prefer to call it, contributes to our feeling of being and it can range from dealing with mechanical issues at one end of the spectrum, and at the other end to matters relating to the spirit. It is something that we cannot help doing: it easily tips over into neurotic introversion for by its very nature it is an introverted activity. A balanced person balances it with some extraverted activity. Clearly it is an activity in which we learn and for this reason many educators believe that our reflective skills can be improved: therefore, we can be trained to reflect. If that is correct then such training will be for a particular context.

Professional education provides two quite different contexts for reflection one of which is totally neglected. It relates to the questions that drive our continuous state of reflection namely – Who am I? What is (are) my purpose(s)? Who is it I want to be? And so on. It is answers to such questions that drive our being, or give us the will to live or as we are becoming more aware not to live. It is evident that some reflection can be harmful. It is equally evident that an education system that does not help “normal” students to answer such questions is failing in its duties. Thus it is that questions about the aims of education become important, and we can only understand the role of reflection when we have a grasp of what it is we believe education should aim to do. Many of the current problems of higher education stem from a complete failure since the end of the second world-war to discuss the aims of education or to assume that no discussion was necessary since they were economic and utilitarian. Yet it is clear that this does not resolve the issue relating to the fundamental questions posed a few sentences above. A liberal education is the only approach that has any conceivable chance of answering such questions, but in current views of the engineering curriculum there is no room for such study. How can a person be expected to develop in the educational context without an education that is liberal? It is only through

a liberal education that a person has a hope of learning about him/herself and the others with whom he lives. It may be argued, and is argued, that such learning is simply obtained from living and that education has little to add to a person’s understanding of living.

The second use of reflection relates to method – in this case the method of engineering.

“A method is a normative pattern of recurrent and related operations yielding cumulative and progressive results. There is a method, then, where there distinct operations, where each question is related to the others, where the set of relations forms a pattern, where the pattern is described as the right way of doing the job, where the operations in accord with the pattern may be repeated indefinitely, where the fruits of such repetition are not repetitious, but cumulative and progressive” (Lonergan, 1971)[34].

Such a pattern is the design process which is a holistic process that relies on particular *operations*, as for example “formulating”, “conceiving”, “deciding” (between alternatives), “marshalling and weighing evidence”, “judging”, “reflecting” and “evaluating”. Some authorities base their assessment schemes on linear models, and the analysis of data of some of these schemes shows that students have particular difficulty formulating problems, in establishing realistic as opposed to nonsensical judgments, and in evaluating their products. There is pretty clear evidence that they can be trained in the short run to perform better in each of these areas, in particular through the use of examples. Evaluating a product that one has designed is also called self-assessment, and some consider it to be a reflective activity. If that is the case some training can be given in reflection, but we will have little idea of what is learnt in relation to the use of the skill in a situation where transfer at a distance (a problem of an entirely different kind) is required.

It seems pretty evident that if a person is to learn these skills for use in design that they need to undertake individual projects in order to develop these skills. It is evident that team projects cannot guarantee learning of these particular skills and that the neglect of individual projects in curricular seriously limits the development of reflective skill in engineering. Just as the development of the other operations is supportive of the skill of evaluation (reflection) so is that skill supportive of the development of the other operations. It is concluded that different learning approaches contribute to the development of different operations of which reflection is one.

XII. FINAL REMARKS

This paper started by reviewing the research and pedagogical approaches in utilization of reflections and various reflective activities in engineering education. Two of the authors provided a critical approach of utilization of

reflections in engineering education from the perspectives of John Dewey and some of the recent engineering educators with more pragmatic inclination in engineering pedagogy. To provide an alternative critical approach, one of the authors provided other perspectives into reflections and their use and meaning in engineering education, and provides practical and important questions and thoughts.

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Challenges in finding a connection between IL education and research problem formulation

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Abstract— The current stage of study covers past 5 years of IL education research focusing on undergraduate engineering students. The first observations have risen a question: Could effective IL education improve students' skills to formulate their research problems? This paper is part of a study which aims to find ways to improve students' research skills based on the development in their information retrieval mindset. Tentative analyses have been made of 111 questionnaires and 36 seminar papers. At the current stage, observations deal with two different types of student groups. One group consists mostly of freshmen and the other group is close to their graduation.

Keywords—*information literacy; research skills ;undergraduate students*

I. INTRODUCTION

Information literacy (IL) means the ability to find, use, and evaluate source material used in various assignments. The concept was first presented in the ACRL international IL competency standards [1]. Internet has changed the role and availability of open information sources. Banks [2] argues, that instead of being cautious about using information found in the open web, information users need to learn to analyze critically the retrieved information. Tingting Liu and Haibin Sun [3] conclude that IL also helps users apply information to solve problems creatively.

Johnston and Webber discuss how American and Australian views of IL differ [4]. American standards focus on outcomes and IL is seen as a "cluster of abilities", while the Australian framework focuses on generic skills, information skills and values and beliefs. Moreover, cultural differences in understanding IL exist even within the same institution. Wilkinson and Bruch present how barriers like the academic culture need to be crossed to build an effective and sustainable IL education program [5].

In universities, IL education has been given to students using four different approaches. According to Wang [6], IL education can be offered as a course outside of academic curriculum, as a session add-in to an academic course, integrated into a course, or as an independent course within academic curricula. While some authors consider IL as an integral and indispensable part of faculty courses, others prefer to see it as an independent discipline [4]. In this paper,

integrating IL education into substance teaching means close cooperation of the faculty teacher and the information specialist so that both have at least basic knowledge of each other's discipline.

Libraries struggle with resource problems. According to Borrelli, Johnson and Cummings, IL instruction in most academic libraries suffers from lack of librarians who would be able to provide meaningful instruction to large student populations [7]. However, even with limited resources carefully planned IL education can give good results [8]. Locknar [9] introduces the Discovering Scientific Information Program (DSIP) which successfully aimed at saving both the faculty teacher's and the librarian's time.

Research on the learning results of IL education in higher education units has mainly studied improved searching skills and changes in students' searching behavior. Kari and Savolainen [10] have, however, studied the connections between information use and the learning process. Students' research skills are hardly covered in literature. If they are, the concept means how to find information and how to understand the process of using information and evaluating the content of it [11, 12].

Modern technological problems have a multidisciplinary nature. This requires advanced skills to find appropriate literature to formulate and solve these problems. This paper presents two cases in which students study production processes and their environmental impacts in connection with certain products. Similar interdisciplinary outreaches have been presented in literature. Vanasupa [13] presents a pattern in which they utilize a modified team based learning structure combining disciplines like nanotechnology, biology, and ethics. Moreover, Locknar and her colleagues [9] have succeeded in their DSIP program for first-year students. In this program, teaching and learning laboratory staff cooperate with a librarian. The aim of the program, in addition to saving teaching resources, is to explore the nature of scholarly literature and the processes and skills needed to search information successfully.

II. BACKGROUND

At Lappeenranta University of Technology (LUT), IL education is integrated into faculty courses. IL instruction is

given by professional information specialists. As in many institutions, teaching resources are limited both in the library and in faculties. Therefore, it is necessary to make the most of the teaching sessions.

IL education at LUT is based on the ACRL international IL standards and national recommendations given by the Information Literacy Network of Finnish University Libraries in 2004 [14] and revised in 2013 [15]. The emphasis is on the education given as part of the Bachelor's seminars. In addition to these, teachers sometimes ask academic librarians to teach their students how to retrieve information for their assignment on courses which require individual information searching.

During the past years, the effects and performance of IL education have been studied at LUT. The results have shown that students struggled with huge numbers of retrieved references and have big problems in finding search words [16]. Recently, the question of the benefits of IL education to students has become a wider issue in LUT research. The main interest has been on the development of students' research skills, meaning, in our case, how they interpret their research problem and turn into a search query, what the quality of referred sources is, and how they utilize the found information. A pilot study was conducted in 2013 [17]. The results showed that IL education has a positive effect on students' information searching behavior and on their ability to do scientific research. One of the key findings was, that after the information literacy instruction (ILI), search queries and the quality of found and used sources improved. Students also handled the subjects more deeply and understood better how to turn their research problem into the process of information retrieval and use [8]. The results of the pilot study had to be verified by a full-scale research. This paper presents findings of the full-scale research project carried out during the academic year 2014-2015.

III. RESEARCH SETTING

This research involved undergraduate engineering students, two information specialists, and two faculty teachers. ILI was given by information specialists and faculty teachers were responsible of their courses into which ILI was integrated.

A. Student groups and their research tasks

Two groups of students were studied. Group of 'Course A' was Master's level students studying 'Selection criteria of construction materials' and 'Course B' mainly (64 per cent) first-year students taking 'The basic course in environmental technology'. Students were divided randomly into the research group that attended ILI and the comparison group that did not attend it.

Student teams wrote seminar papers on given topics. Course A aimed at finding solutions to material selection problems of certain mechanical engineering products focusing in green manufacturing and environment protection. Teams were also supposed to determine their research problem and use literature review as their research method. Course B students' assignments dealt with common consumer products. Using literature, they were to identify environmental aspects in different product life cycle stages, evaluate the significance of various factors and environmental impacts, and suggest

methods for managing them. The research objectives were thus given to the Course B students.

B. IL instruction

To the research groups, ILI was given before students started information searching. The content of ILI followed a set pattern to cover the learning goals of the national recommendations [14] [15]. The topics included characteristics of different information sources, selecting information sources and search words, combining search words, using the e-material portal (Nelli), demos of searching in ProQuest, Science Direct, and Scopus, using the analyzing tool of Scopus, and the meaning of impact factors in Journal Citation Reports (JCR).

Instead of instructing how to use individual databases, emphasis was on teaching information retrieval principles in scientific work and on understanding the information retrieval problem as part of the research problem. The ILI content followed different scientific aspects such as objectivity, critical evaluation, openness of sources, repeatability, and self-repairing.

Using an online survey tool (Webropol), all students were asked about their searching plans before dividing them into research and comparison groups. Another questionnaire was given to Course A students after the lecture to find out possible changes in their information searching mindset. Both Course A and B research group students answered the last questionnaire after the hands-on training session (Course A) / joint lecture and hands-on training (Course B).

C. Faculty teaching

On Course A, emphasis was on solving cross-technological material selection tasks using systematical and analytical approaches. The faculty teacher had concentrated on six main material groups, namely metallic materials, polymers, ceramics, composites, adaptive and nanomaterials, and 54 sub-groups.

Course B top issues were the most significant challenges related to environmental protection from industrial activities and communities, typical management tools of environmental problems, and terminology of environmental engineering. They also learned to understand how other fields of engineering are connected with environmental engineering.

IV. RESEARCH RESULTS

Students' search word use was studied before and after ILI. The results were compared with the appearance of keywords related to the main topics of faculty teaching. The research problems expressed before ILI and those in the seminar papers were also studied and results of IL educated and non-IL educated teams were compared.

A. Search words

Search words that students planned to use and what they eventually used in their searches developed greatly after ILI. At first they mainly planned to use single words. On Course A the use of single words decreased to 1/6 (from 62.5 to 10 per cent) and combining words with Boolean operators (AND, OR,

NOT) increased over four times (from 18.75 to 80 per cent) compared with the initial situation. Course B students' results were parallel to Course A results. Both groups had also learned the idea of truncating words to include possible plurals and endings of words in their searches.

In Course A papers, the appearance of eight keywords (e.g. material selection based on "wear" or "corrosion") describing the main content of the course was calculated. It was found that students concentrated mostly on classical construction materials (metallic materials, polymers, ceramics, composites). Adaptive and nanomaterials were mentioned less. The same grouping could be seen in the way they used search words. In Course B papers 16 keywords (e.g. life cycle assessment based on "sustainability" or "environmental impact") were studied.

The numbers of words representing the observed topics was higher in the research group's papers compared to those of the comparison group's papers. In case of Course A, the differences were statistically significant while in the Course B papers the differences were not equally notable. The class level may explain the variation. Observations of the appearance of the same keywords in the reference lists gave parallel results. The results are shown in Table 1.

TABLE I. APPEARANCE OF TOPICS IN SEMINAR PAPERS

Average number of observed words representing substance topics		
	Research group	Comparison group
Course A, text	189.8	119.8
Course B, text	66.1	58.5
Course A, references	11.4	2.8
Course B, references	9.1	6.9

B. Development of research problem description

Before ILI all Course A students were asked to formulate their research problem. At first, most of the students either had no idea of what a research problem was or they presented the title of the paper or the given task as a research problem. The answers can be seen in Table 2.

TABLE II. ABILITY TO DETERMINE RESEARCH PROBLEM, COURSE A

Ability to determine research problem, before IL instruction	
Classification of research problem	Percentage of students
No idea what 'research problem' means	16
Title of the paper	42
Presented as a task	29
Fuzzy idea of the research problem	3
Clear research problem	10

Seminar papers of Course A were observed to study students' research understanding. Both groups recognized nearly equally that they are making research and differences in their research problem formulations hardly existed. However, the fact that in both groups there were teams that did not understand literature review as a tool to solve their problem was surprising. Final grades of teams that have not understood

literature review as a research method were lower than those of teams that recognize literature review as a research method.

Descriptions of research problems were also observed in the seminar papers. As shown in Table 3, the research group was able to present their research problem more clearly and more reasonably (80 per cent of teams) than the comparison group (25 per cent).

However, one very unclear description of the research problem was discovered in the paper of a team that attended ILI. Therefore we can assume, that variations in these results can be explained also partly by team dynamics and different background knowledge of team members. Team dynamics was visible in two ways: firstly the substance teacher was able to observe the teams' working practices and interaction between team members during ten weekly meetings and secondly some remarks about insufficient team dynamics could be found in the feedback report of the course. Differences in background knowledge were evaluated by the substance teacher based on students' study reports. Moreover, cultural and previous IL knowledge differences as well as diverse educational backgrounds possibly affect the results. According to these findings, faculty teaching seems to have more influence on research problem formulation than IL education does. Grade-wise the overall quality of the IL educated teams' papers was higher than that of the comparison group. The grade average of the research group is one unit higher than that of the comparison group. Results are presented in Table 3.

Parallel results can be seen in Course B papers although the academic level of the work is more elementary. The faculty teacher evaluated the way students used references and the value of referred sources. The score from the use of references accounted for a maximum of 17 per cent of the maximum total score of the team assignment. The score given for the use of references strongly correlated (99.6 per cent) with the overall grade which was given for the assignment. Participation in the IL education and the students' score for the use of references showed a weak positive correlation (7.3 per cent). Results are collected in Table 4.

TABLE III. RESEARCH PROBLEM AND OTHER INDICATIONS OF UNDERSTANDING THE TASK

Seminar paper, Course A, faculty teacher's evaluation			
Teacher's comments		Research group, 5 teams Percentage	Comparison group, 4 teams Percentage
Team has recognized that they are making a research.		60	75
Literature review recognized as a tool to solve the problem	commented and clearly recognized as a tool to solve the research problem	40	50
	mentioned but not as the research method	20	25
	not commented at all	40	25
Research problem and goal description	described clearly	40	25
	described reasonably	40	0
	not clear	20	75
Grade average, max 5		4.1	3.2

The assignments were graded without considering which students had attended IL education. Table 5 shows marginal differences in the total score of the assignment and the final grade of the course between all students together, those student who had not attended the IL education and those students who had attended the IL education. However, both the total score of the assignment and the final grade were better for the IL education students. The biggest difference was in the score of references in the assignment.

TABLE IV. COMPARISON OF GRADES OF COURSE B

Course B scores of seminar papers	Average, all 106 students	Average, 84 students not participating IL	Average, 22 students participating IL
Total score, max. 30 points	25.87	25.64	26.77
Score of the use of references, max. 5 points	3.65	3.49	4.23
Final grade, max 5	3.04	3.01	3.14

In Course B there were students from all class levels of LUT although the major part was first-year students. In each research group team there were 1 to 4 students that attended IL education. There were also students from different faculties attending this course. The class level did not show any significant correlation with the scores given for the use of references in the written report. Respectively, the proportion of those students who had attended the IL education in a team did not show a significant correlation with the scores given to the team. Neither could the field of study reliably explain any variation in the scores of students.

C. Classification of references

Course A teams who attended IL education used nearly twice as much academic references than teams that did not participate in it. On the contrary, research group teams used open web sources much less than the comparison group teams. The average number of references in the research group teams' reports was 23 while the comparison group listed an average of 26.5 references. This is presented in Table 5.

TABLE V. CLASSIFICATION OF REFERENCES

Classification of references, per cent of all referred sources				
	Course A		Course B	
	Research group	Comparison group	Research group	Comparison group
Academic sources	38	20	22	4
Open web sources	23	44	53	65
Average number of references	23	26.5	20.3	15.6

In case of Course B, research group used significantly more academic sources than comparison group. All teams used a lot of open web sources but the research group, however, used them less than the comparison group.

The average number of references in case of Course B research group teams was greater compared with the

comparison group as shown in Table 5. However, teams that had (one or more) students attending ILI had less references in their reference list in 56 per cent of cases compared with the teams which studied the life cycle of the same product and did not have any students attending the ILI. IL education may have affected the quality of the references and more information was gained from fewer references.

V. CONCLUSION

According to this interdisciplinary research, there are signs that IL education has, in addition to improved searching skills, some positive effects on undergraduate engineering students' research behavior and ability to write research papers.

Connection between the formulation of the research problem and the selected search words cannot be explained with a simple correlation of a relationship. Apparently, IL education does not solve the problem of limited knowledge of research methods and methodologies. However, IL educated students expressed more clear research problems than the comparison group students.

There are many factors other than IL education that have an impact on students' ability to formulate their research problem and research questions. Faculty teaching plays a key role in educating students to work in a scientific way. In this paper collaborating student teams' work was studied. It became obvious that e.g. team dynamics and different discipline knowledge backgrounds or former IL skills of individual team members have a considerable influence on the final result. Moreover, especially when students use other languages than their own mother tongue, their language and academic writing skills have a great influence on the final result.

A big challenge is to separate the students' own thoughts and ideas from the guidelines of seminar assignments given by the teacher and from IL education aspects.

Students tend to work as little as possible for a grade that satisfies them. Therefore, the time and effort students put to the assignments may sometimes be inadequate to gain a deep insight into the topic. IL education, at its best, can give students wider perspectives to their topic while it, at the same time, helps them find information more efficiently and thus save their time.

In its initial form, IL education gives students tools to find high quality information. However, the IL teachers face a challenge that they put too much emphasis on the scientific value of retrieved sources. According to the faculty teachers, the application in question determines the relevance of sources which can be high regardless of their scientific level. Even commercial documents can be highly relevant as well as interviews, emails etc. Both IL and faculty education should have a common goal: students need to learn to discuss the topic via referred sources.

Both of the faculty teachers involved in this research seemed to appreciate the work of those students who attended IL education. This can be seen in the distribution of final grades although not all the discovered figures showed better success in completing the tasks, some even vice versa. This phenomenon would be worth further studying.

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Drafting a Code of Ethics for Engineering Education

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Abstract—Some within the engineering education community have asserted that engineering education should be considered a profession. While the formal meaning and identifying characteristics of a profession are debated, in general an individual that is considered professional meets at least three criteria: recognized expertise drawn from a widely accepted body of knowledge, accepted norms of professional behavior, and adherence to codified ethical standards. This paper addresses the third of these issues by exploring canons that could and should be contained within an engineering education code of ethics. To develop the framework for a code of conduct, published ethical codes from four professions—engineering, education, law, and medicine—were analyzed for both content and structure. Both areas of overlap and divergence within the codes were identified. From the areas of overlap between these professional canons a draft code of ethics for engineering education was developed and is compared with the recent American Society for Engineering Education code of ethics. The development process and resulting draft are presented to stimulate larger discussion within the engineering education community around purposes for engineering education.

Keywords—ethics, ethical code, profession, professional

I. INTRODUCTION

Editorials on engineering education have made the claim that it is becoming or should be a discipline [1], or at least a field of scientific inquiry [2]. For the purposes of argument, this paper will posit that engineering education is: 1) a discipline, 2) a professional activity, and 3) distinct from other disciplines an engineering educator may also belong to such as mechanical or civil engineering.

The origin of the word “profession” comes from the Latin for public declaration and was first used in the Middle Ages in a religious context, but over time its meaning evolved to encompass the occupation one professes to be skilled in, an implicit acknowledgement of expertise, and those who are skilled in that occupation. The word “professional” is also used in a vernacular sense to distinguish experts from amateurs, e.g. in sports. Thus a professional has a high level of technique that distinguishes her or him from amateurs. Furthermore a professional is expected to behave as a professional both on and off the field. Technique and behavior set the perceptions of a profession. For example mental images of a physician may suggest dress and work environment. Professional codes often address image and identity either implicitly or explicitly [3]. Many fields seek the designation as a profession for the status and independent governance it brings.

Beyond competence and behavior, a profession is also defined by ethical standards that are freely accepted by those who choose to be members of the profession. Davis states that “ethical standards, not standards of competence or organizations, seem to distinguish professions from other skilled occupations” [4]. Part of being a member of a profession is to agree to abide by that profession’s ethical code. Kallenberg [3] has outlined five ways that a code of ethics supports professional identity.

For engineering educators to distinguish themselves as a profession they must meet the three criteria of: the existence of a common body of knowledge that defines expertise, expectations of behavior that distinguish one from others in society broadly, and ethical standards. While a body of knowledge does exist [5], not all engineering educators subscribe to it in a way that affects their practice. Society does expect certain behaviors of university faculty. Similarly a code of ethics was recently approved and published by ASEE.

This paper investigates the adequacy of ASEE’s engineering education code of ethics by broadly exploring published professional codes in engineering, education, law, and medicine; categorizing canons common to these professions into nine topics; and comparing these to the code of ethics produced by ASEE. Areas of overlap and divergence between canons led to a synthesis that was used to draft a code of ethics for engineering education that addresses canons of professionalism the ASEE code fails to capture. The draft code is explored from a pragmatic standpoint using Kallenberg’s five lenses [3] and from a standpoint of practice using Hoyle’s definitions of extended and restricted professionalism [6].

The act of drafting a code of ethics both frames a moral ideal and acknowledges that engineering education has specific knowledge requirements from which a consensus for how that knowledge should be used needs to emerge [4]. Clearly the authors cannot speak for all engineering educators on what the ideals of our discipline should be. Therefore the intent of this paper is not to present a code for immediate adoption, rather it offers tenets that provide centers of dialog, stimulating discussion within the engineering education community around issues of professional identity. A code of ethics may also be useful for illuminating tensions inherent to the multiple roles assumed by engineering faculty.

II. EXPLORING PROFESSIONAL ETHICAL CODES

While there are many career paths that claim to be a profession [7] in this study we analyzed ethical codes from engineering, education, medicine, and law. The inclusion of

engineering and education are obvious. Medicine is included due to the emphasis on the physician-patient relationship which may provide insights into ethics of student-teacher relations. Similarly law was included since the law is a living body of knowledge that is continually reinterpreted by the legal profession much in the way the engineering state of the art is constantly evolving and needs to be reinterpreted by educators. Codes of ethics from representative professional organizations including engineering (NSPE, IEEE, ASME), education (NEA, English Government, ASEE), law (ABA), and medicine (AMA) were analyzed and the canons grouped into similar broad categories.

The structure of codes varies between professions. While engineering and education codes typically consist of an extensive list of statements that serve as canons, law and medicine define a smaller number of overarching canons which are expanded upon by lengthier, contemporary written opinions. Here we focus only on canons, ignoring opinions. These canons were sorted into nine broad, inclusive topics that are common between most codes, and listed in Table 1. Table 1 also compares similarities and differences between canons of the four professions within these topics.

The overlap of canons with the nine topics is imperfect. Multiple canons may address aspects of one topic or one canon may overlap with multiple topics. Furthermore each profession's canons emphasizes some topics more than others. In addition, most codes have a preamble stating the larger ideals of the profession that the code of ethics serves to support. In the case of engineering the ideal is public welfare or quality of life, in education human dignity and truth, in medicine patient care, and in law justice.

The ASEE board of directors has recently published a code of ethics [8]. The preamble states those members who perform professional work in a technical discipline serve the ideal of public welfare. The code lists fourteen canons that closely align with canons of other engineering codes. Ten of the fourteen canons of ASEE's code align directly with the topics listed in Table 1. The four exceptions are the first three canons of the ASEE code that define obligations members have for students to: understand ethical responsibility, work towards human welfare, and be aware of impact. The thirteenth element of ASEE's code partially aligns with topic (5), professional relationships, but also addresses the stipulation for fair assessment. ASEE's code does not address topic (9), while (1) is addressed through codes of another engineering discipline if the ASEE member does technical work in that discipline. It is not clear what ideals ASEE members follow if they do not perform technical work. Furthermore, since nearly all canons of ASEE's code have correspondences in other engineering codes there is significant redundancy for those ASEE members who are affiliated with a technical engineering discipline. Finally, the close alignment with engineering codes results in ASEE's code failing to capture some canons of other professional codes relevant to education broadly

III. A DRAFT CODE OF ETHICS FOR ENGINEERING EDUCATION

The nine broad topics of Table 1 were used to draft an engineering education code of ethics. For each of the nine topics relevant canons were drawn from ethical codes from the four professions. The synthesized code is given below with canons listed in the same order as Table 1. A preamble outlines the ideals for the profession of engineering education.

Table 1: Topics common between professional ethical codes

Topic	Comparative Notes
1) Obligation for the greater good or public welfare	All explicitly address the greater good, but vary in definitions. Engineering codes put the public welfare above other concerns but do not define it. Medicine is focused more on individuals than the public at large with an emphasis on care, dignity, and rights. Education emphasizes the greater good least with a general statement of belief in the value of education. Law frames good through the lens of justice and places the profession at the nexus of upholding trust in a system of laws.
2) Relation to those outside the profession	Engineering and education treat individuals equally regardless of race, gender, or other factors. In addition the legal and medical professions are charged with providing access to professional services for all individuals.
3) Professional roles and conflicts of interest	Most professions give stipulations about avoiding conflicts of interest but otherwise implicitly assume the professional plays a single role. Law explicitly identifies multiple roles played by lawyers and addresses when these roles are harmonious and how conflicts between multiple roles are to be resolved.
4) Relations with those whom the profession serves	Engineering defines service to employers and clients while educators predominately serve students and to a lesser extent schools. Medicine allows the physician choice of whom to serve with the provision patients are cared for. Law serves clients, but lawyers also act as agents of the court and as private citizens have an obligation to serve justice.
5) Professional reputation, relationships, and responsibilities	All codes of ethics have an obligation to maintain the reputation and standards of the profession and report those whose acts or character are unprofessional. Engineering places the most emphasis on these and medicine the least. Engineering and education put some stipulations on behaviour towards others within the profession. Law additionally requires respect for the legal system and judicial process, as well as independent self-governance.
6) Professional competence	All discuss competence, but engineering places more explicit emphasis on boundaries of competence than other professions and how qualifications are represented. Some educational codes are highly specific.
7) Need for confidentiality	All codes address the need for confidentiality within the limits of law for those they serve. Both law and medicine go into detail in specific opinions that are ancillary to the main canons.
8) Need for continuing education	Some (but not all) engineering and education codes make explicit mention of the need for continuing education and the obligation to contribute to others' professional development. This is not a primary precept for lawyers, but physicians have an explicit commitment to continue their own education, medical and patient education more generally, as well as advance the state of the art.
9) Commitment to advocacy	Engineering and education codes discuss upholding societal values. Law and medicine have canons of advocacy in which medicine advocates for patient interests and law advocates for access to and fairness of justice, particularly for vulnerable members of society.

The Engineering Educator's Code of Ethics

Preamble: Engineering education has a large impact on the world, serving the ideal of human development through education and the ideal of truth through scholarship. Engineering educators respect the impacts culture and individuality have on these ideals. To serve these ideals engineering educators:

- 1) Recognize that engineers and engineering works may impact the world for good or for ill. Engineering educators strive to develop their own and students' capacity for moral purpose, serve as an example of human life lived well, and recognize the rights of others to define their own welfare and quality of life.
 - 2) Treat others fairly, support others' learning at all times, and honor differences between learners that arise through opportunity and culture.
 - 3) Balance responsibilities of the multiple roles they assume within the education system.
 - a. In the role of a teacher or mentor the engineering educator seeks to support learning, professional development, and enabling human thriving through education.
 - b. In the role of a scholar the engineering educator dedicates himself or herself to seeking truth and awareness of his/her own ideology.
 - c. In the role of an administrator, the engineering educator is guided by principles of fairness, justice, and compromise.
 - d. In the role of a patron, constituent, or client the engineering educator provides actionable feedback to improve education and helps support others' professional development.
- While most times these roles are harmonious, in some cases the engineering educator will face ethical dilemmas that arise from overlaps of these roles. Resolving such conflict requires both adherence to law and moral judgment, tempered with respect for colleagues and students, and the recognition that vulnerable populations may often lack a voice. The engineering educator acknowledges the tensions inherent in supporting individual learners and an educational system with limited resources while undertaking unbiased evaluation of learning.
- 4) Serve educational needs through:
 - a. supporting the needs of learners and upholding the rights of all individuals to an education with particular care for the vulnerable and disadvantaged;
 - b. recognizing the impact of credentials and the limitations inherent to measuring learning, and striving to improve how learning is assessed;
 - c. recognizing that learning occurs within a community and valuing the diverse expertise and contributions of their colleagues and the supports offered by the wider educational institution in which they function; and
 - d. building professional liaisons with others across the education system and those who employ engineering graduates.
 - 5) Uphold standards of professionalism in any role they play within the education system.

- 6) Balance their role as an educator with their role as an engineer by accurately interpreting state-of-the-art engineering theory and practice for learners and drawing upon the science of learning to effectively promote and support student development.
- 7) Act in ways that develop and hold the trust and confidence of others so as to support their role as teacher and mentor.
- 8) Seek to advance, apply, and integrate the state of the art in both education and engineering theory and practice and dedicate themselves to life-long professional development.
- 9) Recognize a responsibility to participate in activities that contribute to access to education, and seek changes to situations that are contrary to the best interests of learners.

In creating this code professional ideals were outlined in the preamble since Davis [4] points out that a code of ethics serves "...as a way a profession defines relations between those who want to serve a common ideal..." Adopting other ideals would necessitate changes to the code. To be useful codes need to be written for a given audience; the code above was written for engineering educators to acknowledge the ethical dilemmas potentially introduced by the multiple roles they inhabit. Kallenberg acknowledges that while any code of ethics must be imperfect, imperfect codes may be useful to trained professionals [3]. Such imperfections may be offset by extended written opinions such as those in law and medicine.

Kallenberg [3] points out that ethical code may be interpreted through five different lenses:

1. As an emblem that distinguishes the profession from others in society.
2. As guidelines to action written for those with sufficient expertise in the profession to understand their application.
3. As a covenant of behavior one must agree to in order to retain membership in the profession.
4. As centers of conversation that allow dialog around inevitable ethical tensions.
5. As a framework for what is ethically allowed in a profession rather than what is forbidden.

The code above is designed to the extent possible to serve these purposes. By adopting canons of care and advocacy from law and medicine the code serves as an emblem to distinguish the profession of engineering education from education and engineering more generally. As guidelines to action, the code frames responsibilities around assessment, social justice, and advocacy. As a covenant the code seeks to identify moral purposes which engineering educators can freely commit to. As a center of conversation the code acknowledges ethical dilemmas that may arise from role conflicts in order to stimulate dialog. The code is furthermore written to define and promote behaviors rather than proscribe them.

IV. RESTRICTED VS. EXTENDED PROFESSIONALISM

The draft code of ethics presented previous was drafted to stimulate dialog on one element that engineering education requires to be considered a profession. In a larger sense what does it mean to be a professional? Since a code of ethics is designed to guide behaviors, in crafting the code we consider whether engineering educators are or should be "restricted" or "extended" professionals, borrowing from Hoyle's definition [6]. A restricted professional is one who relies primarily on

their own insights and intuition developed through their day-to-day experiences. An extended professional is guided by the theory underlying their experiences and approaches problems using a more rational and scholarly approach. For example from a historical perspective the 1955 Grinter report [9] defined the ways engineering should be taught to align better with expectations of an extended profession.

Table 2: Restricted vs. Extended Professionalism in Engineering Education

Restricted professionalism in engineering education	(#)	Extended professionalism in engineering education
Instructional skills derived from experience	8	Instructional skills derived from mediation between experience and theory
Perspective limited to immediate time and place	1,3,4	Perspective embracing broader social context of education.
Lecture room and laboratory events perceived in isolation.	4c,7	Lecture room and laboratory events perceived in relation to institution policies and goals.
Introspective with regard to methods of instruction	8	Instructional methods compared with those of colleagues and with reports of practice.
Value placed on autonomy in research and teaching.	4d	Value placed on professional collaboration in research and teaching.
Limited involvement in non-teaching professional and collegial activities	3	High involvement in non-teaching professional and collegial activities.
Infrequent reading of professional literature in educational theory and practice.	8	Regular reading of professional literature in educational theory and practice.
Involvement in continuing professional development limited and confined to practical courses mainly of a short duration.	8	Involvement in continuing professional development work that includes substantial courses of a theoretical nature.
Instruction (teaching) seen as an intuitive activity.		Instruction (teaching) seen as a rational activity.
Instruction (teaching) considered less important than research.	3	Instruction (teaching) considered as important as research.
Assessment is a routine matter. The responsibility for achievement lies with the student	4b,c	Assessment is designed for learning. Achievement is the co-responsibility of the institution, instructor (teacher) and student.

An interpretation of Hoyle's definition [6] for engineering education is provided in Table 2. The alignment with canons of the draft code are shown in the middle column of Table 2 with the numbers corresponding to the numbered points in the code of ethics on the previous page. This distinction between restricted and extended professionalism may help complement the ethical code in several ways. First, while a code of ethics defines what it means to be considered a member of a profession, Table 2 indicates the extent of professionalism and thus may serve as a basis for extended, written opinions like law and medicine have adopted. Second, such a table provides practical guidelines for action and further centers of conversation [3]. Third, Table 2 can serve as an emblem to better distinguish engineering education professionals from engineers or educators more generally.

V. CONCLUSIONS

The code of ethics drafted from common canons of four professions was created for several purposes; to stimulate dialog around engineering education as a profession and to serve as a foil for the ASEE code have already been mentioned. Other questions arise in the application of an ethical code. For example what implications does an ethical code have for technique (pedagogy), and how might engineering education sanction those who are somehow deemed to behave unprofessionally?

There are additionally questions of professional identity [10] that the code raises explicitly. These are highlighted as tensions within the code to highlight that they need to be navigated consciously and explicitly, a question the current ASEE code does not address. These questions of the identity of faculty members are in some ways microcosms of the identity crisis of universities at the present time. As the role of the university in society and the economy has changed over the past decade, these questions of identity loom large. Regardless of economic function and any utilitarian role of a university, a code of ethics stipulates that there is also a moral imperative in claiming to be an educator that transcends this context. This code's canons of advocacy, social justice, and the defining ideals of truth and human development make these explicit. A code of ethics that is well designed should help individuals navigate such dilemmas.

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Competencies for Paradigm Shift “Survival”

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Abstract—The rapid development in the IT area brings a series of shifts, in underlying theories, technology and work practices. In the normal course of events, most changes are evolutionary, with small, incremental improvements being made to theoretical understanding or practical application. Occasionally, however, changes occur of such magnitude that they do not just alter current operational practice but require a thorough reappraisal of the underlying assumptions on which that practice is based. In short, they require a review of the dominant way of thinking, or paradigm. Ability to adapt to evolving circumstances is critical, not only for industrial and commercial organisations, but also for individual employees, to survive and remain successful during paradigm shifts.

How can we prepare our students so they can survive in a working life characterized by frequent paradigm shifts? It is important that CS and IT education prepares students for coping with shifts induced by technological development in their future careers, that students develop the competencies needed. To understand what competencies are needed, it is important to investigate characteristics among employees that have flourished in earlier paradigm shifts and not least to build knowledge on how to develop learning environments where such competencies and personal characteristics can be achieved. This paper is about setting the stage for an action research project aimed at enhancing education with regard to being able to survive paradigm shifts in the IT industry.

Keywords—*paradigm shift; action research; competencies; capabilities; learning environments; adaptability*

I. INTRODUCTION

Adaptation to evolving circumstances and continual management of change are critical features for success in industrial and commercial organisations. In the normal course of events, most changes are evolutionary, with small, incremental improvements being made to theoretical understanding or practical application. Occasionally, however, changes occur of such magnitude that they do not just alter current operational practice but require a thorough reappraisal of the underlying assumptions on which that practice is based. In short, they require a review of the dominant way of thinking, or paradigm. These are “paradigm shifts” in the Kuhnian sense [1] - changes in the “constellation of concepts, values, perceptions and practices shared by a community, which forms a particular vision of reality that is the basis of the way a community organises itself” [2] - and their arrival signifies a period both of creative opportunity and cultural tension and disruption.

We will use the concept of “paradigm shift” in this sense, i.e. one that signals a need for changing fundamental

assumptions about working practices, where previous knowledge and skill sets lose significant amounts of value or, in extreme cases, are made completely irrelevant. It might be argued that this term is being applied too loosely when used to describe the case where IT development puts severe strains on industry and education. However, we argue that the concept of a paradigm shift is appropriate to capture a situation where some of the more technology specific knowledge and techniques that students learn at universities are often already outdated when they obtain their first job, and where employees might find their current skill set to no longer be a valuable asset when new technology is introduced.

Examples of what we see as paradigm shifts in the IT Industry brought on by technological advances are the advent of the Internet and the World Wide Web [3], the introduction of the PC [4], open source [3, 5], and the emergence of new programming paradigms such as object-oriented programming [6] and concurrent programming [7]. Other recent technological advances that have this potential are the development of cloud computing infrastructure and smart devices like mobile telephones and app technologies. That the IT industry has been through a number of these dramatic changes in a short period of time should not be seen as a reason to view this as something less than paradigm shift, or to not take the consequences seriously. The fact that IT companies need to pursue new trends or be quickly overtaken by rivals can be illustrated by examples such as Facit [8] and Nokia.

One potential strategy for coping with such change within a commercial environment is to replace experts in the old paradigm with those who more fully grasp the implications of the new one. However, this would lead to other problems such as critical loss of domain knowledge. Even though new employees may have expert knowledge concerning the new technology, they may lack an understanding of the application domain and tacit knowledge of how the company works. This is due to an increased need to understand the environment in which the IT-system is to be used in addition to knowledge of the latest technology. We will consider this deeper integration into a company as a non-technologically driven paradigm shift. An example of a non-technologically driven paradigm shift is radically increased demand to be able to interact in a wider context, e.g. internationally, across disciplines, and with society at large. From a business perspective, therefore, when paradigm shifts occur, it is of vital importance to maintain some degree of continuity in the core area and have individual employees who can quickly learn and adjust to new situations with new technology or due to changes in work practices.

'Learning to learn' is a competence likely to be important in coping with paradigm shifts. This is also supported by research indicating that competence development will largely be met through employees' own efforts. This is illustrated in a study that indicates that only 10-20% of learning in companies takes place in an organized manner [9]. Other research studies of learning in workplaces have been carried out by e.g. Mittendorf et al. [10], Xiao et al. [11] and James-Gordon and Bal [12]. Much of this research has focused on how companies and organisations can create the conditions for learning [13], which is relevant for the individual's ability to cope with paradigm shifts. We have however not found any work specialising on which competencies for such adaptability are required of the individual or what competencies are required for paradigm shift survival.

The purpose of this paper is to set the stage for an action research project aimed at enhancing education with regard to being able to deal with paradigm shifts in the IT industry. The research questions underlying the work presented in this paper are:

How should a study be designed to investigate what competencies and characteristics an individual IT professional needs in order to cope with paradigm shifts?

and

How can educational settings be constructed to better prepare individuals for a working life with frequently occurring paradigm shifts?

The paper starts by discussing the relevance of the research questions from different perspectives. The impact paradigm shifts have on society is discussed after which research areas of special importance in performing the action research project we propose is presented. There are three such areas, 1) Competencies, 2) Personality, and 3) Learning environments. The paper is concluded with a suggested study design and some conclusions.

II. IMPACT ON SOCIETY

The IT sector represents a significant part of any modern society. For instance, a country such as Sweden has historically built much of its welfare on high technology industry where IT has emerged as a major actor in the last few decades. On the Swedish IT & Telecom Day 2013, organised by the trade and employers' organisation, IT & Telecom Industries, competence (expert) provision was voted to be the industry's key question [14]. There are, therefore, good reasons for studying paradigm shifts in the IT industry, since successful strategies for surviving and taking advantage of these changes are vital. Previous research has pointed to the fact that paradigm shifts might be problematic even for experienced professionals [15, 16].

An unspoken requirement is that individual employees in the IT industry manage to keep abreast of technological developments and, when necessary, learn new technologies [16]. This is visible in different codes of ethics for professional engineers, e.g., IEEE's [17], saying that members agree to maintain and improve their technical competence. This applies

to all employees, including recent graduates. Employees who do not manage to cope with knowledge paradigm shifts will find themselves outpaced by younger or more flexible colleagues. From the company's perspective, rapid turnover in the workforce will mean a loss of general competences and knowledge of the company. It is thus vital for IT companies that their employees can cope with knowledge paradigm shifts.

Due to rapid technological developments, certain technical aspects of a university education might be already outdated at graduation and, consequently, it is necessary for individual professionals to be able to learn new technologies and cope with constant changes in their working lives. Indirectly this means that universities must provide IT students with the competencies needed to cope with such knowledge paradigm shifts. Given this, we suggest that there is an urgent need to investigate the nature of these individual competencies and how educational settings, at universities, in the industry, and individually composed, can provide individuals with appropriate learning experiences in order to develop them. Indirectly this is for the good of a society where IT companies can continue to develop and successfully compete internationally, and adaptable individuals continue to thrive in the face of technology changes.

III. THE COMPETENCIES ASPECT

There is an increased attention to competencies other than purely technical, e.g. as seen in [18, 19, 20]. There is still confusion about what constitutes a competence and the Definition and Selection of Competencies (DeSeCo) project [18] is an effort to aid in understanding competencies in general and place them in the European context. A competence in the DeSeCo project is viewed as knowledge and the ability to deal with complex situations in particular contexts. They further state that what they define as a key competence must:

- Contribute to valued outcomes for societies and individuals;
- Help individuals meet important demands in a wide variety of contexts;
- Be important not just for specialists but for all individuals.

The key competencies belong to three broad categories: being able to use tools for interacting with the environment, being able to engage with others in heterogeneous groups, and being able to take responsibility for one's own life in a broad social context and act autonomously. Important in all categories is the ability to think and act reflectively.

We have in earlier research addressed the competencies aspect in the learning environment area [21, 22], where for instance we have pointed out that there is a gap between what degree programs are supposed to develop in terms of competencies and what is actually covered in the course units comprising the program. There are several reasons for why this is the case, e.g. competencies are seen as being assimilated during education and they are not considered as measurable, and this paper addresses the issue of faculty not realizing what

competencies are, why they are important, nor how to help students develop these competencies.

In the proposed study, we will use a model of competence based on work by Graham et. al [23] and developed by us [24] in which we view a competence as being composed by knowledge, attitude, and skill. This is a model that has been useful in understanding different aspects of what is seen as a competence. There is also an aspect of this model that a person should show all three aspects in order to be seen as having the particular competence. This model also fits well with the idea of communities of practice [25], where each of these aspects can be used to explain why someone moves towards the center of a community whereas others remain on the outer as peripheral members.

The research study we propose is intended to provide understanding and evidence regarding competencies considered crucial to flourish in a fast changing environment. This critical importance provides a motivation to truly reform course units to have learning objectives that includes development of competencies. Such a study would also provide a base for understanding the nature of these competencies, which is a precursor for creating a learning environment in which to develop them.

IV. THE PERSONALITY ASPECT

We have earlier addressed the personality aspect in the learning environment area [26], where we point out research stating that perseverance is a strong predictor for academic success [19], e.g. a study showed that conscientiousness and intelligence were equally strong indicators for academic success in higher education and that they were independent of each other [20]. A study by the Department of Education in the US points out that grit, tenacity, and perseverance are critical factors for succeeding in the workplace in the future [32]. Another study states that conscientiousness is central to the intra-personal competency, which is identified as being highly important for life in general as well as in the work place [33].

There is no doubt that an individual's personality also is a factor when it comes to survival in paradigm shifts. There are strong reasons therefore to take personality into account when studying how individuals cope, partly to get a more holistic view and partly as an indicator of what to address in creating learning environments aiming for preparing students better for coping with paradigm shifts.

There are many issues to consider if personality aspects should be studied. One is which instrument to use when finding out more about the personality of persons. The Five-Factor model [27] is the basis of some of the most commonly used instruments. The name derives from capturing the behaviour as belonging to five more or less independent general personality characteristics; Extraversion, Neuroticism, Openness to experience, Agreeableness, and Conscientiousness. These are defined as subsuming more low-level characteristics, e.g. being strong in conscientiousness is associated with self-efficacy, organisation, cautiousness, self-discipline, and persistence. There is also work that suggests that it would be more interesting to look at personality types and characteristics at a

finer granularity [29], e.g. academic tenacity [30] and grit [31] in the academic success case.

Another aspect to consider is how to capture the personality shown in the work situation in question and also that personality also changes over time, e.g. as a person gets older it is common to mature and in that process score higher in emotional stability (lower in neuroticism), agreeableness, and conscientiousness [28]. That personalities can change is a reason to consider how that could be integrated into education, how educational institutions can foster paradigm shift survivors.

V. THE LEARNING ENVIRONMENT ASPECT

An essential outcome of an action research project such as the one we outline below is that identification of competencies and characteristics will provide important insights for creating educational settings that better prepare individuals for coping with paradigm shifts (as well as ordinary development). A better understanding of which competences and characteristics are important for individual success in a paradigm shift, will form a basis from which recommendations can be drawn for setting up and improving learning environments that help individuals develop in that direction.

There is a gap between what the industry needs short term and what we are supposed to prepare our students for long term and there is also a gap between what is stated as general learning outcomes from degree programs and the learning outcomes of individual course units. We argue that these gaps are partly due to faculty and education developers not having a vocabulary to express competencies and personal characteristics in terms of education, which also leads to students not being familiar with these concepts nor motivated to take them seriously if addressed in a course unit. Breaking up a degree program into a set of rather small course units also undermines development of perseverance as such.

In [34] we reason about development of competencies in terms of a model based on Stahl's model of collaborative knowledge-building. We will here give a short summary. Stahl's theory draws on organizational learning [35] and communities of practice [24] and is attempting to:

"... understand learning as a social process incorporating multiple distinguishable phases that constitute a cycle of personal and social knowledge-building. The cyclical character of this process allows increasingly complex questions to be posed on the basis of more and more sophisticated understanding". [36]

We intended the model to be used to help build a foundation to describe how development of competence is related to a social context. A key element in Stahl's model is social knowledge construction where discussion and analysis leads to formation of a shared communal perspective. This crucially depends on individuals being capable of clearly

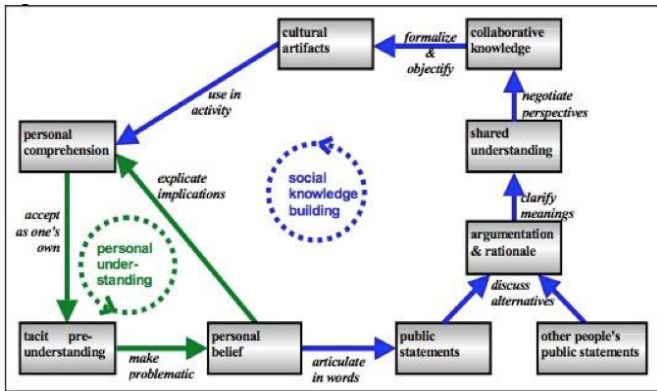


Fig. 1. Stahl's Model of Collaborative Knowledge-Building (from [36], p. 3).

articulating views and insights. Lack of clarity or completeness as well as issues with not valuing what each other contributes will lead to limited analysis and rigour of the subject matter. Such deficiencies hinder creation of shared understandings of the subject and thus leads to difficulties for collaborative knowledge-building. Artefacts created under poor conditions will have limited usefulness and will thus be hard to use to build group identity. The cycle described in figure 1 relies on a high quality of reflection and perceptions of value.

The basic idea in Stahl's model, see figure 1, is that tacit pre-understanding is the foundation of personal knowledge [37] and that this leads to individual and collective understanding which shape how we perceive the world. Sometimes elements of these understandings conflict with experience [38]. Dealing with this conflict is part of the process in this model that eventually leads to new tacit understanding, from where new understanding and learning can start [36]. For us, an interesting aspect of this model, apart from describing a learning process, is that it captures interaction between an individual and others, including use of artefacts.

Of particular interest is the key role a shared language plays. This fits well with our ambition to identify and describe competencies and personal characteristics useful in paradigm shifts in order to integrate them in a learning environment. This is also consistent with the model of competence where it is seen as consisting of knowledge, attitude, and skill. Competencies are mostly applied in interaction with others, which makes this model particularly useful as a base to develop learning environments suitable for development of these competencies.

We see this model as a means to create a common understanding of how to design learning environments which include development of competencies and personality traits among the students that will better equip them to manage in an environment with continual paradigm shifts.

VI. PROPOSED ACTION RESEARCH PROJECT

We will now outline a design for a study that aims at enhancing university educations when it comes to fostering future employees that are equipped to survive and maintain their productivity in paradigm shifts. The study is based on the idea of studying employees that are regarded as having coped well with at least one paradigm shift to identify important competencies and personality traits. The discoveries can then be used to design learning environments that promote development of these.

The authors of this paper have positive experiences from Action research [39, 40] and suggest that a study should be based on this methodology. This is especially true for the aspect of setting up suitable learning environments. We propose to precede the first action research cycle with a gathering of information phase. The intention of this first phase would be to conduct a fuller literature study, including establishing a definition of what we mean by paradigm shift, competence, and personality in this context.

The first action research cycle is mainly focused around an industry study where information is gathered from selected employees. The preceeding literature study should influence how the investigations are carried out. Potentially useful methods to gather information are semi-structured interviews and questionnaires/instruments based on these interviews. The topics to cover in the interviews, and later in the questionnaires/instruments, will be decided based on an initial study of potentially interesting areas regarding a person's ability to cope with a paradigm shift.

Employees selected for the study should be those that are regarded as having coped well with at least one paradigm shift. Care should also be taken with regard to selection of companies and organisations to study and we suggest that this could be influenced by first identifying which paradigm shifts to look for. Choosing a set of paradigm shifts to look for will help identifying relevant workplaces to study and also provide a basis for comparison. We believe that large companies will, at least in the initial stages, be the ones most relevant to study, but still suggest that also smaller companies should be approached in order to capture a potentially different set of needs. We further propose that large companies and organisations should be approached through their human resource division as these will be helpful in identifying relevant employees to interview and also, subsequently, to distribute questionnaires/instruments. They are also the ones most likely to understand the concepts of competence and personality. We also advise to collaborate with relevant employer's organisations, e.g. Almega [14], in order to both identify companies and find appropriate contact persons within relevant companies.

The stage of conducting semi-structured interviews and sending out questionnaires would be among the early stages in the first action research cycle along with identifying the focus to use. The middle stages of the first cycle should be to evaluate the interviews and questionnaire responses followed

by identifying the general findings. We further suggest that each research cycle should be concluded with a workshop where researchers, and other potentially relevant parties, discuss the findings and plan for the upcoming cycle. Then, in subsequent cycles, the research question can be refined based on the findings in the previous action research cycle and investigations in the industry can be repeated with the refined questions.

This could be seen as an action research study of its own, but we propose that this industry study will be extended, starting from the second cycle, by identifying actions leading to the development of learning environments. The reason to wait until the second cycle would be that information about competencies and personality gathered from the workplace will be available at that time. We propose that this new “thread” should be based on the Stahl model and a model of what a competence is that is based on our previous work on competencies [24]. This is a model where a competence is seen as being composed of three interrelated parts, i.e. knowledge, attitude, and skill. This will allow the capturing of different aspects of what a competence is and to form a clearer understanding of how a competence can be developed in an educational setting. Issues to study in this “thread” should include studies on how the identified competencies can be addressed in education. The intention of the full action research cycle would be to both identify relevant competencies and develop recommendations on how they can be developed in different educational settings, e.g. at universities, companies, and for individuals, and in different formats, e.g. traditional courses, training events, and distance courses (including Massive Open Online Courses - MOOCs). This setting can continue with several new cycles, where we believe that the identifying part will diminish over the cycles and the educational aspects take over.

The intended goal with this proposal is to raise awareness of the value of the competencies and personality traits that are identified as important in coping with a paradigm shift and especially to promote an understanding that these competencies and personality traits can be developed.

VII. CONCLUSIONS

We have identified the individuals coping, or survival in paradigm shifts as an area where further research would be highly valuable and outlined a study design aimed at addressing this area. This paper and other earlier work by the authors provides a first base for engaging in such research. It is also our firm opinion that conducting a study of the type we outline would be beneficial for education developers and teaching staff for achieving broader learning objectives.

Another benefit should be to gain a better understanding regarding paradigm shifts in the workplace, which could be costly if not fully disastrous for a company or organisation. The outlined study involves both academics and industry representatives thus creating an environment where results

from this study can reach the workplace faster than the traditional route of educating new students how to survive paradigm shifts.

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Addressing the Problem of Mal-employment of Liberal Arts Graduates

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Abstract— Unlike technical graduates such as engineering and science, liberal arts graduates usually encounter difficulty finding jobs in their majors. A good percentage of them becomes under- or unemployed. This paper investigates and discusses an innovative approach to address this problem. We provide these students with an accelerated 12-month certificate in advanced manufacturing to help them apply for manufacturing positions. The paper discusses the design and content of the certificate.

Keywords—*Mal-employment; liberal arts graduates; advanced manufacturing; mfg. technology; mfg. innovation*

I. INTRODUCTION

The mal-employment, occurring in the first job, of liberal arts majors is well known and documented [1, 2]. Liberal arts graduates are either under- or unemployed. This hinders their full contribution to society; prevent them from reaching their full potential, and making it hard for them to pay back their students loans. There are many current efforts to encourage students to pursue STEM pathways, but very few programs focus on pathways for cross-disciplinary workforce integration.

This paper presents a model to transform liberal arts graduates to seek jobs in advanced manufacturing, a current field with plenty of jobs that go unfilled each year as manufacturing makes a comeback in the US. The model targets the intellectual and creative talents of recent BA (Bachelor of Art) graduates coupled with internships and skill development.

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The model is centered on offering a fast-track 12 month certificate in advanced manufacturing coupled with internships to prepare BA graduates for career in advanced manufacturing and empower them to compete successfully for manufacturing jobs. BA graduates are viewed as well-rounded individuals with many desired skills. They lack only technical skills. By offering a certificate in manufacturing, they should be ready to join the manufacturing workforce.

II. CURRICULUM DESIGN

The curriculum is a 12-month stackable curriculum in advanced manufacturing. The curriculum has two tracks: manufacturing technology and manufacturing innovation. The manufacturing technology track is for those BA graduates who are interested in day-to-day manufacturing activities and operations. The manufacturing innovation track is for those BA graduates who have the entrepreneurial spirit and would be interested in creating a startup.

The certificate is designed to be 25 semester hours, so students are eligible for financial aid if needed. Students will take a full load (12 semester hours) during summer and fall semesters and complete their co-op internship during the spring semester before graduation.

Each track has required core and elective courses to provide students (BA graduates) with flexibility to customize the curriculum to their personal background, needs and goals. The curriculum details for the two tracks are shown in Tables 1 and 2.

Table 1 Manufacturing track curriculum

	Core courses	Elective courses
Summer Semester	Total of three courses (9 SH): 1. MN121 Mechanical Detailing 2. MN130 Engineering with CAD I 3. NC Programming (<i>new</i>)	Total of one course (3 SH): 1. MN135 Engineering Design with CAD II 2. Applied Computer Science CS 101 class (<i>new, modular course</i>) 3. Career-Readiness and e-Portfolio(<i>new</i>)
Fall Semester	Total of three courses (9 SH): 1. MN261 Animation Materials, 3D Modeling 2. MN140 Project Management 3. IE4530 Manufacturing Systems (@NU and @MBCC)	Total of one course (3 SH): 1. IE5620 Mass Customization (@NU and @MBCC) 2. SCHM2301 Supply Chain and Operations Management 3. SCHM3301 Global Supply Chain Management 4. MN272 Designing Plastic Parts 5. MN 251 Electromechanical Design 6. MN 125 Engineering Computation with Application Software
Spring Semester (Co-op)	1. Co-op dialogue (<i>new</i>)	

	Management 2. Manufacturing Systems (@NU and @MBCC) 3. Sustainability and Innovation (<i>new</i>)	(@NU and @MBCC) 2. MN 261 Animation, Materials and 3D Modeling 3. Career Readiness and e-Portfolio(<i>new</i>)
Spring Semester (Co-op)	1. Co-op dialogue (<i>new</i>)	

The tables for both tracks use this sequence: Classes → Classes → Internship instead of Classes → Internship → Classes. The selected sequence enables BA graduates to do internships during the spring semester instead of the highly competitive summer semester where many college students look for work.

III. COURSE CONTENT

The curriculum is designed to build on the valuable skills and knowledge that BA graduates acquire from their BA degrees. The curriculum is part of a collaborative program between Northeastern University (NU) and Mass Bay Community College (MBCC) in Boston, Massachusetts. A team from both institutions oversees the curriculum design and delivery. Some courses are new. All courses are offered at Mass Bay. Following is list of the courses and their focus for each track.

Manufacturing technology track:

Existing courses at MBCC

MN121 Mechanical Detailing – Uses SolidWorks CAD software and focuses on engineering drawings.

MN130 Engineering with CAD I – Uses SolidWorks and focuses on CAD part design and modeling.

MN135 Engineering Design with CAD II – Uses SolidWorks and focuses on assembly modeling.

MN261 Animation Materials, 3D Modeling – Create assembly animation and realistic rendering models.

MN140 Project Management – focuses on project management theory and use of MS Project software.

MN272 Designing Plastic Parts – focuses on designing Plastic Parts and mold design.

MN 251 Electromechanical Design – Uses SolidWorks to design electrical-mechanical components.

MN 125 Engineering Computation – Introduces students to engineering analysis using MatLab.

New courses at MBCC

CS 101 Applied Computer Science – project-based course teaching computational thinking.

Career-Readiness and e-Portfolio – In this course, students will have a chance to practice interviewing skills, create

Table 2 Manufacturing innovation track

	Core courses	Elective courses
Summer Semester	Total of three courses (9 SH): 1. Applied Computer Science CS 101 class (<i>new, modular course</i>) 2. MN130 Engineering with CAD I 3. Digital Communications (<i>new</i>)	Total of one course (4 SH): 1. MN 121 Mechanical Detailing 2. NC Programming (<i>new</i>) 3. Career-Readiness and e-Portfolio (<i>new</i>) 4. ENTR2301 Innovation 5. ENTR2305 Business Modeling for Entrepreneurs
Fall Semester	Total of three courses (9 SH): 1. MN140 Project	Total of one course (4 SH): 1. Mass Customization

resumes and electronic portfolios, and listen to industry speakers.

Co-op dialogue – This is a 1-credit hour course held in conjunction with the Co-op job experience. This course is an online course with well-organized discussions and topic based presentations. The course is augmented by face-to-face meetings once every month. As part of the course, Students are required to submit a report and create a portfolio.

Existing courses at NU

IE4530 Manufacturing Systems and Techniques – focuses on manufacturing and design.

IE5620 Mass Customization – focuses on manufacturing customized products at mass production prices.

SCHM3301 Global Supply Chain Management – Analyzes supply chain management operations.

SCHM2301 Supply Chain and Operations Management – focuses on management of business activities.

New Courses at NU

NC Programming: focuses on NC concepts for milling and drilling, and G- and M-code.

Manufacturing innovation track:

Existing courses at MBCC

MN130 Engineering with CAD I – see Manufacturing Technology track

MN 121 Mechanical Detailing – see Manufacturing Technology track

MN 261 Animation, Materials and 3D Modeling - see Manufacturing Technology track

MN140 Project Management - see Manufacturing Technology track

New courses at MBCC

CS 101 Applied Computer Science - see Manufacturing Technology track

Digital Communications – focuses on strategies for marketing/branding manufacturing products

Career Readiness and e-Portfolio - see Manufacturing Technology track

Co-op dialogue - see Manufacturing Technology track

Existing courses at NU

ENTR2301 Innovation – focuses on transforming innovation into commercial entities and start-ups.

ENTR 2305 Business Modeling for Entrepreneurs – focuses on business modeling for new ventures.

New Courses at NU

NC Programming - see Manufacturing Technology track

IV. CURRICULUM DELIVERY

The curriculum uses an innovative approach to deliver the above courses to keep liberal arts students interested and motivated. We develop course modules within each course and then cluster different modules to serve the students' needs and interests. For example, in the NC programming course we develop a foundation module (call it NC basics). Then, we offer modules that apply the knowledge gained in the foundation module to different contexts, e.g. machining metals, machining plastics, and prototyping artifacts. This helps liberal arts students stay attracted to the new discipline of manufacturing and preserve their love by mixing art and technology.

We also offer the program courses in dual modes: online and in class. Online courses will have weekly in class face to face meetings. Both NU and MBCC has the infrastructure to offer and support online courses. Both offer full degrees online. We work with the Manufacturing Institute (MI) [3] to recognize (accredit) the new proposed certificates into a badge, we call it M-badge. The MI has embraced the badging concept [4] and is leading the way in creating National Manufacturing Badges. Thus TRANSFORM participants can earn an M-badge representing their M-certificate, thus making their certificate recognizable at the national level by manufacturers.

V. ASSESSMENT PLAN

An evaluation plan of the program success will be conducted by an impartial external evaluator. Evaluation instruments include surveys and interviews with both the BA graduates participating in the program and the industry partners who provide internships for these graduates. Focus groups will also be conducted with BA graduates to seek their feedback on the program. Another metric to measure success is the placement of the program graduates and finding jobs after completing the certificate program.

VI. INTERNSHIP PROGRAM

The internship (co-op) program is modeled and developed after the flagship NU co-op experiential learning program, founded over a century ago. Now, it is one of the largest and most innovative programs in the world. Students alternate semesters of academic study with semesters of full-time employment in positions related to their academic/career interests. Co-op is closely integrated with course curriculum, scheduling, and an advising system. Co-op coordinators in each college provide support for students in preparing them for successful co-op opportunities.

NU leads the development of the internship and infrastructure program and helps implement it at MBCC [5, 6]. The program works with companies interested in partnerships, identify internship positions, formulate them into job descriptions, add them into an internship bank, and coordinate the administrative logistics for student placements.

VII. STUDENT SUPPORT AND ADVISING

In addition to creating a unique BA co-op program, we provide a unique advising and support system for the BA graduates for the two different tracks. The advising system addresses the following issues: (1) Smooth transition from liberal arts to manufacturing; (2) Advise on the two track options, and select the best pathway option; (3) Advise on course selection and schedule; (4) Advise on financial aid resources; (5) Develop technical and social programs to help student retention and motivation; (6) Develop an advanced manufacturing club; (7) Provide support and guidance for students who face personal problems or hardships; and (8) Use existing advising tools and software to keep track of student progress.

VIII. STUDENT RECRUITMENT

The recruitment efforts focus on contacting recent graduates in Massachusetts. Massachusetts enjoys a large presence of many public and private major universities and colleges that offer a variety of liberal arts degrees. We reach out to these universities and colleges in addition to reaching out to NU BA graduates and students from MBCC Liberal Arts Associates degree programs. This BA graduate population is of special interest to us because they have done co-ops already during their BA degrees. This offers us the added benefit of comparing the performance of other BA graduates who come from non-co-op programs against that of NU grads to shed some light on the success of the program.

We utilize social networking and career fairs to raise awareness of our program with our target audience. Also, we share program information with manufacturing firms already committed to new strategies that might address their employment needs.

Our activities to reach out and recruit BA graduates are as follows:

- Identify the targeted population by utilizing current institutional resources in addition to our regional employment boards

- Develop a flyer to be distributed to the target population in collaboration with career service departments at universities across the state
- Develop an online version of our recruitment activities
- Hold information sessions at NU and Mass Bay each spring for the following year program that starts in the summer semester
- Attend career and advanced degree fairs at Massachusetts colleges to share program information directly with potential applicants

We recruit 20 BA graduates per year each for three years from the New England area to test our model. Each of the three cohorts forms a class. We keep the class size small to be able to serve the students well and observe their transformation. We provide each student with a co-op job through the newly proposed co-op program.

IX. CONCLUSION

The paper presents an innovative new model to address the mal-employment of BA graduates. The model hypothesizes BA graduates have strong education and skills that help them make the transition smoothly to manufacturing careers.

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Implied Identity: A Conceptual Framework for Exploring Engineering Professional Identity Practices in Higher Education

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Abstract—Developing a professional identity, as an engineer, has been the focus of engineering educators. However, previous research illustrates a lack of an integrated framework that conceptualizes the process to explain how individuals practice professional identities and what are the relations between educational design and such practices. We respond to this by proposing a conceptual framework that applies two main concepts: 1) a new concept of *implied identity* to refer to different aspects of professional identity perceived by individuals during their experiences and 2) Archer's reflexivity, as an internal dialogue, that mediates between individuals and their social context. We discuss implications of the framework for empirical studies and its contributions to engineering learning and assessment. To illustrate, we draw on empirical data from engineering students' collaborative work and apply the framework to compare different aspects of engineering identity as practiced by two groups.

Keywords — *Engineering education, Implied identity, Professional development, Professional identity, Reflexivity*

I. INTRODUCTION

Universities are expected to prepare students for professional settings. Therefore educational designers are expected to develop learning environments, learning materials and learning activities that promote graduate attributes for work after graduation. Professional identity development is the focus of engineering education scholars to look at engineering learning within the broader frame of becoming an engineer [1-2]. Professional Identity is defined as an important outcome of engineering education and a mediator for other outcomes such as persistence in engineering [1].

II. REVIEW OF THE LITERATURE

Professional identity has mostly been studied based on psychosocial theories of identity to consider both one's own perception and social views of oneself. However, there are different approaches among scholars about how it could be conceptualized. In an attempt to understand professional identity practices in higher education, a line of research focuses on influencing factors that contribute to the process [2-3]. In a study by Meyer and colleagues engineering identity development is modeled using a stage theory from a developmental psychology view [2]. This study suggests three

factors for students' self-identification as engineers. These include making competent design decisions, working with others to share ideas and accepting responsibility.

Walther, Kellam, Schacka, and Radcliffe define engineering education as a complex system with a range of influences some of which are in practice outside the realm of explicit and formal instruction [4]. *Accidental competency formation* is applied in this study to investigate professional formation within engineering programs. The study invites scholars' attention to the conceptions of unintended learning and the notion of hidden curriculum as the things students learn during their informal experiences at university rather than through explicit teaching and learning events. We further note that learning also happens within the broader social context and outside institutional scope as well as through the things that are not included in explicit teaching.

To address how engineering professional identity is practiced, and unpack further how influencing factors are played out, studies have investigated micro level practices as in talk in interaction. Discourse analysis [5-6] and positioning theory [7] are among the approaches used to this purpose.

Among other approaches used in studies of engineering professional identity development is Lave and Wenger's notion of communities of practice [8]. Shaffer's idea frames engineering identity practices by drawing on this looking at professional identity practices as participation in a community of practice that involves developing community's way of doing, and being. According to Shaffer's argument, this practice is seen as an epistemic frame of the engineering profession composed of knowledge, skills, values, identity and epistemologies linked with the engineering profession [9].

In addition, Eliot and Turns describe engineering identity formation as an interaction between the engineering social expectations and characteristics of engineering students [1]. The results of the study show students engage in two processes of sense making, one related to external expectations and one regarding their internal abilities and values as engineers.

Existing research on professional identity practices in engineering education contributes to unfolding different aspects of the processes involved. However, it does not offer a holistic approach to the complex multi layered process of

identity practices to cover and explain both micro level practices of talk in interaction and macro level organizational processes. A broader review of professional identity development in higher education also suggests that further study is required to unpack the term of professional identity and to discuss its possible implications for higher education learning, teaching and assessment [10]. The following questions are still unanswered, as to how professional identity practices happen both within the realm of formal education and through educational design, as well as outside institutional practices and within a larger social context. And what are the mechanisms involved, for specific aspects of professional identity to be practiced by a specific person at the certain point in time.

In the next section we address these questions by proposing a holistic approach based on the social realism view to explain the process of professional identity practices.

III. IMPLIED IDENTITY: A CONCEPTUAL FRAMEWORK FOR PROFESSIONAL IDENTITY PRACTICES IN HIGHER EDUCATION

Scholars in the field often distinguish engineering professional identity practices as separate, external or overlapping processes to learning experiences. We look at engineering education through the lens of engineering identity development. Our definition of professional identity draws on Harre's concept of positioning [11]. Episodes of learning are defined as opportunities to develop a sense of belonging to a community of engineers. Students' learning and assessment experiences are therefore processes of professional identity formation practices through which students position themselves or get positioned by others as engineers.

To understand how such identity practices happen and how educational design could facilitate or hinder these practices, one should address the question of what educational design works invites one to be or to do or to think. Educational design includes anticipated learning events, learning spaces, and learning materials. We suggest the answer to this question lies in the concept of *implied identity*. It originates in the concept of implied reader, first introduced by Iser [12], which refers to a reader as presupposed by a literary text.

The new concept of *implied identity* refers to suggestions of professional identity to individuals through their experiences of identity resources, including educational designs. From a social realism approach, *implied identity* is an emergent property arising from the configuration of identity resources and students' interpretations of them. It may remain unexercised if a relevant identity resource is not experienced by an individual (i.e., an agent). Otherwise, it may hinder or facilitate specific aspects of professional identity in individual's practices.

Professional learning and identity development is a lifelong process shaping and re-shaping through individuals' experiences of identity resources both within and outside the realm of formal education. Professional identity practices emerge at the intersection of identity resources and agency including both individuals and collective. In the proposed view, individuals are seen as active receivers of socially offered *implied identities*. To explain how individuals respond to the perceived *implied identities*, we draw on the Archer's notion of

reflexive deliberation [13] and the emergentist theory of action [14]. Reflexive deliberation, which is at the core of Archer's definition of human agency, is an individual's internal conversation with oneself that mediates between individual and a social context. Reflexivity is firstly seen in contrast to Pierre Bourdieu's concept of *habitus* or socialized norms and tendencies that guide behaviors and thinking. However, Elder-Vass [14] proposes an emergentist theory of action that "explores how human dispositions and reflexive decisions are related to the determination of human action" (p. 1).

As illustrated in Fig. 1, individuals encounter identity resources with dispositions in forms of beliefs about who they think they are, identity concept, and who they want to become as their ideal identity. These dispositions are the result of individual's previous experiences. We argue that a person's professional identity practices are caused non-consciously by his/ her *habitus* if implied identity is compatible with individual's sense of self and his/ her ideal self. However, individual's responses to incompatible *implied identities* happen through reflexive deliberations, which in turn are mediated by their *ideal identity*, and *identity concept*.

In addition, we apply the term *intended identity*, to distinguish between identity as intended by educational designers for students and students' perception of suggested identities (*implied identities*). An example of educational *intended identity* is identity embedded within the list of graduate attributes assumed for engineering students.

The proposed framework extends on previous works (such as [1] and [4]). It proposes a more holistic approach that explains relations between educational designer, educational design works, and learners' professional identity experiences.

IV. STUDY AIMS AND METHOD

An empirical study was designed with the aim of investigating implications of the proposed framework and exploring if it provides a possibility to get an insight into the process of professional engineering identity practices during collaborative work. Here we draw on part of the study to take an in-depth look at two participant groups to address the following research questions: 1) What are different aspects of

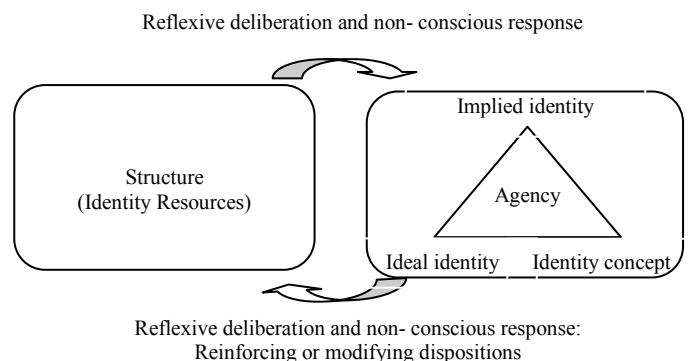


Fig. 1. Implied Identity, A Social Realism Approach to Professional Identity Practices

engineering identity practiced by the two groups of engineering students while working collaboratively on a sustainability task? 2) Is the proposed framework of implied identity explaining the differences between the two groups in terms of groups' decisions for practices of professional identity?

A. Data collection and research setting

Two groups of four undergraduate students of Chemical Engineering worked collaboratively on a sustainability task. A task was designed to address a problem of air pollution in mega cities and participants were asked to provide solutions and prioritize their solutions based on their proposed criteria list. Participants were asked to give a report at the end of their collaborative session. Group 1, consisted of international exchange students who voluntarily participated in the study. Group 2 experienced their participation as part of the course which is an elective subject in their degree. For this group, the collaborative task was one of the assignments, worth 20% of the students' total grade for that unit of study. The collaborative sessions were conducted at a special studio designed for group work, and were video and audio recorded.

B. Preliminary analysis

According to the proposed framework, assessment experiences are themselves resources for learning and identity practices [15]. Hence we look at students' participation as a learning experience and their collaborative work as a learning episode, which can be investigated using the implied identity framework. We identify two main identity resources for the analysis of *intended identities*: 1) the task description and 2) speech acts at the time of conversation. We further investigate students' responses to the task and its *intended identities*, and explore similarities and differences between practices of the two groups.

Audio transcriptions were qualitatively analyzed in NVivo to find practices of engineering identities. To explore aspects of engineering identities, we applied Figueiredo's model where engineering is seen to consist of four dimensions connected within a transdisciplinary relation [16]. These include: 1) engineer as scientist, 2) engineer as designer, 3) engineer as doer, and 4) engineer as sociologist. Sub categories were added according to the description of each category. As an example, using mathematical language and contextual thinking were added to the categories of engineer as scientist and engineer as designer, respectively. A new category was added for engineer as environmentalist to highlight concerns about the environment and sustainability.

V. RESULTS AND DISCUSSION

As the summary of preliminary results illustrate in Table 1, there are similarities between the two groups' professional identity practices in the four categories of engineers as designers, engineer as doers, engineer as environmentalist and engineer as scientist. However, the two groups differ in relation to their practices in the category of engineering as sociologist. In addition, frequency of identity practices differs between the two groups. As an example, Group 2 practice engineering as basic sciences more frequently and these practices cover about

24.34% of group's conversation as opposed with Group 1 with the coverage of 7.51% of their collaboration.

In this paper we focus on the difference between the two groups in the category of engineering as a social science and the subcategory of *education* and *engineering as educator* as one of the emerging differences. Group 1 rejects to see themselves, as engineers, responsible for promoting social awareness, while Group 2 two puts "educating people" in their report as one of their suggested solutions to tackle the problem of air pollution.

Applying the *implied identity* framework for further analysis and explaining the emerging difference, provides an opportunity to look at the *intended identities* and investigate how the two groups interpret the task, and *intended identities*. An identity intended by the researchers through the design of the task was to reflect upon social, ethical and cultural sides of the proposed solutions and to foster inclusion of these aspects in group's discussion and report. We argue that differences in groups' identity practices are the result of how the two groups perceive *intended identities* in the form of *implied identities* through their experience of the task and how they position themselves accordingly.

Members of Group 1 are pre-positioned as "participants in the study" by the start of the collaboration due to their voluntary participation. Once the collaboration starts and they read the task, members of the group re-position themselves as "engineers working in a company" by referring to the task statement "You are invited to join a consulting engineering team". They further continue reading the task and make group decisions based on their new positioning as engineers and their beliefs about who they think engineers in a company are.

However, members of Group 2 are pre-positioned as students in the course. They continue their collaboration in the same position of "students doing an assignment". This influences group's decision to follow steps of the task description more precisely presumably to have a better performance. The pre-positioning of being a student, results in paying no attention to the scenario explained in the task statement "you are engineers working in a company". Group 2 values elements of the task statement including suggested steps to follow in providing a report, such as "make sure you comment on the social and economical aspects" and "address ethical considerations as well as technological ones as part of your discussion".

In terms of the implied identity framework, the same identity resource, the task in this case, is read and interpreted differently by the two groups and proposes different *implied identities*, "being an engineer", to participants. The *implied identity* that Group 1 offers to themselves, which is assumed to be the ideal identity they imagine for "an engineer working in the company", is not engineers as educators. This in turn directs group's decision making in refusing practices such as "educating people and promoting social awareness". This illustrates how group's positioning practices and beliefs in relation to the taken position influences group's decision making. Previous research has also shown how positioning practices influence group's decision making [17].

TABLE I. IDENTITY PRACTICES

Dimension of Engineering	Group 1		Group 2	
	Number of utterances (Coverage)	With references such as	Number of utterances (Coverage)	With references such as
Engineer as Scientist	54 (7.51%)	Using mathematical language; Research and discovery; Analysis and experiment	70 (24.34%)	Using mathematical language; Research and discovery; Analysis and experiment
Engineer as Designer	25 (3.20%)	Contextual/ holistic vision; Intuition; Personal experience	15 (3.75%)	Contextual/ holistic vision; Intuition; Personal experience
Engineer as Doer	66 (7.82%)	Engineering artefacts; Changing the world	11 (3.14%)	Engineering artefacts; Changing the world
Engineer as Sociologist	78 (11.17%)	Management; Social nature of the world; Economic value; Ethics; Art	60 (17%)	Management; Social nature of the world; Economic value; Ethics; Education
Engineer as Environmentalist	10 (1.13%)	Sustainability	1 (0.10%)	Sustainability

^a Preliminary Results

As shown, applying the *implied identity* framework provides a possibility to gain an insight into the process of professional identity practices. It enables us to understand further layers of such complex process by uncovering relations between educational designs and learner's experiences of them. Furthermore, it enables us to look at multiple identity resources simultaneously including micro level resources such as talk in interaction and higher level organizational practices such as being a student or volunteer in the research and how these impact learner's experiences of the task.

We are interested to further investigate how the use of online resources in the two groups provide students with suggestions of engineering identity and how suggested identities are taken up and practiced by them. In addition, we are interested to explore how individuals' reading of the task is communicated between members of the group to gain a mutual understanding of the offered *implied identities* and how this helps a group to make decisions and establish agreement.

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Campus to Career, Understanding How Engineering Student Skill Perceptions link to Future Career Pathways

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Abstract— The National Academy of Engineering's *Engineer of 2020* (E2020) report identifies skills and attributes that engineering undergraduates will need to possess to find success in the engineering workforce. Our study seeks to extend prior research that developed typologies of engineering seniors based on a set of E2020 outcomes to investigate variation in career pathways across outcomes-based groupings of students. Student clusters range from those who self-report highest on each outcome and are the most well rounded (i.e., those who most closely resemble "the Engineers of 2020") to clusters characterized by 50% of the reported abilities of students in the E2020 cluster on different outcomes. In this paper, we examine how six clusters of mechanical engineering students perceive their future career pathways, evaluating the likelihood of students in each outcomes-based grouping to enter an engineering or non-engineering related career path. Findings shed insight on how students' perceived relative competencies on a variety of skills related to their career decision-making and/or views of possible careers. This work serves as preliminary analysis that we will extend across multiple engineering disciplines in our next steps.

Keywords— Pathways; Career; Engineer of 2020; Workforce

I. INTRODUCTION

Members of industry consistently claim that graduates of engineering programs are not prepared when they enter the workforce. Collaborations between members from academia and industry have offered insight into the skills that are needed to support the future engineering workforce. The Engineer of 2020 skills, identified by the National Academy of Engineering in 2004, offer one example of a set of outcomes that engineering graduates should possess to be prepared for industry positions in the future. As educators and employers respond to the President's call to dramatically increase the number of STEM graduates and workers [1], it is important to understand how student-perceived abilities of such outcomes impact their career pathways. By looking at students' perceptions of their skills and abilities versus their anticipated career pathways, we can begin to understand how skills translate to feelings of preparedness for different careers.

Efforts to minimize the skill gap (i.e. the notion that students do not graduate with the skills necessary for day one in the workplace [2]) have highlighted the need for higher education institutions to be more accountable in ensuring student outcomes are met, producing students with the skills necessary to be successful. For this study, we consider that the skill gap might exist because of mismatch

between student skill perceptions and anticipated skills for a particular career pathway. Students may be entering careers in which their skill set is not best fitted, so in response to a poor fit between the job and employee, employers cite the skill gap.

Prior research has taken a similar outcome approach to understanding student career pathways. The Academic Pathways Study and the Engineering Pathways Study has examined student perceptions versus anticipated and actual career pathways in a series of cross sectional and longitudinal studies [3-6]. These findings reinforce the need to further understand the extent to which students' perceptions of their skills impact career pathways.

We hope to contribute to the skill gap literature by shedding light on the fact that a student's self perceived set of skills relates to their career decisions. With this information, we will be better able to determine how we may need to change conversations about what careers entail or how we structure education to change sets of outcomes to better inform students of how their skills map to various career paths. In this study, we identify career pathways as engineering, management/sales, and non-engineering roles post bachelor degree. Also, graduate school with plans to enter faculty, industry, or professional schools are considered potential pathways. This study extends prior research that developed a typology of engineering undergraduates based on a set of E2020 outcomes and investigates variation in career pathways across those groupings of students. This research is a work in progress, and our ultimate goal is to investigate patterns across engineering disciplines.

II. METHODS

A. Data

Drawing on data from the Prototype to Production: Processes and Conditions for Preparing the Engineer of 2020 (EEC-0550608) project sponsored by the National Science Foundation, this study utilizes undergraduate survey data from a nationally representative sample of engineering programs in the United States. Students provided information on their precollege academic preparation and socio-demographic characteristics, curricular and co-curricular experiences, and self-ratings of their engineering-related competencies.

B. Data Collection, Preparation, and Sample

Students were enrolled in a thirty-one institution sample, which were selected to be representative in terms of engineering discipline, highest degree offered, and institutional level control. Because the study seeks to understand the preparation of mechanical engineering students at the point at which they would be ready to enter the workforce, our analyses include only mechanical engineering students in their 4th or 5th years ($n = 771$; the senior response rate was 16%). To account for response bias in an effort to enhance external validity, weights were developed and applied (e.g., [7]) so that the proportional representation of students by gender, race/ethnicity, and discipline within each institution was equal to the population of students at each institution (e.g., a different gender weight was applied for each institution). Weights were also applied to account for differences in institutional response rates.

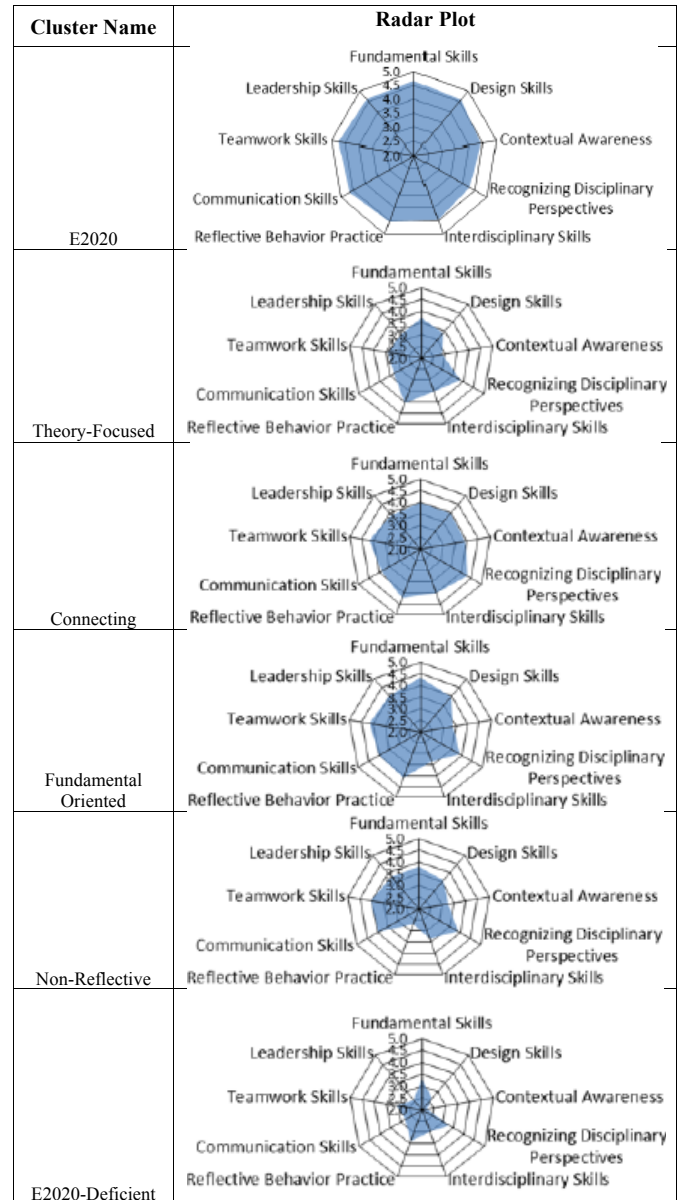
C. Cluster Grouping

Cluster analysis identifies homogeneous groupings in multidimensional space within a sample. Students were clustered into groups using the nine E2020 learning outcome scales. Although all nine E2020 outcomes were used to assign students into clusters, describing a cluster on nine different dimensions was complex, and we describe categories along four categories: Fundamentals, Design, Interdisciplinary, and Professional skills. Radar plots illustrate the reported levels of proficiency and well-roundedness of students in each cluster, see Table 1. The “fundamental skills” scale describes applying foundational knowledge to solving engineering problems and is described on its own (top of plots). Leadership, teamwork, and communication skills are described as a “professional skills” dimension (left side of plot), following the norm set by engineering education researchers and practitioners (e.g., [8]). Design skills and contextual awareness are described together as “design skills” since these are closely related competencies (e.g., [9] [10]) (right of plot). Recognizing disciplinary perspectives, interdisciplinary skills, and reflective behavior practice are described as an “interdisciplinary skills” dimension because items originally were developed to measure this construct (bottom of plot).

D. Variables

Independent variables were six categorical variables, student clusters. Cluster names were chosen to characterize the shape of the shaded area relative to the shaded area of the “E2020” cluster (i.e., the cluster with highest average outcomes and well-roundedness). Each concentric circle represents the grid scale for an outcome, where the center is 2.0 out of 5.0 (no average values were less than 2.0), and the outer ring is the maximum 5.0.

TABLE I. INDEPENDENT VARIABLES, STUDENT CLUSTERS



Dependent variables were the average student ratings for each cluster on the likelihood of entering each of the seven career pathways.

TABLE II. DEPENDENT VARIABLES, CAREER PATHWAYS

Career Pathways
Stem: Three years after you graduate, how likely is it that you will:
Be self-employed in engineering
Be a practicing engineer in industry, government, or non-profit organization
Work in engineering management or sales
Work outside engineering
Be in graduate school preparing to become an engineering faculty member
Be in graduate school in engineering preparing to work in industry, government, or non-profit organization
Be in graduate school in a field other than engineering (business, medicine, law, etc.)

1. Likert Scale Values: 1=Definitely won't, 2=Probably won't, 3=Not Sure, 4=Probably will, 5=Definitely will

E. Analysis

Comparisons across clusters for likelihood of a career pathway three years post graduation used a Kruskal–Wallis test (“K-W test”— the nonparametric equivalent of analysis of variance [ANOVA]). This analysis revealed that clusters did differ across likelihood of career pathways.

To identify specific cluster differences on each career pathway, or each dependent variable, we examined all pairwise comparisons. We conducted pairwise comparisons for all clusters using Mann–Whitney U post hoc analyses, applying a Bonferroni correction when determining significance levels to account for multiple comparison errors.

III. PRELIMINARY RESULTS

In examining the mean rating for each career pathway we conclude that 4th and 5th year mechanical engineering seniors are not certain of what their career pathway will look like three years post graduation. The only career pathway with a mean score above 3 is ‘Be a practicing engineer in industry, government, or non-profit organization,’ which fell above ‘Not Sure’ and approached ‘Probably will.’ Students mean ratings were ‘Probably not’ or approaching “Not Sure” for the remaining pathways.

TABLE III. CAREER PATHWAY PERCEPTION MEANS

Career Pathway	Mean
Be self-employed in engineering	2.14
Be a practicing engineer in industry, government, or non-profit organization	3.82
Work in engineering management or sales	2.77
Work outside engineering	2.44
Be in graduate school preparing to become an engineering faculty member	2.07
Be in graduate school in engineering preparing to work in industry, government, or non-profit organization	2.83
Be in graduate school in a field other than engineering (business, medicine, law, etc.)	2.31

A. Kruskal-Wallis Test (K-W Test)

The K-W test identified statistically significant differences between the cluster groupings for five of the seven career pathways based on an alpha of 0.05. We saw no differences for being self-employed in engineering or for becoming a practicing engineer in industry, government, or non-profit organizations.

TABLE IV. CAREER PATHWAYS

Career Pathway	Sig.
Work in engineering management or sales	0.002
Work outside engineering	0.001
Be in graduate school preparing to become an engineering faculty member	0.025
Be in graduate school in engineering preparing to work in industry, government, or non-profit organization	0.016
Be in graduate school in a field other than engineering (business, medicine, law, etc.)	0.012

B. Pairwise Comparisons

Mann–Whitney U pairwise comparisons revealed which clusters were statistically significantly different when considering the likelihood of entering each career pathway three years post graduation.

Work in engineering management or sales

Students in the E2020 Deficient cluster differed from students in the Non-Reflective ($p=0.038$) and Connecting ($p=0.014$) clusters. E2020 Deficient students were less likely to perceive themselves as working in engineering management roles three years after graduation. This difference is likely due to the fact that these students perceive themselves to lack overall skills (especially design and professional skills) that are most common in a managerial or sales role.

Work outside engineering

Students in the Fundamental Oriented cluster were more likely to perceive themselves as working outside of engineering than students in the E2020 Deficient ($p=0.015$) and Non-Reflective cluster ($p=0.011$). Perhaps students who have higher abilities in engineering have higher self-confidences and think that they can also perform well in a different focus area. Students in the E2020 Deficient and Non-Reflective cluster alternately may perceive their lack of fundamentals as a barrier to working in another discipline or field.

Be in graduate school preparing to become an engineering faculty member

E2020 outcome students were more likely to consider a graduate school to faculty career path than students in the Non-Reflective cluster ($p=0.030$). E2020 outcome students are those who perceive themselves as highly skilled across all outcomes. In contrast, students in the Non Reflective cluster might perceive their lesser developed design and interdisciplinary skills as barriers to being faculty.

Be in graduate school in engineering preparing to work in industry, government, or non-profit organization

Theory-Focused students ($p=0.038$) are more likely to perceive themselves as attending graduate school to prepare to work in industry, government, or a non-profit organization than Non-Reflective students. Students who tend to be strongest in fundamentals relative to the other skills tend to be more likely to choose this pathway than the ones who are weaker on reflective skills. It is not clear why this difference exists, future work will need to investigate this relationship further.

Be in graduate school in a field other than engineering (business, medicine, law)

Students in the Fundamental Oriented cluster were more likely than the Theory-Focused group ($p=0.035$) to be in graduate school in a field other than engineering. The Theory-Focused group had lower perceptions of their interdisciplinary skills in addition to professional skills and excelled on core engineering skills. Theory-Focused students might feel more comfortable remaining in the engineering field based on their comfort and/or expertise with engineering theory. Students in the Fundamental Oriented cluster, rather, similarly perceive themselves as having strong core engineering skills, but they also perceive themselves to be more well-rounded; they might be more

likely to consider how engineering thinking may apply to other fields.

We still have more work to complete to understand these relationships, but our preliminary results suggest that senior engineering students differ in their likelihood of entering different career pathways based on their self-assessment of a variety of outcomes.

IV. NEXT STEPS

Future work includes examining other engineering disciplines and identifying similarities and differences to understand how students perceive career pathways across majors. Additionally, we plan to compare these findings to similar analyses using alumni three years out from school.

Academia could use this information to inform programming and curriculum to support competency development that offers students a broader set of career options. Additionally, academia could offer more tailored recommendations for specific experiences (e.g. internships, co-ops) based on a student's career interests and skill perceptions. Industry can benefit by planning recruitment efforts to highlight how student skills map to different engineering roles. Additionally, industry can benefit by understanding how students perceive their skills to fit the field and support training for new hires to assist in the school to workplace transition.

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More Missing the Boat - Arduino, Raspberry Pi, and Small Prototyping Boards and Engineering Education Needs Them

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Abstract—In this work, we describe a range of prototyping boards such as Arduino, Raspberry Pi, and BeagleBone Black, and we show how these devices are being used in our ECE curriculum in a range of courses for projects. We describe the continuing challenges we have with adopting such technology from an educational standpoint, and some best practices/techniques we have learned and adopted to include these devices in our courses. We believe integrating these devices into our course flow is of a huge benefit to both our curriculum and our students.

I. INTRODUCTION

In 2011, we wrote a paper called “Arduino for Teaching Embedded Systems. Are Computer Scientists and Engineering Educators Missing the Boat?” that asked the question if electrical and computer engineering (ECE) was ignoring the growth of Arduino (arduino.cc) prototyping boards as a platform to teach aspects of ECE, and in particular, to teach embedded systems [1]. At that time, the Arduino world was showing large growth because the artist created community was allowing people from all walks of life to use a micro-controllers and electronics to implement all sorts of projects in a strong sharing community. This community differed significantly from the heavy front-end learning expected by engineers who used and supported traditional microprocessor boards. We felt that these devices had some place in traditional ECE education and we described how a course on embedded systems used Arduinos and the pros and cons of such devices.

The Arduino has continued to have success in the “Maker” world, and our curriculum has expanded the use of the Arduino to more than the embedded system course. Additionally, we have opened our embedded system design course to more than just Arduino boards and have seen students use Raspberry Pi (raspberrypi.org) and BeagleBone Black Boards (beagle-board.org). These new boards still have much of the open source and maker communities, but the devices themselves are more powerful allowing even more design possibilities.

In this paper, we describe what these devices are, and then, we describe how these devices are being used in our ECE curriculum in a range of courses. With our experiences, we describe the continuing challenges we have with adopting such technology from an educational standpoint and some best practices/techniques we have learned and adopted to use these

devices in our courses. In particular, with the large wealth of open source projects available online, how do we assess projects to determine what students are building and learning. Additionally, we make claims as to why we believe integrating of these devices into our course flow is of a huge benefit to both our curriculum and the student.

The remainder of this paper is organized as follows: section II provides a background these prototyping devices and open source and how people have assessed projects. Section III takes a more detailed look at the prototyping devices, and section IV describes student projects that used them. Section V provides a description of best practices we have adopted for using these devices in courses. Section VI includes a short discussion and conclusion of this work.

II. BACKGROUND

The three main areas we address in this paper are Project Based Learning (PBL), open source projects assessment, and prototyping boards used in ECE curriculum.

A. Project Based Learning

Project Based Learning (PBL) curricula (which is a version of Problem Based Learning and has a wide literature base [2]) is normal in many fields with examples in engineering, business, and medicine [3], [4], [5]. PBL pedagogy centers learning around the activity of the student. The approach focuses on building projects and allowing the student to learn on the fly as they face problems. Projects are spaced throughout the degree, hence the name PBL curriculum. The accreditation agency, ABET, among other entities, influenced engineering programs into including a major capstone around 1995 to 1997 [5]. For computer engineering curriculum, lab only courses [6], [7] slowly evolved to include both labs and final projects. The senior capstone has been studied to help understand how to prepare students for this culminating experience [8], [9].

Among the vast range of research on the impact of PBL on engineering curriculum (among other areas) there has been some focus on both the usefulness [10] and the assessment of projects (though assessment is still lacking). Much of the

research on assessment of PBL is lacking and most contributions are focused on describing the PBL course [11]. There are some academic reviews by Dym *et. al.* [3] and Graham [12].

B. Open Source Projects

Within the domain of PBL, two questions tend to arise: First, should projects be allowed to use the available plethora of projects on the web released as open source software (OSS) and projects (OSP)? Second, if OSS and OSP are allowed to be used, then how do we assess students contributions and learning?

The majority of literature that, partially, address these issues is from the OSS and computer science and software engineering education. In particular, many of the early documented attempts are in teaching software engineering use OSS [13], [14]. This includes using the most popular OSS project, Linux, to help teach operating systems [15], and includes senior capstone student work [16].

Assessment of these projects is not not deeply examined, but there are a few documents that talk to the issue. Nascimento *et. al.* go into the most depth with their study on the research issues of using OSS in courses [17]. In addition, Pedroni *et. al.* take a look at assessment techniques, but focus more on student perception of the value of the experience [18]. Unrelated to academic class assessment, Rigby *et. al.* [19] take a look at peer-review assessment of software, which is a common practice in software design, and has some ideas that could be used in a classroom setting.

C. Prototyping Boards

In electrical and computer engineering (among other majors) the prototyping board is a prefabricated board that includes a microchip or set of chips that allows various types of systems to be experimented with, designed, and tested without having to build the PCB (Printed circuit board) and test that part of the system. The word *prototyping* implies that the system, once, completed, could be designed more efficiently, but during prototyping most of the systems features can be used on these boards. These boards are used both in industry and education.

We do not provide a comprehensive list of such boards, but some common examples include: Altera's [20] FPGA prototyping boards such as Terasic's DE2 board that allow full systems to be implemented. Similarly, an open source FPGA related board called, NetFPGA [21], is being used to kickstart a prototyping board - ONetSwitch www.kickstarter.com/projects/onetswitch/onetswitch-open-source-hardware-for-networking. DSP boards, such as Texas Instrument's TMS320C6713 DSP Starter Kit (DSK) www.ti.com/tool/tmdsdsk6713, can implement DSP applications. Microprocessor boards, including the ones we will discuss in this paper (Arduino www.arduino.cc/, Raspberry Pi www.raspberrypi.org/, and BeagleBoard beagleboard.org, allow embedded systems to be prototyped. Ettus Research's USRP devices used in implementing Software Defined Radio systems, might also be considered as a form of prototyping board that has had an impact on education by allowing students to work in the radio domain [22].

Though these boards are used in undergraduate education, there is little discussion or evaluation on how to use them in courses. Pritchard and Mina do take a look at similar types of prototyping boards and classify them from three perspectives: hardware intensive, software intensive, and ease of implementation. Other work has focused on remote lab implementation, which includes a large body of scholarly work (we suggest a review paper [23]). Additionally, since microprocessors were available they have been included in labs and continue to be a major part of computer engineering [24]. PBL and prototyping boards make a good mix and multiple efforts have focused on this including robots embedded throughout the curriculum [25] [26], and FPGA boards for projects and learning digital logic [27], [28], [29].

The major question we have is with the availability of open source designs, cheap prototyping boards, and access to hobbyists and professional, how do we include these powerful tools in the modern ECE curriculum?

III. ARDUINO, RASPBERRY PI, AND BEAGLEBONE BLACK ... OH MY

A. Arduino

"Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments" [30].

The UNO (the base system) consists of a microcontroller (an ATmega328 [31] microprocessor), a USB to serial chip, and an AC to DC power converter. The UNO can either be built by hand or can be bought premade from a seller such as sparkfun.com costing approximately 25 USD. The Arduino software platform is written in Java and is based, mainly, on Processing [32] (a language developed for artists). The IDE is installed on a machine and then can program the UNO over the USB. The base IDE includes a number of examples for blinking LEDs, making noises, etc. The UNO is only one type of Arduino board and many others exist in varying form factors.

We would classify the Arduino UNO as a simple microprocessor board that is easy to use for bit-banging based projects. Bit-banging is the fine grain manipulation and control of single bits or pins. The device is easy to learn to the point that the student can learn how to use the device with web resources alone without any formal instruction. This is because of the community that supports Arduino started with artists and these people provide significant help to beginners (as they are) as opposed to engineering forums for other microprocessors, which include responses such as, "go do your own homework/assignment". The ease of use and friendliness of the community does, however, bring a challenge to educators when assessing projects developed on these devices (which we will discuss later).

B. Raspberry Pi

"The Raspberry Pi is a low cost, credit-card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. It is a capable little device that enables people of all ages to explore computing, and to learn how to

program in languages like Scratch and Python” raspberrypi.org.

The Raspberry Pi (we will call it just Pi) is a full-fledged computing system with a 900 MHz ARM based processor (www.arm.com/). The board can be loaded with the Linux and GNU tools, a monitor can be connected to it via the HDMI port, and input devices, such as a mouse or keyboard, can be connected to the USB ports. In other words, the Pi is a full computer that can be used for embedded system projects, but is also useful in the domain of implementing servers and other computer system applications. The additional processing power makes the Pi a much more powerful device, but accessing and using the general purpose input/output (GPIO) ports is more difficult and makes the Pi less useful as a starter device when controlling (bit-banging) simple electronic circuits. The Pi costs approximately 40 USD.

The Raspberry Pi community is also very active and helpful. However, a student needs to learn command line usage in Linux, programming tools in Linux, and other computing concepts/skills, which makes it harder to use for beginners to programming. Since the device is newer than the Arduino there are not as many open source resources, but there is more projects than one person can track meaning that assessment is equally challenging.

C. BeagleBone Black

“Makers, educators, explorers, professional engineers and corporations seeking to build upon a rich ecosystem are all encouraged to participate in BeagleBoard.org. With so much openness and thousands upon thousands of examples of people doing fun, interesting and profitable things with Beagles, you’re missing out if you don’t count yourself in for whom Beagle is intended. beagleboard.org”

The BeagleBone Black (which we will call BBlack) provides functionality of both Arduino and Pi. The BBlack has a powerful processor (ARM processor at 1GHz) that can run Linux similar to the Pi, but the BBlack also has I/O capabilities to do simple bit-banging with circuits to the point that the BBlack can run the Arduino IDE (with a little bit of configuration www.logicsupply.com/blog/2014/09/24/tutorial-running-arduino-ide-beaglebone-black/).

The BBlack is also low cost and costs approximately 45 USD. The community is open and helpful, but is smaller than other two groups, but has the benefit of leveraging various projects that are designed for the other prototyping boards.

IV. STUDENT PROJECTS AND COURSES USING THESE BOARDS

A. Courses using these boards

At Miami, the Arduino UNO has been used in a number of courses. In particular, the UNO is used in our introductory electrical and computer engineering course (ECE 102), our second course on circuits (ECE 303), our embedded systems design course (ECE 387), and optionally, in our computer organization course (ECE 289) and our senior capstone. In the introductory course and the circuit course, the department provides kits for the students, but for the other courses,

students are expected to purchase the device in lieu of a textbook.

For projects in both our Senior Capstone and embedded system design, both the Pi and BBlack are common choices depending on the needs of the project. Again, these devices are purchased by the students both because of their low cost and student preference to have the device to play with and use outside their course work.

The amount of instruction provided on how to use these devices is very little. In the introductory course (ECE 102), the Arduino is introduced over two 55 minute lectures where the instructor shows how to connect an LED and pull-up switch. A basic program that shows how a light can be dimmed using pulse width modulation is shown to the students. From there, a student is expected to complete six labs using arduino and basic circuits to complete 3 assigned tasks:

- Knight Rider display which is a timed lighting of a series of LEDs
- Control a servo with a switch
- Build a simple ball catching system

and 3 student/TA created challenges that create a problem that needs to be solved using the device, some components, and some creativity.

In the circuit course (ECE 303), additional instruction is provided on the Arduino since some of the students come from outside the electrical and computer engineering department (for example, mechanical engineers), and they require a basic introduction to the board. Other than this, students are expected to learn how to program and interface their circuits with the Arduino by accessing tutorials and projects on the web.

For the Pi and BBlack, no formal instruction is provided, and students are expected to learn how to use these devices on their own. Computer engineering students will have learned command line Linux instructions and the compilation process in their computer organization course (ECE 289), but electrical engineers, who do not have this training, are expected to learn this as needed for their projects.

B. Student Projects

With these devices, students have created some impressive projects. The majority of these impressive projects are built in the ECE387 course and senior capstone design projects. For example, in ECE387 students created auto-tracking paintball guns, built a segway like device, built a bug-tracking system, and hypno-cubes. Videos and source code for many of these projects can be found at www.users.miamioh.edu/jamiespa/teaching.html, but as Google Code hosting service will be terminated in 2015, the availability of these design files will be for a limited time.

There are also a number of senior design projects that use these devices as the microprocessors in the student’s designs. For example, in 2015 a group of students is building a microphone array that can distinguish people location in a room based on conversation. In 2014, a group of students used vibration sensors and a Raspberry Pi to triangulate the location of people based on their foot steps. These are just

a few examples of complex systems that students can create with these devices.

Lastly, the IEEE student group commonly uses these devices for their projects which includes a 60 inch spectrum analyzer (built with CPU fans, foam chips, and led lighting) and a coin operated arcade game emulator. The availability of these boards has vastly expanded the projects that the student run group can do.

V. CHALLENGES WITH ADOPTING PROTOTYPING BOARDS

As great as these microprocessor prototyping boards are based on functionality and low cost, including them in courses has a number of challenges. In particular, the most difficult challenge is with how to deal with the availability of open-source projects and shields and libraries, and then assessing what a student has done. We will describe what our current best practices are, but by no means have we solved the problem of assessment and project creation completely.

A. Assessing Projects with the Availability of Open-Source

We have been using Arduino UNO in classes since 2010 and were one of the earlier adopters in this community. In 2010, there was a significantly large community of users and open source projects, but since then there has been a continuous increase of projects and people. The number of Arduino shields and supported libraries, where a shield is an easily connectable separate device that can be attached to an Arduino and allows interfacing with another chip (for example a motor drive shield), has also increased significantly making it possible to use complex chips without students having to understand much on interfacing. Additionally, libraries that support both shields and interfacing with sensors, actuators, and other chips are continuously being improved. All of this means that there is a massive amount of information, code, and designs that students can leverage in creating their own designs. The question remains, how can we assess the idea of “their project” and verify that students are learning.

One simple solution is to move towards first principles and push students to do low-level interfacing without libraries. Arguably, this approach should be done at least once since it helps student’s understand some of the details in interfacing. However, forcing students to reinvent the wheel for every device they will use is less useful since, arguably, in their industrial jobs the goal will be to leverage existing designs and code bases to create larger systems.

Another solution is to allow students to use any code base and assess the system based on the final product. In this approach, the instructor assumes that to create a complex system that a student will spend significant time understanding existing libraries, how those libraries can be used, and mixing more than one library/api together to achieve a complex task. We used this approach for a number of years, but we have begun to notice that some students are building projects that are similar to complete kits that can be purchased. For example, the hypno-cubes student’s created in 2010 and 2012 can now be built with the purchase of a kit. For this reason, these types of projects are no longer considered an appropriate project.

The third approach we have used is to have the students deliberately prepare a document that shows what code they

used and what they have added/designed. In this approach, we allow students to use any code, but they are required to show how their code is differentiated from the existing code. In this way, a student is required to describe how they created their system and used existing modules within their system. This process is similar to a diffing a code-base from the open-source base, but we require the student to illustrate this in a single organized document that allows instructors to easily see what the students have done and what was already available. The downside of this approach is that it requires the students to spend additional time organizing their design in the final deliverable. Also, this approach can make the students design appear simple, when in reality, to even get each device to interface requires significant time and learning even with an existing code base.

Of each of these approaches, the main question is what are the learning objectives. In the courses where we use these devices, the main learning objectives in the third year is a “create” (metacognitive and create) and in the introductory courses is a “use” (metacognitive and apply) in the Revised Bloom Taxonomy [33]. At these levels in the taxonomy, the question of what the student is learning is mainly related to the product, and all three approaches are sufficient for assessment. However, to promote creativity and reflection, we are moving towards our last approach in which students need to show their contributions differentiated from existing code-base and examples.

B. Project progress and success

Another significant challenge with projects, which is true independent of working with the above described prototyping boards, is scale of projects and ensuring student progress towards completing a successful project. In particular, students that transition into college think that a project can be completed in a single (long) evening, have a difficult time creating a project, and have very little skill at project organization. Additionally, students face many challenges in terms of working in group projects such as finding common meeting times, and dealing with non-contributing team members [34], [35], [36].

For project creation, we use one of two approaches; first, student’s propose (orally and written) what they would like to do, which the instructor can modify, make suggestions, and provide fallback options, and two, a custom project is created that all students will do in the class. In both situations, the projects are successful based on the experience of the instructor and their understanding of what is doable in the time allotted.

To ensure progress we have tried to implement progress meetings, and these are successful for senior design projects, but they seem to have very little impact on early courses. We believe reality is that until a student experiences how difficult a project is to complete in a very short period of time, they do not learn to work continuously through a semester. As much as we provide direction, the learner has to experience how hard it is to get things built and working.

We also provide instruction on the use of design methodologies such as agile design [37], but this is not necessarily the focus of the courses the projects are in, and are ideas that tend to be taught later in the curriculum. Even with knowledge of these methodologies and best practices, students still have a

difficult time applying the techniques to improve the progress of their projects.

VI. CONCLUSION

In this paper, our goal was to expose educators to the benefits and challenges of using modern prototyping micro-processor boards - Arduino, Raspberry Pi, and BeagleBone Black. Each of these devices has been used in a number of our courses for student projects of many different levels. The main challenge with using these boards is identifying and assessing student projects based on the availability of open source designs and the community that supports these projects. We describe how we approach these problems, but we still do not believe we have perfected the use of these devices.

Overall, the students like the low cost of these devices and the ease of use that allows them to create significant projects. As instructors, the projects that are being delivered show that students are improving on system design and are delving into real engineering systems motivated by their own creativity. This we believe justifies adopting these boards in a curriculum with the risks described earlier.

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Design and Implementation of a Microcontroller Based Workstation with Educational Purposes for the Control Systems Area

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Abstract—This paper presents the design and implementation of a microcontroller based workstation for improving the learning process of undergraduate students in the Digital Control Systems Area. High level tools such as Simulink® and Labview® have provided excellent results in the development of laboratory experiments due to their ease of use and friendly user interface. Students that develop their control projects using these tools do not commonly learn important concepts such as motor driver implementation, digital to analog converter and analog to digital converter. The implementation of this work is based on a pedagogical experiment that includes a set of workshops and a course project development. Workshops were designed following a backward design approach in which the content, assessment, and pedagogy used to implement the proposed system are aligned. Assessment tools revealed that the learning objectives were accomplished and students showed an acceptance toward this tool.

Keywords—ball-and-beam system, digital control systems, education, laboratory experiences, microcontroller applications.

I. INTRODUCTION

The use of microcontrollers is playing an increasingly important role in a wide range of engineering applications [1]. Specifically, the area of control systems depends significantly on the use of microcontrollers for control systems implementation.

Most of the course projects in the Control Systems Area are implemented using high level simulation tools and data acquisition boards. These methods have yielded excellent results because they offer a block based environment which makes all the internal details transparent for the user. However, they have the disadvantage of not exposing students to implementing digital controllers directly with microprocessors. Furthermore, programming skills are becoming more important nowadays and a drag-and-drop block based environment does not provide enough understanding on how a digital controller is implemented in real world using computer programs. Multiple approaches teach students how to develop digital controllers directly with microcontrollers [2, 3, 4, 5, 6]. However, there is no formal course design to implement these tools. Additionally, is not common to find formal assessment methods to measure the effectiveness of their approaches. Our

approach is to align assessment methods with course content and delivery.

Beauchamp-Jimenez, et al, analyzed performance of two implementation methods for the controller of a Ball-and-Beam (B&B) system: Using a Microcontroller Unit and using Simulink [7]. They used the bilinear transformation and the z-domain direct design process to implement the controllers. The author showed that the implemented controller yielded similar but not identical results in both implementations (Simulink, MCU). This work followed a hybrid problem-based methodology which was implemented with a group of students of the University of Puerto Rico at Mayaguez (UPRM). A limitation of this work was that there were no formal methods to validate assessment and the effectiveness of this approach in an educational environment.

In this paper we document the development process of a microcontroller based control system (MCS) with pedagogical purposes. This MCS is intended to be focused in the improvement of the Digital Control Systems (DCS) course project. The MCS uses the Texas Instruments C2000 TMS320F28069 microcontroller and the DRV8412 motor driver.

The implementation of this work is based on a pedagogical experiment that includes a set of workshops and a course project development. These activities are part of the Digital Control Systems course of the Electrical Engineering program in our department. Workshops were designed following a backward design approach in which the content, assessment, and pedagogy used to implement the proposed system are aligned [8]. The professor evaluated student's performance through oral presentations using a rubric that has been designed to measure student outcomes as established by ABET criteria. These evaluations were compared against those students who did not receive the workshops in previous years.

II. EDUCATIONAL SETTING

A. Program Structure

The Digital Control Systems (DCS) course is currently offered as an undergraduate technical elective in the UPRM Electrical and Computer Engineering Department (ECE). The

Introduction to Control Systems and the Signals and Systems courses are prerequisite for the DCS course.

The undergraduate Electrical Engineering Program in the Electrical and Computer Engineering (ECE) Department consists of 165 credits that should be completed in a period of 5 years. The curriculum provides students with a general education background in mathematics, science, and humanities. The program has four areas of emphasis: Applied Electromagnetics, Communications and Signal Processing, Control Systems, Electronics, and Power. Most students in the DCS course are in their fourth or fifth year of their course plan and are specializing in the area of Control Systems.

Some of the students in this course have already taken the microprocessors course, which is one of the core courses in the curriculum. At this point, students have basic knowledge on the use of microcontrollers but they do not have the required skills to create an embedded controller.

B. Course Structure

The DCS course has as an objective making students proficient in analyzing, designing and implementing digital control systems for single-input single-output physical systems [9]. To achieve this objective, students should take classroom lectures, homework assignments, and a term project.

1) *Classroom Lectures:* As part of the classroom lectures, students learn the theoretical background of digital control systems. The topics covered in the DCS course include modeling of discrete-time control systems, using the z-transform to analyze discrete-time systems, stability criteria, and root locus design in the z-domain. These topics appear commonly in digital control systems textbooks [10,11,12,13].

2) *Homework Assignments:* Students receive a set of exercises that should be delivered before each exam. Thus, students reinforce the theoretical knowledge learned in class.

3) *Term Project:* Students are organized in teams of two or three students and the instructor specifies an assignment to carry out one or more tasks that lead to the design and implementation of a digital controller for the Quanser's Ball & Beam experiment [14] (see Fig. 1) available in the Process Instrumentation and Control Laboratory (PICL) [15]. The controllers should be implemented using microcontrollers as well as with Simulink through Quanser's Quarc® tool. Finally, students should make a comparison between both implementations.



Fig. 1. Ball & Beam Experiment.

To document the project, students should prepare a time schedule, two progress reports, and one final report. The time schedule is used by the students to organize the time needed for each task. Progress reports allow instructor to assess the current state of the work for each team. Teams must present a demonstration and an oral exam to validate these reports. In the final report, students are expected to explain the development process of the B&B controller by applying the theory acquired in lectures and assignments.

III. MICROCONTROLLER BASED CONTROL SYSTEM

The microcontroller based control system (MCS) integrate the Texas Instruments (TI) C2000 TMS320F28069 Microcontroller [16], the DRV8833 motor driver [17], and a custom made Analog Signal Conditioning Board. A general system overview of the MCS is shown in Fig. 2. One of the most important components of the system is the Analog Signal Conditioner Board. This board converts the voltage levels from the Quanser analog sensors to a range that could be read from the microcontroller (0-3.3V). Also, a DC motor driver (DRV8833) was configured and used. The motor driver receives PWM signals generated by the microcontroller to change the average output voltage applied to the motor. The Optical Encoders send two square wave signals to the microcontroller according to the shaft angular position and rotating direction. Finally, a Timer Interrupt Unit sends a signal to the CPU indicating when the control action should be performed.

The MCS uses a C2000 TMS320F28069 microcontroller. It operates at 80MHz and is equipped with 16 Analog-to-Digital Conversion (ADC) channels with a resolution of 12 bits, 2 Quadrature Encoder read-modules (eQEP), 16 independent 32 bits PWM channels, Floating Point Unit (FPU), JTAG emulation tool, and other characteristics that make this microcontroller ideal for high capacity digital control purposes.

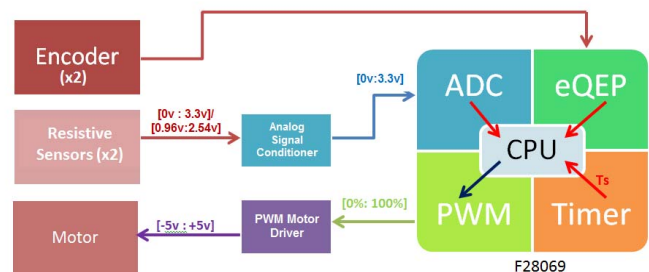


Fig. 2. MCS System General Overview

A. Analog Signal Conditioning Board

The MCS was designed to work with two Quanser® analog sensors, these resistive sensors were designed to have a dual power supply of -12V to +12V. Using a couple of 7kΩ bias resistors, they convert this voltage level to -5V to +5V. For this reason, a Signal Conditioner Circuit is used to convert these voltage levels to a range of 0V to 3.3V which is the operative range of the microcontroller ADC unit.

The use of negative polarization voltages represents a disadvantage because the system should use a dual voltage power supply, making it less portable and incrementing costs

of production and flexibility. The proposed solution was to use a single power supply of 3.3V on the resistive sensor; this yielded an output voltage range between 0.96V and 2.33V. See Fig. 3.

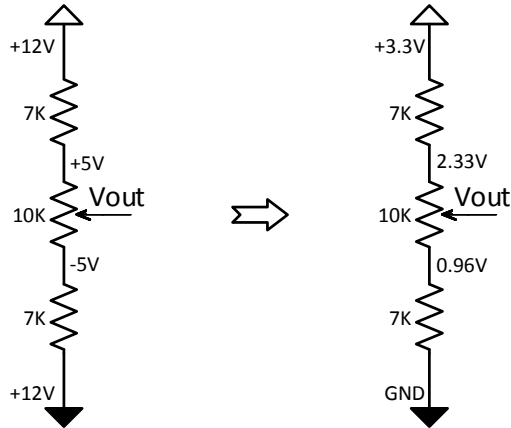


Fig. 3. Quanser® Resistive Sensors Voltage Levels. Left: Quanser® Power Supply Voltage Levels. Right: Proposed Power Supply Voltage Levels.

Thus, it is necessary to amplify and add an offset this signal to read it adequately with the microprocessor. The AD623AN instrumentation amplifier was used for this task. It allows a single power supply and its gain is set using only one resistor R_G defined as: $R_G = R_{AG} + 49.9k\Omega$. Fig. 4 shows the proposed analog signal conditioning circuit design. The output voltage is given by

$$V_{out} = \left(1 + \frac{100k}{R_G}\right) \left(V_{in} - \frac{3.3R_{OFF}}{R_{OFF} + 4.87k}\right) \quad (1)$$

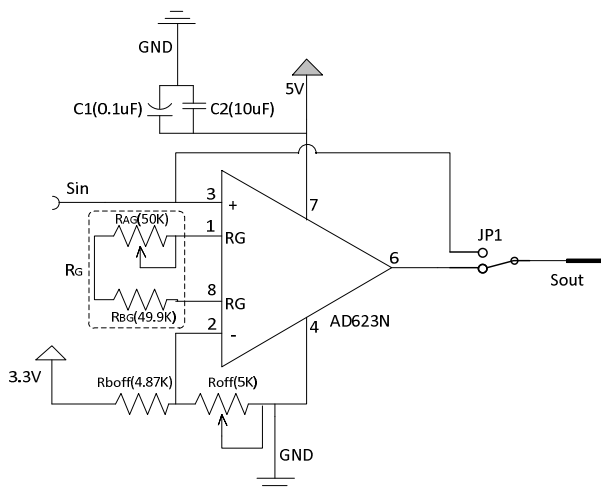


Fig. 4. Analog Signal Conditioning Circuit

The desired amplifier gain and DC-offset is obtained by adjusting R_G and R_{OFF} . Values of $R_G = 71.42k\Omega$ and $R_{OFF} = 2.005k\Omega$ are obtained. The output equation that converts the input signal range of 0.96 to 2.33V to an output signal range of 0 to 3.3V is given by

$$V_{out} = 2.4(V_{in} - 0.9625) \quad (2)$$

A voltage divider was used in the analog signal conditioning circuit to provide an offset voltage of 0.96V on pin 2 of the AD623N. The variable resistor R_{OFF} is used for calibration to minimize tolerance errors. The two capacitors C1 and C2 are used to isolate noise from the microcontroller and other digital circuits. A 3 pin jumper JP1 was used at the output to bypass the amplifier in the case when the sensors already work at the same voltage range of the microcontroller ADC and their signals do not need to be conditioned. This circuit was simulated using ORCAD Capture™ and it showed adequate performance. Fig. 5 shows that the input signal (purple line) is amplified to be in a range of 0-3.3V (red line).

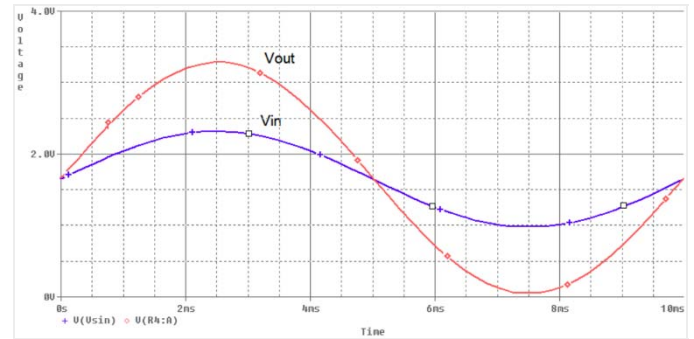


Fig. 5. Signal Conditioner Simulated Results

The S_{out} pin is connected to the ADC pin of the microcontroller development board. This board has all the protection circuitry required to prevent from input over-voltage or input inverse-voltage. This is accomplished using diode voltage clippers at the input of the ADC pins of the microcontroller.

A PCB layout was developed using Eagle®. Several factors had to be taken into account for the PCB design, for example, conditioned signals should have a testing point for troubleshooting and path widths should be wide enough to prevent ground loop noise. A photo of the PCB prototype is shown in Fig. 6.

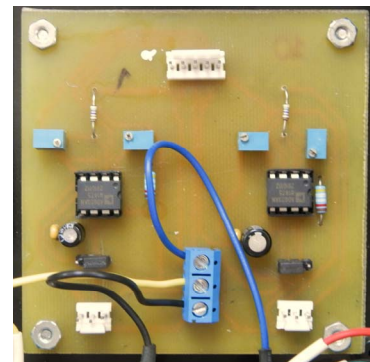


Fig. 6. Photo of the Analog Signal Conditioning Board

B. System Assembly

Each of the twelve MCS stations was packed in an enclosure with a power supply port, sensor ports for the connections with the Quanser® Experiments, and test different situations that may appear in practice such as overvoltage and bad connections among others. Fig. 7 shows photos of the final box assembly. The MCS is organized so that the student may visually identify its main modules and use them with little risk of damage.

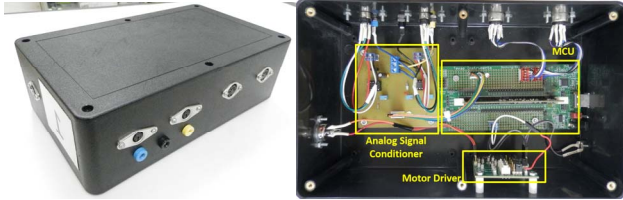


Fig. 7. Photo of the final box assembly of the MCS stations. Left: External view. Right: Internal View.

C. Peripheral Configuration Libraries

The implementation of the digital controller using the MCS differs significantly from the Virtual Instrument in Simulink because the controller should be coded in C language and all the I/O functions of the microcontroller must be configured separately. Students received a set of C code configuration libraries for the most used peripherals in the development of digital controllers. Students were trained about how to modify these libraries to meet the signal requirements of each experiment actuator and sensor. The configuration libraries are based on the TI Control Suite™ package. It contains some sample projects for configuring the main peripherals of C2000 microcontrollers [18].

1) *Analog-to-Digital Converter (ADC)*: ADC unit is used to read from analog sensors. The MCS uses 2 ADC channels (A6, A7) triggered in continuous mode. This means that every time the ADC produces a conversion, an End of Conversion (EOC) flag is set; this flag initiates the next conversion and so on. The window size is set to 7 clock cycles, this is the minimum amount of time that the ADC needs to produce a reliable conversion.

2) *Enhanced Quadrature Encoder Unit (eQEP)*: Most of the Quanser® rotational sensors use quadrature optical encoders for angle measuring. An optical encoder is a sensor that generates 2 square wave signals indicating angle and rotating direction. Fig. 8 shows both signals and their meaning.

Each signal has a 90 degrees phase shift from the other depending on the rotating direction. TMS320F28069 microcontroller has 2 eQEP units capable of decoding these signals and counting the rotating steps in the sensor. Encoder input pins are located for Channel A in GPIO pins 20 and 21, and for Channel B in GPIO pins 24 and 25.

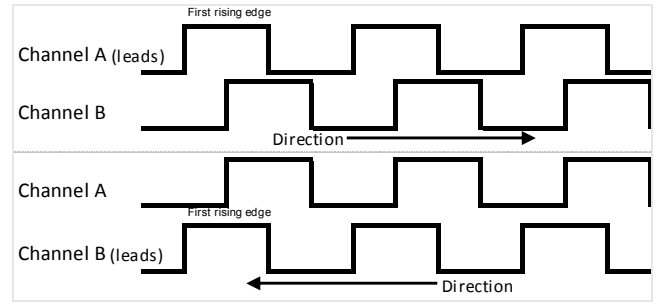


Fig. 8. Quadrature Encoder Signals

3) *Enhanced Pulse Width Modulation Unit (ePWM)*: The DRV8433 [17] motor driver was used to generate the voltage needed to move the SRV-02 motor. Changing duty cycle affects the output voltage of the motor driver, see Fig. 9. Two independent PWM Channels were used for this task. To move the motor clockwise (CW), pulse width in PWMA channel must be fixed to 100% and the pulse width in PWMB channel determines the CW angular velocity. To move the motor counterclockwise (CCW), pulse width in PWMB channel must be fixed to 100% and the pulse width in PWMA channel determines the CCW angular velocity.

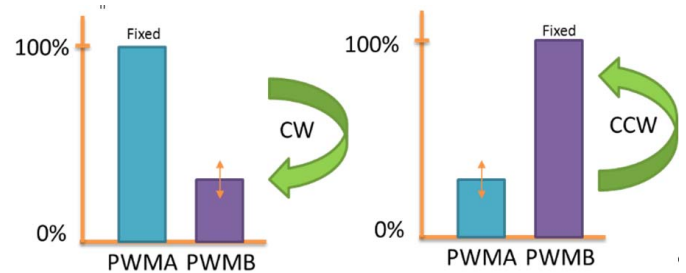


Fig. 9. Effect of changing duty cycles difference on the motor speed.

4) *CPU Timer Interrupt Unit*. This Unit is used to generate interrupts at a fixed time interval; this allows using the microcontroller in between control actions, taking advantage of all the features that it offers. When these interrupts occur, the processor will execute the difference equations that realize the control action.

IV. BALL & BEAM CONTROLLER

A. Controller Design

A Lead-Lag Controller for the B&B system was implemented using the MCS. Fig. 10 shows a block diagram of the B&B digital controller. The blocks inside the dotted rectangle represent the difference equations performed by the digital controller, while the blocks outside the dotted rectangle represent the dynamical system of the B&B system.

System Transfer Functions are derived in *Quanser's Student Handout* [14]. A sampling period of 30ms was selected according to Shannon's sampling theorem [13]. Controller requirements were established according to experience in previous courses. The ball position controller was specified to have an overshoot under 30% and a settling

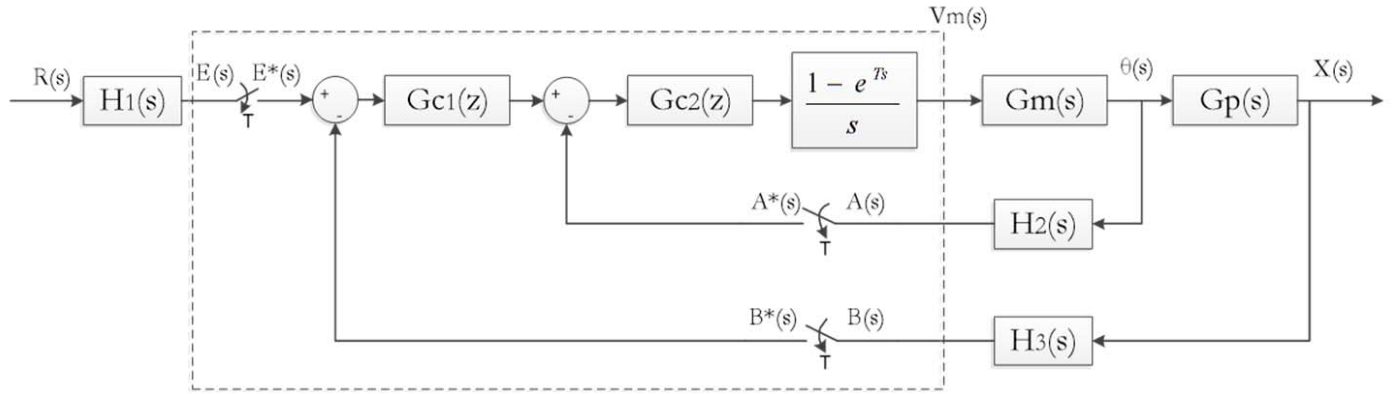


Fig. 10. Ball & Beam Controller Block Diagram

time under 5 seconds. According to these specifications, a Lead-Lag compensator was designed using z-plane root-locus methods. The Lead-Lag controller has two poles and two zeros. A pole-zero pair corresponds to the Lead compensator and the other pole-zero pair corresponds to the Lag compensator. The Lead compensator has its zero to the right of its pole in the z-plane while the Lag compensator has its pole to the right of its zero; but very close to each other. The designed Lead-Lag Controller resulted in

$$G_{cl}(z) = \frac{\theta_{ref}(z)}{X_{error}(z)} = 82.86 \frac{(z - 0.986)(z - 0.995)}{(z - 0.6287)(z - 0.999)} \quad (3)$$

where $\theta_{ref}(z)$ is the Z-transform of the output of the controller and $X_{error}(z)$ is the Z-transform of the error between the reference position and the actual position of the ball. To obtain the difference equations, it is necessary to apply a Z-transform property

$$Z^{-1}\{z^{-k}\theta_{ref}(z)\} = \theta_{ref}(z)[k - n] \quad (4)$$

This property is called *Time-Shift* and states that whenever a z^{-k} factor multiplies a discrete time function, it generates an n -times translation in time that is interpreted as a register in the microcontroller program. The difference equation performed by the lead-lag controller (3) is given by

$$\begin{aligned} \theta_{ref}[k] &= 82.86x_{error}[k] - 164.145x_{error}[k-1] + \dots \\ &81.291x_{error}[k-2] + 1.627\theta_{ref}[k-1] - 0.628\theta_{ref}[k-2] \end{aligned} \quad (5)$$

The motor Angular Position Controller was chosen to be a proportional controller with $K=4.7$. The output voltage applied to the motor is given by

$$V_m[k] = 4.7(\theta_{ref}[k] - \theta[k]) \quad (6)$$

Once (5) and (6) were obtained and all the peripherals were configured, a control action should be performed each time the CPU generates a timer interrupt. The values of all the registers in the controller are updated every time (5) and (6) are executed.

V. WORKSHOP DEVELOPMENT

The implementation of this work includes a set of workshops to train students in the use of the MCS. The workshop content was designed to assist participants in accomplishing ABET student Outcome E of the DCS course [19, 9] which is expressed as: *Implement a digital controller using a digital computer and software*. Workshops were designed according to Streveler's Outcome Based Education (OBE) framework [8] which follows a *Backward Design* approach as presented by Wiggins and McTighe's book [20] [21] and the *How People Learn* framework presented by Bransford, et.al [22]. Refer to [23] for more details about the pedagogical design of this approach.

Workshops were given in the PICL and were two hours long each. Students were organized in pairs and were assigned a computer workstation and an MCS workstation. The instructor gave a tutorial where a step-by-step guidance was given according to the learning objectives of the session.

Workshops were dictated alongside the development of the course project. According to this, students were evaluated in their progress reports on how they integrated the use of the MCS in their projects. Three different workshops were designed to achieve the learning objectives:

- The first workshop focuses on the fundamental elements of embedded control systems. Students recognized the main differences between implementing a digital controller using an MCS and using high level tools. Also, in this workshop, students learned basic operations in a C-code programming through the use of the Code Composer Studio Development Software. Finally, students implemented a basic C-code blinking-led program which allowed them to familiarize with the Code Composer Studio Environment.
- The second workshop trains on the configurations and a hands-on experience with the microcontroller stations. Students learned how to use the microcontroller peripherals to read signals from sensors and to control the motor driver. They were expected to learn about the working principle of each sensor of a Ball & Beam system and to read them using the microcontroller. Then, students learned to

translate the signals coming from the peripherals to the international system units (meters, radians, Volts). Finally, students created a GUI to view the variables measured by the sensors.

- The third workshop was about implementing a real controller using difference equations and the Texas Instruments GUI Composer. This workshop synthesized the concepts learned in the two previous workshops by implementing a digital controller using C-code. Specifically, students were expected to learn how to transform a z-domain transfer function to a difference equation and how to convert this difference equation into a C-code program to control a servomotor.

VI. RESULTS

A. GUI Implementation

One of the most important features of the Texas Instruments® C2000 microcontrollers and Code Composer Studio™ is the debugging tool. GUI Composer™ is an extension of this software. This tool allows developers to create Graphical User Interfaces (GUI) to access directly to the microcontroller registers in real time. Once the student develops the software, he or she can create a Graphic Panel where the defined variables can be watched in real time and parameters may be modified on-the-fly. The student is able to change zeroes, poles, and all the controller parameters. Three sample GUI's were created to be used as templates for other projects: SRV-02 Proportional Controller, SRV-02 Lead-Lag Controller, B&B Lead-Lag Controller. Additionally, further implementations in the discrete-time state-space were developed with aims to be implemented in the Linear Systems Analysis Course.

The B&B Lead-Lag controller performance acquired from the GUI Composer Interface is shown in Fig.11. The blue line is the reference signal, the orange line is the actual ball position in response to the reference signal. Fig. 12 shows the controller performance of the same controller using Simulink. Both controllers have similar performance.

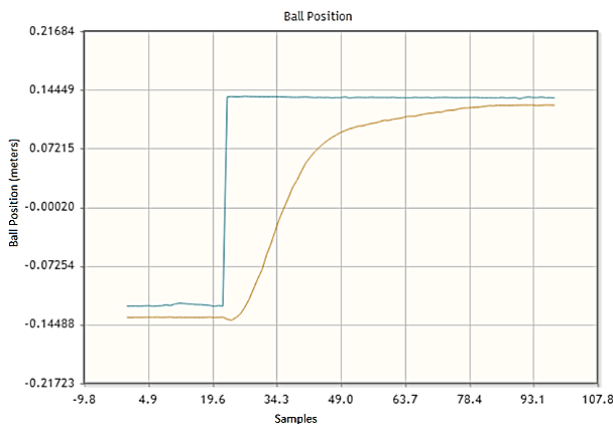


Fig. 11. Ball & Beam Controller Performance using the MCS

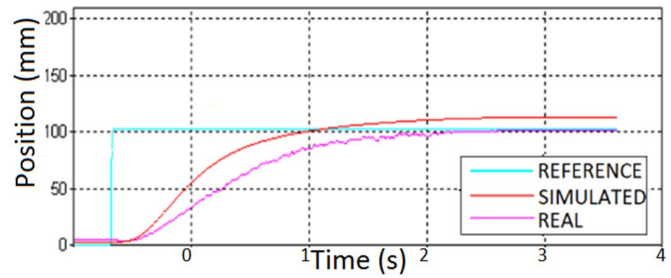


Fig. 12. Ball & Beam Controller Performance using Simulink

B. Workshop Assessment

To assess the contribution of this work, we evaluated students' performance in their term project compared to those students who did not receive the workshops in previous years. For this, we developed a set of rubrics written according to the cognitive domain of Bloom's Taxonomy and ABET criteria [24, 19, 23]. Final project reports provided enough information about students' fulfillment of the project outcomes for those students that took the course in previous years. Specifically, we assessed the ability of students to implement and validate a digital controller using Simulink and Microcontrollers. A total of 18 reports were assessed divided in three categories:

- (1) 6 reports from Students from 2013 Fall semester who implemented and validated digital controllers using only Simulink.
- (2) 4 reports from Students from 2013 Fall semester who implemented and validated digital controllers using Simulink and additionally implemented their controller on a microcontroller voluntarily. These students were not trained in the use of microcontrollers for digital control implementation.
- (3) 8 reports from Students from the 2014 Fall semester who were required to implement and validate digital controllers using both Simulink and MCS. These students were trained with the workshops developed in this work.

Reports were assessed in a scale of three levels: Good (80-100), Acceptable (70-79), and Insufficient (0-69). Average results of the assessment analysis are presented in Fig. 13. Each team was evaluated according to five main course outcomes:

- Punctuality (Outcome 7).
- Design of Controllers (Outcome 3).
- Simulations (Outcome 8).
- Controller Implementation (Outcome 4):
 - Using Simulink.
 - Using Microcontrollers.
- Controller Performance (Outcome 5):
 - Using Simulink.
 - Using Microcontrollers.

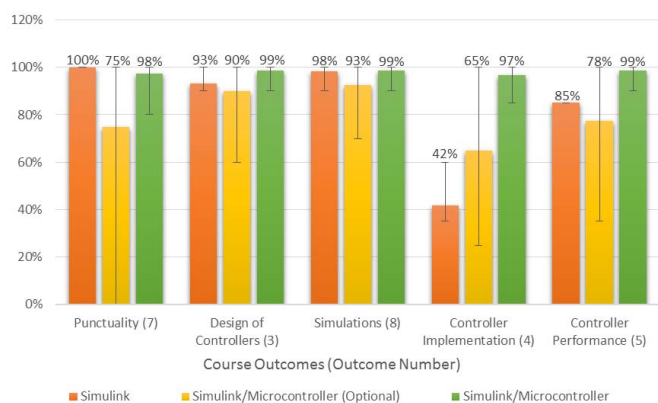


Fig. 13. Outcome Assessment Compared to Previous Years

Fig. 13 shows that students who only used Simulink had excellent scores on punctuality, design, and simulations. However, they had lower scores on controller implementation and performance. This is because they did not accomplish the microcontroller component.

Those students who used Simulink and used the microcontroller voluntarily had lower scores in all outcomes. These students did not receive any training on the use of microcontrollers for digital control implementation.

A deeper analysis of the project reports revealed that students could not focus on the project because they spent too much time dealing with the microcontroller configuration and hardware connections. In fact, some students could not finish their project and thus, did not pass the course. These students repeated the course in 2014, attended the workshops, and had an average score over 90% on the project using the MCS.

Finally, those teams who used Simulink and microcontrollers yielded the best performance. These were students who received the workshops developed in this work and learned about the use of microcontrollers for digital control implementation.

Results revealed that those students who were trained on the use of microcontrollers for digital control implementation had better scores than those who were not. This indicates that the DCS course was improved by enhancing the performance of students in the project. In the past, students were not able to fulfill project outcomes related to the microcontroller implementation.

To guarantee inter-rater reliability, a second evaluator assessed a representative sample of 9 groups: 3 for the first category, 2 for the second category, and 4 for the third category [25, 26]. The results of this evaluation were compared against the results obtained by us. A mean correlating factor [27] of 0.93 was obtained. According to Cohen this indicates that no arbitrary considerations were made in the evaluation of project reports [28].

VII. CONCLUDING REMARKS

To the best of our knowledge, only a small number of the reviewed works teach students how to develop digital controllers directly with microcontrollers using C language. However, there is no formal course design to implement these

tools. Finally, in the works reviewed, it was not common to find formal assessment methods to measure the effectiveness of their approaches.

A set of workshops were developed following an outcome-based education and a backward design approach. The DCS course was improved by enhancing student outcomes fulfillment in the implementation of the project.

A microcontroller based system was developed for the project implementation. Experimental results indicate that the controllers implemented with the MCS have the same performance to those controllers implemented using Simulink or LabVIEW. Also, the MCS demonstrated to be well designed since it was an effective tool for implementing the digital controllers of the student projects.

The workshops provided students with a good understanding of embedded control systems. The process of programming the controller provided students a deeper understanding of how digital control systems are implemented in real world through embedded systems. Also, using Texas Instruments® Code Composer helped in the debugging process. In the past, digital controllers were implemented using microcontrollers, but there were no formal debugging methods for troubleshooting.

The methodology presented in this work could be used in the future to introduce new tools in other courses in the engineering discipline. Also, the MCS represents a multi-purpose platform that can become a commercial product of pedagogical interest that may be used to improve the learning process in a higher education setting.

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Autonomous Robot: An Intellectual Way of Infusing Microcontroller Fundamentals into Sophomore Students

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Abstract — Use of microcontrollers has become inevitable in almost every field of engineering. Thus in our program, we have adhered to the idea that knowledge in microcontroller fundamentals is necessary for all types of engineering majors. However, the difficulty arises when a traditional classroom teaching with examples and non-creative projects instill boredom amongst students. Students fail to make the connection of how important this understanding will be in their future studies, be it mechanical, electrical or other majors.

We feel there is a missed opportunity to engage engineering students early in their program with a highly relevant and easily tangible experience working with intellectual microcontroller-based projects. In order to improve the experience, we introduce our students to the basics using laboratory exercises on the Arduino platform and then transition to a full-featured in-house autonomous robot platform for the final project.

The paper first talks about our current approach in teaching microcontroller topics to the students followed by the need to develop the autonomous robot platform. The robot platform was developed in-house by the undergraduate students using the available in-house resources. The autonomous robot utilizes a commercial chassis, wheels and tracks along with geared DC motors that include embedded quadrature position encoders. In addition to the chassis, the undergraduate students have also used off-the-shelf hardware for robot control and Arduino interface for student developed code. The paper then talks about the various kinds of laboratory exercises and projects that can be implemented on this platform by the students in their introductory digital systems course that they take as sophomores.

We further include student assessment data that supports our approach and shows that the students appreciated this intellectual way of learning microcontroller fundamentals so that they can apply the concepts they have learned in a logical and sequential manner to solve practical engineering problems. Finally, we conclude the paper with lessons learned and ideas for an improved learning experience.

Keywords — microcontroller, autonomous robot, Arduino

I. INTRODUCTION

With the technological advances in semiconductor electronics, manufacturing and process; control problems are now being solved more effectively and reliably using microcontroller rather than mechanical and electrical switching systems. Microcontroller-based sensing and control has become imminent in almost every field. This increased use of microcontroller in the industry has led to a new era of teaching microcontrollers in the academia. An area that has traditionally been reserved for electrical or mechanical engineers is now multidisciplinary, integrating digital electronics, communications and computing with a variety of systems ranging from medical to biological to environmental. Thus in our program, we have adhered to the idea that knowledge in microcontroller fundamentals is necessary for all types of engineering majors [1][2]. The new trend is to take this area beyond the traditional engineering setting and to make it accessible to students from various disciplines in a way that would foster their practical understanding and use of it.

Initially, the microcontroller fundamentals were taught in a traditional classroom setting where the instructor used to lecture and the students used to learn through listening and observation. Throughout the course, the students used to learn about the microcontroller theory and interacted with the microcontroller only through a simulator. This approach did not benefit the students since they had difficulties working with a real microcontroller in an embedded setting. With microcontrollers becoming inexpensive, a new approach called *Hands-on Learning* [3][4], started becoming popular. This approach allowed students to have a greater control on what and how they learn by allowing them to try things that are beyond the scope of traditional classroom setting. This approach emphasized on group-activities and learning exercises that required students to work with the microcontroller hardware in the classroom.

Faculty in School of Engineering at Grand Valley has taken this approach a step ahead by incorporating an in-house autonomous robot designed by two undergraduate students to infuse microcontroller fundamentals to the sophomore students in their course *EGR 226: Introduction to Digital Systems*. The primary objective of this approach is to present

microcontroller theory in a way that is appealing and applicable to all engineering disciplines.

This paper describes our approach of using autonomous robot to teach the microcontroller fundamentals to the sophomore students in our introductory digital systems' course. The paper is organized as follows: the next section describes the robotic platform that we introduce to the students in our Digital System course. The paper then describes the development of our laboratory exercises and how they build towards the final project assigned to students. We further include student assessment data that supports our approach and shows that the students appreciated this intellectual way of learning microcontrollers. We finally end the paper with our concluding remarks.

II. ROBOT PLATFORM

In order to integrate hands-on learning with the microcontroller, the students were required to purchase the Arduino Uno board for the course. The Arduino board [5] and programming language is an inexpensive way for faculty to teach microcontroller fundamentals in introductory courses. The students were assigned learning exercises in class and laboratory exercises where they had to use the Arduino board to complete them. With this being said, we still felt that the spark was missing that would instill excitement in the students and provide them with an educational learning experience with the microcontrollers.

Brainstorming session with two undergraduate students working in the electronics laboratory support led to the idea of designing autonomous robot [6][7] that would be utilized in the laboratory by other students taking the course. Since the two students had already taken the Digital systems and Circuit analysis courses, it made sense to assign them the task of designing the robots. The next task was to identify the wireless communication scheme to autonomously control the robot. After extensive research, the students were able to find a low-cost and reliable radio frequency (RF) chip (Nordic NRF24L01)[8] that had an improved range and greater programmer flexibility. It was also decided that it would be beneficial to design an RF transmitter to be able to communicate with the robot.

After several iterations of prototypes, final product specifications were finalized and the two students began working on the final product. Students used *Solidworks* for prototype modeling, 3D-printer (*Makerbot*) for printing enclosure, *Eagle* for circuit layout and soldered components on the printed circuit board and took them about 4 months to get the final product (RF-LCD controller and RF-robot) as shown in Fig. 1. After the final product was created, it went through severe testing to make sure everything worked as expected. Since we had a tight budget constraint, the robot platform was developed in-house by the using the available in-house resources.



Fig. 1. RF-LCD Transmitter and RF-robot

The RF-LCD controller housed following components:

- Nordic NRF24L01 RF chip
- Arduino compatible LCD shield
- Breakout board for connecting Arduino board
- Connectors for accessing Analog pins of Arduino

The RF-robot housed following components:

- Nordic NRF24L01 RF chip
- Commercial chassis, wheels, tracks and geared DC motors with embedded quadrature position encoders
- Motor shield
- Gadget shield (with peripherals like buttons, LEDs, potentiometers, speaker, microphone, accelerometer and many more)
- Breakout board for connecting Arduino board

This design and build process was a very good learning experience for the two undergraduate students who were assigned the task of building the robots.

III. SAMPLE LABORATORY ASSIGNMENTS AND PROJECT

The course laboratory exercises are meant to help students design and understand the use of microcontroller in an electro-mechanical system. The course laboratories are structured as four assignments and one project. They cover the following topics: introduction to the microcontroller platform; general purpose input output; timer peripherals; interrupt mechanism and analog-to-digital conversion. These laboratories expose the students to become familiar with the microcontroller platform and learn to program a microcontroller to perform the desired functions. Each laboratory has a set of deliverables; typically including the successful demonstration of a working design, source code with comments, and a brief report.

The following is an outline of the four laboratory assignments that we offer in the course:

- **Laboratory #1:** The purpose of the laboratory was to introduce students to the microcontroller platform that

they use in the course. The laboratory teaches students to write and upload C programs for the microcontroller platform. The laboratory also provides an insight into some of the built-in functions that is available through the open source database and then makes them write their own custom functions that provides the same functionality.

- **Laboratory #2:** The purpose of the laboratory was to teach students to work with general purpose input and output (GPIO) of microcontroller and communicate with Arduino over serial interface. To be able to do this we provide students with an add-on shield (Gadget shield as shown in Fig. 2) that has several peripherals and sensors that students can take advantage of. In this laboratory, students are required to display the least significant 4-bit representation of the character user enters on the terminal window on the Gadget shield LED's.

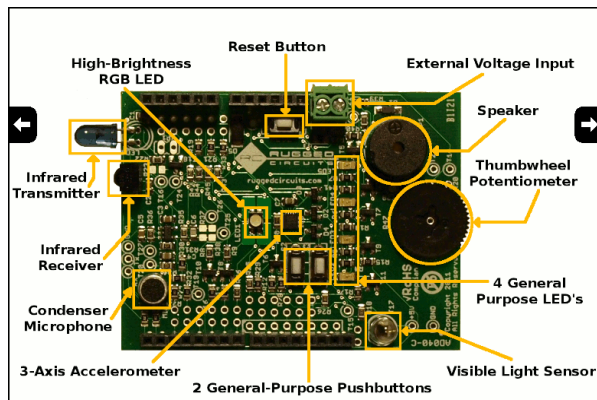


Fig. 2. Sensors and actuators on the Gadget Shield

- **Laboratory #3:** The purpose of the laboratory was to teach students to interface Arduino with the liquid crystal display (LCD). For this laboratory, we provide students with the RF-LCD controller that has the LCD module embedded in it and students insert their own Arduino board into the controller. In this laboratory, students are required to design Rock-Paper-Scissors game that the user plays with the microcontroller. For this laboratory, we allow students to use some of the pre-built functions for random number generation. Sample output of the game is shown in Fig. 3 below.



Fig. 3. Sample output for Rock-Paper-Scissors game

- **Laboratory #4:** The purpose of the laboratory was to teach students the principle of pulse-width modulation (PWM). In this laboratory, students were required to design a menu-driven LED dimmer application that varies the intensity of the LED on the Gadget shield based on user input.
- **Final Project:** The final project is spread over two weeks where students learn about interrupt mechanism and analog-to-digital (A/D) conversion and apply those concepts during the first week of the project. In the second week, students integrate everything together (knowledge about GPIO's, timers, PWM, interrupts, A/D conversion) to create a working application. The students are given two weeks to design and implement the project by using pre-designed components from the laboratory assignments and/or creating new components from scratch.

With the introduction of RF-LCD controller and the autonomous robot, students are required to accomplish RF communication between two RF-LCD controllers during their first week of the project. In the second week, students put the RF-receive code on the robot along with interrupts, A/D conversion and PWM functionality of the microcontroller to move the robot in the maze based on the commands send by the RF-LCD controller (that has the RF-transmit code).

IV. ASSESSMENT

The course "Introduction to Digital Systems" introduced the autonomous robots for the first time in Winter 2015 with an enrollment of 54 students. In order to obtain finer-grained feedback from the students, at the end of the semester we encouraged the students to complete a customized anonymous questionnaire to learn the benefits of using the autonomous robots and help improve the efficiency of the robot usage for future semesters. All of the students filled out the questionnaire to identify their actual impressions of using autonomous robots in this course.

A. Questions

The students were asked four questions as well as they were given the opportunity to include written comments. The questions were rated on a five point scale, where '1' indicates "not at all" and '5' indicates "very much". The questions were:

1. Was there a benefit to learn writing custom functions rather than using Arduino built-in functions?
2. Did the laboratory exercises allow you to apply theoretical concepts in a practical manner?
3. Was the Final Project "Autonomous Robot Navigation" appropriate for the course?
4. Did you enjoy your experience with the RF-LCD controller and the Autonomous Robot?

5. Please provide comments/suggestions as to how the experience can be made more beneficial in future offerings.

B. Questionnaire Results

Fig. 4 shows the graphical representation of the feedback received from the students. Each bar in the graph represents the question number in the questionnaire and the bar shows the average ratings by the students for each question asked.

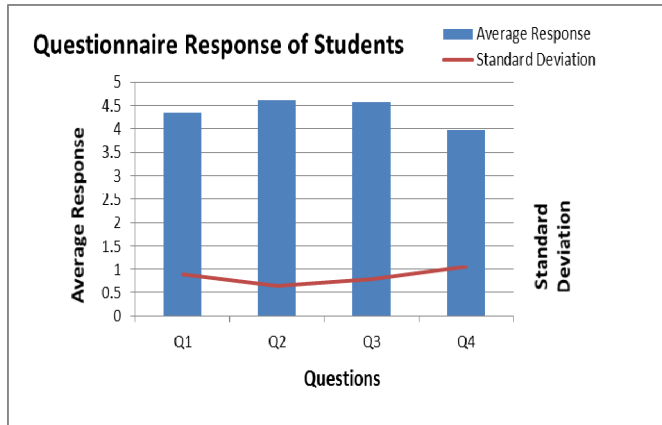


Fig. 4. Student Questionnaire Results

C. Written Comments

As previously noted, this was students' first introduction to the autonomous robot device and majority of the students appreciated the opportunity. However, the students indicated that it would be best if the autonomous robot was used very early in the course in the subsequent laboratory exercises. Students also feel that they would benefit by learning about the RF communication in the lecture so they could write the entire code by themselves rather than relying on the template that was provided to them. These views are reflected in the sample student comments below:

"Give more time to work on the robot. So you can refine the specific speeds and make it more of a racing competition"

"I would like to know more about how the RF works because we were given the template and asked to structure the code accordingly"

"Difficult subject matter made fun. The physical hands-on learning is always easier for me to understand"

"I really enjoyed learning new custom functions and RF communication"

"Incorporate more robot labs since they can be fun compared to other labs. Possibly using RF chips to perform other unique applications"

These written comments support the findings that we have already mentioned.

V. CONCLUSION

Autonomous robot is an excellent platform for infusing microcontroller fundamentals into sophomore students. Teaching microcontrollers this way presents an integrated approach to target student's knowledge of microcontroller to a practical application of maneuvering the robot through a custom built maze. The laboratory activities introduce students to the various concepts and systems discussed in lecture. The projects are used as a mechanism for the students to apply the concepts they have learned in a logical and sequential manner to solve practical engineering problems. While sometimes challenging for students, using this robot provides them the opportunity to grow significantly early on in their academic career and with generous help, most students can succeed.

In the assessment, student reaction to using autonomous robot in the course was positive apart from little inefficiency such as less exposure to RF communication theory and some hardware inconsistencies. The approach seems to have the right blend of incorporating the theoretical fundamentals into a real-life experience for the projects. We conclude by stating that in our experience, giving students this opportunity with some modifications to remove inconsistencies is an intellectual way of imparting the required knowledge to the students.

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Development of a Novel Modular Integrated Stackable Layer - Analog System Environment (MISL - ASE) Platform for Embedded Systems Education

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Abstract— With the support of Texas Instruments and NASA, a novel Modular Integrated Stackable Layer - Analog System Environment (MISL - ASE) platform has been developed to provide a comprehensive educational hardware environment for three embedded system design courses and two capstone design courses in the Electronic Systems Engineering Technology (ESET) program at Texas A&M University. The MISL-ASE platform uses the TI-MSP430 intelligence layer of the MISL architecture as the main core and control system that can be directly interfaced to the ASE board. Moreover, the MISL-ASE platform encompasses various analog and digital peripherals, such as GPIO outputs/inputs, LEDs, 7-segment displays, audio system, switches, keypad, and TFT LCD with touch screen, typical signal conditioning circuits such as A/D and D/A conversion for analog voltage simulation, battery life and light density measurement, 3-axis accelerometer, high-resolution external ADC converter, multiple analog signal generators, and motor control, etc. Several communication interfaces and protocols are also available such as UART (USB, RS-232/485, Bluetooth, and Zigbee), SPI (Ethernet, Wi-Fi, Micro SD card, and flash memory), I²C (DAC and EEPROM), and 1-wire communication devices. Additionally, the robust design of the ASE board facilitates it being interfaced to a number of other embedded intelligence boards such as the Launchpad development system. This paper will discuss the overall design and capabilities of the MISL-ASE platform and the development of a series of laboratory assignments that can be accomplished using this novel MISL-ASE environment in the area of analog electronics, digital interfacing, and communications.

Keywords— *Modular Integrated Stackable Layer (MISL); Analog System Environment (ASE); Embedded Systems*

I. INTRODUCTION

Over the last decade, the rapid advancement of computer, sensor, communication, data storage, and IC technologies has had a tremendous impact on embedded system design in many different types of industries [1]. For example, Bluetooth has emerged as a standard inter-device communication protocol in embedded systems. Traditional data measurement methods are being steadily replaced by

one-wire communication technology for numerous embedded systems. Thus, there is an acute need to integrate new and relevant devices and technologies into current embedded system teaching and learning processes. Moreover, design and implementation of embedded systems requires a broad knowledge in the areas of analog electronics, digital interfacing, communications, real-time operating systems, and software development, which are not traditionally covered in any one discipline. As faculty members, we often observe limitations in student performance when integrating multiple engineering concepts into an embedded system. Thus, it is very important to establish an integration platform that can incorporate recent advances in development tools and design methodologies, as well as the knowledge gained from different disciplines to develop practical new design techniques, so students may easily apply those new techniques to the design of state-of-art and real-time embedded systems.

Unfortunately, none of the existing development platforms/boards [2,3,4] are able to meet typical academic needs. With the support of Texas Instruments and NASA, a novel Modular Integrated Stackable Layer - Analog System Environment (MISL - ASE) platform has been developed for three embedded system design courses and two capstone design courses in the Electronic Systems Engineering Technology (ESET) program at Texas A&M University. The MISL-ASE platform: 1) provides a comprehensive educational hardware environment to support embedded hardware and software design, development, and test; 2) supports laboratory-based experiential learning in digital/analog interfacing and wired & wireless communications; 3) gives students the opportunity to design embedded systems using TI advanced microcontroller technology and a wide range of new analog and communication devices; and 4) helps students learn and use the NASA-designed, space qualified MISL architecture and assemble their own MISL stacks, e.g., power layer, intelligence layer, sensor layer, communications layer, and actuator layer, etc.

II. CONCEPTUAL DESIGN

The MISL-ASE platform mainly consists of two parts: the MISL intelligent layer and the analog system environment (ASE) board. Fig.1 illustrates the conceptual block diagram of the platform with many of the implemented features.



Fig.1. Conceptual block diagram of the MISL-ASE platform.

The MISL intelligent layer, typically the TI-MSP430 [5,6], can be directly interfaced to the ASE board. To integrate new and relevant devices and technologies into current embedded system education, the ASE board encompasses various analog and digital peripherals. Included in this suite of capabilities are GPIO outputs/inputs, LEDs, 7-segment displays, audio system, buzzer, switches, matrix keypad, and TFT LCD with touch screen, typical signal conditioning circuits such as A/D and D/A conversion for analog voltage simulation, battery life density measurement, 3-axis accelerometer, high-resolution external ADC converter, multiple analog signal generators, and motor control, etc. Several communication interfaces and protocols are also available such as UART (USB, RS-232/485, Bluetooth, and Zigbee), SPI (Ethernet, 2.4 G Wi-Fi, Micro SD card, and flash memory), I²C (DAC and EEPROM), and 1-wire communication devices. Furthermore, the robust design of the ASE board supports interfacing to a number of other embedded intelligence boards such as the TI Launchpad development system. Students can program on-board features with other microcontrollers through header pins and jumpers. A fully populated ASE board with the MSP 430 layer installed is shown in Fig.2. The two-board system is a complete development environment suitable for a wide range of embedded systems courses from entry level to advanced.

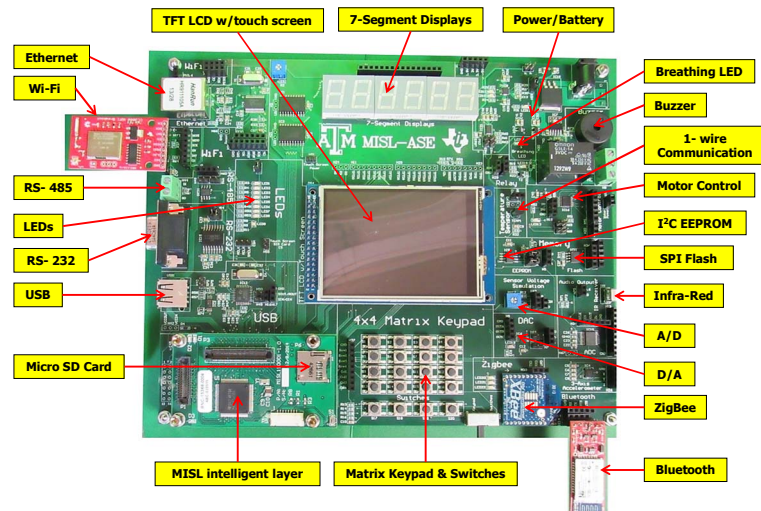


Fig.2. MISL-ASE platform with MSP-430 microcontroller.

III. DEVELOPMENT OF THE MISL-ASE PLATFORM

A. Overall Functional Diagram

The MISL-ASE platform incorporates many features that directly interface to the MSIL-MSP430 layer. Fig.3 shows the overall functional block diagram for the platform, which has four major parts: 1) MISL architecture – TI-MSP430 intelligent board; 2) GPIOs; 3) Signal conversion (A/D and D/A); and 4) Wired & wireless communications.

Objects shown in red are parts that were provided by Texas Instruments. The features outlined in red represent off-board connections. These are modules that plug-into the ASE board.

The unique features of the MISL-ASE platform are discussed in more details in this paper.

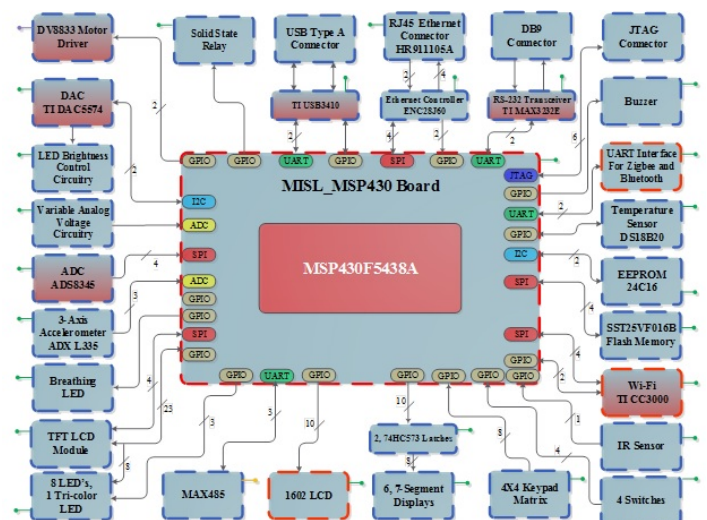


Fig.3. Overall Functional Design of the MISL-ASE platform.

B. MISL Architecture

The Control and Data Handling (C&DH) Branch (located at the NASA Johnson Space Center south of

Houston, Texas) designed and developed the MISL architecture. The C&DH Branch subsequently invited the ESET program to collaborate on the NASA development. ESET accepted three primary responsibilities of the partnership: 1) Co-development of new MISL layers, 2) Integration of the MISL architecture into undergraduate/graduate education curricula, and 3) Establishment of an open environment to make the technology available to all embedded system designers.

The C&DH Branch has developed and maintains control of the MISL form factor, Power Buss and Data Buss definitions. These specifications are available on the web [7] and can be used to support system developers using currently available layers as well as those wishing to develop new layers with expanded capabilities. Additionally, the C&DH Branch will perform space qualification testing on new layers that have value to its mission and development goals. Fig. 4 depicts the layout of a MISL layer and the location of the 40 pin Power Bus and 100 pin Data Bus.

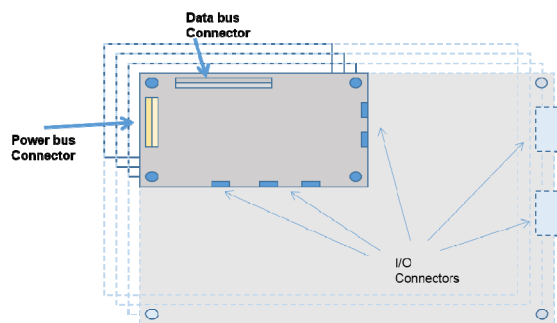


Fig. 4. MISL Layout showing Power and Data Busses.

C. GPIO inputs and outputs

GPIOs are one of the most valuable resources in embedded systems providing the ability to communicate with the external world through digital lines that configured to operate as either inputs or outputs.

1) *GPIO- outputs*: when configured as outputs, GPIOs can control the binary status of external devices by setting an external voltage level to either a logic high or logical low. The typical external devices are LEDs, buzzers, LCDs, and relays. GPIOs have been implemented on most development boards (e.g., TI launchpads). The MISL-ASE platform not only includes those devices, but includes three unique features.

a) *Breathing LED (PWM)*: The Breathing LED is a feature that simulates a breathing response by fading the LED intensity in and out. It is controlled by using the PWM duty cycle function of timers and GPIOs.

b) *Mutiple 7-segment displays*: The MISL-ASE platform incorporates 6 common cathode 7-segment displays that are controlled by 2 octal D-type latches (74HC573). One latch is used to select which display to use and the other latch is used to select what to display. The latches are controlled through the latch enable (LE) pins to prevent the latches from overriding each other. This noval display design only uses one I/O port (8-bit I/O

pins) to control multiple displays instead of using multiple GPIO ports.

c) *TFT LCDs with touch screen*: TFT (Thin-film transistor) LCDs with touch screen are widely used in mobile phones, handheld video game systems, personal digital assistants, navigation systems projectors, etc. On the MISL-ASE platform, a 3.2" TFT LCD Display module is employed, which includes the display controller (ILI9341), the touch IC (XPT2046), and a SD card. The MISL- MSP430 layer uses 20 GPIO pins and a SPI interface to communicate with this TFT LCD display.

2) *GPIO -inputs*: Mechanical contact switches are one of the components most commonly interfaced to microcontrollers as a typical GPIO input example. There are two GPIO input features on the MISL-ASE platform: the 4x4 matrix keypad and the 4 switches. The keypad uses one of the GPIO ports (8 pins) of the microcontroller, where 4 pins are for the columns and 4 pins for the rows. The column pins are shared with the 4 switches. A 4PDT switch is used to switch between the two features.

D. Signal Conversion

One common task for embedded systems is to measure analog signals from the outside world, e.g., pressure, temperature, humidity, flow rate, etc. On the ASE board, the analog-to-digital conversion part includes several typical analog devices interfaced to the MSP430 microcontroller: 1) Potentiometer: it is used to simulate a varying analog input voltage; 2) 3-axis accelerometer (ADXL335): The X, Y, and Z channel outputs of the ADXL335 are connected to three of the 12-bit internal A/D converter inputs of the microcontroller to detect the static acceleration of gravity in tilt-sensing applications, and dynamic acceleration resulting from vibration, shock and motion; and 3) 16-bit, 8-channel SAR external ADC (ADS8345): it is also available so students can gain experience with a high-resolution ADCs instead of the 12-bit internal ADCs.

E. Wired and wireless communications

Most popular wired & wireless communication interfaces and protocols are available on the MISL-ASE platform. These include: 1) four-wire communication networks: SPI (Ethernet, 2.4 G Wi-Fi, Micro SD card, and flash memory); 2) two-wire communication networks: UART (USB, RS-232/485, Bluetooth, and ZigBee); 3) two-wire communication networks: I²C (DAC and EEPROM); and 4) 1-wire communication networks: DS18B20.

1) *SPI*: the Serial Peripheral Interface (SPI) is a synchronous serial bus standard with full-duplex capability to support communications between a master (e.g., microcontroller) and one or multiple slave peripheral devices. On the ASE board, the Ethernet, 2.4G Wi-Fi modules (TI-CC3000 and nRF24L01), the Micro SD card, and the flash memory (SST25VF016B) are able to communicate with the MISL-MSP430 stack via SPI

interfaces. For example, the interface between the MSP430 microcontroller and the Ethernet controller chip (ENC28J60) is based on the SPI bus protocol. The SI, SO, SLCK, and CS pins of the Ethernet chip are connected to SPI pins (MOSI, MISO, SCLK, and CS) of the microcontroller. With this Ethernet feature, many different devices and equipment can be remotely accessed, monitored, and controlled through internet, such as web-based home automation, remote environmental monitoring, Voice Over IP, etc.

2) *UART*: The Universal Asynchronous Receiver / Transmitter (UART), is a very useful feature of microcontrollers for communicating serial data (text, numbers, etc.) to computers or devices. The MISL-ASE platform not only contains typical UART standards (RS232, RS485, and USB), but provides new wireless communication standards (ZigBee and Bluetooth) via UARTs. ZigBee is a reliable, low-cost and low-power, wireless networks based upon the 2.4 GHz IEEE 802.15.4 radio protocol. The ZigBee module (XBee2) is used on the platform and allows students to create wireless distributed sensor networks to remotely monitor and control electromechanical systems in their home, office, or other areas. The RN-42 is a Class 2 certified Bluetooth module, which can be connected to the ASE board to communicate with personal electronic devices, e.g., cell phones, wearable devices, etc.

3) *I²C*: The Inter-Integrated Circuit bus (I²C) is a synchronous serial communication protocol to support on-board interconnection of integrated circuit devices. On the platform, the I²C uses two lines (SDA and SCL) to establish a half-duplex communication bus between the master (MSP430) and slave devices: 16K EEPROM (24C16) and Digital-to-Analog converter (DAC5574).

4) *One-wire communication*: The digital thermometer (DS18B20) is employed on the platform to teach students how to develop distributed temperature monitoring systems through one-wire communication bus in lieu of the traditional measuring method using temperature sensors, signal conditioning circuits, and A/D converters.

IV. MISL-ASE PLATFORM EVALUATION

Final debug and testing of the MISL-ASE Board was completed during the Spring 2015 semester. Based on these results, an initial order of 50 boards were procured and populated. To reduce the overall cost of the boards, ESET students will become part of the development team by hand soldering all through-hole components on the boards they use in lab.

To assess the value and acceptance of the new systems, two students from the entry-level C Programming course were asked to use the new environment for one of their laboratory projects. All students are familiar with the MSP430 microcontroller architecture and software

development environment based on previous labs performed on a MISL stack composed of a 1) Battery Power Layer, 2) MSP430 Intelligence Layer, and 3) Signal Breakout Layer.

The assessment was anecdotal in nature and sought to evaluate the value of the new embedded software environment to support the experiential education aspects of the ESET program. This informal assessment resulted in the following information:

1. Both students liked the idea of having all hardware interfacing requirements available on the MISL-ASE system. Other students using the three-board MISL stack were required to spend time wiring and debugging circuitry rather than focusing on designing, development, testing, and documenting their programs.
2. The students enjoyed the engineering experience of using block diagrams and detailed schematics in determining the ports that would be used and the configuration options of the ASE system.
3. The interest level of the students concerning other MISL-ASE capabilities increased through the use of this environment. Realizing the wide range of technologies available on the ASE platform stimulated the students' interest in doing future labs using the platform.
4. With the feedback from the informal evaluation of the MISL-ASE system, other ESET faculty members have become interested in leveraging the technology. The capabilities of the environment and working knowledge that the students will have after the three-course (sophomore/junior) sequence may allow for more extensive course projects to be considered. The course director for the two-semester, senior-level capstone design experience sees significant value in having the MISL-ASE resource. Being able to use the features of the MISL-ASE environment augmented by other MISL layers, will provide a marked increase in the rapid prototyping of the embedded system necessary to transition a customer's problem/opportunity to fully functional prototype.

V. CONCLUSIONS AND FUTURE WORK

This paper presents the overall design and capabilities of the MISL-ASE platform and the development of a series of laboratory assignments that can be accomplished using this unique MISL-ASE environment in the area of analog electronics, digital interfacing, and communications.

For our future work, we will focus on finalizing the MISL-ASE platform. Students from three embedded systems courses and two capstone design courses will be using and evaluating the platform starting Fall, 2015. The outcomes from using this platform will be quantitatively and qualitatively assessed through the observation of students' performance in the lab/class, their feedback, and surveys. Also, the RTOS (Real-time Operating Systems) education systems will be developed based on the MISL-ASE platform.

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Vamonos: Embeddable Visualizations of Advanced Algorithms

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Abstract—We present Vamonos: a new framework for algorithm visualization, designed from the beginning to support embedding, interaction, and unlimited scope. Visualizations are executed entirely client-side on any device that supports a modern web browser; they can be embedded into any website or online textbook. Users can specify breakpoints, watched variables, provide inputs to the algorithm (e.g., by drawing a graph using a mouse), and be prompted for interaction by the visualization. The core framework supports any algorithms and data structures that can be implemented in Javascript. We have implemented a wide range of visualizations of advanced algorithms topics, including dynamic programming and graph algorithms (e.g., spanning tree, max-flow, bipartite matching algorithms).

I. INTRODUCTION

Algorithm visualizations (AVs) have long been appealing to both educators and students alike. Yet, they have not been as widely adopted as one would expect. There has been a great deal of research into effectiveness of AVs in general (e.g., [11], [7]) as well as usability aspects of AV systems which hamper or facilitate their adoption (e.g., [9]).

At the same time, web-based educational resources have become more sophisticated, due to overall advances in web/browser technology and facilitated by the increased popularity of massively open online courses. Specifically, AVs have evolved from static animations (famously [1]) to interactive Java/Flash applets (e.g., [16]), and recently, full-featured web applications (e.g., [6]) that take advantage of standard modern browser features.

Now, with increased effort being placed into high-quality online, *interactive* textbooks (e.g., [14], [17]), interactive visualizations are becoming replacements for the static figures of paper textbooks. Indeed, online textbooks/lessons seem to be the ideal venue for AVs, as [20] found that AVs should be paired with motivational goals and instruction, and [11] found that AVs are most effective in a homework/self-study (rather than exam) setting.

II. RELATED WORK

There are a number of ongoing AV projects that share our goal of leveraging recent developments in webrowsers.

The Javascript Algorithm Visualization Library (JAVL) [10] provides a framework for educators to create browser-based visualizations, with the stated goal of supporting online textbooks. In particular JAVL was created to support the OpenDSA project [19] [5] which seeks to provide a free interactive online data structures and algorithms textbook. JAVL visualizations are highly interactive, with built-in mechanisms (“proficiency exercises”) for quizzing the user. JAVL can follow along as the user simulates the algorithm, providing feedback when mistakes are made. JAVL is very high-level in the sense that it favors visualizing more conceptual rather than procedural aspects of algorithms.

The recent PythonTutor framework [6] is a popular and very successful example of an AV tool that can be embedded into online textbooks. In contrast to JAVL, PythonTutor’s focus is on visualizing low-level, introductory programming concepts (Python syntax, flow control, arrays, references, calling conventions) to novices. Indeed, the AV landscape skews heavily towards introductory material (e.g., sorting algorithms). Shaffer et al. [18] surveyed a wide range of AVs and found that coverage of advanced topics (e.g., dynamic programming, network flow) is lacking, by comparison.

III. OUR WORK

Inspired by the success of PythonTutor, we set out to make a web-based AV framework that supports more advanced algorithmic topics, which are typically expressed in very high-level pseudocode and involve more sophisticated data structures. Since web browsers already have the capability to execute arbitrary Javascript, we also wanted to forego PythonTutor’s reliance on a server-side component. In the context of embedded visualizations in textbooks, client-side visualizations allow the material to be learned away from an active internet connection (or after the server-side maintainer has let the service lapse).

In addition, like PythonTutor, we wished to provide a close coupling of a visualization to the code itself - in our case pseudocode. This provides the end-user with more flexibility and transparency than offered with a visualization in JAVL. With Vamonos, users can see exactly how a line of pseudocode changes the underlying data structure. In contrast, JAVL visualizations provide an English description of what occurs in each frame out of context of the rest of the program. Furthermore, JAVL does not support the visualization of loops, recursion, and other control structures as they work inside an algorithm.

Ihantola et al. [8] give a taxonomy of AV “*effortlessness*” — features of a system that reduce barriers for educators to adopt and maintain visualizations. Among our goals was to achieve a high degree of effortlessness. We highlight some important features of Vamonos, using this taxonomy:

Integrability denotes qualities that make the system attractive to use and easy to set up, encompassing installation, customization, platform independence, internationalization, documentation, interactive prediction support, course management support, and integration of hypertext.

Being web-based, Vamonos has very high integrability. Visualizations require no installation barrier beyond a modern web browser (for either AV producers or consumers) so are inherently cross-platform. At the extreme, all of the page data (HTML, Javascript, CSS) of a visualization can be inlined into a single HTML file. We also inherit all of the power of modern HTML for layout, CSS for stylization, as well as accessibility features (i.e., visualizations are natively scalable). And, of course, the visualizations can be easily embedded.

Scope denotes how widely one can apply the system, encompassing difficulty in installing and running the system, and educational context (how many topics can the system be used for?). We created Vamonos to have essentially unlimited scope within the domain of algorithms, supporting both low-level concepts (arrays, calling conventions, basic flow control) and very high-level ones (e.g., graphs and geometric algorithms). The core framework can, at least in principle, support any algorithm & data structure that can be implemented in Javascript.

Interaction denotes how deeply the consumer can modify a visualization. Lawrence et al. [12] showed that students’ ability to design their own inputs to algorithms is a key factor in AV effectiveness. In Vamonos, the consumer can specify her own inputs to an algorithm: even graphs. Further, the consumer can set breakpoints and watched variables, and step forward and back through the algorithm’s execution. Meta-aspects of the execution are also displayed (e.g., active line of execution, complete

call stack). We also support several kinds of interactive quiz capabilities. (See Section IV)

IV. USE CASES / VIGNETTES

We introduce Vamonos by presenting use cases that take advantage of its highly interactive nature and broad scope.

A. Ford-Fulkerson Algorithm & Eliciting Interesting Inputs

Consider the Ford-Fulkerson algorithm for computing maximum flow. The input to such an algorithm is a flow network — a complicated data structure consisting of a directed graph, with integer edge labels / capacities, and two distinguished vertices (designated source and sink).

Using a Vamonos visualization of Ford-Fulkerson, a student can draw any such flow network using the mouse (see Figure 1). S/he can then execute the algorithm on the graph of her/his choice and see how the max flow is iteratively obtained and how the residual graph is updated.

One particularly challenging concept about the Ford-Fulkerson algorithm is that during the course of the algorithm, flow does not monotonically increase along every edge. Consider the following application for a Vamonos visualization embedded in a web-based textbook. After discussing why it might be necessary to reverse the flow along some edge, the textbook can present an embedded visualization and prompt the reader to draw an example input on which such flow-reversal is necessary. Vamonos supports this kind of input-based quizzing, where the user is asked to provide an input that triggers a certain internal condition to happen; for example:

- An edge case in an algorithm is triggered (e.g., there is a tie among shortest paths).
- Dijkstra’s algorithm proceeds by maintaining upper bounds on each vertex’s distance from the source. These distance estimates are reduced until they converge on the true distance. The user can be prompted to input a graph for which some vertex has its distance estimate modified at least 5 times.

B. Depth-First Search & Topological Sort

In Vamonos, graphs can be manipulated with the mouse not only to draw the input to an algorithm, but to rearrange the graph during the AV’s display mode (this is an optional setting, as it would not be advisable to rearrange vertices while running an algorithm that uses the graph’s planar *embedding*).

We provide a ready-made visualization of depth-first search (DFS), and, following the textbook of Cormen et al. [4] (CLRS), we label each vertex with its “start” and “finish” time (i.e., the time at which it entered and left the stack). For acyclic graphs, CLRS prove that sorting

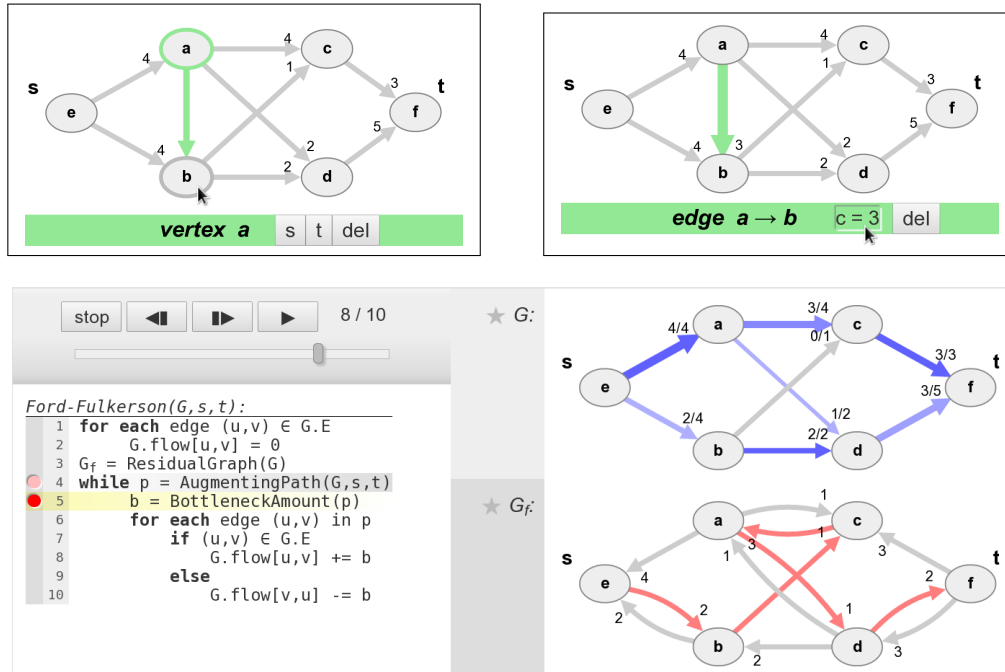


Fig. 1. Vamonos is a web-based algorithm visualization framework that supports high-level data structures like graphs. This series of screenshots shows a Vamonos visualization of the Ford-Fulkerson max-flow algorithm. The two upper screenshots show the modal interface by which a user can input a graph using the mouse. In the upper-left screenshot, the vertex a is modally selected, and a green potential edge ab is shown when the user hovers over b . Buttons below can delete vertex a or set it to be source/sink. In the upper-right screenshot, an edge ab is modally selected, and it can be either deleted or its label/capacity changed. In the bottom screenshot, a user has finished drawing the input graph G (labeled G), set two breakpoints, and stepped through 8 of 10 frames of the algorithm's execution. The red path in the residual graph G_f shows the augmenting path p . In the flow network G , the color denotes saturation: edges with zero flow are gray; saturated edges are completely blue; other edges are an appropriate mixture.

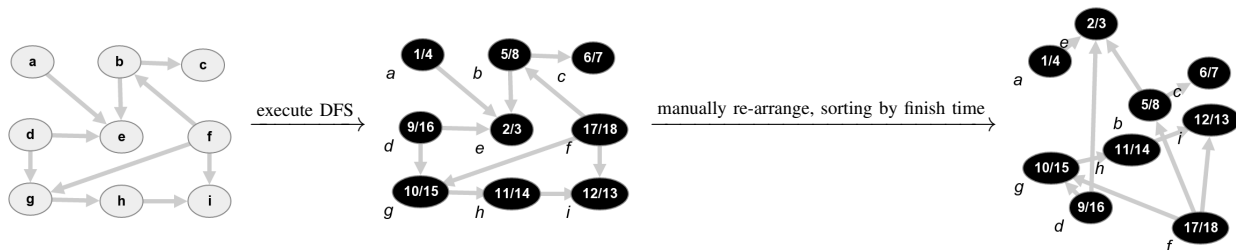


Fig. 2. A visual demonstration of a topological sort based on DFS. Vertex labels represent “start / finish” times. In the final image, it can be visually verified that all edges point upward, hence the ordering corresponds to a topological sorting of the vertices.

the vertices by decreasing finish time yields a topological ordering.

As an in-class demonstration or a guided self-study lesson, a user can execute DFS on a graph so that each vertex is labeled with its finish time. S/he can then drag vertices around to place them in order according to finish time. It can then be verified *visually* that the resulting embedding has all edges pointing in the direction of decreasing finish time. (See Figure 2).

C. Breadth-First Search & Bipartiteness

Other properties of graphs are illustrated well using a similar approach. For instance, consider executing

breadth-first search (BFS) on a graph to label each vertex with a distance value. Then arrange the vertices into columns, one column for each possible distance value, in increasing order. In the resulting graph, it can be visually verified that for every edge uv , we have $|u.d - v.d| \leq 1$. That is, no edge can skip a “height/level” in the BFS tree.

Along the same lines, we have included a visualization for a variant of BFS that colors vertices red and blue, where the colors are chosen to disagree along an edge as it is traversed by BFS. If an edge is encountered with monochromatic endpoints, the algorithm stops highlighting the problematic edge.

When an edge has monochromatic endpoints, an

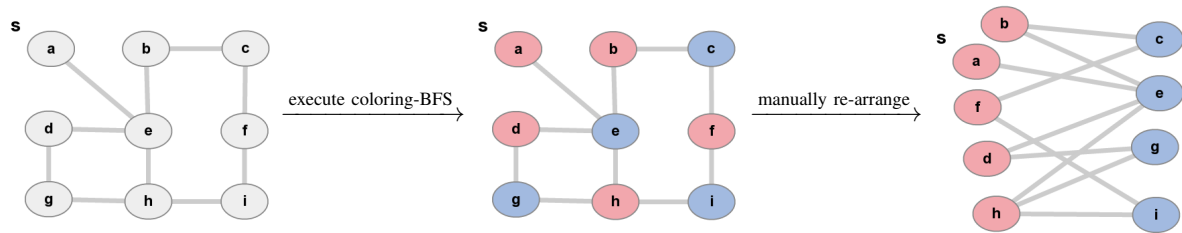


Fig. 3. A visual demonstration of a bipartiteness algorithm based on BFS. After manually rearranging, it can be visually verified that all edges have one red and one blue endpoint.

odd-length cycle can be easily found visually (hence, the graph is not bipartite). If the algorithm terminates without a monochromatic edge, then the graph can be rearranged with red vertices to the left and blue vertices to the right. Students can then verify visually that all edges cross from left to right; hence, the graph is indeed bipartite. (See Figure 3.)

V. DESIGN & IMPLEMENTATION

The Vamonos framework consists of CSS and Javascript libraries (compiled from Coffescript), along with popular Javascript library jQuery and graphical library D3 [2]. Visualizations (of which we provide a collection of examples) are HTML files that load these libraries.

A. Visualization Engine & Lifecycle

Vamonos visualizations are managed by an instance of a **Visualizer** object. A **Visualizer** object is instantiated with a **callback** that implements the algorithm to be visualized (more details of this are discussed in Section V-C) and a collection of **widget** objects which implement the user-facing elements of the visualization (described immediately below).

Vamonos visualizations are modal, with two modes. By default, a visualization begins life in **edit mode**. (It is possible to make a visualization that exists only in display mode. This may be useful for visualizations with fixed inputs.) In this mode, widgets are collecting input from the user: inputs to the algorithm, and other parameters of the algorithm execution like breakpoints and watched variables.

When the user is satisfied, she uses the controls to finish edit mode. At this point, the **Visualizer** object will execute the algorithm and periodically collect snapshots of the algorithm's state, called **frames**. Each frame contains the contents of all variables, call stack, active pseudocode line, etc. Indeed, the main responsibility of the **Visualizer** object is to constantly maintain a representation of the call stack, manage the various

procedure-local name spaces for variables, and determine the appropriate times to take a snapshot of the current state.

Then the visualization enters **display mode**, in which the widgets display the contents of these frames. Using on-screen controls, the user can navigate through this collection of frames to see the execution of the algorithm. While the user has a sense of being able to pause/rewind the execution of an algorithm, it is important to note that the collection of snapshots is generated all at once and then fixed (until the next edit/display lifecycle). The user cannot change variables, breakpoints, watched variables on the fly. This is primarily because our method for implementing the actual visualized algorithm is not re-entrant, so does not support stepping backwards; again, see Section V-C.

B. Widgets

Generally, a **widget** is any part of the visualization that interacts with the user. The **Visualizer** object provides a standardized API for widgets. In edit mode, widgets may set variables and other execution parameters (like breakpoints and watched variables). In display mode, widgets receive the current frame to display. Widgets are also the mechanism by which the **Visualizer** changes modes and navigates through the collection of frames.

We give a summary of the various widgets implemented so far:

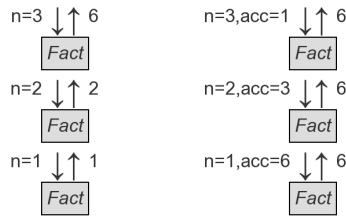
Pseudocode displays the pseudocode of the algorithm. In edit mode, allows users to specify breakpoints by clicking in the gutter (mimicking the interface of a standard IDE). In display mode, highlights the pseudocode line that just finished executing, and the line about to execute.

We point out that the lines of code in the pseudocode widget are purely cosmetic, and have no bearing on what code is actually *executed* to generate the visualization (see Section V-C for more details). Hence, the pseudocode widget can be used to show a very high-level or a very low-level algorithm.

In the example below, lines 4 & 5 are set as breakpoints. In this frame, line 4 is about to execute, and line 3 has just finished.

```
SelectionSort(A):
1 for i = 0 to A.length-2
  # find smallest item in A[i..]
2   m = i
3   for j = i+1 to A.length-1
4     if A[j] < A[m]
5       m = j
6   swap A[i] and A[m]
```

CallStack, in display mode, shows a dynamically updating representation of the call stack. The procedure name, arguments, and return values are all displayed. Vamonos supports algorithms with multiple procedures, and also supports tail calls. Below are two call-stack visualizations for different factorial functions (both showing the final result).



Array displays an array data structure. In edit mode, allows WYSIWYG editing of an input array. In display mode, shows the contents of an array in the given frame. The widget also supports various styling features: the array can be annotated with array index variables from the algorithm, and CSS rules can be applied to cells based on index variables. Array cell zero can also be hidden, to mimic 1-indexed arrays common in many texts.

Below is an example from a dynamic programming visualization that uses the recurrence

$$opt[k] = \max_i \{ price[i] + opt[k - i] \}.$$

Hence, we show variables k and i indexing into $price$, we shade the not-yet-used portion of $price$ (beyond index k), and we show *expression* $k-i$ indexing into opt .

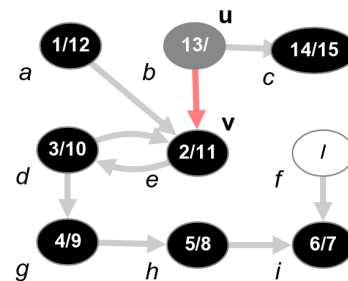
```
new Widget.Array({
  varName: "price",
  showIndices: ["k", "i"],
  cssRules: [[">", "k", "shaded"]],
  ...
})
new Widget.Array({
  varName: "opt",
  showIndices: ["k", "k-i"],
  ...
})
```

price:	1	2	3	4	5	6
	1	5	8	9	10	14
				i	k	
opt:	0	1	2	3	4	
	0	1	5	8	10	
		$k-i$		k		

Graph displays a graph data structure. Edges can be directed/undirected, and optionally weighted. In edit mode, the widget area is a canvas on which the user can draw a graph using mouse/touch actions. **Graph** widgets support a wide variety of informative styling in display mode: vertex labels, edge labels, and CSS styles can be determined according to arbitrary vertex/label attributes set by the algorithm. Variables that take on *vertices* as values can be displayed as annotations similar to how array indices annotate the appropriate cell in an **Array** widget.

In the depth-first-search example below, a directed graph is shown. The `v.color` attribute determines the CSS class of the vertex; the contents of the vertex are computed as "`v.start / v.finish`". Vertex variables u and v are displayed as annotations *à la* array indices. The edge u to v is highlighted red.

```
new Widget.Graph({
  vertexLabels: {
    inner: function(v) {
      return v.start + "/" + v.finish;
    },
    sw: function(v) { return v.name },
    ne: ["u", "v"],
  },
  vertexCssAttributes: {
    color: ["white", "gray", "black"],
  },
  edgeCssAttributes: { red: "u->v" },
  ...
})
```



UserQuiz creates a modal user dialog in display mode that cannot be dismissed until the correct answer is given. The quiz is parameterized by a *condition* (on which frames will the dialog be displayed), a *question* to be asked, and a correct *answer*. Each of these parameters can be computed as a function of the current frame. In the following example, a dialog will be displayed whenever algorithm variable $i > 5$ and the frame was taken just before pseudocode line 4 was to be executed.

```

new Widget.UserQuiz({
  condition: function(frame) {
    return frame.i > 5
      && frame._nextLine == 4;
  },
  question: function(frame) {
    return "What will algorithm put "
      + "in A[" + frame.i + "]?";
  },
  answer: function(frame) {
    ...
  }
});

```

ResultProperty provides an easy way to display a message on the page conditioned on some event happening in the execution of the algorithm. This can be used to make visualizations with self-tests of the form “find an input that causes behavior X from the algorithm.” (See Section IV.)

C. Internals & Creating Visualizations

An Vamonos visualization is concretely an HTML document that imports the Vamonos library. This HTML file contains Javascript invocations of the **Visualizer** and other widgets, as well as HTML layout information and accompanying page content.

1) *Laying out the widgets*: Most widgets are user-facing, and draw elements to the page. The relative layout of these widgets is completely unconstrained (though we provide default HTML/CSS templates), so that a visualization’s collection of widgets can be placed anywhere within a document.

When generating a visualization, the producer typically specifies the visual location of a widget by inserting an empty `<div>` HTML tag into the page source, e.g.:

```
<div id="some-widget"></div>
```

Then the associated widget object instance is attached to this tag in its constructor arguments:

```

new Widget.Array({
  container: "some-widget"
  ...
});

```

2) *Algorithm callbacks*: An AV producer must specify an implementation of the algorithm which is to be run. Naturally, this can be done by passing a callback to the **Visualizer** object. However, there are two major challenges: (1) Stopping the callback mid-execution to take snapshots of its internal state. (2) Providing the **Visualizer** object with access to the internal variables of the algorithm.

We solve these challenges in the following way. For concreteness, consider the following Javascript implementation of Horner’s polynomial evaluation method:

```

function Horner(P,x) {
  var res = 0;
  var i = P.length - 1;
  while (i >= 0) {
    res = res * x + P[i];
    i = i-1;
  }
  return res;
}

```

We solve the first challenge by having the the **Visualizer** pass a callback to the algorithm. By convention we name this argument “_”. The algorithm should invoke this callback with a number *n* to indicate that it is about to execute *pseudocode* line number *n*. This provides a hook to return control flow to the **Visualizer** object so it can generate a new frame if desired. Again we stress that the correspondence between the actual algorithm implementation and lines of pseudocode is arbitrary. Conveniently, the **Visualizer** can also raise an exception if it suspects an infinite loop in the algorithm.

Addressing the second challenge, when the **Visualizer** executes the algorithm callback, it first sets Javascript special global `this` to be a “scope object” in which local variables are stored. As long as the algorithm refers to `this.varName` rather than a local variable `varName`, both the algorithm and the **Visualizer** will have common access to these variables. To further cut down on the extra syntax imposed, we use Javascript’s somewhat obscure `with` statement. Assuming that `this.i` exists in the scope object, all references to variable `i` inside the scope of `with(this){...}` will really refer to `this.i`.

In the end, our example from before becomes:

```

function (_) {
  with (this) {
    _(1); res = 0;
        var i = P.length - 1;
    _(2); while (i >= 0) {
    _(3);   res = res * x + P[i];
          i = i - 1;
        }
    _(4); return res;
  }
}

```

This callback can then be passed as a parameter to the **Visualizer** object via:

```

var viz = new Visualizer({
  widgets: [ ... ],
  algorithm: function (_) { ... }
});

```

3) *Multiple procedures*: An AV producer can specify an algorithm with several named procedures. Instead

of passing in a single callback, an associative array of name→callback values should be given.

The **Visualizer** engine adds a wrapper around each callback which facilitates the calling conventions in several ways. This wrapper is where the engine can maintain its representation of the call stack. The wrapper also handles argument passing, which is not positional but done by name. Finally, the wrapper populates the `this` “scope object” with the (wrapped) procedures, so that the procedure-calling syntax is natural when writing the visualization. A special argument to these wrapped procedures is used to specify tail-call optimization of the call stack.

4) *Watched variables via serialization*: Vamonos supports generating snapshot frames whenever a variable is changed. We achieve this functionality for completely arbitrary data types by using the browser-standard JSON (Javascript object notation) serialization features. Each watched variable is serialized to a JSON string, and these strings can be compared to detect when a variable is changed. Hence, one can set a graph variable to be watched, and a frame will be captured whenever any of the constituent vertices has an attribute changed.

Serialization also allows an easy way to save and share user-provided inputs. When a user enters an input to an algorithm, an encoding of that input is placed in the URL. Students can use this mechanism to submit answers to homework questions (of the form “find an input that causes behavior X”) or share with peers.

5) *Inlining visualization*: One of the benefits of basing our framework on native, client-side web technologies is that visualizations can be contained in a single page. We have avoided use of images in our default styles, and as such, the visualizations require only HTML, CSS, and Javascript resources. These can be inlined into the main HTML page, and we provide a simple script to do so. Without taking any effort to minimize the size of our source files, a complete stand-alone Vamonos visualization (including all prerequisite libraries) is less than 1 megabyte.

VI. ONGOING WORK

So far, our focus has been implementing a fully-featured core system. Our next step is to add levels of abstraction facilitating AV production by non-experts. Ultimately, we envision a workflow in which a user compiles a high-level pseudocode-like language into a Vamonos visualizations, similar to PythonTutor [6] and PCIL [13]. Students themselves could then create fully functional Vamonos visualizations without needing to interact with HTML and Javascript boilerplate.

A particularly interesting direction is to explore the extent to which “visualizable aspects” of high-level code can be automatically deduced from the source code, as

demonstrated in [15]. It seems likely that a compiler would be able to infer which variables/expressions are used as array indices. However, other more sophisticated run-time properties could be automatically inferred and inform the visual presentation. For example: if an array index i monotonically traverses the array, and only indices at most i are ever accessed, then the portion of the array beyond i can be shaded (we hard-code such visual rules already).

A formal evaluation of the current system’s efficacy is also needed, particularly when used in an embedded form in an electronic textbook. User study results would help guide our ongoing development and addition of features.

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International iCampus Forum (IC15)

on

“Smart Education in Smart Cities”

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Abstract— The IC'15 iCampus Forum is part of the International iCampus Initiative led by Etisalat BT Innovation Center (EBTIC) – a joint British Telecom (BT) research centre located in the middle-east region. More information about the initiative can be found in <http://www.intelligentcampus.org>.

I. AIM OF THE EVENT

The educational landscape is changing; some have termed it as the “climate change” in education. The students of today engage with the learning environment differently from the students of yesterday. The traditional landscape is often perceived as “formal”, “passive”, “direct”, and “push” learning environment designed largely for the knowledge consumers; and the modern landscape is often perceived as “informal”, “active”, “collaborative”, “social”, and “pull” learning environment designed not only for the knowledge consumers but also for the knowledge creators. This has since brought about the recent launch of several “Smart Learning” initiatives across the various continents, including the “Education” vertical pertaining to the societal “Smart Society” or the wider “Smart City” initiatives as well as several others. Such advances have never been at a greater pace than those experienced today, and have the promise of revolutionizing educational practices and changing the world of education in the modern knowledge-based economies internationally. This paradigm shift in education is imminent and has gathered a lot of interests, among the academia and the industry, in an attempt to bridge the technological gap in the educational sector.

To meet the overall needs and prevailing demands towards the global “smartization” movement within the education sector, the central theme of this year iCampus Forum (IC'15) is set on “Smart Education in Smart Cities”, in particular the smart “technological” and/or “pedagogical” aspects of education. The aim of this forum is to complement the FIE event, by gathering like-minded and cross-disciplinary research communities together, in conjunction with the iCampus consortium, to network, share and discuss as well as be informed of the current frontiers of research in this domain (number of attendees is expected to be about fifty or so). This would also aid to encourage new research ideas and foster cross-collaborations among the researchers internationally.

II. TOPICS OF THE EVENT

To keep up with the changing landscape, this forum will address the various pertinent topics of interest that are aligned with the international “Smart Learning”/“Smart Society”/“Smart City” initiatives in the roadmap towards the smartization as well as the advancement of educational research and innovation within the education sector. To do this, a new paradigm of thinking pertaining to a holistic intelligent campus (iCampus) environment will be investigated which encompasses several domains of intelligence. Some of the topics of interest include (but is not limited to): Cloud Education, Big Data for Education, Social/Collaborative Learning, Blended/Hybrid Learning, Personalised E-Learning, Mobile Learning, Edutainment & Game-Based Learning, Pedagogy for the Internet Age, Smart Classroom, Virtual Classroom/Laboratory, Educational Technology Innovations, Remote Education, Ubiquitous Learning Systems, Digital Library or E-Education, Peer-to-Peer Learning, & Other research issues for iCampus.

III. DETAILS OF THE EVENT

The forum is comprised of two main sessions, namely (1) a research paper session to set the scene and background of the panel, followed by (2) a roundtable/panel session to discuss in-depth into the issues.

To aid in the panel discussion, a total of 5 papers have been submitted by a subset of the key iCampus collaborators/supporters. The papers are categorised into two categories so as to introduce some aspects of the scene and background: (a) pedagogical-oriented; and (b) technological-oriented. As a summary, the former would cover the following papers (1) iCampus: An Exploration into the Attitudes of Young Girls Toward the Field of Computer Science (to bring out the gender aspects and considerations in engineering education), and (2) iCampus: Interaction Driven Composition of Student Groups for Optimal Groupwork Learning Performance (to look into the students dynamics in collaborative learning so as to maximize the full potential of learning and teaching); the latter would cover the following papers (3) iCampus: Development and Implementation of Game-, and Computer-Based Learning in a General Chemistry for Engineering (to explore and report on the results in the use of game-based learning in the engineering

education course), (4) iCampus: Grouping Tool Portal for Collaborative Learning (to propose and assess smart student grouping portal for education), and (5) iCampus: Smart Text-Classification of User-Generated Data in Educational Social Networks (to put forward the use of social networking tools for learning purposes).

All these papers are specially selected to put forward a few snapshot perspectives in the ‘smart-ization’ of the education domain so as to give an introductory overview for wider panel discussion in the technological and pedagogical aspects in smarter education. To ensure the quality of the panel, all these papers have gone through the same FIE review process and only the best papers that have been accepted would be incorporated in the session.

IV. PREVIOUSLY ORGANIZED EVENTS

Please kindly visit “2013 International iCampus Symposium on Smart Learning (IC’13)” in <http://IC13.intelligentcampus.org> or “2014 International iCampus Forum on Smart Education for the 21st century (IC’14)” in <http://ic14.intelligentcampus.org>; or, alternatively, our international iCampus conference series in <http://intelligentcampus.org/events>

V. ORGANIZERS/PANEL CHAIRS OF THE EVENT

The organizers/panel chairs of the International iCampus Forum (IC’15) are:

Jason W.P. Ng
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An Exploration of the Attitudes of Young Girls Toward the Field of Computer Science

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Abstract—This paper addresses the continuing problem in the United States of a lack of female professionals in Computer Science. The research team conducted surveys of middle school students and working adults to examine their attitudes, motivations, and experience with Computer Science. Based on the survey findings, the researchers are able to evaluate the effects of early, positive exposure to computer programming and give recommendations on how to improve the attitudes and confidence of young girls toward a possible career in Computer Science.

Keywords—education, computer science, programming, middle school girls, STEM.

I. INTRODUCTION

THIS research is conducted for a Middle School in Southern California, under the supervision of one master teacher. The Computer Science career field is severely under-represented by females. Many factors contribute to the lack of females interested in Computer Science. Based upon this teacher's experiences and research, many young middle school girls are not afforded the opportunity to learn computer programming, therefore, lack the knowledge and motivation to strive for a Computer Science degree.

Computer Science is one of the most in-demand and fastest growing career fields, with a projected growth of 22% in the next 8 years [1]. Computer Science encompasses everything from network design and engineering to software development. This career field requires extensive knowledge/skills of math and coding. However, designing computer applications can be fun, and it requires a creative mind.

This study took on the challenge of discovering answers to the aforementioned problem, by studying an exemplary computer science classroom in this middle school. This master teacher was awarded the Lowe's Champion Grant to transform her technology class to a computer science class. The goal of this grant is to steer girls towards a Computer Science career by giving them the opportunity to program through inventing 2-D animation and coding. The research team implemented a pre- and post- survey in a class of 7th and 8th grade students in this School District comparing their attitudes towards Computer Science. The target audience was the female students in this teacher's computer technology class, but data were collected from all of the students, male and female. The students are taught by this teacher to create their own computer applications using the MIT App Inventor 2 program. The results can be used to encourage other school districts to adopt a similar class in middle school. This research will be valuable to educators and curriculum planners to empower young girls to pursue a high-paying, in-demand, and rewarding career. Our goal, as a team, is to find a change in the girls' attitudes and thoughts toward Computer Science after completing the class and gaining positive exposure to computer programming.

II. LITERATURE REVIEW

The team wrote two separate literature reviews, both with the purpose of exploring the factors which contribute to young women's attitudes and perceptions of attaining a Computer Science degree and profession. The first review focused on female professionals in computer science to include the topics of: the history of women in computing, women in computer science majors, women in the computer science workplace, and obstacles women face. Based on the literature reviewed, the conclusions are stated below.

1. Women can excel in computer science. History has shown that women were pioneers in the early development of computers and that they can continue to contribute to advancing new computer technologies. Also, while women are

represented in computer science by a small percentage in the United States, the majority of programmers in Malaysia are women [2].

2. More women are needed in computer science. Research shows that programming teams with gender diversity are more effective at meeting users' needs. Women are also highly valuable as mentors to other women in the career field and as professors of computer science.

3. Girls need positive, confidence building exposure to computer science in high school or earlier. Even females who choose to major in computer science during college feel less prepared and confident than males. Hewlett, Sylvia Ann comment in their research: "women are actually excelling in science, engineering and technology, despite the fact that the schools are not very good at encouraging them" [3]

4. Women face many obstacles and negative stereotypes that need to be changed in order for there to be significant progress in recruiting and retaining a larger number of females in computer science. 52% of females leave their computer science job between the age of 35 and 40 [3], due to various reason such as improper treatment, stress of a 70 hour workweek, or starting a family.

The second set of reviews examines academic articles pertaining to the gender gap in the field of Computer Science. The reviews explore STEM strategies and pedagogical practices that motivate and engage young female students. The literature review also serves to explain the severe shortage of women and their lack of interest in computer science. Many factors have contributed to the negative attitudes women and girls hold toward a career in Computer Science. Despite the many efforts to add programs and initiate interest in computer science, the shortage of young girls in STEM classes has declined in the recent years. Further research must be done to explore different ways to ignite young girls' interest and to find solutions for the lack of participation in these programs.

Teachers need to be aware of the factors that contribute to gender bias in the classroom with regard to girls and computer use. Young girls often are discouraged from pursuing their interests in computer science due to several sources of gender bias including common stereotypes, media bias, biased societal role models, resources, software, and the attitudes of parents and teachers [4]. Young girls tend to enjoy software that is free form, exploratory, has free choice, and allows for communication. There are several strategies suggested by McNair, Kirova-Petrova, and Bhargava [4] that can minimize gender bias in the classroom including, but not limited to:

1. Providing equal access for all students to computers and programs, providing software that appeals to girls as well as boys
2. Creating non-competitive or threatening computer tasks and projects that are engaging and include social interactions
3. Providing examples of female role models such as professionals in the CSE (Computer Science Engineering) fields
4. Allowing students to work in supportive pairs

5. Giving students adequate amounts of time to complete computer tasks and scaffolding to build confidence.

With these strategies in place McNair, Kirova-Petrova, and Bhargava [4] believe that teachers can create a safe classroom environment that will promote secure computer learning for all students.

There are several factors that are related to the under-representation of women in the CSE (Computer Science Engineering) and STEM (Science Technology Engineering and Mathematics) career fields. According to Denner and Werner, the factors that deter young girls and women from pursuing a career in CSE include a competitive, masculine and socially isolating culture, low self-confidence in problem solving, a deficiency in early interventions and an inadequate understanding of the underlying causes [5]. Denner and Werner believe that, "working together with a partner in a collaborative way is appealing to girls, because it is aligned with their social interests" [5]. Young girls and women with social interests often view CSE careers as isolating, competitive, and masculine. Denner and Werner's study of pair programming brings awareness to the need for a culture of collaboration in CSE careers to entice young women to enter the male dominated field of study.

Many elementary and middle schools are implementing technology as a tool to teach their classes and improve motivation and engagement. The use of technology in the classrooms is one way to peak student interest especially young girls. At this point further studies are still needed to see the effects of the handheld computing pedagogy's and the needs of future generations. The research will continue to try and find different ways to ignite young girls' interest and find solutions to the lack of participation in these programs. This research will provide insights into how to better encourage and prepare females for careers in technology and computer science.

These reviews helped formulate our research survey questionnaires and interviews as we studied the students' attitudes throughout their Computer Science class.

A. Contextual Features

This study is being conducted at a school in a Southern California school District in a low socio-economic community. The project began in March and continued throughout the rest of the school year. The students who are involved in the project are 7th and 8th graders in middle school. The team conducted a quantitative online Qualtrics survey of the students before they began the class, as well as at the end of the trimester to discover changes in attitudes regarding Computer Science. The team also conducted on site interviews of the students who were involved in the project. The research should help us to determine the limitations and delimitation of this study. Some possible factors that could limit the outcomes of this study include:

1. The main constraint is timing. The whole research time period might not be long enough to have distinguishable differences in the learning process.
2. It is difficult to have close contact with those female students to see their reaction in every class. Interviews and on-

line surveys would assist the researcher in obtaining more survey data, but making an effective survey may be challenging.

3. Not all the female students in this class completed the pre- and post-survey.

By having the students focus their full attention on the project in an elective class that will be part of their school time, the limitations that a public school has during regular school time are avoided. Other limitations that could be a factor are the lack of participation from young ladies in these classes. Some young ladies may feel that this specific area is not for them or more of a male dominated field. Nevertheless these same obstacles and limitations can be overcome by giving young ladies the time to understand and evaluate what the class and program is all about. By addressing these limitations, it is possible that teachers and administrators would be more willing to implement Computer Science programs within the curriculum, since it is the fastest growing career.

III. RESEARCH

A. Methodology

This study tracked the responses of 42 middle school girls in the same computer science class at the beginning of the trimester and at the end of the trimester in order to determine a shift in aptitude and attitude via a pre- and post- survey. Several students were also interviewed concerning their experiences, attitudes, and opinions about computer science.

B. Sample Population

To study whether a computer technology class in middle school impacts students' interest in the computer science field, especially female students, the team found participants through a computer programming class at a Southern California Middle School. Since the study is focused on the attitude change of female students after finishing this class, the team did a survey and interview on both male and female students, while focusing on the female students. Both surveys and interviews are provided in this study. Around 42 female students enrolled in this class and also participated in the online survey. The ratio of male and female of this online survey is approximately 1:1. The team interviewed around 30 7th and 8th grade students in one of the computer technology classes. The ratio of students interviewed, male and female, is about 2:1. Apart from the study of middle school students, an online survey was sent by email to professional women who work in the computer science field to attain more information about female attitudes in the professional computer science field.

C. Instruments

Survey: The team developed surveys for middle school students and professional women who are working in the computer science field. For the survey of middle school students in the computer technology class at this Middle School, the group conducted a pre- and post- survey. The

outcome of the pre- and post- surveys provided the group with more data to compare the change of attitude and interest of female students in the first quarter of the class and after taking the class. The middle school students' survey is more focus on the attitude, interest, and knowledge about the computer science field and also the attitude and expectation of the computer technology class. The survey of professional women in the computer science field has more emphasis on the background, experience, attitude toward this job, obstacles faced in the job, etc.

Middle School Survey:

https://sdsueducation.qualtrics.com/SE/?SID=SV_07ETaP0vMANk66V

Computer Science Professionals Survey:

https://sdsueducation.qualtrics.com/SE/?SID=SV_8Bb2X1seVhOqTEV

Interview: To attain more information about the thoughts and attitudes of middle school students in the computer science field, the pre- and post- interviews were conducted. About 30 students participated in the interview (with representation from both male and female students). Apart from the survey questions, the interview questions are more focused on students' understanding and their perception of this field. For instance, what they think the computer scientists do for their job and why they think there are more males joining this field than females. Through the face-to-face interviews, the group has collected first-hand information from the participants. More importantly, the post- interviews showed the change of attitude, knowledge, and interest of those participants after finishing the computer technology class, which help the group to see if the class enhanced students' understanding of the computer science field and increased their interest in this field.

IV. ANALYTICAL RESULTS

A. Girls Aptitude and Experience with Using Technology

The pre and post surveys show a minimal shift in the girl's aptitude and experience with using technology. Most of the girls are significantly more comfortable using social media, gaming, and the Internet than using academic programs like PowerPoint or Excel. This data suggests that the use of social media programs is high while the use of academic programs is low. The survey data also indicates that the girls have more experience using programs like Photo shop, than in fixing the internal components of a computer, or creating a web page. The most significant shift is seen in the area of defining key terms relating to computer science. Students became more confident in their ability to define key terms by the end of the trimester as seen in Fig. 1.

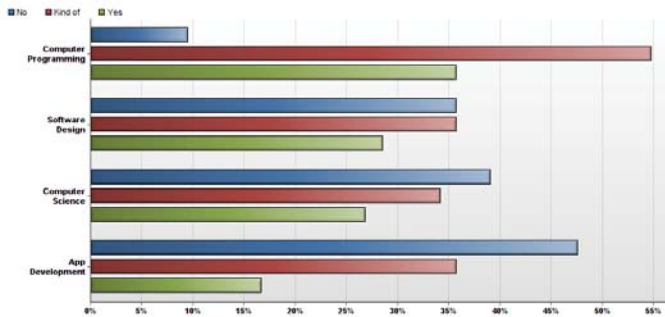


Fig. 1a Pre Survey: How confident are you that you can define the following key terms?

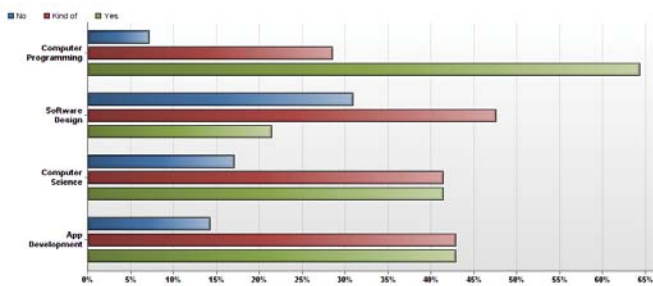


Fig. 1b Post Survey: How confident are you that you can define the following key terms?

B. Girls' Attitudes and Interest Levels Toward Technology and the Computer Sciences

During this trimester the girls' interest in Computer Science became stagnant and in some cases their interest decreased. The girls' excitement and motivation to learn more about the field of Computer Science decreased by the end of the trimester. In the beginning of the trimester, 62% of the girls were excited to take this class and learn more about Computer Science. By the end of the trimester, 40% of the girls still held this attitude as seen in Fig. 2. As shown in Fig. 3, the pre-survey indicates that 38% of the girls either agreed or strongly agreed that they would consider a Computer Science degree. In the post-survey, 26% agreed or strongly agreed that they would pursue a degree in Computer Science. Likewise, the desire to learn more about Computer Science decreased over the trimester from 70% agreeing or strongly agreeing to 53%. Also, the desire to create something unique decreased by 6%. Similarly the girls desire to use technology to help people decreased over the trimester as well going from 93% agreeing or strongly agreeing to 64%. The girls' confidence in their own ability to do anything as long as someone assisted them also decreased from 81% agreeing or strongly agreeing to 76%. Over the trimester the girls' individual attitudes and personal interest level in computer science subsided.

The most likely explanation for this decreased interest level is the timing of the post-survey. At the time of the survey, the students were just beginning to start their final projects where

they their own computer application. They may still be lacking confidence in their ability to program because they have not seen their own finished product. Completing the application should increase their confidence and positively change their attitudes in a way that the basic instruction they received to this point cannot.

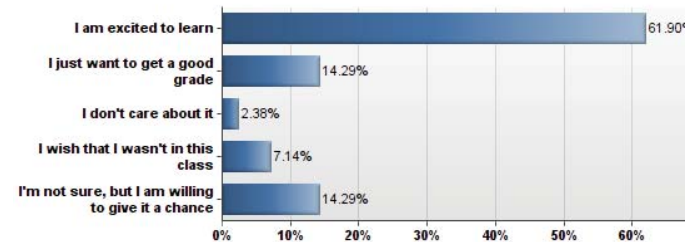


Fig. 2a Pre Survey Results

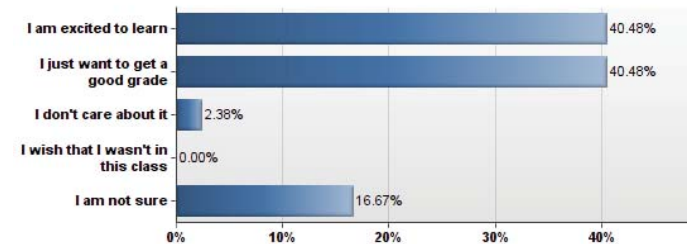


Fig. 2b Post Survey Results

Conversely, the girls' positive attitudes increased in the areas of women's abilities to do jobs that men typically hold, their belief that they are smart enough to become a computer programmer, and their belief in women achieving in the math and sciences. The girls' confidence in their ability to enter the field of Computer Science increased. At the beginning of the trimester 51% of the girls agreed or strongly agreed that they were smart enough to be a computer programmer. At the end of the trimester 56% of the girls agreed or strongly agreed that they were smart enough to be a computer programmer. When asked if their attitudes have positively changed toward computer science after taking this class 71% of the girls agreed. However, when asked if they would continue down a computer science career path in the future 70% of the girls replied 'no'. It appears as though the girls are gaining confidence in the capabilities of women entering Computer Science fields as well as in their own abilities; however they appear to lack the desire and interest to pursue such a career.

To test the statistical significance of the results, the research team compared data from the two questions that best represent girls' attitudes about computer science. They were both from the Likert scale, asking their level of agreement with a series of statements.

1. I want to learn more about computer science.

2. I am smart enough to be a computer programmer.

The students could choose 1 through 5, strongly disagree to strongly agree. The following figures show the results of comparing the before and after answers to these 2 questions.

	N	Mean	Mean SE	SD
3 Before	41	3.8	0.15	1.0
3 After	41	3.4	0.18	1.2
Differences	41	0.4	0.24	1.6

Fig. 3a. I want to learn more about computer science

	N	Mean	Mean SE	SD
6 Before	41	3.4	0.18	1.2
6 After	41	3.7	0.17	1.1
Differences	41	-0.3	0.23	1.5

Fig. 3b. I am smart enough to be a computer programmer

The girls' desire to learn more about Computer Science appears to decrease slightly; with the average response dropping from a 3.8 to 3.4, where 3 represents "neither agree nor disagree" and 4 represents "agree". Conversely, their belief that they are smart enough to be a computer programmer appears to increase slightly, with the average response moving up from a 3.4 to a 3.7.

To determine if these results are statistically significant, the team used a Student's t test to compare the pre and post survey data. The following figures show the results of this test.

Student t test	
Hypothesized difference	0
t statistic	-1.70
DF	40
p-value	0.0975

Fig. 3c. I want to learn more about computer science

Student t test	
Hypothesized difference	0
t statistic	1.17
DF	40
p-value	0.2484

Fig. 3d. I am smart enough to be a computer programmer

Assuming a confidence interval of 95%, a p-value greater than $p=.05$ indicates that there is no statistically significant difference between the pre and post survey answers to either of these 2 questions. This means that no conclusions can be drawn about the change in the girls' desire to learn more about Computer Science or their belief that they are smart enough to be computer programmers.

A common theme appeared within the final interviews. When asked to define Computer Science, 36% of the students were able to define some aspect of the field. 42% of the students interviewed had extremely positive opinions about the class, stating that it was "fun" and "I like it a lot". The students were also asked to comment on why they believe that women are not going into the field of Computer Science. Several of the girls made thought provoking comments that

should be considered when looking at this study. One of the girls hypothesized that "Girls are just not interested in computers. They are more interested in things like beauty." Another student hypothesized that older women didn't have the proper background knowledge. Insinuating a possible generational gap that may in time correct itself if more classes are offered for girls in schools at a younger age.

A. Professional Women in the Computer Sciences

The professional survey asked the participants to describe the moment, time period, or circumstances that first motivated them to pursue a career in computer science. Several participants mentioned that they became interested in the computer sciences in their college years. For example one participant mentioned, "during the time I was doing my under grad, computer was the buzzword. I started exploring more in the computer world and was amazed by the fact that so much can be done using computers. That was the time I got interested in computers." A second participant recalled, "I took a computer science class freshmen year after a friend recommended it." These responses coincide with the responses given by the middle school students in their post interviews hypothesizing that girls are not exposed to the computer sciences at an early enough age to motivate and inspire them to choose that career path. This gap is shown in Fig. 4.

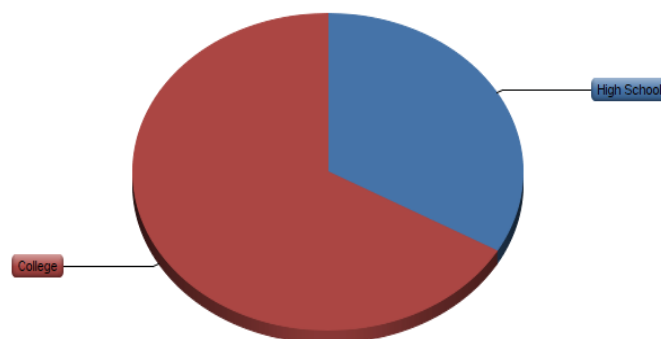


Fig. 4 When did you become interested in computer science?

V. CONCLUSION

Although there seems to be a general decrease in the attitudes of the girls toward Computer Science over the trimester, there are underlying factors that may be contributing to the girls' lack of excitement and motivation to pursue this field of study. Possible factors may include gender bias, rigorous curriculum leading to frustration, school year burnout, assignment relevance to individuals, or learning environment. It is evident that further research in a variety of areas needs to be considered to determine the source of this decline in interest.

In conclusion, there was a change in the attitudes of the girls in the class by the end of the trimester. While the data show that the girls are less inclined toward a career in computer science, they believe that women are capable of being competitive in this field. Early positive exposure to the

computer sciences appears to be the first step in mending the gender gap and encouraging more young girls and women to explore careers in computer sciences.

By having this program it allows young girls to experience learning in a new way with a focus on integrating technology while maintaining the school's focus on the core curriculum. However, the data gathered in this research might be inconclusive. Results would likely be different if the post-course survey was actually conducted at the end of the class. This class culminates in the students creating their own computer application. The satisfaction of using computer programming to create something will likely increase their confidence and provide the positive exposure to change their attitudes about computer science as a possible career.

ACKNOWLEDGMENT

Special thanks to this master teacher and the School she was teaching.

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Interaction Driven Composition of Student Groups for Optimal Groupwork Learning Performance

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Abstract—Collaborative Learning (CL) has been considered as an effective way to improve the learning outcomes of students in contrast to individual learning. However, assigning a groupwork task to a team of students does not guarantee a successful performance, and in fact could hinder the benefits of group learning if the members do not interact as expected. Indeed, group learning performance is largely dependent on group composition. In this work we address the challenge of identifying the characteristics of the individual group members that have the significant impact on the performance of the groupwork. Specifically we investigate the impact that a combination of individual student performances and gender have on the group performance and intend to find generic segmentation guidelines that would map smoothly onto the groupwork performance. A novel grouping method is proposed, which splits the set of students into groups that maximize one of the two desired criteria: the expected average groupwork performance or the average improvement achieved by a student as a result of synergic group learning and interaction effects. The model uses global optimization approach to identify optimal students allocation into the groups that best satisfy the optimization criteria. We illustrate our findings on the data obtained from the trial of the Collaborative Learning Environment (CLE) software. The CLE was developed at Etisalat British Telecom Innovation Centre (EBTIC) and tested over one semester with a sample of 122 students working in different groups in the Engineering and Molecular Biology courses at Khalifa University. The results of our method can not only help to understand the significant factors impacting group performance in group-based learning, but can also provide practical strategies on optimal group composition for collaborative learning activities.

Keywords—Collaborative Learning, learning performance evaluation, group composition, global optimization, Genetic Algorithm

I. INTRODUCTION

Collaborative Learning (CL) is defined by Johnson, et al. as the instructional use of small groups so that students work together to maximize their own and each others learning [1]. In CL, learners engage in common tasks and each individual capitalizes on resources and skills from one another [2], [3], [4]. It is based on the model that knowledge can be created within a population where members actively interact by sharing experiences and take on asymmetrical roles [5], [6]. In recent decades, it has been considered as an effective way to improve the learning outcome of students in contrast to individual learning [7], [8], especially with the rapid growth in cheap and powerful knowledge access technologies connecting and enabling students to carry out ever more learning, coursework and assessment tasks together [3], [9], [10], [11], [12], [13].

However, assigning a groupwork task to a team of students does not guarantee a successful performance, and in fact this could hinder the benefits of group learning if the members do not interact as expected. In the typical scenario of a joint group assessment, practiced in educational institution worldwide, the weaker group members might contribute less or even nothing at all, given the lack of pressure, while better student will be left overloaded and hence stripped from the opportunities for creativity, sharing and further development. All

the participants of such unfortunate group will lose out as a result. This indicates that proper student grouping is rather important in collaborative learning and can largely influence learning outcome.

A group is usually characterized by its size, gender and learning ability levels of its individual members. It has been studied in the literature that the composition of groups with different abilities and genders of students is closely related to the ways students engage, collaborate and learn [14], [15], [16], [17], which consequently influences learning performance. In this work we intend to address the challenge of identifying the characteristics of the individual group members that have the significant impact on the performance of the groupwork. Specifically we investigate the impact that a combination of individual student performances and their gender have on the group performance, and try to find generic segmentation guidelines that would map smoothly onto the groupwork performance. We propose a novel grouping method that splits the set of students into groups to maximize one of the two desired criteria: the expected average groupwork performance or the average improvement achieved by a student as a result of synergic group learning and interaction effects. In our method, student grouping to identify optimal student allocation into the groups is modelled as an integer optimization problem solved by using the global optimization technique.

A collaborative learning environment (CLE) platform has been developed under the iCampus initiative [?] at Etisalat British Telecom Innovation Centre (EBTIC) [9], [10] to capture the complete process of collaborative learning in sufficient detail. It was trialed over one semester with 122 students working in different groups in the Engineering and Molecular Biology courses at Khalifa University. During the trial, collaborative learning styles and their dynamics and outcomes were evaluated using three, group-based, formally assessed assignments. We illustrate our findings on the trial data. The results of our method can not only help to understand the significant factors impacting group performance in group-based learning, but can also provide practical strategies on ideal group composition in collaborative learning activities.

The remainder of the paper is organised as follows. Section II introduces the CLE developed at EBTIC, discusses its features and briefly describes the trial setup. The proposed grouping method based on global optimization is presented in Section III. The characteristics of the individual group members significantly impacting on the performance of the groupwork are discussed in IV. Finally, the concluding remarks are given in Section V.

II. COLLABORATIVE LEARNING ENVIRONMENT TRIAL

The Collaborative Learning Environment (CLE) is a system developed at EBTIC [9], [10] that brings together a collection of

tools and functionalities enabling communication, information sharing and collaborative document creation within the same environment. As opposed to individual communication and sharing tools like Skype, Facebook, or Google Drive which focus on a specific interaction or activity, the CLE is designed to integrate these different functionalities together into one cohesive formal learning environment.

The CLE is implemented as a set of modules for Moodle, an open source learning management system (LMS), and as such is able to capitalise on existing Moodle functionalities like group creation, file sharing and forums. By leveraging the flexibility of open-source technologies, the CLE integrates seamlessly into the LMS, providing a workspace that is familiar to both students and faculty, thereby reducing cognitive load and enabling more focus to be placed on the collaborative process.

The aim of the CLE is to stimulate the collaborative learning process and enable instructors to facilitate collaborative assignments more easily. Moreover, the whole interaction history is logged, thereby enabling dynamic analysis of contributions, usage and participation as well as enabling more advanced future functions such as knowledge elicitation. A screenshot of the CLE is shown in Fig. 1.

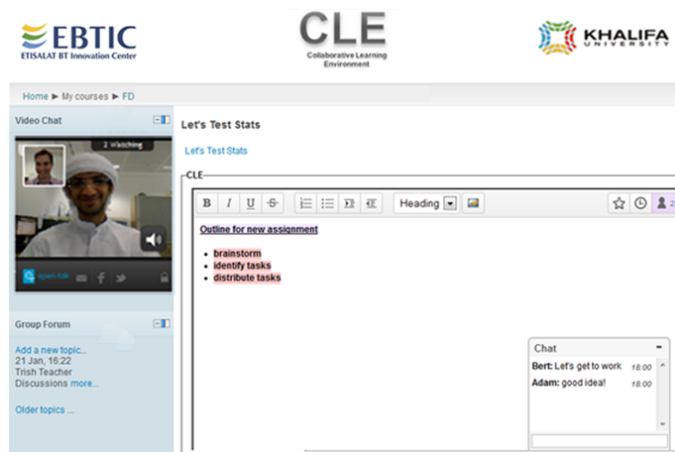


Fig. 1. Collaborative Learning Environment (CLE) in action.

Communication features of the CLE include synchronous text chat and audio/video communication, which allow participants to exchange ideas and communicate directly with each other regardless of their geographic location. Additionally, a collaboration area is provided to allow students to either synchronously or a-synchronously create an assignment. This area, called the collaborative editing pad, provides a canvas on which students can contribute and revise their ideas. Each contributor to the pad is assigned a unique color, so individual contributions are evident, and each keystroke, whether it is an "add", "edit" or "delete" is recorded by the pad. All individual students' assignment progress time series are merged into a single colour-coded progress timeline. Students' collaborative work on the same assignment followed many different patterns, from sequential to concurrent contributions, from one person dominated to evenly distributed workloads, from continuous progression of contributions to sudden bursts of activity and/or paste-ins. Figure 2 illustrates several examples of progress timelines, signifying different patterns of group interactions while working on a single assignment. The vertical axis measures the cumulative volume of the assignment content changes recorded by the CLE, and the horizontal axis represents the

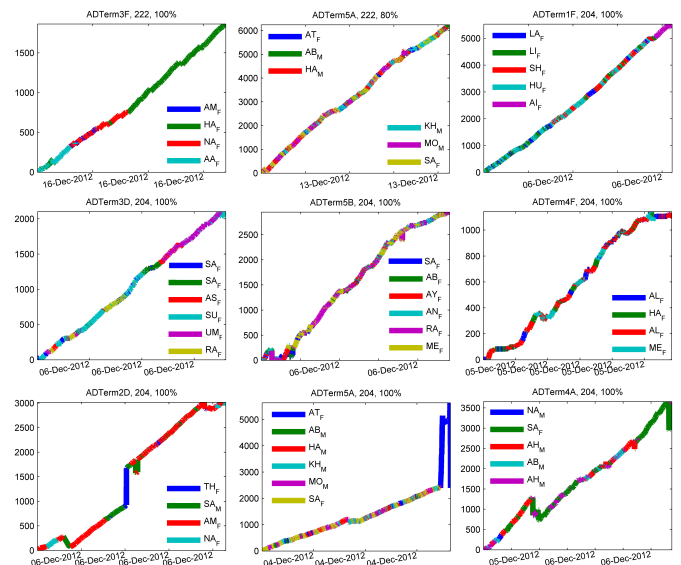


Fig. 2. Sample patterns of student interactions while working on group assignments: progress timelines.

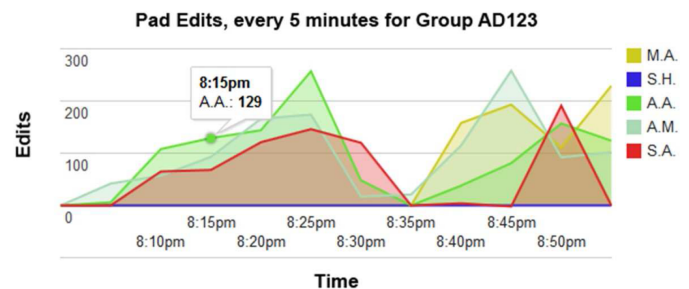


Fig. 3. CLE statistics module, sample group contributions graphs.

time stamps of these changes up to 1s resolution. These progress timelines provide a summarised view of how the contributions from each group member evolved over time.

Another way to illustrate the students' interaction data is by depicting the volume of edit activity at a higher time resolution level. An example of such an edit activity plot for another group of students is depicted in Fig. 3. These two illustrations are just some examples of the interesting insights into how the group collaborated together. There are many other aspects of collaboration within CLE that can be analysed, for example monitoring the exact locations of different contribution edits to assess whether the members work independently on the same or different parts of the assignment or actually trying to understand and assess the value of individual contributions.

All the above approaches to analyse collaborative learning data harvested by the CLE are supported by a statistics module that can output detailed usage statistics at different aggregate levels. Such insights are invaluable for the instructors as they allow them to obtain, in an instant, a detailed analysis of how the group assignment was completed and what were individual members' effort and actual contributions. Beyond statistics, the CLE also provides a playback feature, that allows both the students and instructors to watch the entire creation of the assignment, from start to finish, much like watching a video.

Both the statistics and playback features of the CLE were used by the instructors of the Freshman Design Engineering Course at Khalifa University to assist in analysing student group adherence to a prescribed engineering design cycle throughout the Autumn 2012 semester. Overall 122 students participated in the trial, and their interactions within groups over a sequence of 3 assignments were recorded at up to 1s time resolution. Each group's assignment is assessed by the teachers and a single grade is allocated for the whole group. In the next section, we attempt to identify optimal grouping of students with an aim to maximize the collaborative learning performance. Due to the biased grade distribution of the 1st assignment in the trial where most groups achieved full marks, only the last 2 assignments are covered in our study.

III. GROUPING VIA GLOBAL OPTIMIZATION

In our work, student grouping is modelled as an optimization problem and solved by using global optimization technique, which will be elaborated below.

Let S and G be the set of indices of students and groups, i.e.:

$$S = \{1, 2, \dots, NS\}, \quad G = \{1, 2, \dots, NG\}, \quad (1)$$

where NS and NG are the number of students and groups, respectively. Our objective is to identify optimal student allocation into the groups that maximize the predicted group performance or the difference between the group performance and the average of individual members' performances. These two objective functions with respect to student allocation represented by x used in optimization can then be defined respectively as

$$obj(x) = \frac{\sum_{g=1}^{NG} grade_g}{NG}, \quad (2)$$

and

$$obj(x) = \frac{\sum_{g=1}^{NG} (grade_g - \frac{\sum_{s=1}^{NS_g} grade_s}{NS_g})}{NG}. \quad (3)$$

In (2), $grade_g$ is the predicted group performance of the g^{th} group and can be calculated as

$$grade_g = \sum_{s=1}^{NS_g} |C_s| * grade_s. \quad (4)$$

The second objective function in (3) is to maximize the performance improvement, where NS_g is the number of students in the g^{th} group. In the objective functions, $grade_s$ is learning performance of the s^{th} student, which is estimated here by using the comparative model [18]. In practice, one can also use the grade of a related course taken in the previous semester, or grade point average (GPA) achieved so far, to represent student performance. $|C_s|$ in (4) is the potential contributions of the s^{th} student in corresponding groupwork he/she will participate, which can be estimated from previous groupwork or simply considered all students within a group having the same contribution. We use the actual contributions captured in the trial of CLE software, which is represented by the absolute number of changes (positive: adding / negative: deleting) carried out by the student. Note that the contributions of all students within a group should be normalized to have a summary of 1.

The optimization problem is then defined as

$$\arg \max_{x \in S} obj(x). \quad (5)$$

TABLE I. DESCRIPTION OF CLE TRIAL DATA USED IN EXPERIMENTS.

Number of student	100, 47
Number of assignments	2
Number of groups	26, 20
Sizes of groups	[1 – 6]

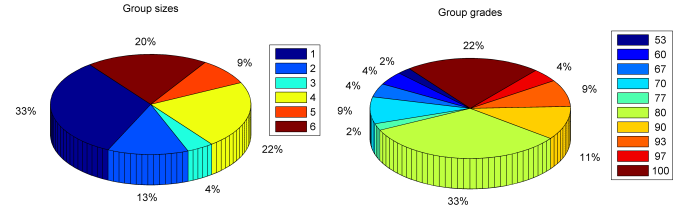


Fig. 4. Distributions of group sizes and group assignment grades.

Student allocation, x , is represented using an integer vector with a dimension of $1 \times NS$, where each of element, x_s , represents the group id of the s^{th} student, i.e. $x_s \in G$.

In our method, the Genetic Algorithm (GA) is applied to find the optimal grouping scheme that splits students into groups and maximizes the objective function. The GA is an artificial genetic system based on the principle of natural selection where stronger individuals are likely the winners in a competing environment [19]. The intrinsic ability to cope with nonlinear problem makes the GA a suitable solution to solve assignment problems. In the GA, the chromosomes are represented using integer numbers, which represent potential grouping arrangements, i.e. x . An objective value according to (2) or (3) is then calculated for each chromosome. A population is formed with a certain number of chromosomes. Fitter chromosomes in a population are selected based on Roulette Wheel Selection strategy [19], so that the fittest chromosomes have better chances to be chosen and allowed to reproduce. The selected chromosomes are treated as parents to produce new chromosomes called children by genetic operations. Crossover is a basic operation to create a generation of new chromosomes - the offsprings, which then undergo a process of mutation that randomly changes one or more genes to maintain the population diversity. After the crossover and mutation process, the population of new offsprings is chosen to replace the same number of chromosomes in the old population to form a complete new generation. The replacement strategy used is the Generation-Replacement method plus the Elitist Strategy [19] to retain the best chromosomes at every generation. The whole process from encoding and selection to crossover, mutation and replacement follows an iterative cycle that evolves the population towards fitter solutions until it converges or the termination conditions are met.

To illustrate the effectiveness of the proposed grouping method, we compare the group performance of the optimal solutions generated by the GA and that in the CLE trial. Among 122 students participates in the trail, 100 and 47 students were partitioned into 26 and 20 groups, for the 2 considered assignments, respectively. The group sizes varied typically between 3 to 6 students, however there were instances when only 1 or 2 students contributed. Table I summarizes data used from CLE trial. For each assignment, the teacher assessment grade is allocated to the whole group. The distribution of group sizes and grades for both assignments are shown in Fig. 4.

If the group composition is optimized by using the GA based method with an objective function of (2), the group performance is

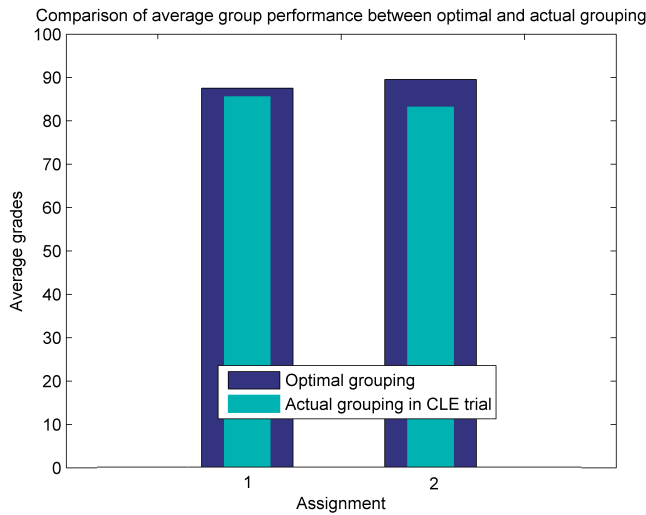


Fig. 5. Comparison of average group performance between optimal grouping and that in the trial.

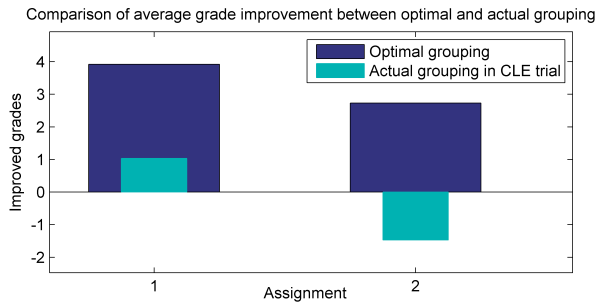


Fig. 6. Comparison of the average grade improvement between optimal grouping and the traditional ad-hoc grouping in the trial.

estimated based on the generative mixture model proposed in [18]. When the objective function (2) is employed during optimization, the average of group performance is maximized. Fig. 5 illustrates the average group grades estimated based on the optimal grouping scheme generated by the GA, which are compared with those captured in the CLE trial. It can be seen from the figure that in both assignments the average performance of the associated with the optimal grouping is higher than that achieved by the traditional grouping in the trial.

Let us now consider the objective function (3) in the optimization. Fig. 6 illustrates the average performance improvement between the predicted group grades generated by the optimal grouping solutions consisting of 26 and 14 groups in the 2 assignments, respectively, and the individual student performance. For comparison purpose, the improvement achieved in the CLE trial is also depicted in Fig. 6. As shown in the figure, the expected group performance can be higher than individual student performances in both assignments with the optimal grouping solutions, and the grade improvement is also higher than that actually achieved in the trial by 2.9 and 4.2 marks in the 2 assignments, respectively. The negative improvement in the second assignment achieved in the trial further indicates that student grouping is extremely important to improve learning outcomes. It can be seen from Figs. 5 and 6 that the optimal grouping of students can significantly improve learning in collaborative learning activities.

The statistics of individual student grades and predicted group

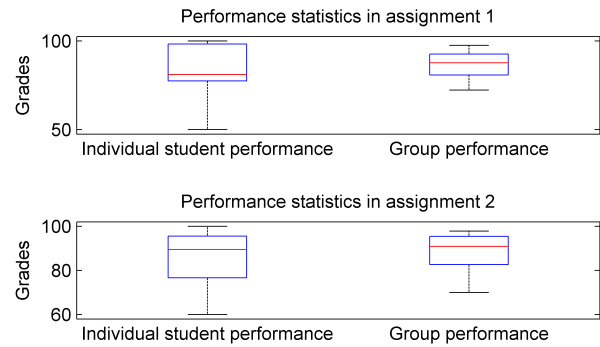


Fig. 7. Statistics of individual student grades and the predicted group grades.

grades with optimal grouping in the 2 assignment are compared in Fig. 7. As shown in the figure, lower performance of individual students has been significantly improved in collaborative learning activities. This is coincide with the findings reported in [16] that low-ability students having high-ability peers as teammates are more likely to significantly improve their performance and thus lower-ability students tend to benefit much more via collaborative learning than higher-ability students [20].

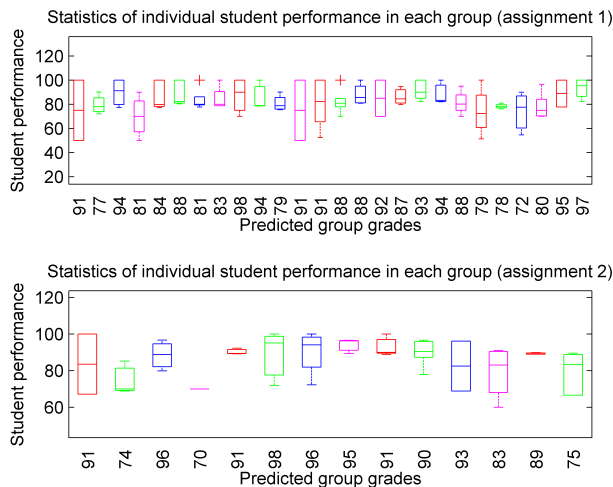
IV. FACTORS OF GROUPING INFLUENCING LEARNING OUTCOME

It is believed that the composition of groups of diverse students, i.e. with different learning abilities, genders and other features can largely influence learning performance. These differences affect the ways students engage, collaborate and learn [14], [15], [16], [17], and thus influence learning performance. In this section, we investigate the impact that a combination of individual student performances and genders have on the group performance.

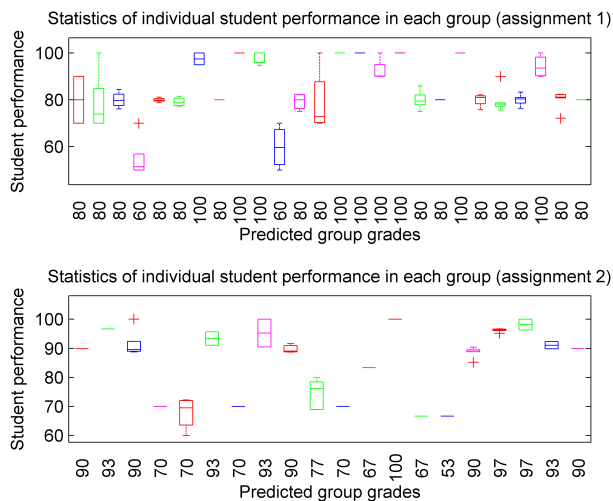
It has been shown in [17] that both interaction patterns and collaboration effects are varied across various compositions of individual student performances in the group.

Fig. 8 illustrates the performance statistics of individual student members within each group allocated either according to optimal grouping solutions (Fig. 8(a)) or the group allocation used in the trial (Fig. 8(b)). The horizontal axis shows the grade of each group ordered by the group *id*. It can be seen from the figures that the groups in Fig. 8(a) have wider distribution of student learning abilities than those in Fig. 8(b). The fact that the average group performance in the former is higher than that in the latter in both assignments provides us with a strong support for encouraging groups' heterogeneity of members' skills and learning abilities in collaborative learning.

Significant research has been dedicated to study and compare the effectiveness of single-gender and mixed-gender education with various gender compositions in classrooms. These studies suggest that gender composition can largely influence learning outcome in collaborative learning. Fig. 9 illustrates the gender composition of each group obtained for GA-optimized grouping and the traditional ad-hoc grouping applied in the trial. The label of each bar indicated the grade of each group. As shown in Fig. 9, most of groups, i.e. only 10 out of 40 groups allocated according to optimal grouping have single-gender, while 39 out of 46 are single-gender groups in the trial. This can partially explain the source of higher improvement



(a) Optimal grouping



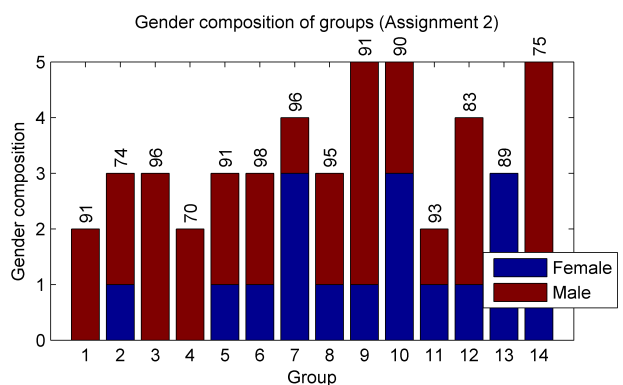
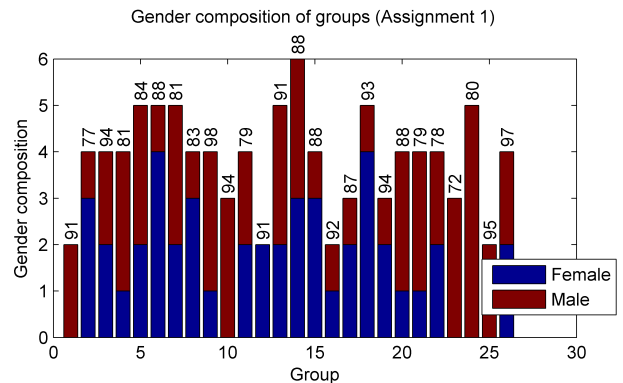
(b) Grouping in the trial

Fig. 8. Statistics of individual student performance in each group for optimal grouping and that in the trial.

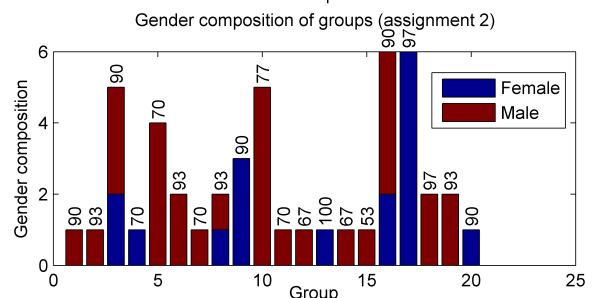
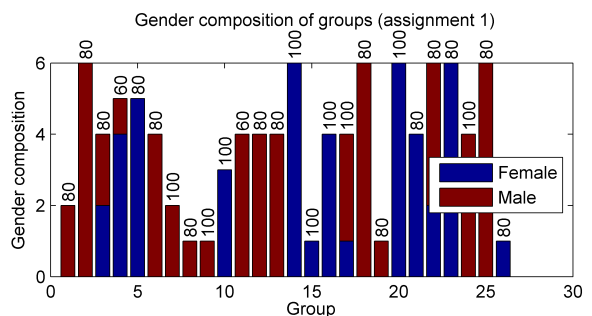
of performance expected from optimal grouping, as shown from the performance statistics in Fig. 7.

V. CONCLUSION

This paper introduces a novel grouping method that splits the set of students into groups so as to maximize one of the two desired criteria: the expected average groupwork performance or the average improvement achieved by a student as a result of synergic group learning and interaction effects. The impact that a combination of individual student performances and their genders have on the group performance is investigated following generic segmentation guidelines that map smoothly onto the groupwork performance. Our findings are supported by the series of experiments carried out on the data obtained from the trial of the Collaborative Learning Environment software, developed at Etisalat British Telecom Innovation Centre (EBTIC). The trial was tested over one semester with a sample of 122 students working in different groups in the Engineering and Molecular Biology



(a) Optimal grouping



(b) Actual grouping

Fig. 9. Gender composition of each groups for GA-optimized and ad-hoc trial grouping.

courses at Khalifa University. The results indicate that our grouping method that utilizes the genetic algorithm provides a practical and well performing strategy for achieving optimal group compositions in collaborative learning activities. Our method also helps to identify the factors that play a significant role in successful groupwork and enable the measures of their impact. In a subsequent research we will attempt to investigate further the role of the amount and the quality of the individual student contributions on the groupwork performance.

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Experimental Development and Implementation of Computer-Based Quiz Games in General Chemistry for Engineering

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Abstract— Interactive learning through computer quiz games has been introduced to improve teaching and learning in a freshman engineering chemistry course. This is accomplished through a series of JAVA-based, weekly general chemistry quiz games, developed and implemented as a supplemental and augmentative tool in delivering freshmen chemistry for engineering majors. The introduction of quiz game is anticipated to increase the engagement of students in chemistry classes by improving their attitudes towards chemistry and their overall chemistry achievements. Kolb's four-stage learning cycle is introduced as a possible model for a role the computer quiz games could have in the overall learning process, where the games are anticipated to serve as alternate mode of learning and as an additional motivational tool. In addition to introducing weekly computer quiz games, we report on the effort made to assess their effectiveness. For this purpose, we propose a novel chemistry achievement test developed in this study, Freshman Engineering Chemistry Aptitude Test (FECAT), which aims to comprehensively cover the freshmen engineering chemistry course. Additionally, we implemented an attitude questionnaire. The findings of this pilot study help to advance our understanding of the practical contribution of game-based learning to students' achievement in chemistry and also their attitudes towards learning chemistry at university. At the time of the pilot implementation, we hypothesized that the major benefit of the interactive game would be an increase in students' overall interest in chemistry, with an associated improvement in achievements in the course.

Keywords: *interactive engagement, computer games, game based learning, freshmen science courses, Kolb's learning cycle, Hake's gain, Dellwo's gain.*

I. INTRODUCTION

Two major novel trends have affected improvements in teaching and learning over the past two decades. One is increased research, development and implementation of teaching techniques based on the interactive engagement approaches [1], and the other is an increased use of sophisticated, personalized, easy-to-use computing devices [1]. This report relies on efforts related to and depending on both trends, and represents a pilot study in which we developed computer quiz games (CQGs), which are short (10 min per week), full engagement, single player activities

for students. The current aim and reach of the CQGs activity is that they serve as a complementary and augmentative activity to the traditionally delivered freshmen engineering chemistry course. We see considerable potential for future upgrades and expansion. As a result of a recent curriculum reform, all undergraduate engineering students at Khalifa University College of Engineering (KUSTAR, Abu Dhabi, UAE), now take *General Chemistry for Engineering Students* as their first science course. The population of students majoring in engineering disciplines at Khalifa University is unique in several ways. More than 97% of students are ESL (English-as-Second-Language) speakers, they come from very diverse socio-economic backgrounds, and they belong either to a large group (~ 80%) of UAE nationals or to a small (~ 20%), but diverse group of predominantly MENA (Middle East and North Africa) region expatriates. Nearly all of the KU freshmen students graduated from local (UAE) high schools, so some features of this study also represent an indirect assessment of the effectiveness of general chemistry instruction in UAE-based secondary education.

Game-based learning has become a topic of increased interest in educational technology [2]. From the literature review, many studies present the view that games have potential as an educational tool [3-9]. It is said that games can enhance students' learning and complement traditional lectures [10-12]. For instance, Moore & Dettlaff [13] suggest that game-based learning could be used as a supplement to traditional methods, because games can add flexibility to the classroom, allowing students to adjust to the way in which they learn best.

For the purpose of increasing students' level of engagement and achievement in a basic science course, such as the *General Chemistry for Engineering Students* course, we implemented a set of weekly computer quiz games (CQGs) consisting of a finite number of questions (total of nine for one weekly CQG) via game-based and computer-implemented interactive engagement classroom activities. This effort echoes other current trends worldwide and in the MENA region, where, according to Nicks-McCaleb [14], there has been some shift in focus from more traditional

education methods, to contemporary approaches following the dramatic growth of the Arabian Gulf region over the past three decades. For example, the UAE Ministry of Education has developed *Education 2020* framework a series of ambitious five-year plans, that are designed to bring a significant qualitative improvement in the education system, both in course delivery and in students' learning [15].

In this study, we explore the effectiveness of our computer-based, interactive learning methods for chemistry learning, and compare these results with those for a more conventional, paper-based quiz activity.

II. EXPERIENTIAL LEARNING PROCESS

Kolb's experiential learning cycle is a known construct from traditional learning theories [12, 16]. We have adopted it in this study, as we hypothesize that it represents a useful framework for understanding the role of game-based learning, as shown in Fig. 1.

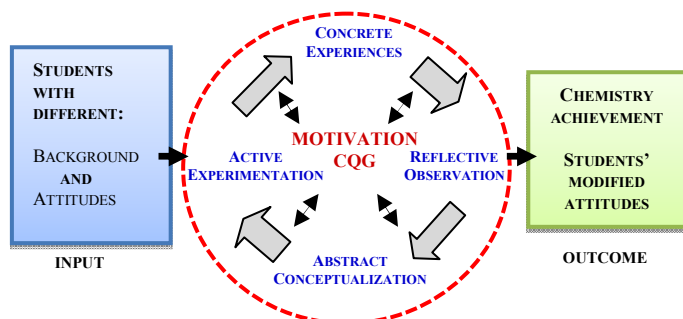


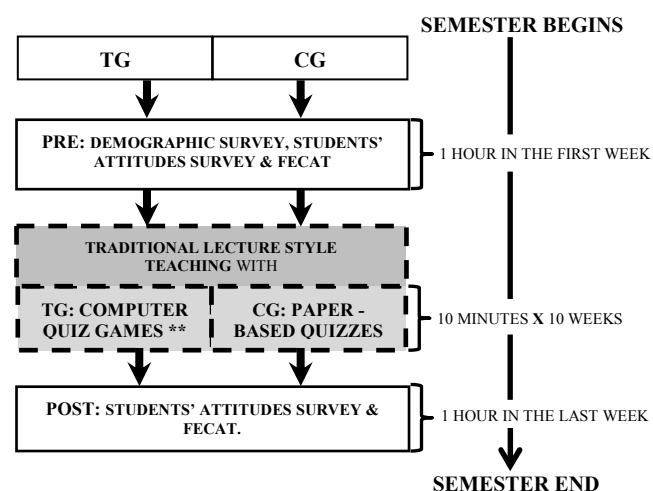
Fig. 1. Experiential learning process

The experiential learning process with Kolb's cycle is used to highlight the anticipated science game-based learning process and its effect on students' chemistry achievement and students' attitudes towards learning chemistry. Here, we briefly explain the implementation mechanism. Students attend the traditional lecture sessions three times a week, and are actively involved in the chemistry learning process while playing the computer quiz games (CQG) during one of these lectures (typically, but not exclusively, the last lecture meeting of the week). They reflect on the topic related from the lecture while answering the CQG questions. During this game, they are allowed to choose to answer questions of different difficulty levels, with the caveat that they don't know the actual content of the question (only the estimated difficulty, where the estimation is performed by the research team beforehand). Throughout the game playing process, students conceptualize, understand and familiarize themselves with chemistry concepts. They actively engage in the game session and other class activities to enhance their knowledge, before moving to the next learning session to continue the chemistry learning process. The CQGs serve as a supplement to the teaching and learning process and are conducted as a part of a classroom-based lecture, but were

not used as an assessment method. They can thus be considered as a motivation enhancer.

A. Methodology development

Fig. 2 illustrates the methodology of this pilot study.



**link to Fig. 1: Experiential learning process

Fig. 2. Research methodology; TG refers to treatment group and CG refers to control group.

Students enrolled the *General Chemistry for Engineering Course* were invited to volunteer to participate in the pilot study. Volunteers were divided into paper-based quiz game (control group – CG, for short) and computer quiz game (treatment group – TG, for short) groups. Separation into two groups was motivated by the need to monitor the effect of quiz taking from the effect of using computer. A set of short surveys was administered for all the volunteers; specifically, a demographic survey and a students' attitudes survey, are administered both at the beginning of the semester and at the end of the semester. Also, in order to assess the students' possible progress in acquiring general and conceptual knowledge a test of such knowledge was created with the working title "Freshman Engineering Chemistry Aptitude Test" (suggested abbreviation: FECAT). This test is utilized according to a standard education research paradigm "posttest vs pretest", allowing for the collection of students' answers to the same test twice in the semester, at the start and at the end of the semester. The FECAT answer data are then analyzed following the Hake's gain expression [17], as well as Dellwo's gain paradigm [18]. The pilot study was carried out during 12 weeks of the Fall 2012 semester, and some highlights of the initial data are presented here. A more thorough study will be forthcoming [19].

A series of JAVA®-based, general chemistry CQGs are games explicitly designed for educational purposes. They are somewhat similar to exercise-based computer games proposed by Kablan [7] and exercise games proposed by

Allessi & Trollip [3] that are intended to be used to increase the learning performance. The games are designed to allow maximum flexibility for any interested future instructors to include their own material in preparing the quiz, because the quiz files are relatively easy to edit for content and each individual question (and its corresponding answer) could come in the form of text, graphics or a combination of both. The CQGs are administered once a week for approximately 10 minutes, typically near the end of the last lecture of the week.

We emphasize that there are no overlaps between the questions asked in computer (or paper) game quizzes and the questions asked on the FECAT test, and that effort was made by the teaching team to avoid assigning homework questions of the same content.

B. JAVA™-based, general chemistry quizzes

An example of two consecutive screenshots displaying the CQG “front end” and an example question are shown in Fig. 3.

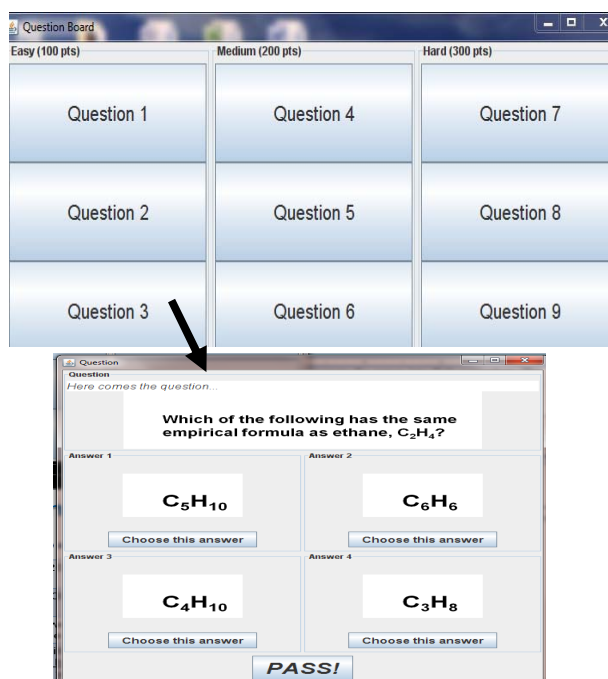


Fig. 3. A snapshot of the computer monitor while a student is playing the game. (upper) the interactive panel which allows students to choose a question of the desired difficulty level; (lower) example of a question and four offered “answers” (only one choice is correct in all questions).

In the course of playing the game, a student is asked to choose any 5 questions (one question at a time) out of a total of 9 from three categories of difficulty (“easy” worth 100 points, “medium” worth 200 points, or “hard” worth 300 points). After choosing the question from the category a student is comfortable with, she/he is then presented with a specific question, where “click-on” provides student’s answer input together with a timer (the

timer is an integral part of the developed application, and is always visible to students, but is not shown here for the sake of brevity). If the answer is wrong, the right answer “pops up” and the player loses points; if the answer is right, the player earns points. Student can choose not to answer the question by clicking the “Pass” button. In this case, no points are earned or lost. The “Help” button (also not shown) is also provided to help the student answer the question more easily by eliminating two of the (wrong) answers. In order to avoid abuse of the “Help” button, student can only use it twice in any game-session.

C. Freshmen Engineering Chemistry Aptitude Test

Due to the lack of a general chemistry assessment test that encompasses both fundamental concepts and elementary knowledge for ESL (English as Second Language) engineering students, we developed the Freshmen Engineering Chemistry Aptitude Test (suggested abbreviation: FECAT). The test follows the US style freshmen chemistry curriculum, but the style of questions differs markedly from examination questions and from questions on weekly computer and paper based quiz games, to ensure no overlap. FECAT has been developed partly as an assessment instrument to be independent of instructors’ individual teaching styles and the content and format of the semester final exams, and partly for application with the standard post-test vs. pretest education research methodology, such as the pilot study we report on here. It can be used for other purposes, including: (a) assessment of students’ readiness to take a one-semester engineering chemistry curriculum, such as the one commonly implemented in US style engineering curriculum, (b) to help instructors in tailoring the focus of lectures during the semester, if used as a diagnostic test in the first week of the semester, and (c) for other purposes, as instructors see fit.

The pilot version of the FECAT contains 36 questions, divided into five topical groups: (1) basic properties of matter and laws of nature; (2) chemical properties of elements and compounds; (3) chemical reactions; (4) energy and heat; and (5) atomic structure and chemical bonds. The KR20 statistical test shows the value of 0.848 (pretest) as well as 0.787 (posttest) and Cronbach’s alpha coefficient is 0.845 (pretest) and 0.766 (posttest), indicating the FECAT can be accepted and has a good reliability. According to Fraenkel *et al.* [20] and Johnson and Christensen [21], coefficient reliability value must be equal to or higher than 0.70 in order to be accepted. A common accepted rule for describing internal consistency in the case of the Cronbach’s alpha test is a value between 0.7 and 0.9, which leads to the test being described as “good”, as also reported in [22, 23].

As mentioned earlier, the FECAT is also administered at the end of the semester, so it serves as an education research instrument in the assessment of learning gain via Hake’s definition [17] (i.e. $GAIN = [POSTTEST\ SCORE - PRETEST\ SCORE]$).

SCORE]/[100 – PRETEST SCORE], where “SCORE” value is between 0 and 100).

D. Students' Attitudes Survey

In this study, students' attitudes survey consists of: motivation components adapted from Science Motivation Questionnaire (SMQ) by Glynn & Koballa [24] and motivation survey developed by Kebritchi *et al.* [12]. A Likert-type scale with Strongly Agree (SA), Agree (A), Not Sure (N), Disagree (D) and Strongly Disagree (SD) was used as the response format of the survey.

III. RESULTS AND DISCUSSION

A pilot study involving 70 students (34 playing CQG, and 36 playing a control paper quiz) was conducted during the Fall 2012 semester. Below are the results for our pilot study. Out of 36 questions on the FECAT, students had negative learning gain on 3 questions only, on 4 questions they had a gain between 0% and 9%, on 9 questions the gain was between 10% and 19%, on 6 questions the gain was between 20% and 29%, on 6 questions the gain was between 30% and 39%, on 2 questions the gain was between 40% and 49%, and on 6 questions the gain was higher than 50% (see Table 1).

Table 1. Summary of the Hake's gain in FECAT

Gain	No. of Questions
negative	3
0 - 9%	4
10 - 19%	9
20 - 29%	6
30 - 39%	6
40 - 49%	2
50% and above	6
Total	36

To offer readers a more concrete, deeper insight into the technical details of the FECAT, we selected four questions and listed them in the Fig. 4. A more thorough report will contain a detailed look of various FECAT features [19].

Q11. Pure substances:

- A. Rarely exist around us
- B. Are homogeneous and have unchanging chemical compositions
- C. Are heterogeneous and have unchanging chemical compositions
- D. Only exist in cubic shape
- E. Mostly exist in regular shapes, like spherical

Q16. Which of the statements below about electrolyte is INCORRECT?

- A. Electrolytes are compounds whose aqueous solutions conduct electricity
- B. Non-electrolytes are compounds that cannot conduct electricity either in solid or aqueous solution
- C. Strong electrolytes are solutions that are a good conductors of electricity
- D. Weak acids or bases are considered weak electrolytes as all the molecules react with water to form ions

- E. A non-electrolyte does not conduct electricity because no ions are present in solution.

Q19. Potassium chloride solution is added to silver (I) nitrate solution in the beaker, and kept for some time, while a precipitation reaction occurs. The new precipitate formed in the beaker is:

- A. Silver (I) chloride
- B. Silver (I) nitrate
- C. Silver (II) chloride
- D. Potassium nitrate
- E. Potassium (II) nitrate

Q22. Which is TRUE during a phase change, such as water boiling or steel melting?

- A. Both temperature and heat energy change
- B. Heat energy remains constant but temperature increase or decrease
- C. Temperature remains constant but heat is absorbed or released
- D. Both temperature and heat energy remain constant
- E. Temperature and heat of the energy either both increase or both decrease

Fig. 4 The content of selected questions on FECAT discussed on this report.

The Fig. 5 shows the comparative gain for these four questions for both students' groups.

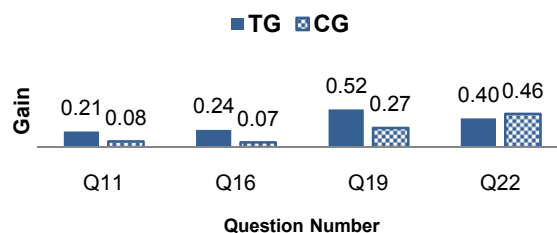


Fig. 5 The gain for selected four questions from Fig. 4 above.

We wish to emphasize that there is no specific reason why we selected these particular questions, other than to illustrate that the individual question's learning gains range as indicated in Table I above, and that learning gains can be higher for treatment group in some questions and for the control group in others.

As implied early in this manuscript, this effort is a part of a broader goal of evaluating effectiveness of the novel, partially computer-based interactive course delivery methods. In this regard, the use of Hake's gain has been suggested to be an insufficiently precise measure, in part because it neglects the nuances of the possible processes whereby students improve their post-test score over the pre-test one [18]. For example, Dellwo [18] points out that there can be four options how the answer to a given question on a **pre-test** (FECAT in the case of this report) could change at the time a student takes the same test in the **post-test** mode. In no particular order, the pretest correct answer (T) can remain the same (T) at the posttest level indicating the process we will label as (TT), or it can change to a wrong

answer (F), the process here to be labelled as (TF), potentially (but not exclusively) indicating that a student may have been making a “lucky guess” at the time of taking the pretest. Similarly, the incorrect answer (F) on the pretest could remain incorrect on the posttest, (FF) process, or can lead to the correct answer on the posttest, here labelled as (FT) process. We are interested in these four possible answer “switches” because in interactive engagement course delivery, one wishes to understand which concepts are more easily learned (FT process), compared to those that persist as wrong (FF), whether on the skill and knowledge level or on the level of the concept. For this reason, we plot the percentage of students for each four possibilities (“switching states”) (TT, FT, TF, FF), for both, the treatment group (CQG playing) and control group (paper quiz). The results are shown in Fig. 6, where percentage of students in each “state” is shown for both student groups.

We also employed inferential statistics to analyze students’ performance. The independent pre–post differences in each group were explored using the paired-sample t-test. The pre-post differences in each group (CQG for treatment group and paper quiz for control group) were explored using the paired sample t-test. The results showed that there is a small difference between the two groups, (TG, $t = 6.983$, $p < 0.05$), (CG, $t = 7.200$, $p < 0.05$). This is also in agreement with the comparable Hake’s gain for both groups (29% and 32%, respectively). At first sight, the Hake’s gain result would be discouraging as to the effectiveness of the application of computer based games, except that we found that our group design introduced significant, yet unintended bias. Here, by group design, we mean the assignment of students to a particular group – treatment (CQG for the whole semester) or control (paper based activity for the whole semester). The performance of the control group was enhanced due to overall pre-existing skill and knowledge; namely, the overall English and elementary math skills were appreciably higher in this group), which is something we could not have fully controlled for at the time of the start of the pilot study (due to the lack of access to registration data). We have further established this by analyzing final exam performance, which is common in content and paper-based for the entire class (both groups of students in this study), and, when final exam differences are accounted for, we establish both a small statistical significance and Hake’s gain in favor of the treatment group.

Specifically, corrected (normalized for the final exam average) Hake’s gain is 32% for the treatment group and 28% for the control group).

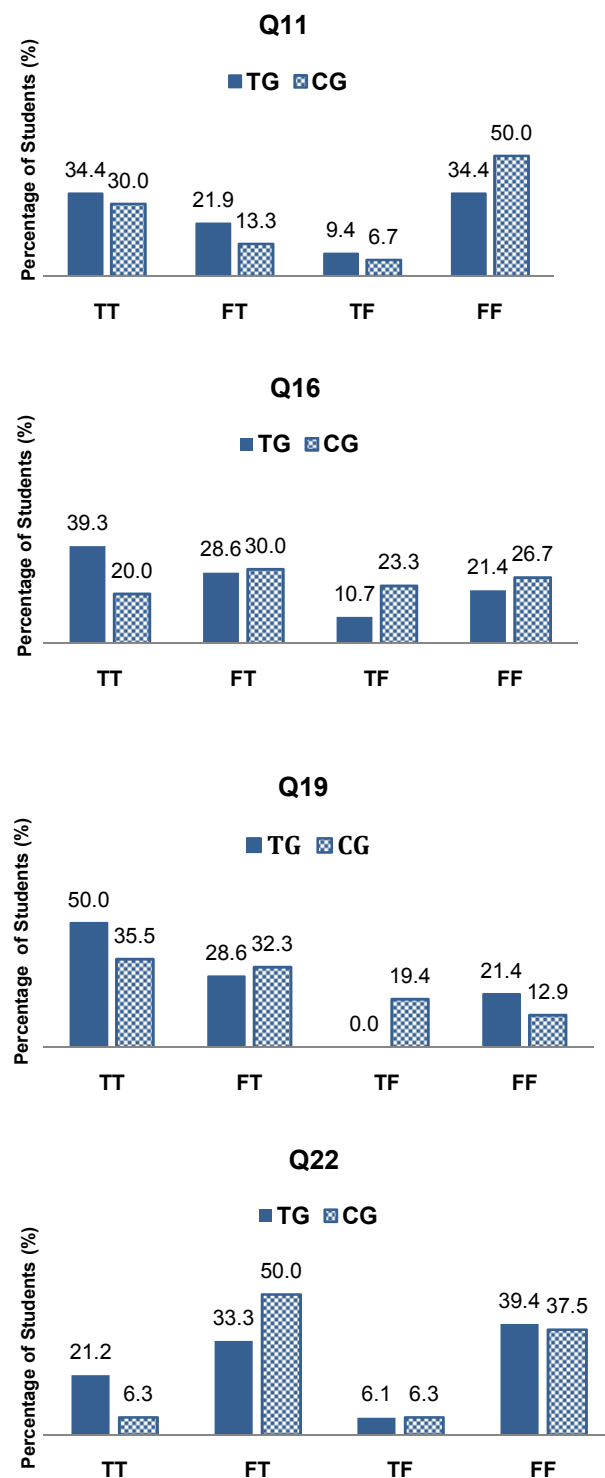


Fig. 6. Analysis of the error pattern in answering FECAT

Next, we proceed to discuss a characteristic outcome of qualitative survey, and we selected the question “*I find learning chemistry interesting*”, where students entered their preference on the five point Likert scale, as shown in Fig. 7 below. The comparison is shown below for CQG and paper group for a survey data taken at the end of the semester (post-test)

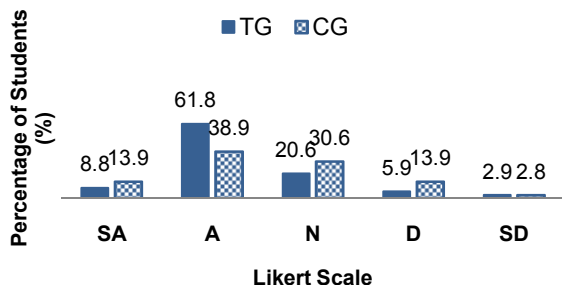


Fig. 7 Difference between students' attitude towards learning chemistry, where “SA” stands for “strongly agree”, and “SD” for “strongly disagree”.

We find similar differences on some other questions on the attitudes' survey, such as question “*I like chemistry lectures*”. The preceding statement and data in Fig. 6 and the preceding are very encouraging information regarding the relatively positive effect of the CQGs on student motivation and enjoyment.

Generally, our results indicated that there is an improvement in students' chemistry achievement and students' attitudes toward chemistry in the group taking CQG compared with those participating in the more traditional paper quiz of the same content. These results suggest that CQGs can have a positive effect on the student performance, lending some quantitative credence to the hypothesis that CQGs provide either a support to the traditional lecture delivery or an alternative method of learning in a freshmen engineering chemistry course.

IV. CONTRIBUTION AND NOVELTY

Before we discuss the overall relevance of this contribution, we would like to remind readers that several other gaming-for-learning attempts have been publicized in recent 15 years or so. Some of the developments in recent years include “Concentration” game [25], based on matching question and answers, “Go Chemistry” game [26], played as the card game focused on a specific goal, for example, the comparison between ionic and covalent compounds, and “Chemistry Taboo”, [27] which separates all clues into allowed and forbidden ones, thus motivating deeper, more discerning engagement with the course material. Introducing a combination of computer- and game-based learning as a supplement to traditional teaching learning in chemistry is challenging, especially at university level in UAE, given the diverse pre-college educational background of students. The approach described here

provides an alternative way to improve pedagogical practices in science and develop novel curriculum elements to augment chemistry learning. The research findings offer an understanding of the strengths and weaknesses of the implementation of game-based learning approaches from the view of instructors and students alike.

For policy makers, the results of this research can provide a source of information regarding contemporary science education issues and trends. Furthermore, the results help the education authorities gain insight towards improvement of the quality of science education. Another contribution of this study is to help in advancement of our understanding of the practical contribution of game-based learning.

Our next contribution and claim to novelty has to do with the context of our study. Introducing a culturally diverse Middle-Eastern audience, for whom the quiz is written in a second language, to game-based learning provides some of the strongest evidence yet of the method's efficiency and widespread applicability. Furthermore, the approach that is introduced in this study is very practical to use, and instructors do not have to change their general delivery method, as the team designed the game engine specifically for this purpose.

V. SUMMARY AND CONCLUSIONS

This is a pilot report on the development and implementation of computer quiz games in introductory freshmen engineering chemistry class, where we show how playing one computer quiz game per week, while following the traditional US-style curriculum enables instructor and students to alter the expectations and attitudes in terms of possible improvement of learning gains. In addition to development and implementation of computer quiz games, we developed and implemented novel chemistry aptitude test, FECAT, which is designed to serve as both, research instrument for pre- and post-test applications and as assessment tool.

ACKNOWLEDGMENTS

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Smart Grouping Tool Portal for Collaborative Learning

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Abstract—Learning theory in education has progressed dramatically with the rapid development of modern technologies. Modern learning theory has found that learning performance can be improved effectively through cooperative/collaborative learning. How to group students in one class based on their different learning capabilities is a key to success in education. Two grouping types of homogeneous and heterogeneous have been applied into class grouping. Research proves that homogeneous groups are good at specific goal and heterogeneous groups are better in expanded tasks. Learning efficiency is affected in both group level and individual level by different grouping method. However grouping students in an optimal way is a difficult NP-hard research problem with high complexity; and to achieve the best results, such grouping can be very time consuming and tedious for the teachers to perform manually, especially when local cultural context (for instance, gender parameter) has to be taken into account, such as in the Middle East region. So the ability of allowing educators to define rules describing groups is very important for both homogeneous and heterogeneous grouping capabilities. This paper thus describes a smart grouping tool portal which is easy to access and user friendly, and aims to assist teachers to automatically group students based on different criteria. This portal has been trialled at Khalifa University of Science, Technology & Research (KUSTAR). A case study of the trial has also been analyzed to illustrate the derivative benefits of our smart grouping tool portal.

Keywords—cooperative/collaborative learning; student grouping; learning analytics

I. INTRODUCTION

Research into the efficacy of cooperative learning (as defined in [1-3]) in education has primarily taken place within a “conditions” paradigm, where factors such as group composition, task features, collaboration context and means of communication, are investigated for their causal role, if any, in the development of domain expertise among group members, with results most often interpreted within the framework of Piaget’s developmental model and the social-constructivist’s model from Vygotsky (see [4] for review). Briefly summarizing these models, the cognitive development of a learner proceeds through definite stages, with each characterized by the manner in which the learner constructs meaning about the world and solves problems [5]. Development and learning are often triggered by cognitive conflict with and facilitated by social interactions with peers of greater task-relevant knowledge, but with such skill differences being within an optimal “zone of proximal

development” [6]. In other words, skill differences among members that are too small are unlikely to produce conflict, while skill differences that are too great can lead to confusion, demotivation, or create perceived authority figures within the group or other counter-productive behaviors among members.

For this reason, conditions of group composition in general and the distribution of the group’s task-relevant skill levels in particular, have been investigated more than any other factor [4]. However, the question of ‘what represents the ideal group formulation?’ remains an active area of investigation, partly because of a lack of wide agreement on (1) the definition of a “collaborative group”, particularly in terms of proximity (e.g. do we include 1,000 students in a project-based MOOC as forming a ‘group’?) and (2) how to measure relevant learning specifically resulting from peer interactions [4]. These issues are difficult to resolve partly due to the difficulty in studying large populations with a consistent methodology, large numbers of different definitions of ‘group’ and different teaming recipes, and analyzing large sets of assessment data for the individual learners.

To address this issue, we have designed a standalone grouping tool application based on a set of user-defined rules under the iCampus initiative (<http://intelligentcampus.org/>) at the Etisalat BT Innovation Center (EBTIC) [7,8]. To make it more easily accessible and applicable for further learning analytics, we have also upgraded it into web portal termed as “Smart Grouping Tool”. To maximize the practicality and usefulness of the tool, we have focused the functions offered around solving the problem of creating student groups within one class or section of a course (i.e. one instance of a course where students would be physically present with one another during a scheduled contact time). This approach is practical because teaming students in such a setting is a recurring task of instructors using team-based pedagogies. And it is a useful approach because this specific teaming task is, when done manually, often very time consuming and difficult to apply consistently, for a given rule set or teaming recipe. This approach is also very relevant for research purposes, since providing an algorithm that gives the ability of following user-defined teaming recipes consistently will help other investigators eliminate systematic errors and better compare data sets collected under different settings. Lastly, the teaming recipe itself, when constrained by many rules, can present a tricky non-deterministic, polynomial-time-hard (or “NP-hard”) problem.

A sample of representative research suggests that task-relevant, skill-homogeneous groups are good at narrowly defined, more analytical tasks, while heterogeneous groups perform better in extended, more synthetic tasks requiring learning, creativity and ideation [9-14]. Research in recent years has also seen many efforts aimed at defining student spaces and learning styles [15, 16]. Algorithms based on feature distance have been used on grouping tasks [12,17-20], however is difficult to be adapted to apply on rule set based grouping tasks. In addition, as previously mentioned, grouping is an NP-hard problem, so complexity and speed are two important considerations. Some optimal algorithms might not be practical in the real scenarios, while for the most existing algorithms, the user is not allowed to define the rule set and therefore they become inflexible for real world usage.

The paper is organized as follows: In Section II we describe our smart grouping tool portal and show the prototype with some user interfaces snapshots. In Section III, we report a case study with University Physics I students at Khalifa University of Science, Technology & Research (KUSTAR). We then conclude with current progress and future work in Section IV.

II. SMART GROUPING TOOL PORTAL

The culture in the Middle East is very much different with other regions. For example, Gender needs to be considered seriously in some place, so does Nationality. So the class grouping has to be more flexible to allow some defined rules. That means the class grouping tool must have both homogeneous and heterogeneous grouping capabilities. From the point view of the Middle East Culture challenge and our research, we built up our smart teaching assistant class grouping tool web portal platform. Our motivation is to have a class grouping tool that both “Smart” enough to handle the practical constraints in the Middle East and “Flexible” enough to understand user requirements and make the results understandable to the user. Figure 1.A describes the workflow of our smart grouping tool portal. Our motivation is to have a class grouping tool that is both “Smart” enough to handle the practical constraints in real classrooms (e.g. incomplete data sets) and “Flexible” enough to understand user requirements and make the results understandable to the user. A server database will store registered user information (instructor’s class data) and monitor the user’s login status. The user uploads student data files (.csv format) as the system input. The final grouping results will be generated and downloadable as an Excel™ file (.xls).

Figure 1.B shows the upload file interface as seen by the user. The file is allowed to include any attributes/features of the students. The example file we use includes the student information like Identifier, Course Section, FCI Pretest (%), UAE National, Gender, IELTS, KU Math Placement Score (%), Lecture Quiz (1-3) Avg (%), Midterm Exam (%), Round 1 Team No., Round 2 Team No. which are used in Khalifa University of Science, Technology & Research (KUSTAR).

Figure 1.C shows the rule/force interface. Column headings are taken as variables and rows as student identities by the algorithm. Any alpha-numeric data types are allowed, including numerals like boolean, integer, and reals, and

non-numerics like gender, ethnicity, etc. A user can upload their student data, then construct custom rules for carrying out the grouping calculation using the rule/force interface. The user may also specify on a student-by-student basis, special exceptions, hence the “force” in “rule/force” interface. For example, if two students are known for having personal conflicts, but are likely to be grouped based on their skills, the user can force the grouping algorithm to keep looking for solutions that do not include those where the two students in question are in the same group.

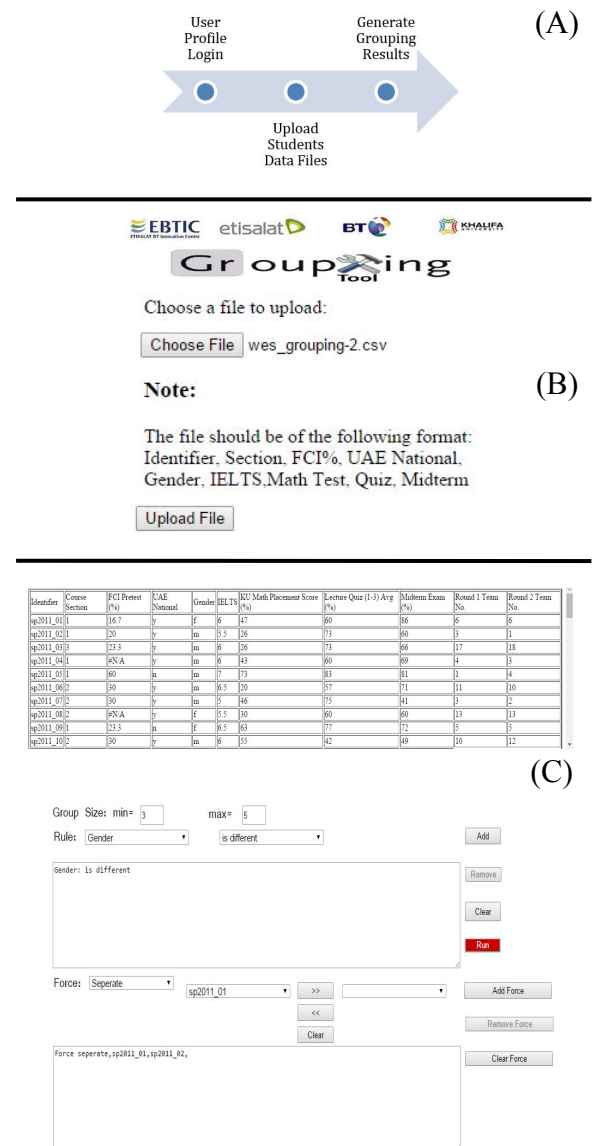


Fig. 1. Workflow for the smart grouping tool portal (A). The upload file interface page (B). The rule/force interface page (C).

Table I shows the operator options available for users to construct grouping rules, depending on the data type. The grouping tool is intelligent and able to automatically identify the type of the data; Boolean values, integers, reals, and text strings. Based on the properties of the data type, the tool then automatically creates and populates drop-down menus of operators (verb-phrases), for each column/data field, that can be used for flexible construction of nearly-natural language rules.

For example, an instructor might upload data that indicates in a column if a student is repeating the course or not and indicate this with a Boolean value; 1 – for repeating the course, 0 – for first-time registration. The grouping tool will automatically populate a pull-down menu for this column, with the following options; “is at least one”, “is the same”, “is different”, and “new member more than one”. If the user selects “1” for the value and “is at least one” for the operator then, when run, the algorithm will search for a solution where all groups formed from the uploaded roster have at least one member who is repeating the course. Multiple rules can be defined on the same data and multiple data may have rules defined for them, so that these rules can be combined together as user wishes. For real number data types, alternative options of “is at least one highest”, “is at least one lowest”, “difference is larger than”, and “difference is less than”. For rules constructed with either the “...highest...” or “...lowest...” operators, the tool determines how values for the real data field are distributed among the students, determines the top, bottom, and middle thirds, then assigns membership in groups accordingly. For rules using “...difference is...” operators, the tool searches pairwise among students, to find grouping solutions that have satisfactory differences between members’ values. For example, an instructor might include student age data in a column and define a rule for the age value with “is at least one highest”. When run, the algorithm will return a grouping solution where every group has a member from the top third of the age distribution in the class. Table II shows the user options for grouping rule construction in our case study for University Physics I students at Khalifa University of Science, Technology & Research (KUSTAR).

TABLE I. USER OPTIONS FOR GROUPING RULE CONSTRUCTION

Data Type	Operator Options for User Rule Construction
Boolean	{“is at least one”, “is the same”, “is different”, “new members more than”}
Integer	{“is at least one”, “is the same”, “is different”, “new members more than”}
Real	{“is at least one highest”, “is at least one lowest”, “difference is larger than”, “difference is less than”}
Text String	{“is at least one”, “is the same”, “is different”}

TABLE II. CASE STUDY OF USER OPTIONS FOR GROUPING RULE CONSTRUCTION


Rule	Options	Value
Identifier	{“is at least one”, “is the same”, “is different”}	non-numerical
Course Section	{“is at least one”, “is the same”, “is different”}	non-numerical
FCI Pretest (%)	{“is at least one highest”, “is at least one lowest”, “difference is larger than”, “difference is less than”}	numerical
UAE National	{“is at least one”, “is the same”, “is different”}	non-numerical
Gender	{“is at least one”, “is the same”, “is different”}	non-numerical
IELTS	{“is at least one highest”, “is at least one lowest”, “difference is larger than”, “difference is less than”}	numerical

KU Math Placement Score (%)	{“is at least one highest”, “is at least one lowest”, “difference is larger than”, “difference is less than”}	numerical
Lecture Quiz (1-3) Avg (%)	{“is at least one highest”, “is at least one lowest”, “difference is larger than”, “difference is less than”}	numerical
Midterm Exam (%)	{“is at least one highest”, “is at least one lowest”, “difference is larger than”, “difference is less than”}	numerical
Team	{“New partners more than”}	numerical

Figure 2 shows the final generated grouping results according to the defined rule set. The result is downloadable as an Excel™ file.

III. CASE STUDY

Trials were performed using the smart grouping tool portal in Spring 2011 and Fall 2011 term offerings of the University Physics I course at Khalifa University (populations A and B, respectively), using the recently developed Collaborative Workshop Physics (CWP) pedagogy, described in detail in [22]. Population A consists of 75 students and population B consists of 85 students.



Identifier	Course Section	FCI Pretest (%)	UAE National	Gender	IELTS	KU Math Placement Score (%)	Lecture Quiz (1-3) Avg (%)	Midterm Exam (%)	Round 1 Team No.	Round 2 Team No.
group 1										
sp2011_01	1	16.7	y	f	6	47	60	86	6	6
sp2011_05	1	60	n	m	7	73	83	81	1	4
sp2011_73	3	23.3	y	f	6	33	63	55	19	20
group 2										
sp2011_02	1	20	y	m	5.5	26	73	60	3	1
sp2011_04	1	#N/A	y	m	6	43	60	69	4	3
sp2011_67	2	40	n	f	6.5	50	48	0	13	13
sp2011_03	3	23.3	y	m	6	26	73	66	17	18
group 3										
sp2011_06	2	30	y	m	6.5	20	57	71	11	10
sp2011_07	2	30	y	m	5	46	75	41	3	2
sp2011_09	1	23.3	n	f	6.5	63	77	72	5	5
sp2011_69	1	36.7	n	f	6	63	92	91	7	6
sp2011_08	2	#N/A	y	f	5.5	30	60	60	13	13
group 4										
sp2011_10	2	30	y	m	6	55	47	49	10	12

Total No. of Groups is 14

Fig. 2. On-screen display of an example solution, in this case, for 14 groups of 3-4 students each, satisfying five user-defined rules on a variety of data. The result is downloadable as an Excel™ file.

The Force Concept Inventory (FCI) [23] was administered both as a pre-test and a post-test to measure learning gains and was used, along with other data, in the grouping rule definitions. Strict matching between FCI pre-test and post-test was applied, so that only individual students with both scores were included in the analysis. This defined corresponding Samples A and B, consisting of 62 students (32 male and 30 female) and 68 students (35 male and 34 female), respectively.

The CWP pedagogy, both its rationale and efficacy, are described in detail in [22]. For the sake of brevity, here we only point out that it is largely based on Cooperative Group Problem Solving (CGPS) in physics [10,11], a pedagogy which calls for students in teams of 3-6 to conduct lab experiments and problem-solving recitations/tutorials on open-ended, context-rich problems, rather than traditional

‘recipe labs’ and ‘end-of-chapter’ problems. The pedagogical goals are to emphasize deep conceptual learning over rote memorization and formula usage, and shift classroom norms away from an emphasis on ‘answer-making’ and toward an emphasis on ‘sense-making’ [24], consistent with the larger body of findings in physics education research (PER) [25]. Another important component of maximizing the pedagogy’s effectiveness is designing and assigning students to heterogeneous teams and reassigning them multiple times over the course, maintaining heterogeneity with aggregated performance data, such as exam and quiz scores. Students are typically re-grouped in this way 3 to 5 times over the semester, and consequently, it is a labor-intensive task for instructors to continuously create teams based on a consistent recipe for high-heterogeneity, with an ever-growing amount of performance data to work with.

Table III shows an example of the grouping rules used for creating the first set of student teams in both Populations A and B. Teams for Population A were created by section instructors manually, by hand, following these rules. Whereas, the smart grouping tool portal was used in Population B. In both sets, all groups were 3-5 students, for 14 to 24 total groups on any given round of (re)-grouping.

TABLE III. EXAMPLE OF USER-DEFINED GROUPING RULES, FOR SAMPLE A AND SAMPLE B STUDENTS IN THE CASE STUDY

Data	Data Type	Grouping Rules Constructed with the Tool
FCI Pretest	Real	Groups have “at least one highest” FCI Pretest Score
Gender	Text String	Groups are “(is) the same” Gender
UAE National	Boolean	Groups have “at least one” not a UAE National
IELTS ^a	Real	Groups have “at least one highest” IELTS score
Math Placement Test	Real	Groups have “at least one highest” Math Placement Test

^a. International English Language Testing System (IELTS) is a test of English proficiency.

Comparison of Teaming Methods

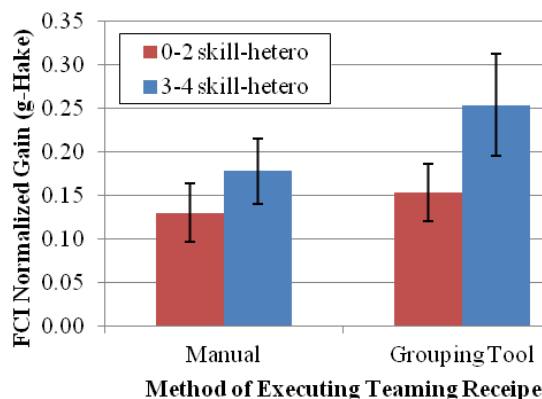


Fig. 3. Comparison of teaming methods, for few (0-2; red) versus many (3-4; blue) experiences solving problems with skill-heterogeneous teams, in the Collaborative Workshop Physics session [22].

Table IV shows results from FCI pre/post-test data, analyzed to determine the efficacy of skill-heterogeneous teaming, in terms of normalized learning gain, $\langle g \rangle$ [26]. Here, we define a team as “Skill-Heterogeneous” in narrow terms, by (1) whether or not Rule 1 (“Groups have at least one highest FCI Pretest Score” (top-third as determined by the smart grouping tool portal) is satisfied, which was not always possible, and (2) if the team also contains a member with an FCI pretest score from the bottom-third of the distribution. In Table III, N gives the number of individual students in the Sample, in terms of how many times they were members of a skill-heterogeneous team.

In both Samples, the fraction of students experiencing the course content in large numbers of skill-heterogeneous teams (3-4 out of 4) was comparable (50% and 40% respectively). Most interestingly, there is a relatively strong ($r = 0.87 - 0.89$), and significant (0.06 – 0.08 two-tailed p -value) correlation between the number of such experiences and normalized learning gain. Figure 3 shows learning gains data from Table III, from manually (left) and grouping tool-created (right) teams. Red columns show normalized FCI gain for students having 2 or less experiences in skill-heterogeneous teams and blue columns shows that same for student having 3 or more. Most relevant to the present study, is the ease of determining the groups. Sample A contains a total of 80 teams which a total of 12 person-hrs to determine. Sample B contains 72 teams which required a total of 40 person-min. a substantial time saving.

IV. CONCLUSION

Our smart grouping tool portal is very useful in the Smart Teaching area and could be a very good teaching assistant to help teachers to conduct cooperative and collaborative learning. Our tool is easily accessible and flexible with user defined rules. It can be used to re-group students based on the educator’s requirement so as to fit his/her teaching purpose. Our motivation is to have a grouping tool that is both “smart” enough to handle the practical grouping constraints and “flexible” enough to understand user requirements and, as such, make the results understandable to the user. It is also very useful for researchers to understand the group dynamics and the co-construction of knowledge using trial results. The trial results presented here add to evidence in the literature that skill-heterogeneous teams promote greater learning in individual students. Further study, to replicate and deepen our understanding of this result is greatly enhanced by the grouping tool, allowing researchers to maintain consistent teaming recipes over multiple settings and large population sizes. Our future plan is to do large-scale user testing and get feedback to do learning analytics in the future.

TABLE IV. USAGE CASE DATA FOR MANUAL VS. SMART GROUPING TOOL PORTAL-GENERATED TEAMS IN COLLABORATIVE WORKSHOP PHYSICS

Teaming Method	N	No. of Skill-Heterogeneous Team Experiences	FCI <g> _{Hake}	N	No. of Skill-Heterogeneous Team Experiences	FCI <g> _{Hake}
Manual (Sample A)	7	0	0.10 ± 0.05	31	0-2	0.13 ± 0.03
	4	1	0.15 ± 0.18			
	20	2	0.14 ± 0.04			
	14	3	0.19 ± 0.06	31	3-4	0.18 ± 0.04
	17	4	0.18 ± 0.05			
		Pearson- <i>r</i> : 0.87				
		<i>p</i> -value (two-tailed) ^b : 0.06				
Smart Grouping Tool Portal (Sample B)	9	0	0.09 ± 0.05	42	0-2	0.15 ± 0.03
	16	1	0.09 ± 0.03			
	17	2	0.25 ± 0.06			
	26	3	0.25 ± 0.06	26	3	0.25 ± 0.06
		Pearson- <i>r</i> : 0.89				
		<i>p</i> -value (two-tailed) ^b : 0.08				

^b. p -values are for the Pearson- r correlation coefficient and were determined by permutation test.

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Smart text-classification of user-generated data in educational social networks

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Abstract — Nowadays, face-to-face interpersonal communication has been gradually replaced by communications via virtual social network platforms, which applies to the new generation of education. The amount of user-generated data in social networking sites is increasing day by day. Understanding and consuming this great amount of data has become a harder task. Classifying the user-generated data (mainly text) can help simplify the user experience by providing them dynamic personalized recommender. Filtering the data, and providing users with what is relevant to them, will help them utilize this data more effectively. In education, recommending relevant learning content to learners in educational social networking sites saves them the arduous task of sifting through a huge amount of information.

This paper introduces the partial-supervised learning for Hierarchical Dirichlet Process (HDP) for text classification with inherent hierarchical structure in education. This enables the use of partial known model structure and labels as expert knowledge to guide the model learning procedure from the text without labels. Compared with the existing partial/semi-supervised HDP, the proposed method is able to make use of the known labels for not only structure construction, but also parameter learning. This enhancement provides a more flexible way and better guide for the model learning from the unlabelled documents. We experimentally investigate the contribution of partial knowledge to guide the model learning process. The proposed partial-supervision for HDP is applied to student micro-blog automatic classification and adds intelligence to our student social media platform (ELSE).

Keywords—*Hierarchical Dirichlet Process (HDP), semi-supervised learning, partially-supervised learning, document classification, text mining, social networks, informal learning*

I. INTRODUCTION

We currently live in a digitally connected world, where the amount of information available is increasing at an unprecedented rate. Information sharing has become significantly simpler, and the creation of content, its decimation, availability, and distribution is expanding at a record pace. All these, have been made possible through advancements in ICT in general and the Internet, social media and Web 2.0, in particular. Web applications have penetrated & reached almost all walks of life. Moreover, the increase in processing power, quality and availability of mobile devices have further contributed to this digital content exchange bonanza, providing instant access, as well as user alerts, ubiquitous access and simpler ways of managing information. Cloud Computing on the other hand, is now providing us with

cost effective reliable and scalable data handling & processing capabilities to manipulate and analyse this valuable information.

Enterprises and businesses have embraced such technologies, and are leveraging them to help them on all levels, business development, people development, value creation, marketing, collaboration, innovation, customer management, supply chain management, and so forth.

In education, the picture is not different, “The Internet, social media, and Web 2.0 are becoming important components of students’ education as schools increasingly provide a laptop or other portable device to each student, but just how these new ICTs should be used is still a topic of debate [1].”

A substantial amount of work and research is being undertaken to enhance education and learning, identifying new opportunities, and tackle old challenges with new methods, and addressing new arising ones. Today’s students are changing in capabilities, and expectations (both in what they expect and what is expected from them). Fluency in ICT, is almost implied for students who are expected to survive, and excel in a global digital, and connected economy. Traditional collaboration boundaries have come tumbling down, and a new set of drivers and rules have emerged. Educational institutes are becoming more complex in terms of their setup and pedagogical requirements. They are also becoming more capable in terms of data collection and analysis, mostly due the fact that the new systems provide educators, as well as learners, with more information that can be studied to help them improve.

Hence, we see a growing trend globally focusing on the use and impact of these technologies on education. Studies are ongoing to ascertain how traditional learning methods and techniques can be adapted to deal with the new complexities, in order to leverage them to deliver a more effective learning for the 21st century student.

We are witnessing an increasing use of social network applications in education, whether this is the use of well-established systems such as Facebook and Twitter, or specifically developed systems such as Ning and Mixable. The primary driver for such systems, whether they are for formal or informal learning is to encourage collaboration and knowledge sharing to achieve better learning.

However, “Till now, the success of social applications for collaboration has not been consistent and the ability of these social applications to stimulate their subscribers to contribute varies greatly. The work on encouraging the participants to contribute has been more of an art than science [2].”

One such project that is looking at using social networking to drive collaboration, and information sharing, in an informal

learning setting, developed by the Etisalat BT Innovation Centre (EBTIC), in collaboration with Khalifa University in the UAE. The project, which is known as EBTIC's Learning and Social Environment (ELSE), is part of EBTIC's overall education initiative; the Intelligent Campus (iCampus). ELSE, forms the foundation for the iSocial pillar within iCampus. It is aiming at leveraging advances in social networking and intelligent systems to augment learning. It is to be achieved through collaboration between students as well as faculty and create a user centric, user & time relevant collaboration platform, for creating, sharing and distributing knowledge. EBTIC is using its research and development work on semi-supervised and Hierarchical Latent Dirichlet Process (HDP), which is a document/micro-blog classifier to add intelligence to the ELSE platform.

This paper will use the user input data (comments and posts) gathered during the ELSE platform 3 months trial at Khalifa University campus in Abu Dhabi, and classify them by topics using EBTIC's micro-blog LDA engine. This work demonstrates the engine's effectiveness within an education environment. The ELSE platform is introduced in Section II. Our proposed partial supervised learning for HDP is explained in Section III. We show how the proposed partial supervised HDP work for the student posts from the ELSE platform in Section IV. Last, the conclusion is given in Section V.

II. ELSE PLATFORM

ELSE is a system that leverages advancements in social networking, and intelligent systems, to create a proactive, and adaptive platform that promotes informal collaborative learning. ELSE provides the usual social networking tools such as activity wall, groups, file sharing, etc. However, it is different in that, it does not solely rely on the user to find content, search for groups and identify friends and collaborators. It aims to use various techniques that are being researched and investigated to automatically identify content, collaborators and groups that are relevant to a particular user at that point in time and then make appropriate recommendations. Therefore, it supports the user in achieving his/her learning and social objectives more efficiently.

ELSE aims to automatically populate and maintain part of the student profile with available data from the university systems (integration is required). This ensures the changes in the studied subjects are taken into account as the student progresses through the academic year, and avoids spamming him/her with no longer needed material. It will also monitor user contributions, and activities, to enrich the profile through current data reflecting current user interests. The user will naturally retain the manual ability to modify and change the profile (learned by ELSE) as needed.

In summary, the recommendations will not be based on a static list of interests and common friends, but rather on current interests derived from user activities, educational needs, expertise level and even social activities and club memberships where appropriate. For example, a student who is studying astronomy and in need of help might be put in touch with another student, who is a member of the astronomy club, and is known to have contributed in that subject, even though he

might be an engineering student. The environment also considers various motivation theories to incentivise users, to collaborate and share information in a fair and objective manner, to ensure its long-term sustainability.

To achieve active recommendations, an intelligent and flexible document classifier is needed. The classifier should be able to deal with not only formal long documents (which is comparatively an easy task), but also short informal messages (e.g. comments & status updates), and the mixture of long and short text (the length of forum post varies). In addition, the classifier should be able to deal with complex problems with inherent hierarchical logic structure which is a reflection of the real world. Hence we propose to add partial supervised learning to Hierarchical Dirichlet Process (HDP) [3], because HDP itself has the capability of dealing with complex problems with inherent hierarchical structure. Our introduction of partial supervision adds flexibility to the user control and as a result improves the final accuracy. The proposed partial supervised learning is explained in the next Section.

EBTIC and Khalifa University ran a 3 months live user trial of ELSE. The trial included about 100 students and their lecturers. The system was available on the world wide web and accessible from within as well as outside the campus, it also included and IOS 6 native application for the iPhone and iPad devices. The native mobile application provided immediate and quick access to the platform on the move as well as user notification capabilities. We collected the data from the ELSE trial and analysed the collected data by using our proposed method (see Section III). The analysis results are shown in Section IV and will be used to realise dynamic profiling and smart recommendation.

III. THE PROPOSED IMPROVED HDP

A. Hierarchical Dirichlet Process

Hierarchical Dirichlet Process (HDP) [3] was proposed after Latent Dirichlet Allocation (LDA) [3] by Blei to investigate and represent more complex corpus/data with inherent hierarchical structure. HDP does not need the number of topics as user input and it is assumed that there is always a possibility that there exists new topic(s) for new documents. Parameter γ is introduced and it indicates a possibility of introducing a new topic, which is the number of imaginary documents belonging to a new topic that does not exist in current model.

Collapsed Gibbs sampling [5] is usually used to build up the HDP model, which is divided into two iteratively cooperative sampling stages: sampling for the path and sampling levels for each word along the sampled path. The path sampling for document d is based Equation (1), where the prior probability $P(\mathbf{c}_d | \mathbf{c}_{-d}, \gamma)$ for path \mathbf{c}_d is calculated by Equation (2) and probability of the data $P(\mathbf{w}_d | \mathbf{c}, \mathbf{w}_{-d}, \mathbf{z}, \gamma)$ for \mathbf{c}_d is calculated by Equation (3). n_i is the number of documents having path getting through $node_i$. γ is the parameters indicating how many imaginary documents do not belong to any existing nodes. \mathbf{c}_{-d} and \mathbf{w}_{-d} in the equations mean that the influence (word counts in document d) for d has been removed and will be re-sampled. $n_{l,-d,w}$ is the count of word w at level l without considering the word counts for

document d . $n_{l,w}$ is the number of word w in document d at level l . W is the total number of vocabulary in the dictionary. η is the Dirichlet distribution parameter for words. Γ is standard gamma function defined as $\Gamma(z+1) = z \times \Gamma(z)$.

$$P(\mathbf{c}_d | \mathbf{w}, \mathbf{c}_{-d}, \mathbf{z}, \eta, \gamma) \propto P(\mathbf{c}_d | \mathbf{c}_{-d}, \gamma) \times P(\mathbf{w}_d | \mathbf{c}, \mathbf{w}_{-d}, \mathbf{z}, \gamma) \quad (1)$$

$$P(\mathbf{c}_d | \mathbf{c}_{-d}, \gamma) \propto \begin{cases} \prod_{i=1}^{L-1} \frac{n_{i+1}}{n_i + \gamma} & \text{if all nodes along } \mathbf{c}_d \text{ is existing nodes} \\ \prod_{i=1}^p \frac{n_{i+1}}{n_i + \gamma} \times \frac{\gamma}{n_{p+1} + \gamma} & \text{if first } p \text{ nodes along } \mathbf{c}_d \text{ is existing nodes} \end{cases} \quad (2)$$

$$P(\mathbf{w}_d | \mathbf{c}, \mathbf{w}_{-d}, \mathbf{z}, \eta) \propto \prod_{l=1}^L \frac{\Gamma(\sum_w n_{l,d,w} + W\eta)}{\prod_w \Gamma(n_{l,d,w} + \eta)} \times \frac{\prod_w \Gamma(n_{l,w} + \eta)}{\Gamma(\sum_w n_{l,w} + W\eta)} \quad (3)$$

Given a path sampled through equation (1), word level sampling is calculated based on equation (4), where $P(l_{d,z,w} | l_{d,-w}, \alpha)$ is the level distribution and calculated by Equation (5), and $P(w | l_{d,z,w}, c_d, \mathbf{w}_{-d,-w}, \eta)$ is the probability of the given word w based on a possible assignment and is calculated by Equation (6). $n_{l_{d,z,w}}$ is the word count in document d at level z along the path c_d . $n_{c_d,l,w}$ is the word count for word w at level z in all documents along the path c_d . W is the total number of vocabulary in the dictionary.

$$P(w_z | l_{d,z,-w}, c_d, \eta, \alpha) \propto P(l_{d,z,-w} | l_{d,-w}, \alpha) \times P(w_z | l_{d,z,-w}, c_d, \eta) \quad (4)$$

$$P(l_{d,z,-w} | l_{d,-w}, \alpha) \propto n_{l_{d,z,-w}} + \alpha \quad (5)$$

$$P(w_z | l_{d,z,-w}, c_d, \eta) \propto \frac{\eta + n_{c_d,l,w}}{W\eta + \sum_w n_{c_d,l,w}} \quad (6)$$

B. Partial Supervision

The proposed Partial-Supervised learning for HDP has the advantages of: model structure partial definition, parameter partial-supervised learning, and consistent process sampling within the sub-space constrained by the defined labels.

Although HDP does not require the number of topics as user input and determines the number of topics automatically, the resulting model usually has more topics some of which are not interpretable by a human. The user needs to control the number of topics/sub-topics for better understanding of each node (topic/sub-topic). We can see from Section III.A, whether a new node/topic/sub-topic is added to HDP depends on the path sampled to one document which is controlled by Equation (2). In Equation (2), if not all nodes on the sampled path are existing nodes; then a new tree branch is created and added to the existing model. The path sampling process is done step by step from the root node down to the leaf node. Each lower-level path node sampling is dependent on its higher-level path sampling. At each level, say the $(i+1)$ th level sampling, there is a chance of $\frac{\gamma}{n_i + \gamma}$ to sample out of the existing nodes/topics/sub-topics and create a new branch. The way to stop new branch creation is to set the parameter of γ as zero. Then the chance of sampling out of existing branches is $\frac{\gamma}{n_i + \gamma} = 0$. Then the step-by-step sampling, can be written as Equations (7) and (8):

$$P(\text{child_node}_i | \text{parent_node}, \gamma) = \frac{n_{\text{child_node}_i}}{n_{\text{parent_node}} + \gamma} \quad (7)$$

$$P(\text{new_child_node} | \text{parent_node}, \gamma) = \frac{\gamma}{n_{\text{parent_node}} + \gamma} \quad (8)$$

To control the number of children for each node; we need to reset the parameter of γ as zero when the number of child nodes reaches its defined maximum number. Then Equations (7) and (8) can be rewritten as Equations (9) and (10);

$$P(\text{child_node}_i | \text{parent_node}) = \frac{n_{\text{child_node}_i}}{n_{\text{parent_node}}} \quad (9)$$

$$P(\text{new_child_node} | \text{parent_node}) = 0 \quad (10)$$

Hence to control the model structure a monitor and intervention is added to use either Equations (7) and (8) or Equations (9) and (10) for the next-level path node sampling.

Now we consider a problem as a collection of M documents, $\mathbf{D} = \{d_1, d_2, \dots, d_M\}$, which is composed of M_L labeled documents $\mathbf{D}_L = \{d_1, d_2, \dots, d_{M_L}\}$, and M_U unlabeled documents $\mathbf{D}_U = \{d_1, d_2, \dots, d_{M_U}\}$, where $M_U + M_L = M$. We assume we have K defined topics $\mathbf{T} = \{T_1, T_2, \dots, T_K \dots\}$ in current model (and initially $K = 0$), each document d_i in \mathbf{D}_L has one or more assigned topics $\mathbf{T}_i = \{T_{i_1}, T_{i_2}, \dots, T_{i_k}\}$, where either $T_{i_k} \in \mathbf{T}$ or is a new topic to be added. In the Gibbs sampling process, the target topic for any labelled document d_i in \mathbf{D}_L is restricted to belong to the set of labels $\mathbf{T}_i = \{T_{i_1}, T_{i_2}, \dots, T_{i_k}\}$, and the target topic for any unlabelled document d_j in \mathbf{D}_U is restricted to belong to the whole topic domain $\mathbf{T} = \{T_1, T_2, \dots, T_K, \dots\}$ and possible new topics.

For documents with defined labels, to guarantee that we always get a valid label constrained to the defined labels, Equations (7) and (8) for path sampling is modified to Equations (11) and (12). If the defined topic/sub-topic has been included in the existing model then equation (11) is used to sample the path; otherwise new nodes (path branch) are created and added to the model according to Equation (12).

$$P(\text{child_node}_i | \text{parent_node}) = \begin{cases} \frac{n_{\text{child_node}_i}}{\sum_{\text{child_node}_j \in \text{defined path}} n_{\text{child_node}_j}} & \\ 0 & \text{otherwise} \end{cases} \quad (11)$$

$$P(\text{new_child_node} | \text{parent_node}) = 1 \quad (12)$$

For documents without defined labels, the Gibbs sampling process follows Equations (7) to (10). Given the sampled path $\mathbf{c} = \{c_1, c_2, \dots, c_L\}$, the word level sampling process is exactly the same with HDP: Equations (4) - (6) as discussed in Section III.A.

IV. EXPERIMENTAL RESULTS

We are applying the proposed partial learning for HDP to education recommender system. We need a document classifier to identify relevant learning contents which is a comparatively easier task (for formal document classification) and not discussed here. The second task is to identify the group of students who are interested to the identified documents from their user-generated text hence we need to classify students' posts/comments. We ran the ELSE platform trial for a 3 months period and involved students from two classes studying C++ and English. Totally 1615 posts/comments were collected ranging from short messages such as "test" or "hello world" to

full paragraphs of programming code. This data unbalance presents a great challenge in achieving satisfactory accuracy. After cleaning the messages (non-English posts/comments are removed) we were left with 1200 English posts/comments. We then manually classified the 1200 English posts/comments to 2 high-level categories and 3 sub-categories in each high-level category (as shown in Figure 1).

We ran the 10-fold cross-validation to test the accuracy by using different percentage of labelled information and the result of average accuracy is as shown in Figure 2. We can see a small percentage of labelled posts/comments (0.1 labelled ratio) provides a guide to map the model output to the realistic outputs however cannot provide a satisfactory accuracy. When we improve the ratio of labelled posts/comments, we can see the improvement in accuracy. The tendency of accuracy improvement is obvious before the labelled ratio reaches 0.5. Beyond a ratio of 0.5 of labelled posts/comments, the accuracy improvement in relation to the increase in labelled posts/comments ratio is very limited. In other words, for this application to function properly, 50% of manually labelled posts/comments is good enough for training/testing accuracy.

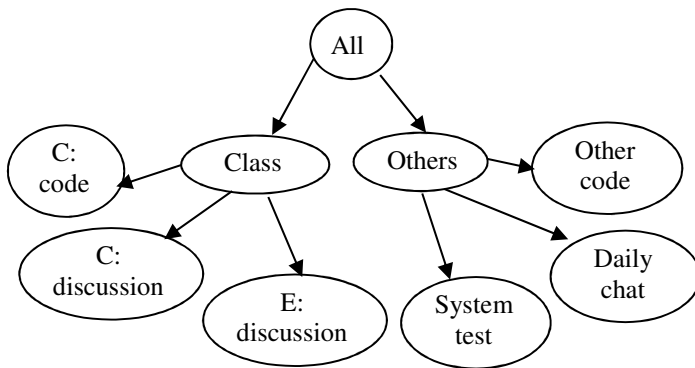


Figure 1. Hierarchical topic structure for students' post/comment

In addition, note that HDP itself without partial supervised learning can only address clustering, not classification. So another advantage of introducing partial supervised learning to HDP is that, the modelled categories are automatically mapped to the real world categories. Otherwise, it will be a trial & error to find the best match from the model categories to the real world categories (in this small application we need 72 tries).

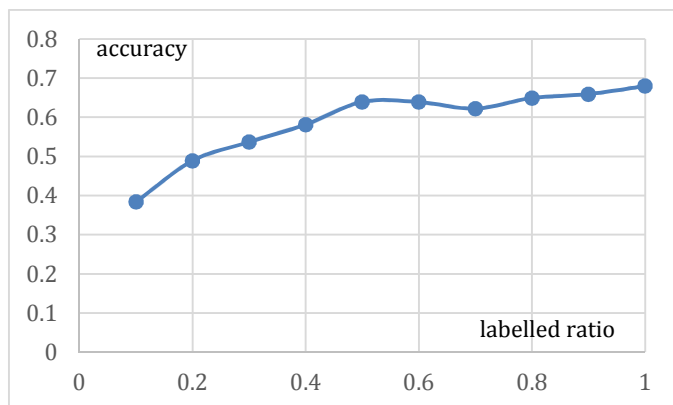


Figure 2. Accuracy by using different ratio of tagged posts/comments

The accuracy of the student's posts/comments classification is not very high (between 0.6 to 0.7). The reason for the low accuracy is due to the low number of training documents and the overlapping of topics. We can see from Table 1, the most confusing category is 'daily chat' which covers a broad range of free topics and tends to be close to any possible topic. For example, system bug and performance messages are exchanged in an informal way which is very close to 'daily chat', which creates the confusion between the category of 'daily chat' and 'system test'. The accuracy for other categories is better, above 0.83.

Table 1. Result of one running in 10-fold cross-validation

Model output Target	daily chat	system test	other code	E: discussion	C: discussion	C: code
daily chat	15	6	4	2	5	1
system test	1	9	1	0	1	0
other code	1	0	12	0	0	0
E: discussion	0	0	0	12	0	0
C: discussion	2	4	2	0	29	2
C: code	0	0	0	0	0	7

V. CONCLUSION

In this paper, we proposed partial supervised learning for HDP which enables HDP to make use of partial known knowledge to guide the model learning process. This partial learning enables HDP which is aimed at solving clustering problems to tackle classification problems and meanwhile partial supervised learning helps improve the classification accuracy.

We applied the proposed partial supervised learning for HDP to classify posts (micro-blogs) in an educational environment. The proposed partial supervised learning proves to perform reasonably well. This directly contributes to dynamic profiling and recommendations within the ELSE platform. The next step is to expand the usage of the ELSE platform and carry out further data analysis. The accuracy is expected to be greatly improved provided having access to more training data.

Our work in this paper provides an accurate classifier which works well for both long documents and short messages with comprehensive hierarchical structures and this is the key work to realise dynamic profiling and smart recommendation in today's smart learning and smart education.

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A B-Learning New Approach Applied to a Practical Power Electronics Converters Course

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Abstract—An Industrial Electronic discipline, involving different topics and technologies was designed to improve the sequence of activities within the available time and learning resources. The b-learning new methodology, applied in the University of Vigo, Spain, is composed of lectures, self-study sessions, quizzes, design problems, emulations, and laboratory sessions, integrated to achieve a better pedagogical environment.

Most of the resources are available online without time restrictions, thus providing the students the opportunity to choose where and when they can learn, interact with the emulators, the remote laboratory and self-evaluate.

Five flexible and powerful emulators have been developed for the buck, boost, buck-boost, forward and flyback converters. Emulation sessions provide a fast and easy path to understand the required concepts.

The laboratory sessions are implemented by means of existing automatic test equipment (ATE), drive by a dedicated online server with new specific custom made software.

The students provided positive evaluations of the methodology, and achieved a better degree of knowledge acquisition.

Nowadays students from the University of Minho, Portugal, are also using remotely the set of resources available. The future work on this methodology will integrate the resources developed in both universities, to include more aspects of power electronics converters.

Keywords—Power engineering education; Educational activities; Problem-solving; Electronic learning; Remote Laboratories.

I. INTRODUCTION

In recent years, higher education institutions in Europe have undertaken major educational reforms focused to improve the learning process of students. An important change in approach with regards to traditional model of teacher-centered learning is presented. In this traditional model, it is the teacher

who defines and organizes knowledge to be transmitted to the student to achieve the expected results. Students often take a passive role, limited to perform memory learning with very little critical or creative component.

Moreover, under the new educational trends, the focus moves from teacher to student emphasizing the active role in his own learning process. In this model, learning is interpreted as a natural and constructive process where the student uses personal processes to strategically regulate the behavior and immediate environment of learning [1].

Therefore, an important objective was to enhance the process of self-regulation, so the students activate different strategies in order to plan, to control and to assess their own learning process to approach it successfully [2]. Although this learning model is centered on the student, the teacher's role is crucial. One of the key is mentoring, therefore, it is the teachers's responsibility to design an appropriate learning environment and another key is that students express a high degree of motivation for learning.

As a whole, engineering education is a complex task. Specifically, power electronics disciplines involve different fundamental topics and technologies, so that power electronics courses contain plenty of previously learned topics on mathematics, physics and other technological skills [3]. Usually, a high load of lectures and tutoring sessions are essential due to the high amount of information related to all the technological and functional aspects implied. Simulation sessions provide a fast and easy path to understand the required concepts, but simulated results do not adequately represent real-world systems and behavior. The laboratory sessions complete the knowledge acquisition process [4]; offering the students a rich set of experiences that cannot be acquired by any other means.

The fundamental objective of laboratory experiments is to improve students' creativity and capability in real-world problems solving. However, conduct experimental activity in-class involves a series of drawbacks:

- The equipment for power electronics test and laboratory is often sparse and expensive [5] [6]. Also the circuits under study integrate expensive components and complex drivers.
- Laboratory's measurement equipment can be easily damaged under misuse by inexperienced students.
- The students have little time to interact with the power electronics labs; and as consequence the acquisition of new competencies by the students is curtailed [7].
- Due the tight schedule of lectures and laboratories time slots, the student does not have the opportunity to repeat the design process for a given component if the theoretical results and the measurements do not match.
- Usually, laboratory sessions are carefully prepared by professors so that the probability of student success is high. But this approach does not allow the student to develop skills relate to creativity, autonomous learning and self-regulation.
- Frequently, laboratory sessions are designed for full-time students. They are not conceived for students who try to balance their studies with a job.

Added to which, one of the goals of the European High Education Area (EHEA) [8] is that students can combine work with their studies; and the solution is to establish mechanisms that allow communication between students and teachers through virtual systems.

In order to develop an integrated training system based on the previous premises, the authors have developed a new b-learning model [3]. This new model is composed of lectures in classroom, self-study sessions, quizzes, design problems, emulations, emulations problems and laboratory sessions, organized and coordinated to achieve a better pedagogical environment.

The central element of the planning methodology is the sequential exposure of the whole set of activities and tasks for guiding the experiences that the student has to cover along the process of teaching-learning. The proposed activities are supervised by the teacher, giving a new dimension to the university tutoring.

The laboratory sessions are implemented by means of existing automatic test equipment (ATE), drive by a dedicated online server with new specific custom made software. The server allows students to share the ATE resources for testing DC-to-DC converters. The laboratory sessions can be made local or remote [9]. More tools were added from other closely related developments [10]-[15].

The feedback of professors is very important regarding the achievement of skills, because different evaluation strategies are used. In this way, the students are fully aware, at any time, of the degree of achievement of their objectives.

II. COURSE SYLLABUS AND LABORATORY SETUP

The University of Vigo offers a graduate program titled

'Engineering in Industrial Electronics and Automatic Control' (*Ingeniería en Electrónica Industrial y Automática*). It is equivalent to a B.Sc., with a total duration of 240 European Credit Transfer and Accumulation System (ECTS) in four years. ECTS is a standard for comparing the study attainment and performance of students of higher education across the European Union and other collaborating European countries. For successfully completed studies, ECTS credits are awarded. One academic year corresponds to 60 ECTS credits that are equivalent to 1500–1800 hours of study in all countries respective of standard or qualification type and is used to facilitate transfer and progression throughout the Union. In Spain, one academic year is equivalent to 1500 hours (600 attendance hours and 900 student's autonomous work hours).

Inside this program students can choose among two intensifications: Industrial Electronics or Automatic and inside the pool of electives for the Industrial Electronics intensification, the Electronic Technology Department taught a course on Industrial Electronic" (*Electrónica Industrial*), with a total of 6 ECTS credits (60 attendance hours and 90 student's autonomous work hours). It is offered during the second semester of the fourth year as an intensive course during January, February and March.

This course is devoted to switch-mode DC-to-DC power converters and it has four global topics: first an introduction to power converters; second, power converters topologies and circuits; the third topic is modeling and simulation; and the last one is control methods.

The introduction is intended to show the common subjects for power converters, that later will be applied to the different types of circuits. In order to gain insight of the differences, not only mathematical analysis is used, but also some modeling for the power stages. Being one of the latest courses in the program, control loop analysis and design is also included. With these topics the theoretical knowledge will be enough to achieve satisfactory practical skills.

The evaluation of the topics is established into a continuous assessment, providing students with a set of activities that let them perceive the degree of acquisition of knowledge, and also provide the professors with a valuable feedback of the evolution of the course.

A. Course Methodology

To expose the topics in the syllabus and achieve all the goals cited in the introduction, a blended methodology was developed by adding a wide set of resources and ideas positively tested in previous courses [9]. In the course four basic topologies were shown, analyzed and tested in the remote laboratory. For each one, the same set of activities was held, as the one in fig. 1.

Theoretical lectures and problem solving exercises are essential due to the high amount of information related to all the technological and functional aspects implied in power electronics converters. The total dedicated time for the lectures was 18 hours (0.72 attendance ECTS credits).

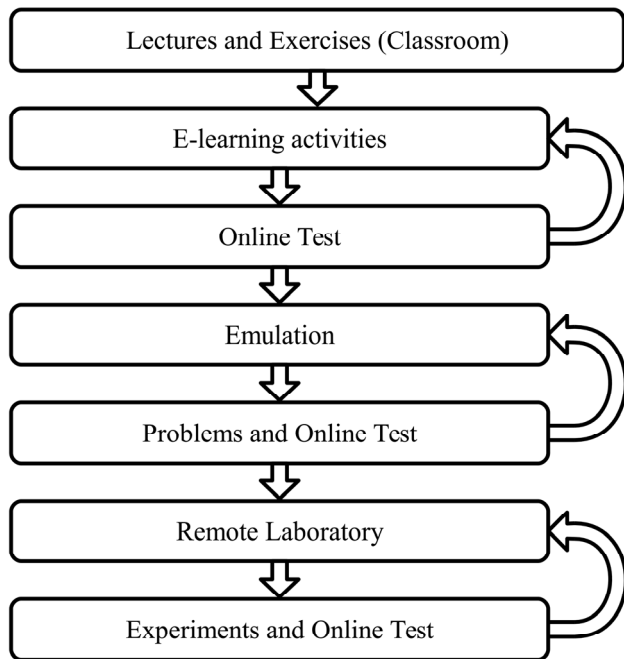


Fig. 1. Sequence of activities to be performed for each basic topology.

Following the lectures for a given converter, online activities were open for students. A set of documents with animated figures and graphics were used as reference. More exercises and design problems help students to reinforce the knowledge acquisition process. Finally, an online test is used to evaluate the students. If they fail to pass the test, then a new round of activities is proposed. During this step of the process it is critical to make the students understand that they cannot go ahead without properly learned concepts. Therefore, in some cases, the next step remains locked.

Emulation sessions provide a fast and easy path to understand the required concepts. For the first time this kind of session is held in a classroom, professor explains how the emulator works. The developed emulators are complex flash animations, based on equations that describe the ideal behavior of switch-mode converters. Five flexible and powerful emulators have been developed for the buck, boost, buck-boost forward and flyback converters [9][14][15]. Associated to the emulators, a set of design exercises are proposed, that must be solved and answered online. For online activities and emulations, tutoring from professors is available face to face on designed hours and via email. Total time dedicated with the professor in classroom and/or laboratory is close to 12 hours (0.48 attendance ECTS credits).

The laboratory sessions provide to the students a set of rich experiences that cannot be acquired by any other means. The first experiments are based on measurements of open loop power stages of each converter. These measurements are to be contrasted against calculated variables provided by the emulator. Then closed loop experiments are held, to demonstrate how a complete converter behaves. The total time dedicated to these activities with the professors is 10 hours (0.4 attendance ECTS credits).

All these steps are included into the evaluation process. Some of them provided direct marks on students' activities and some other provide insight on how the students are acquiring skills and knowledge.

When all these steps are applied to the four basic converters circuits, every student must design parts of the circuit of a predefined prototype. The resulting circuit must be calculated, simulated and tested in the remote laboratory setup. Tutoring in this stage is provided by the professors, in the laboratory. The time employed in this activity is 9 hours (0.36 attendance ECTS credits). The final assessment is composed of a series of design problems of input filters, compensating loop components and snubbers networks for the semiconductors and the magnetic components. Some of these tasks include simulations and other imply the use of remote laboratory setup, to test the selected components on a previously defined converter. For tutoring this task a total of 11 hours (0.44 attendance ECTS credits) are reserved by professors.

B. Methodology Implementation.

Resources available through Internet access are by far the most accepted among students. A Moodle server provided the framework to allocate all documents and also to aggregate some other online tools: the tests, the design problems, the emulators and control the access to the remote laboratory [9].

The main reason for using blended learning is that most of the resources in the server are available online without time restrictions, thus providing the students with the opportunity to choose where and when they can learn, interact with the remote laboratory and self-evaluate. This also gives more flexibility to professors, as some steps of the learning process can be keep open and available during more days along the semester. As consequence, the students are tutored in a more positive way, because they know that tutoring time is not scarce nor crowded.

Using emulation instead of simulation was a choice made on the available time and required effort of students. Simulation programs are powerful mathematical tools [16], but for switching circuits, like the ones in this course, can be too complex to use. Emulators provide easy to use interface and fast results, allowing the students to focus their attention on the converter behavior knowledge rather than in simulation problems, like convergence. An example of an emulator is shown in fig. 2 [14].

There are two reasons for using a remote laboratory setup. The first one is that the use of programmable remote instrumentation implies that an ordered sequence of actions, programmed on a script, is needed to make experiments. Indirectly, this requisite demands a pragmatic and organized sequence of actions in order to execute the experiment. The second one is that the laboratory sessions are held partially in the school and later from home, if needed. This feature removes pressure to finish the experiments, and even provide a late opportunity to change the experimental measurements from home if something wrong is detected. The remote laboratory setup [9] is shown in fig. 3.

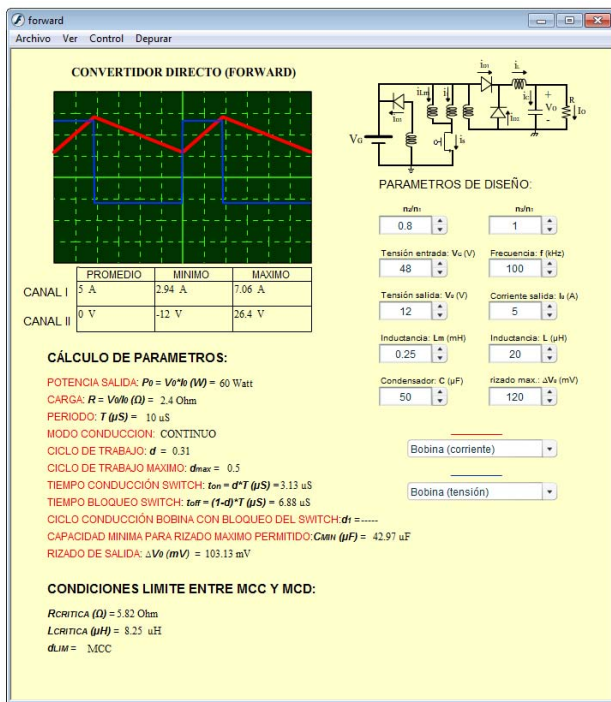


Fig. 2. Forward dc-to-dc converter emulator showing continuous current mode operation.

The students were requested to calculate, with the help of emulators, the voltages and currents for each converter, and contrast with measurements, for the open loop test. When the control circuit is added to the loop, they are asked again to come up with theoretical results. And as some of the passive elements of the control can be changed, some of the questions involved modifications in the desired dynamic response.

As a final assessment, each student is asked to design parts of a pre-defined converter. The circuit must be emulated and/or simulated, physically assembled and tested in the remote

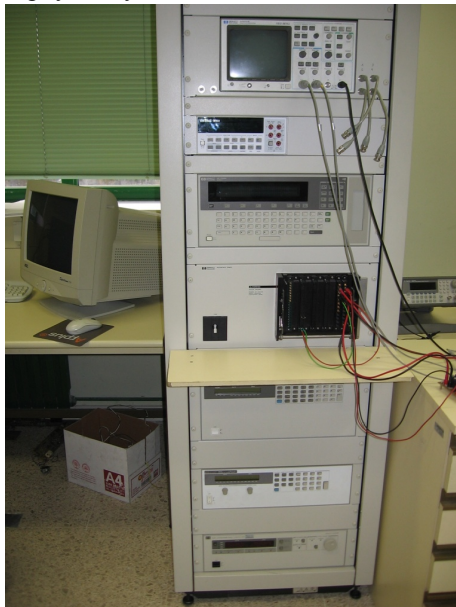


Fig. 3 The automatic test equipment in the remote access laboratory.

laboratory. To simulate the converter design, SPICE and PSIM simulators are available. Once these results have been evaluated as correct by the professors, the student receives a prototype with the main components already assembled and empty sockets to place the designed components.

Specifically, the student must complete the input filter, the snubber networks and the feedback loop. This way, topics that are studied only on lectures are completed and reinforced by practical application. Some technological related topics, as losses in high frequency transformers or loop stability constrains due to the selected components values are added to the knowledge acquisition process. The converter behavior is tested not only by the student, but also by all others classmates. As an example, in fig. 4 it is shown a flyback module with indicated places where the students can change the components of the input filter (A), the compensating loop (B) and the snubber networks for the semiconductors and the transformer (C). A report and a brief oral exposition of the design is the final part of the assessment.

The five task evaluated as marks are the online tests for each topology (T1), the power stage design with the use of the emulators (T2), the control loop design with the use of simulation tools (T3), the results of laboratory tests for input filters, compensating loop and snubber network (T4) and the final report with oral exposition of the assessment (T5).

III. STUDENT ASSESSMENT AND FEEDBACK SURVEY.

The number of students enrolled in the course over the two last academic years (2013/2014, 2014/2015) was 25. This number is not very high due to the environment in which the subject is located. As discussed in section II it is an elective course of an intensification. From the set of 25 students, 20 were men and 5 women, aged between 21 and 24 years.

The following performance indicators, are used to measure progress of the student assessment:

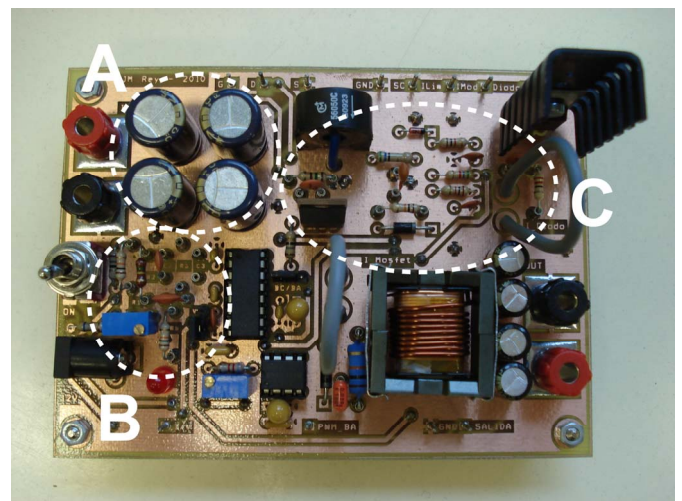


Fig. 4 The flyback module showing the components that students can change to test their design.

- A. Performance Rate: number of students who passed a task vs. number of students presented (%). This indicator is related to student motivation and to the transfer of knowledge.

- B. Efficiency Rate: number of students who passed all tasks vs. number of students presented (%). This indicator measures student achievement of the acquired knowledge to design a predefined prototype

- C. Success Rate: number of students who passed the course vs. enrolment (%).

- D. Assessment Rate: number of students who passed the course vs. number of students presented (%).

- E. Dropout Rate: number of students who dropped the course (%).

The indicators B, C, D and E show the results obtained by the proposed methodology in this subject versus the average results obtained by students in the graduate program.

With the aim of know the degree of satisfaction of students related to the new b-learning approach and compare their opinion with the results obtained by the above indicators, a survey was elaborated. The authors have help in the design of the questions from the Department of Didactics, School Planning and Research Methods, of the University of Vigo.

The survey consists of 20 questions grouped into three blocks; and one observations field, for the students freely write all they consider important but not previously asked.

The first block is devoted to know the satisfaction degree of the students on the use of the didactic platform and how adequate is to the learning methodology.

The second set of questions is to determine the degree of satisfaction of students in lectures. Also values the support it can bring to learning through this methodology.

The last block comprises a group of questions about the satisfaction of the students related to the professors.

The most important questions are shown in tables 1, 2 and 3.

The answers to all these questions were measured using a six points Likert scale: 1- Totally Disagree, 2- Disagree, 3- Partially Disagree, 4- Partially Agree, 5- Agree and 6- Totally Agree. The survey data was collected during the last course week, prior to the final exams. All students answered all questions.

IV. RESULTS AND DISCUSSION

Taking into account the small number of students and that responses in different academic courses are alike, the authors have decided to include 25 polls into a single study.

A. Analysis of Performance Indicators.

The figure 5 shows the results of the performance rate. A high percentage of students have completed all the tasks.

TABLE 1
RELEVANT QUESTIONS ABOUT THE DIDACTIC PLATFORM

Number	Question
1	Your motivation towards the course has increased during this experience.
2	The sequence of topics blocks and their formative relevance are adequate.
3	The objectives of the course are coherent with the training plan.
4	The length of the course promotes the mastery of all the topics in the course.
5	The proposed learning activities are consistent with the required difficulty level.
6	The laboratory sessions have a correct timing and resource design.
7	There is coherence between activities and the evaluation criteria and objectives.
8	The clarity and appropriateness of the methodological guidance has been consistent with the approaches of the experience.
9	There were major technical difficulties for the development of laboratory sessions.

TABLE 2
RELEVANT QUESTIONS ABOUT LECTURES FOR SUPPORTING THE LABORATORY

Number	Question
10	During lectures to support the laboratory sessions there was: communication, assertiveness, neatness, conceptual clarity and correct exposition rhythm.
11	The printed and/or audiovisual materials used have been useful for taking the laboratory sessions.
12	There is a good climate of coexistence in the course.
13	The tutoring sessions favored the adequate acquisition of contents and help clarify any doubts.
14	The supervision of the tasks and the received aid was adequate, and the information received was clear and adequate.

TABLE 3
QUESTIONS ABOUT PROFESSORS

Number	Question
15	The assessment tools types and adequacy: are consistent with the objectives, the knowledge content, and competencies.
16	The professors' specific knowledge of the subjects is relevant and considered adequate.
17	The professors offered guidance on improving learning strategies when presented difficulties.
18	The professors demonstrated adequate and up to date skills on the technology.
19	The professor has prepared the lectures.
20	The professor is on time for lectures and laboratory sessions.

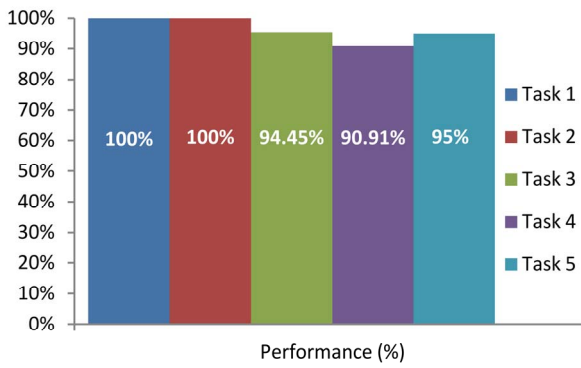


Fig. 5. Performance rate.

Special mention for the first two tasks (T1, T2) in which the student uses the emulator. It is confirmed that the use of this tool helps students to successfully pass the desired objective.

It must be emphasized that the value obtained in the last task (T5) of 95% is obtained on the total number of students who have passed the previous task (T4).

In order to establish a comparison frame between our course and the fourth year of the Industrial Electronics and Automatic Control graduate program, statistical data provided by the Industrial Engineering Scholl is used. The students enrolled in the graduate program in the two last academic years was 48.

Figure 6 shows the efficiency rate. This indicator is compared with of the graduate program and an improvement of 7 points is observed. The efficiency rate of 86.36% is obtained on the total number of students who have presented the finished tasks.

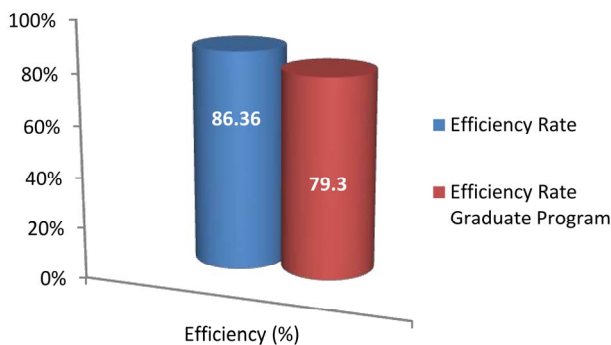


Fig. 6. Efficiency rate.

The results of the success rate, assessment rate and dropout rate compared with those of the graduate program are shown in fig. 7. The first two rates include the results of students in the laboratory sessions using the remote ATE laboratory. The increasing success and assessment rates and the decreasing dropout rate confirm the improvement in knowledge transfer.

The data provided by the school is the same used for quality assessment of the graduate program. Highlight that decreasing the dropout rate by 10 points confirms that the use of the proposed tools improves student motivation, helps to achieve the goals outlined in the proposed methodology and reinforce the quality of the program.

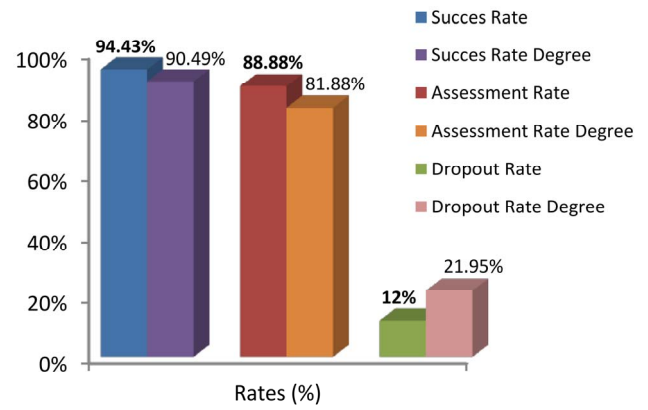


Fig. 7. Comparison between the success rate, assessment rate and dropout rate of the course and the degree.

TABLE 4
SURVEY DATA

Points on Lickert Scale	Block 1	Block 2	Block 3
Totally Agree	246	180	282
Agree	440	265	375
Somewhat Agree	108	132	100
Somewhat Disagree	93	27	9
Disagree	46	0	0
Totally Disagree	15	0	0

B. Analysis of Feedback Survey.

The Cronbach's alpha coefficient from the variances is calculated to measure the reliability of the survey. The survey has obtained a coefficient $\alpha = 96\%$. It can therefore be considered that the survey has a good level of reliability. The score of students' satisfaction of the three blocks is show in Table 4 and graphic in fig. 8.

A 72.4% of the students totally agree or agree that the methodology used and the resources from the learning platform are useful for this course.

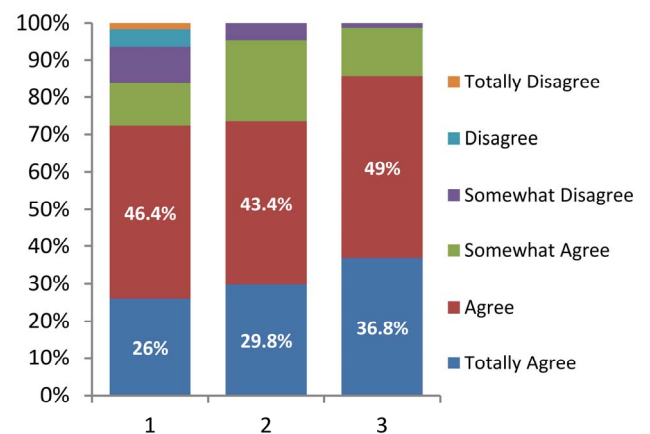


Fig. 8: Poll results data grouped by blocks of questions.

Questions 3, 4 and 8 are the most significant for evaluating the satisfaction degree related to the use of the platform and the skills acquired by using it. A 77.2% of the students agree or totally agree (73.29% agree) that the platform helps them to master the knowledge of the course.

The results for the second block of questions, relative to lectures, indicate that a 73.2% of the students agree or totally agree that these sessions provide valuable help to solve doubts and clarify concepts. The global results of the questions are depicted in the second column of Figure 8. The questions 13 and 14 are the most significant to know the degree of satisfaction with tutoring and task supervision. The satisfaction degree reaches a 70.42%. These results indicate that above the importance of the online learning experience is the supporting presence of tutors, being this fact more important for complex activities in laboratory.

The last block of the survey is to evaluate the students' satisfaction with the professors. The global results of the questions are depicted in the third column of Figure 8. The 85.8% of the students totally agree or agree with the knowledge and performance of professors. In this block the professors can be scored with two subsets of questions: the knowledge of the course contents with questions 16 and 18, and how this knowledge was transferred by professors to students with questions 17 and 19. For the first subset, the satisfaction degree is 82.78%, and for the second subset is 84.76%.

Finally, in the remaining questions of block 3, students were asked about the evaluation procedure. The question was intended to evaluate the consistency and coherence of the assessment tools with the course objectives, the knowledge content and the acquired competencies. For this single question, the students agree or totally agree in a 76.67%.

V. CONCLUSIONS, PRESENT AND FUTURE LINES

In this paper, a b-learning approach in the implantation of a practical course in the power electronic field is shown. The major effort is devoted to coordinate and integrate a set of previously successfully tested tools for e-learning, emulation, remote laboratory access and evaluation procedures with the classical lectures and laboratory sessions. These resources are sequenced as a set of activities and tasks, in order to give the students a better knowledge acquisition framework, promote students' autonomous work and improve students' motivation. As a whole the authors aimed to achieve a better pedagogical environment.

Several conclusions can be drawn:

- It is confirmed that the use of the implanted methodology helps to successfully achieve the desired objectives.
- Using emulation the students can focus their attention on the converter analysis and study. 100% of students passed the tasks in which they must use the emulator.
- Online access to the laboratory facilitates the use of time and self-pace progress of students. No laboratory session was unfinished due to the lack of time.
- Online and face to face tutoring sessions provide a better

human interaction among participants.

- The performance indicators of this course are higher than the average of the graduate program courses. A 94.43% of the students enrolled passed the course. The efficiency rate of this course is 7 points higher than the whole graduate program and the dropout rate indicator is less than 10 points compared to the graduate program.

- A 72.4% of the students agree or totally agree that the methodology used and the resources from the learning platform are useful for this course.

During the months of June and July 2014, students from the University of Minho, Portugal, used remotely the set of resources available. The objective was to share the available b-learning tools to implement a similar methodology in cooperation with the professors of the Industrial Electronics Department. Another future action will be to integrate the remote laboratory into the PILAR project. The aim of this project is an Iberian Peninsula Universities Federation of remotely accessed laboratories, part of an educational innovation action, where a unique repository and online showroom will allow students to use different setups on participating departments.

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Initial Investigation into Engineering Students Problem Solving within Controls

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Abstract— The middle years of college-level engineering have been identified as an area that needs increased research attention. To date, little has been done to understand how students' learn conceptual knowledge in engineering science courses. This study examines how students use conceptual knowledge during the learning of control systems engineering. This work in progress will discuss the initial findings of a study examining junior-level mechanical engineering students solving controls homework and laboratory problems, exploring topics such as PID control, state feedback, and pole placement.

Keywords—controls; middle years; conceptual knowledge; engineering education

I. INTRODUCTION

The middle years of college-level engineering have been identified as an area that needs increased research attention [1]. In between the freshman cornerstone [2] and senior capstone projects, these middle years are when students take courses in core disciplinary subjects. To date, little has been done to understand how students learn conceptual knowledge in engineering science courses [3].

This work in progress is the beginnings of a project examining exactly how students use conceptual knowledge in the solving of homework and laboratory-based problems within a typical controls course. Over the past ten years, a number of new innovative methods of instruction have been proposed and leveraged in engineering classrooms. These methods include project based learning [4], flipped classroom model [5], and even purely online experiences (Coursera, Khan Academy, edX). While these innovators are prevalent in the forefront of educational research circles, the majority of established instruction continues to use a lecture teaching method with problems sets and laboratory exercises as learning tools and exams as evaluation. While there is some acknowledgement this is not the best form of instruction [6] proposed alternatives are typically material intensive and more

laborious to evaluate, thus providing a barrier to entry for teacher looking to transition.

Despite lecture-based methods being the most prevalent for teaching engineering science course at the university level, little research has actually been done on student learning in these courses. This project aims to understand better how students are developing and applying conceptual knowledge, through examination of homework and laboratory problems in a typical controls system course. This research will optimistically lay the groundwork for supporting further innovations in engineering teaching methodologies.

II. LITERATURE REVIEW

Student learning in traditional engineering science courses during the sophomore and junior years has received less research focus than design and team based courses. As of late, many universities have adopted a “bookend” [7] model of engineering education, with cornerstone and capstone design courses in the first and final year with core content courses delivered in the middle years. Despite this period containing the largest portion of conceptual knowledge learning, limited research applied to studying these middle years [1] with more attention given to retaining freshman and measuring the skills of graduating seniors.

A. Conceptual Knowledge

The study of conceptual knowledge has received significant attention within physics education (e.g. [8]) and in that field served as a foundation for instructional curriculum reform. Streveler, Litzinger, Miller and Steif [3], in their literature of prior studies on students conceptual knowledge of mechanics, thermal science, and direct current circuits, call for more studies about the conceptual learning of engineering students. Litzinger et. al. [9] began this work with one investigation of students' problem solving in statics. In think-aloud sessions, they asked strong and weak performing students to solve a number of different statics problems, simulating the process of completing homework. These were then scored by six expert instructors and coded by the research team for evaluation of the

students' metacognitive processes of monitoring and evaluation. They found weaker students were poorer performers in creating free body diagrams and students able to use self-explanation as a strategy to guide them through the problem were mostly the strong performers.

B. Controls Education

In the past 20 years research on controls education has been more focused on incorporating new tools and technologies into the teaching methodology, especially within laboratory experiences. While research agrees the laboratory section is an important part of the course as it links the theory students learn in lecture to the real world hardware and construction of control systems [10], the literature debates the best delivery method of this material. To ensure every student has access to laboratory experiences, professors more recently have designed take home labs [11-13] and online experiments [14-16]. Others have preferred to keep the laboratory on campus, but innovate by integrating new technologies into the course [17-19]. Others have called for pedagogical enhancements such as the open lab concept [20], inquiry based instruction [22], and new graphical user interface (GUI) designs [23]. While these innovations keep teaching methods up to date with new technologies, little is reported in this work of how these improvements affected student learning. This work hopes to fill this gap in the literature to better understand how the use of these tools and technologies in laboratory problems aid students in learning conceptual knowledge.

III. COURSE DESCRIPTION

System Dynamics and Controls is a junior level course taught every spring semester at a small private university in the northeast of the United States. This course is a requirement for students to graduate with a bachelors degree in mechanical engineering. The two sections of the course are taught by two different members of the faculty, loosely coordinated but each in their own style. Each section is taught lecture style over two 75- minute blocks twice a week and averages about 24 students per class. In spring 2015, each course required one homework assignment (problem set) due per week, excluding exam weeks, and five laboratory exercises that were done in class throughout the semester. Laboratory exercises were completed using Arduino Uno boards and various LEDs, sensors, and actuators assembled in kits for students to assemble in breadboards for different kinds of labs.

Both professors' lectures were traditional lectures that involved collaborative learning between professor and students. The professor of Section A used real world examples to communicate processes of analyzing and tuning controls systems. He discussed personal experience with creating and tuning controls systems to illustrate many different practical methods in system design. The professor of Section B leveraged outlined "skeleton notes" students completed and flushed out during lecture that broke down important equations and analytical processes. For some parts of the lecture, the professor gave the students 2-5 minutes to solve a part of a problem or complete a portion of a derivation before he presented the answers.

TABLE I. COMPOSITION OF COURSE SECTIONS

Course Section	Total Students	Males	Females	Research Participants
Section A	24	20	4	11
Section B	24	15	10	6

Students self-selected to participate in research and were not given any incentives to participate. Laboratory and homework groups were formed by students prior to the beginning of the research study. Students were not grouped by grade point average or perceived ability in the course. No changes were made to the course instructions due to the research except grouping research participants in the same groups for two laboratory exercises in Section A. The research team purposely made no intervention to the course in order to record the course activities as is. The researcher attended one lecture per week to keep current with the material.

This study examines the two types of problems found in these controls courses. Homework problems are those usually found in textbooks. These normally present the student with a system for them to evaluate by finding specific values of system elements and improving the theoretical system performance through mathematical derivation. An example of a homework problem is shown below.

A system has the transfer function

$$G(s) = \frac{2}{s + 3}$$

where the input is in the units of Newtons and the output in units of m/s.

- Plot the Bode plot for this system. It is fine to use Matlab in any way you want. Please show the commands you used to generate the plot.
- If I drive the system with a 3 Newton peak force at 20 Hz (Hz! Not rad/sec!!) at steady state (after any transients have died out) what will be the:
 - Frequency of the response
 - Magnitude of the response
 - Phase of the response relative to the drive

Figure 1: Example homework problem

Laboratory exercises typically ask students to set up (construct) a physical system and execute a program (code) to take initial data. Students modify this initial program based on the collected values leveraging different methods of control to improve the performance of the system. Both of these types of problems were given to students in these two courses.

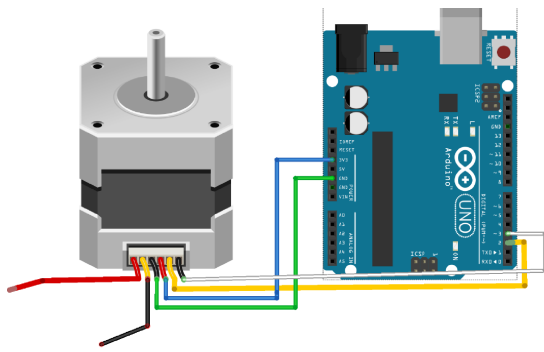


Figure 2: Diagram to aid students wire up their motor and encoder

IV. RESEARCH DATA COLLECTION

Video data of students solving both homework problems and laboratory exercises were collected. All data is of pairs or groups of students working together in order to encourage discourse about the problems. Homework problem were collected by meeting undergraduates in classrooms and conference rooms in the engineering school as they were working collaboratively on their homework. Multiple cameras and angles were needed to simultaneously capture students' paper, discourse, and overall context.

Laboratory exercises were completed each during scheduled class periods (one period per lab) at various points throughout the semester. 24 hours of homework and laboratory session were collected. Six hours were collected of student homework sessions with up to five cameras capturing different views of students and student tools during each one of the hours. Five groups total were filmed completing three or four laboratory exercises (see Table II below) for a total of 18 hours of video data.

The authors collected data in this manner to capture authentic student activities. While past studies have been successful with think-a-loud protocols in laboratory settings [9,23], the authors aimed not to alter the natural environment and process of student work. A goal of this study was to evaluate this protocol as a way to identify conceptual knowledge without hampering students.

TABLE II. LABORATORY EXERCISES IN COLLECTED DATA

Section A	
Lab	Topic
Control Actions as Difference Equations	Low pass filter, proportional control, interregal control, derivative control
Vehicle Control Using IR Distance Sensor	Proportional control
Motor Velocity Control	Using Simulink for motor control
Temperature Control	Proportional-integral (PI) control

Section B	
Lab	Topic
System Control Using a Motor with an Encoder	Proportional control, proportional-integral (PI) control
Control Using a Motor win an Encoder Continued	Proportional control, proportional-integral (PI) control
Step Response	Step response of a system

V. INITIAL OBSERVATIONS

Analysis of video is currently in the early stages. The majority of the data collected was around the completion of laboratory exercises. Initial observations indicate student discourse between partners mostly revolves around procedural activities, interpreting results, and solving issues with hardware and code, rather than the actual application of concepts. When the system performance was unlike the students' predictions did conceptual knowledge begin to enter the discourse, only as means to analyze the system performance. Conceptual knowledge also is used to discuss expected performance and real performance of the system and then to make adjustments to modify this performance. Presence of the professor or teaching assistants, either checking in or to resolve issues, occasionally also began discourse around the conceptual knowledge.

VI. FUTURE WORK

The research team will continue to analyze the data collected within these courses. During the analysis, the research team will identify moments of application of conceptual knowledge within the data to assist in building a case library of these instances and the associated types of problem solving related to each. Video clips from the courses related to these occurrences will be used with both instructors in connection with discussions around teaching strategies to also incorporate their view of conceptual knowledge use into the analysis. Attention will also be given to differences between application of conceptual knowledge in the two different sections and if these can be attributed to differences in teaching style. The research team will work to develop a list of conceptual knowledge in controls to be reviewed by experts, for refinement to then be used in further analysis here and in future data. Findings from the data will also be used in a redesign of the study methodology (data collection and analysis) before the next academic year begins. Findings from all these activities will be shared with the academic community with hopes of better supporting the educational innovations around teaching methodologies in the field of controls.

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Optimal Control Design and Implementation for the Double Inverted Pendulum System in a Graduate Control Course

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Abstract - This paper presents an optimal control design methodology used in a graduate electrical engineering course. The proposed methodology was applied and used on the double inverted pendulum system. The regulators presented are based on the state-variable feedback with Linear Quadratic Regulator (LQR) design. An asymptotic observer was designed to estimate the state-variables of the system. A Kalman Filter was designed as an alternate estimator to include sensor and process Gaussian noise. The Loop Transfer Recovery technique was used to recover some of the robustness properties that can be lost when implementing the Kalman filter. The Kalman Filter resulted in a better state estimator with less estimation noise on the velocities state variables, compared to the velocities state variables that were estimated with the asymptotic observer. Furthermore, Loop-Transfer Recovery allowed for a better tuning of the Kalman filter based controller and resulted in a better time response of the system. Theoretical aspects were experienced and confirmed in a laboratory setup as each design technique was applied and implemented sequentially in the real system. This is an innovative practice because the students learn by doing in a deductive way, as they build upon their design.

Keywords – *Double Inverted Pendulum System, Kalman Filter, Linear Quadratic Regulator (LQR), Loop Transfer Recovery, Asymptotic Observer, Optimal Control, State Variable Feedback.*

I. INTRODUCTION

This paper describes a term project used in a graduate control course designed to enhance the learning of optimal Linear Quadratic Regulator (LQR) design techniques. The course is on Optimal Control and follows the book by Lewis, et al. [1]. A design and implementation methodology is proposed to complete the design project successfully. The system chosen to illustrate the proposed methodology is the double inverted pendulum. The design methodology may be applied to other systems if the steps presented in this paper are followed.

The term project tasks were developed and evolved

along the semester as the theoretical aspects were discussed in class. Using a design project as a teaching and learning tool, provided the students with an interactive framework that facilitated the understanding of a complex theory. The design and implementation of the controllers allowed the students to reinforce the theory and the design techniques. This is an innovative practice because the students learn by doing in a deductive way, as they build upon their design.

The controllers for the system are designed in four stages. The first controller was a simple LQR design assuming that all state variables were available for feedback, then an asymptotic observer was designed and implemented to estimate all the state variables of the system. Later, a Kalman Filter was designed to reduce the noise that appears on the estimated state variables. Adding an asymptotic observer or a Kalman filter can cause the system to lose its robustness properties [1]. To recover these properties, a regulator using the Loop Transfer Recovery technique was designed and implemented.

Section II presents the double inverted pendulum system model used for the implementation of the regulators designed. Section III presents the design techniques used for designing the regulators. The results are presented and discussed in Section IV and conclusions are given in section V.

II. DOUBLE INVERTED PENDULUM SYSTEM

The double inverted pendulum system, consists of an upper pendulum and a lower pendulum, connected to a cart that slides along a linear track. See Fig. 1. The mechanical system has three degrees of freedom: the position of the cart, the angle of the lower pendulum with respect to the cart and the angle of the upper pendulum with respect to the lower pendulum. The actuator that moves the cart is a DC servomotor equipped with a gear system. The sensors that read the position of the cart, and the two angles of the pendulums are quadrature optical encoders. The system used was developed by Quanser [3]. The system was controlled via a Q4 data acquisition card and the QUARC® program, both developed by Quanser. A state-space nonlinear model of the system is derived from the Euler-Lagrange equations [2]. These equations are then linearized about an operating point. The linearized state-space model is

then used to design all of the state-feedback controllers. The performance of each controller is simulated and evaluated via Simulink. Once the simulated performance is deemed satisfactory, the controllers are implemented in the real plant to validate their performance.

A. Double Inverted Pendulum Linearized Dynamic Model

A Double Inverted Pendulum system is illustrated in Fig. 1, where $x(t)$ is the cart position, $\alpha(t)$ is the angular position of the lower pendulum mounted on the cart with respect to the vertical axis, $\theta(t)$ is the angular position of the upper pendulum with respect to the lower pendulum. The corresponding velocities are $\dot{x}(t)$, $\dot{\alpha}(t)$, and $\dot{\theta}(t)$.

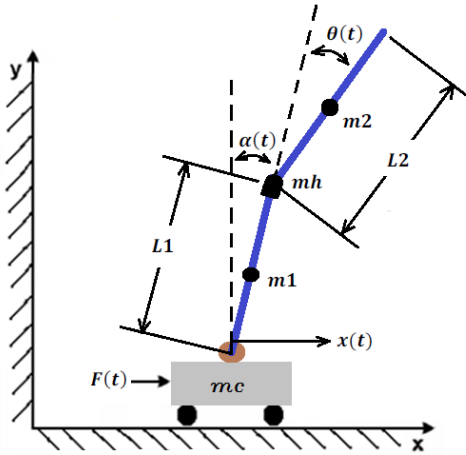


Fig. 1. Simplified Model of the Double Inverted Pendulum System

The state-variables are defined as,

$$\begin{aligned} x_1 &= x(t) & x_4 &= \dot{\alpha}(t) \\ x_2 &= \dot{x}(t) & x_5 &= \theta(t) \\ x_3 &= \alpha(t) & x_6 &= \dot{\theta}(t) \end{aligned}$$

The nonlinear differential equations were linearized about an operating point defined as zero for all state variables. The resulting linearized model is of the form

$$\dot{x}(t) = Ax(t) + Bu(t) \quad (1)$$

$$y(t) = Cx(t) \quad (2)$$

The nonlinear state equations and the system parameters may be found in [3]. The linearized model is

$$\begin{bmatrix} \dot{x} \\ \dot{\alpha} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & -13.7315 & -5.96 & 0 & 0.136 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 95.1 & 109.19 & 0 & -50.95 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & -98.64 & -113.25 & 0 & 131.68 & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \alpha \\ \dot{\alpha} \\ \theta \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} 0 \\ 3.07 \\ 0 \\ -21.28 \\ 0 \\ 22.07 \end{bmatrix} u(t) \quad (3)$$

$$y(t) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \alpha \\ \dot{\alpha} \\ \theta \\ \dot{\theta} \end{bmatrix} \quad (4)$$

III. DESIGN TECHNIQUES

A. Linear Quadratic Regulator

The Linear Quadratic Regulator (LQR) is a special case of the optimal control problem which minimizes the performance index

$$J = \int_0^\infty (x^T Q x + u^T R u) dt \quad (5)$$

The solution of the LQR problem reduces to solving the Algebraic Riccati Equation (ARE) [1]

$$0 = A^T P + PA - PBR^{-1}B^T P + Q \quad (6)$$

Where Q is a positive semi-definite ($Q \geq 0$) state weighting matrix and R is a positive definite ($R > 0$) control weighting matrix. LQR controller tuning is achieved by varying the Q and R matrices until the controlled system performs as desired. Matrices Q and R penalize the magnitude of the state variables and the magnitude of the control action respectively. Bryson and Ho [4] suggested a way for choosing starting values for the Q and R matrices. For the double inverted pendulum system we chose Q to be diagonal and R to be a scalar

$$Q = \begin{bmatrix} q_{1,1} & 0 & 0 & 0 & 0 & 0 \\ 0 & q_{2,2} & 0 & 0 & 0 & 0 \\ 0 & 0 & q_{3,3} & 0 & 0 & 0 \\ 0 & 0 & 0 & q_{4,4} & 0 & 0 \\ 0 & 0 & 0 & 0 & q_{5,5} & 0 \\ 0 & 0 & 0 & 0 & 0 & q_{6,6} \end{bmatrix} \text{ and } R = r$$

Where $q_{i,i}$ is the weight attributed to state variable x_i and r is the weight attributed the control action $u(t)$. The initial weights for the Q matrix are assigned as

$$q_{i,i} = \left(\frac{1}{x_{i\max}} \right)^2$$

The initial weight for the control action is assigned as

$$R = \left(\frac{1}{V_{\max}} \right)^2$$

Where $x_{i\max}$ is the maximum allowable value for the position of state variable x_i and V_{\max} is the maximum allowable value for the control action. In our case, V_{\max} is the maximum voltage allowed to be applied to the motor. After choosing the Q and R matrices, the ARE (6) is solved for P and the feedback gain is computed as

$$K = R^{-1}B^T P \quad (7)$$

The control action is defined as

$$u(t) = -Kx(t) \quad (8)$$

Fig. 2 shows a block diagram of the regulator when the LQR is implemented assuming that all state variables of the system are available as measurements.

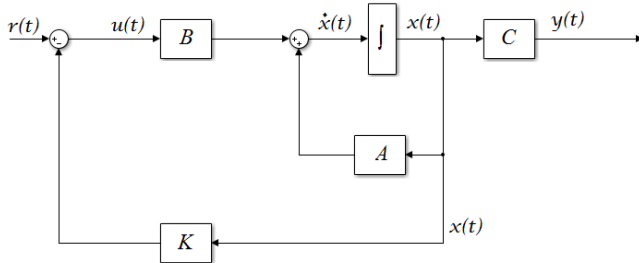


Fig. 2. System Block Diagram for the LQR Implementation

As is usually the case, not every state variable of a system is available as a measurement. Therefore, it is not possible to implement an LQR as illustrated in Fig. 2. It is often necessary to add state estimators to implement a state-feedback controller. For the double inverted pendulum system, the most basic controller is an LQR with feedback gain K , where the angular positions of the pendulums and the linear position of the cart are measured by sensors while the unmeasured velocities are estimated using first-order derivative filters given by

$$G(s) = \frac{as}{s + a} \quad (9)$$

Where,

a –The pole of the first-order derivative filter.

s –The complex frequency.

B. Asymptotic Observer

The problem of implementing the LQR controller with gain K by estimating the unmeasured velocities of the system with first-order derivative filters is that it results in a noisy estimation of the state variables. This can be problematic since it adds high frequency noise to the control action applied to the plant which in turn may damage the servomotor brushes and the gear system if the situation persists for a long time. The asymptotic observer is presented and designed as an alternative to this method.

An asymptotic observer can be designed and implemented if the system is observable [2]. Observability of the system implies that the poles of the asymptotic observer may be assigned arbitrarily, provided they are a self-conjugate set. The state observer state-equation is given by

$$\dot{\hat{x}}(t) = (A - LC)\hat{x}(t) + Bu(t) + Ly(t) \quad (10)$$

Where $\hat{x}(t)$ is the state vector estimate. Fig. 3 shows the block diagram of the LQR implemented with an

asymptotic observer. When designing the asymptotic observer, its gain matrix L is chosen in such way that the poles of the observer matrix $(A-LC)$ are faster than the poles of the plant with feedback $(A-KB)$, so that the poles of the observer do not affect the dynamics of the closed-loop system. Matrix L of the asymptotic observer may be assigned by using the “place” command in MATLAB®, which is based on the pole placement method develop by Kautsky, Nichols, and Van Doorens [5]. A usual starting point that produces good results is to select the poles of $(A-LC)$ to be negative real numbers, 10 times larger to the left of the poles of the closed-loop system. If such a selection does not produce satisfactory results, then choose different positions for the poles and assign them with the “place” command until the system is controlled satisfactorily.

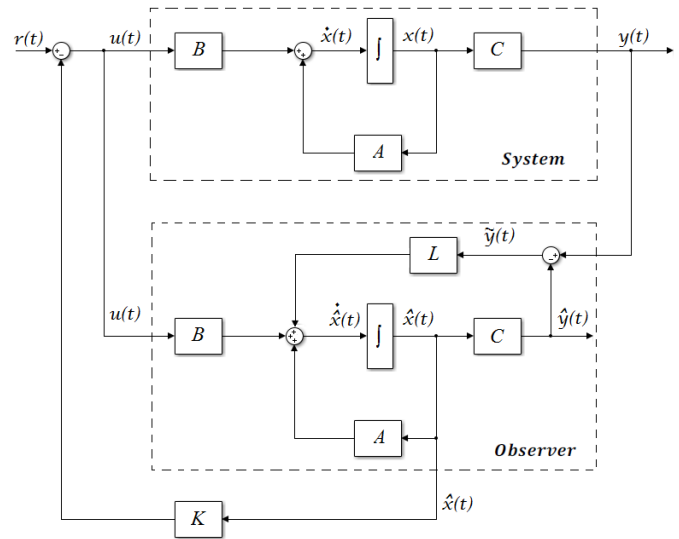


Fig. 3. System Block Diagram for the Asymptotic Observer, Kalman Filter, and Loop Transfer Recovery Controllers.

The controller for the system with the asymptotic observer is designed in the same way as the LQR problem with the exception that in this case, the control action $u(t) = -K\hat{x}(t)$ is used instead of $u(t) = -Kx(t)$. That is, the state-vector estimate is used for feedback instead of the real state-vector.

C. Kalman Filter

The control implementations of the LQR and observer problems have been done assuming that there was no noise in the measured states. Those implementations have not taken into account the complete dynamics of the system, disturbances, and the noise coming from the measuring sensors. The Kalman filter is an alternative that uses probability theory to treat the inaccuracies inherent in the linearized system models used [1]. The Kalman Filter can also be implemented as in Fig. 3. The system with process and measurement noise is described by

$$\dot{x}(t) = Ax(t) + Bu(t) + Gw(t) \quad (11)$$

$$y(t) = Cx(t) + n(t) \quad (12)$$

$$x(0) \sim (x_0, P_0), w(t) \sim (0, Q_k), n(t) \sim (0, R_k)$$

Where $w(t)$ and $n(t)$ are white noise processes orthogonal to each other and to $x(0)$. The Q_k and R_k matrices in this case are not the same as those used for the LQR design. The subscript k , as in Kalman, is used to distinguish them from the Q and R of the LQR problem. Moreover, Q_k and R_k are not weighting matrices but noise spectral density matrices [1]. The Kalman filter is designed as follows:

Initialization: set

$$\hat{x}(0) = \bar{x}(0)$$

Solve the error covariance Kalman filter ARE:

$$AP + PA^T + G^T Q_k G - PC^T R_k^{-1} CP = 0 \quad (13)$$

Compute the Kalman gain:

$$L = PC^T R_k^{-1} \quad (14)$$

Implement the state estimate dynamic equation:

$$\dot{\hat{x}}(t) = (A - LC)\hat{x}(t) + Bu(t) + Ly(t) \quad (15)$$

D. Loop Transfer Recovery

It is well known that the guaranteed robustness properties of using the full state feedback is generally lost when using an observer or even a Kalman filter [1]. A technique for designing Kalman filters, called Linear Quadratic Gaussian/Loop-Transfer Recovery (LQG/LTR) may be used to recover the robustness properties that the LQR feedback control has [1]. This is accomplished simply by tuning a scalar parameter v . For the system described by (11) and (12) with

$w(t) \sim (0, M)$ – White Process Noise

$n(t) \sim (0, v^2 N)$ – White Measurement Noise

M – Process noise spectral density matrix

N – Measurement noise spectral density matrix

v – Scalar parameter (Nu)

The process noise spectral density matrix is defined as

$$M = v^2 M_o + BB^T, \quad M_o > 0 \quad (16)$$

The Kalman filter using the loop-transfer recovery technique is designed as follows:

Solve loop-transfer recovery (LTR) Kalman filter ARE:

$$AP + PA^T + (v^2 M_o + BB^T) - PC^T (v^2 N)^{-1} CP = 0 \quad (17)$$

Compute loop-transfer recovery Kalman Gain:

$$L = PC^T (v^2 N)^{-1} \quad (18)$$

The following procedure, described by Lewis et al. [1], is used to design a Kalman Filter using the Loop-transfer

recovery technique:

1. Use the LQR control ARE (6) to design a state-feedback gain K with desirable properties. Which involves an iterative design varying the Performance Index weighting matrices Q and R .
2. Select $G = I$ (Identity Matrix), $M = v^2 M_o + BB^T$ – Process noise spectral density, and $v^2 N$ – Measurements noise spectral density

For a positive definite matrix M_o , and a positive definite matrix N . Fix the design parameter v (Nu) and then solve the LTR Kalman filter ARE (13) for P and compute the Kalman gain L (14).

3. Plot the maximum and minimum singular values of the regulator loop gain $L_r(s)$ and verify that the robustness bounds are satisfied. If they are not, decrease v and return to 2.

Since in our course we did not cover robust control topics, step 3 was accomplished by observing how the system response improved or deteriorated as the design parameter v was decreased.

IV. RESULTS

A simulation of the system with the regulator was performed with MATLAB® and Simulink® before implementing it on the real system. Virtual Instruments were then created in QUARC® to implement the LQR, Asymptotic Observer, Kalman Filter, and Loop-Transfer Recovery controllers on the real system. Next we will present the results obtained after implementing each controller on the real system.

A. Linear Quadratic Regulator Results

The first-order derivative filters (9) were used to estimate the unmeasured velocities with $a = 20$. The initial values chosen for the Q and R matrices were determined by choosing the maximum allowable values of the state variables and the control action as: $X_{max} = 0.1$ meter, $\dot{X}_{max} = \infty$, $\alpha_{max} = 0.105$ rad (aprox. 6°), $\dot{\alpha}_{max} = \infty$, $\theta_{max} = 0.105$ rad, $\dot{\theta}_{max} = \infty$, $V_{max} = 5$ Volts. When those maximum values were used, the Q and R matrices become

$$Q = \begin{bmatrix} 100 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 90 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 90 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \text{ and } R = 0.05$$

Then the value of gain K was found by using the “lqr” command ($K = \text{lqr}(A, B, Q, R)$) in MATLAB®, resulting in

$$K = [50.0000 \quad 35.0725 \quad 146.8321 \quad 36.0010 \quad 270.0862 \quad 32.7691]$$

However this K caused the cart to react too fast to control the system and there was too much noise fed to the motor. Thus, it was decided to reduce the amount of weight

attributed to the positions of the cart and pendulum angles to reduce the reaction of the cart, allowing for a more relaxed control action. Also, it was decided to increase the weight attributed to the control action so that it would apply a lower voltage to the motor. With those changes, the system performed better. After various changes, it was realized that the weight assigned to the position of the cart could be much less than what we started with. Finally, we ended up with the following Q and R matrices

$$Q = \begin{bmatrix} 0.75 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 35 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 30 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \text{ and } R = 0.04$$

The final value of gain K and the poles of the closed-loop plant ($A-KB$) are

$$K = [3.8730 \ 3.2136 \ 45.3633 \ 13.6046 \ 131.5116 \ 14.9450]$$

$$\text{LQR poles} = \begin{bmatrix} -23.7816 + 16.5569i \\ -23.7816 - 16.5569i \\ -7.0555 + 2.7091i \\ -7.0555 - 2.7091i \\ -1.1264 + 0.2362i \\ -1.1264 - 0.2362i \end{bmatrix}$$

This K value kept both pendulums in a vertical position, with the least amount of oscillation and with the best reaction in response to disturbances. The experimental results of the LQR implementation are shown in Fig. 4 and Fig. 5. It can be seen from Fig. 4 that the velocity estimates contain high frequency noise signals. When those signals are used for feedback control, they cause high frequency noise to appear in the control action signal $u(t)$ as shown in Fig. 5. The presence of noise in the control action can even be perceived by the sound generated by the DC servomotor.

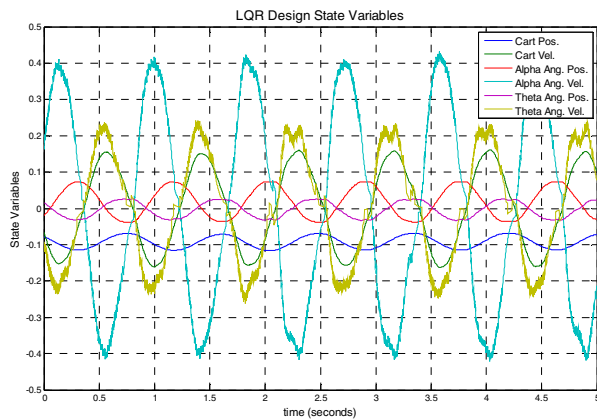


Fig. 4. Measured State Variables of System using LQR

B. Asymptotic Observer Implementation Results

When implementing the asymptotic observer, the value of gain K used was the same as the one found for the LQR

implementation. The Observability Matrix of the system was computed with the “*obsv.m*” command of MATLAB® to evaluate the observability of the system. The Observability Matrix is determined to be full rank using the “rank” command of MATLAB®. This proves that the system is observable and that an asymptotic full-state observer can be designed and implemented.

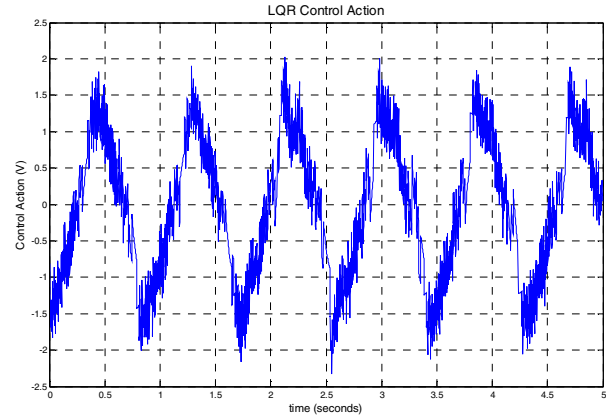


Fig. 5. Noisy Control Action (Vm) using LQR.

When designing the asymptotic observer, the poles of the observer matrix ($A-LC$) were chosen to be faster than the poles of the closed loop plant ($A-KB$). Matrix L was found by using the MATLAB® “place” command ($L = \text{place}(A', C', P_o)$), where P_o is a vector that contains the location of the desired observer poles. The initial choice for observer poles locations was

$$P_o = [-100 \ -102 \ -104 \ -106 \ -108 \ -110]$$

The resulting L matrix was

$$L = 1.0e+04 * \begin{bmatrix} 0.0196 & -0.0001 & -0.0002 \\ 0.8294 & -0.0134 & -0.0222 \\ 0.0094 & 0.0206 & -0.0003 \\ 1.8479 & 0.0001 & -0.0633 \\ -0.0100 & 0.0001 & 0.0214 \\ -1.9463 & -1.9463 & 1.1792 \end{bmatrix}$$

However, when the observer implemented with this L matrix was not able to keep the pendulum stable. Thus, it was decided to assign slower observer poles. After various trials, we ended up with P_o and L matrix that resulted in the best system behavior

$$P_o = [-30 \ -60 \ -62 \ -64 \ -66 \ -68].$$

$$L = 1.0e+03 * \begin{bmatrix} 0.0685 & 0.0038 & -0.0036 \\ 0.2304 & 0.1845 & -0.1805 \\ 0.0225 & 0.1349 & -0.0069 \\ 1.8833 & 5.0005 & -0.8359 \\ -0.0226 & -0.0074 & 0.1329 \\ -1.9065 & -0.9597 & 4.8851 \end{bmatrix}$$

Figs. 6 and 7 show the experimental results of the asymptotic observer implementation. It can be seen from

Fig. 6 that there are still high frequency noise signals in the velocity estimates, but with lower frequency content than the estimates in the LQR case of Fig. 4. These state variable estimates produce a control action $u(t)$ with less noise than the previous LQR implementation, as it can be seen from Fig. 7 when it is compared to that in Fig. 5. However, this level of noise in the control action is still unacceptable since it can still be perceived as sound generated by the DC servomotor.

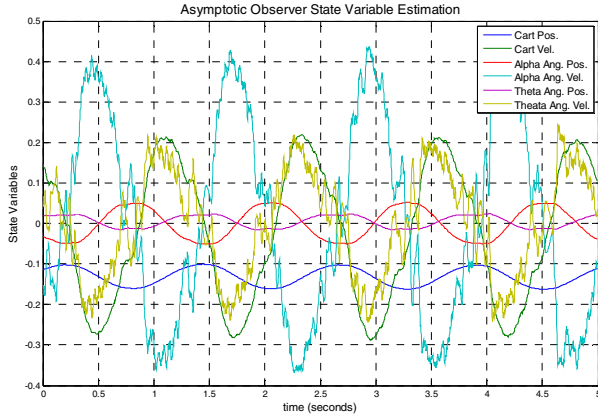


Fig. 6. Measured State Variables of System using LQR with Asymptotic Observer

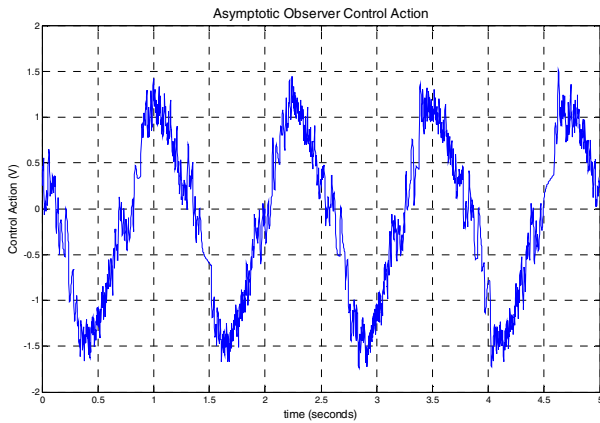


Fig. 7. Control Action (Vm) using LQR with Asymptotic Observer

C. Kalman Filter Results

For the double inverted pendulum system we did not have any information of what values to use for the spectral density matrices Q_k and R_k , but we had the position of the poles and the value of the L matrix that produced good results when implementing the asymptotic observer. Those could be used for comparison. It was decided to start with intuitive and reasonable values for the spectral density matrices Q_k and R_k . Our starting value for R_k was

$$R_k = \begin{bmatrix} 1/20 & 0 & 0 \\ 0 & 1/20 & 0 \\ 0 & 0 & 1/20 \end{bmatrix}$$

To choose a starting value for the spectral density matrix Q_k , we started by looking at the state variable measurements of Figs. 6 and 4 and noticed that the signals with the highest amount of noise density were the angular velocity estimates. Thus, the elements in Q_k matrix that represent those state variables should have values with a greater magnitude than the ones of the angular position state variables. We also noticed from Figs. 4 and 6 that the state variables representing the position and velocity of the cart show small amount of noise compared to the angular velocity state variables. Thus, smaller numbers were used for these state variables. Based on the described analysis, the initial spectral density matrix Q_k was assigned to be

$$Q_k = \begin{bmatrix} 15 & 0 & 0 & 0 & 0 & 0 \\ 0 & 20 & 0 & 0 & 0 & 0 \\ 0 & 0 & 5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 100 & 0 & 0 \\ 0 & 0 & 0 & 0 & 10 & 0 \\ 0 & 0 & 0 & 0 & 0 & 100 \end{bmatrix}$$

With those choices for matrices Q_k and R_k , and defining G as $G = I$ (Identity Matrix), we solved the Kalman filter ARE with the MATLAB® “lqe” command ($[L, P, E] = \text{lqe}(A, G, C, Q_k, R_k)$). This resulted in the Kalman gain L and poles for the observer matrix $(A-LC)$.

However, this first L value did not control the system well because the control action did not have enough strength to maintain system stability. However, our intuitive values looked promising. Changes were made by trying out different values in the diagonal elements of the spectral density matrices Q_k and R_k and comparing the resulting L and poles for the observer matrix $(A-LC)$ to those found with the Asymptotic Observer. We knew we wanted the poles for the observer matrix $(A-LC)$ to have their real negative parts as farther to the left of the poles of the plant with feedback $(A-KB)$ as possible. This was taken into consideration when we ran the “lqe” command in MATLAB®. When we saw that the resulting observer matrix $(A-LC)$ poles generated by changing the matrix Q_k and matrix R_k were promising, we ran simulations and then tested it on the real system to see how it responded. Taking those steps, resulted in the final value that were used for the spectral density matrices Q_k and R_k that produced a Kalman gain L that produced enough control action strength to maintain the stability of the system. The final values for Q_k and R_k , Kalman gain L , poles of the Kalman filter are

$$Q_k = \begin{bmatrix} 500 & 0 & 0 & 0 & 0 & 0 \\ 0 & 506 & 0 & 0 & 0 & 0 \\ 0 & 0 & 12 & 0 & 0 & 0 \\ 0 & 0 & 0 & 50000 & 0 & 0 \\ 0 & 0 & 0 & 0 & 6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 50000 \end{bmatrix}$$

$$R_k = \begin{bmatrix} 1/10 & 0 & 0 \\ 0 & 1/10 & 0 \\ 0 & 0 & 1/10 \end{bmatrix}$$

$$\text{Kalman filter poles} = \begin{bmatrix} -70.7032 \\ -19.656 \\ -20.7147 + 16.7508i \\ -20.7147 - 16.7508i \\ -19.9185 + 17.6866i \\ -19.9185 - 17.6866i \end{bmatrix}$$

$$L = \begin{bmatrix} 70.7398 & 0.1109 & -0.1629 \\ 2.0759 & 4.2701 & -9.6560 \\ 0.1109 & 43.4210 & -3.7564 \\ 8.9965 & 889.7540 & -138.8682 \\ -0.1629 & -3.7564 & 43.7332 \\ -9.4068 & -188.5399 & 933.3635 \end{bmatrix}$$

Figs. 8 and 9 show the experimental results of the Kalman filter implementation with LQR. It can be seen from Fig. 8, when compared to Figs. 4 and 6, that the estimated state variables generated by the Kalman Filter essentially do not contain high frequency noise signals on the velocity estimates. When those state variable estimates are used in the control law $u(t) = -K\hat{x}(t)$, they no longer cause high frequency noise to appear on the control action, as can be seen from Fig. 9. When this controller design was implemented on the plant, there was no perceived sound generated by the DC servomotor. Also, the movement and reaction of the cart and pendulums were more fluid and it was observed that the system was kept stable with more ease.

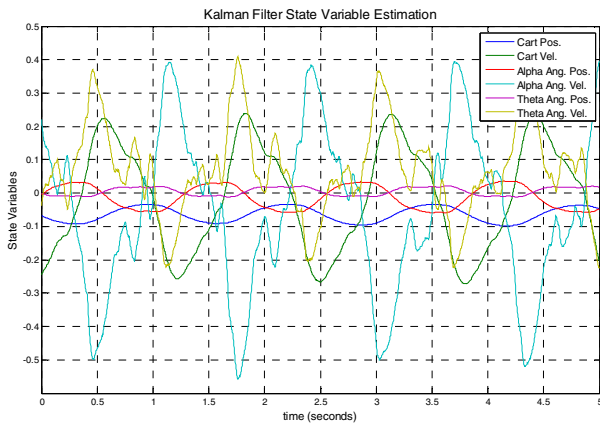


Fig. 8. Measured State Variables of System using LQR with Kalman Filter.

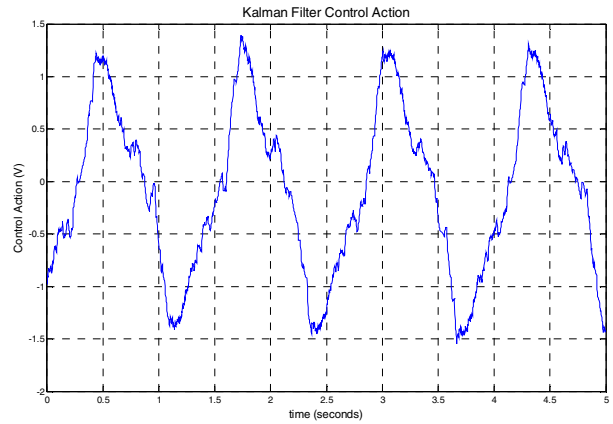


Fig. 9. Control Action (Vm) using LQR with Kalman Filter.

D. Loop Transfer Recovery

To implement the loop-transfer recovery technique we started by assigning spectral density matrixes Q_k and R_k found for the Kalman filter, as the corresponding starting values of the spectral density matrixes $M_o = Q_k$ and $N = R_k$ so that the iteration process explained by Lewis [1] could start.

In the previous step, both M_o and N are required to be positive definite matrixes ($M_o > 0$) and ($N > 0$). The procedure described by Lewis [1] and reproduced in section III.D was used to design a Kalman Filter using the Loop-transfer recovery technique. This procedure was performed first off-line with the system model to determine how it would change the gain L and the observer matrix ($A-LC$) poles compared to those found with the Kalman filter and then we ran simulations. Later, the procedure was performed while the system was running with the data acquisition system displaying the graphs of the estimated state variables to find out how it was affecting the system. Start with the same Kalman gain K used for the previous controllers. Set design parameter $v = 1.0$, then solve the LTR Kalman filter ARE (18) for P and compute the Kalman gain L (19) by using the "lqe" command of MATLAB®. Observe the resulting gain L and the observer matrix ($A-LC$) poles, and compare them with those found with the Kalman filter. If we saw no appreciable change on the system performance, we returned to step 2, reduced the design parameter to v , and made the same observation.

Repeating steps 2 and 3 of the procedure and updating the Virtual Instrument gains while the system was running, allowed us to see the effect of reducing the design parameter v . We finally arrived at design parameter $v = 0.02$ because it produced the best results. Those are shown in Figs.10 and 11. However, if the design parameter v was reduced too much, the loop-transfer recovery would begin to produce high frequency noise in the velocity state estimate variables, causing a control action that had too much noise. Those results are shown in Figs. 12 and 13 when the design parameter $v = 0.001$ is used.

Figures 10 and 11 show the experimental results of the Loop Transfer Recovery implementation when the design

parameter $\nu = 0.02$. The estimated state variables generated by the Loop Transfer Recovery were used and applied with the feedback gain K . It can be seen from Fig. 10 that the estimated state variables generated by the Loop Transfer Recovery essentially have no high frequency noise signals on the velocity estimates. Also it can be seen from Fig. 10, when compared to Fig. 8, that the amplitude of the velocity estimates oscillations was reduced. When those signals are used in the feedback control law, they basically cause very little high frequency noise to appear in the control action signal $u(t)$ as shown in Fig. 11.

Again, there was no perceived sound generated by the DC servomotor, as the system was running. It was observed that the movement and reaction of the cart and pendulums were more fluid and the system was keep stable with both pendulums in an even more vertically straight position and with more ease than with the regular Kalman filter. There was less swing movement on the pendulums and the reaction to stabilize the system when it was disturbed was done faster, with more ease and fluidity than with the previous asymptotic observer or the Kalman filter.

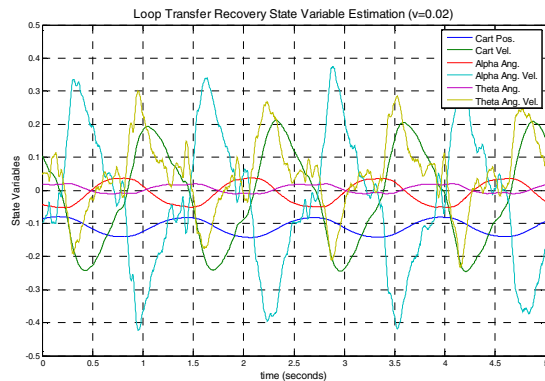


Fig. 10. Measured State Variables of System using LQR with Kalman Filter and Loop Transfer Recovery ($\nu=0.02$).

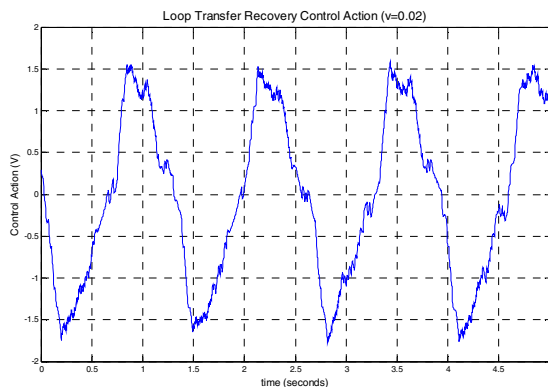


Fig. 11. Control Action (Vm) using LQR with Kalman Filter and Loop Transfer Recovery ($\nu=0.02$).

Figures 12 and 13 show the experimental results of the Loop Transfer Recovery implementation with LQR when the iterative value of the scalar constant ν is reduced too much, without considering the effect it might have on the estimated state variables and control action of the system or

whether or not the robustness bounds of the system are satisfied. Figure 12 shows an extreme amount of high frequency noise signals on the velocity estimates. When those signals are used for feedback, they cause high frequency noise to appear on the control signal $u(t)$ as shown in Fig. 13, which is even worse than what was observed for the case of the LQR implementation (Fig. 5).

V. CONCLUSIONS

An LQR design methodology that may be used as a technologically-based educational and learning tool for teaching a graduate optimal control course was presented. The methodology was applied by a team of two graduate and one undergraduate student in the course term project. The methodology starts with the most basic LQR design using MATLAB® design tools. Then, an asymptotic observer, a Kalman Filter, and a Kalman Filter with Loop transfer Recovery are designed and implemented sequentially to obtain increasingly improving performance of the regulator. The methodology served to enhance the teaching practice while providing effective learning opportunities since the students were discovering the improvements of each additional design method while they were confirming theoretical aspects in an experimental setting.

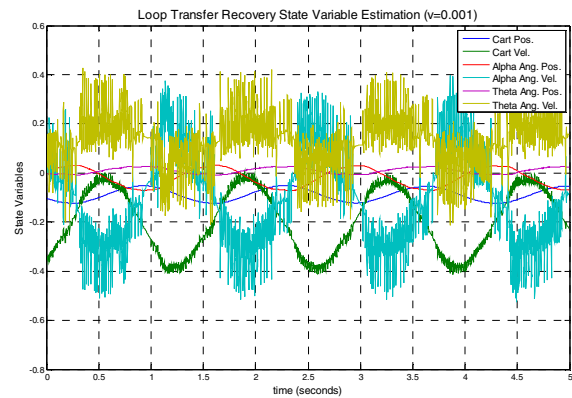


Fig. 12. Measured State Variables of System using LQR with Kalman Filter and Loop Transfer Recovery ($\nu=0.001$).

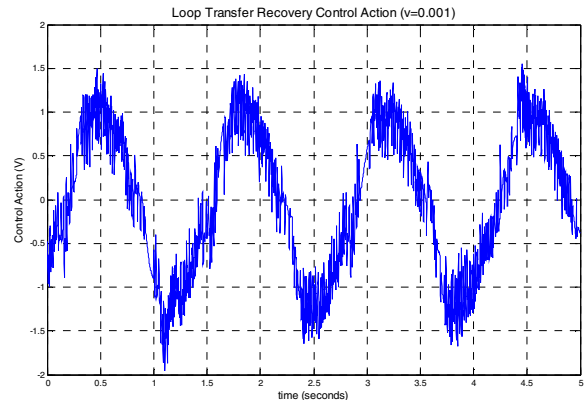


Fig. 13. Control Action (Vm) using LQR with Kalman Filter and Loop Transfer Recovery ($\nu=0.001$).

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A Low-cost System for Experiments with Digital Circuits

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Abstract—The first digital circuits course becomes a lot more interesting for students when it involves practical experiments in the laboratory. Motivation is higher when students use old digital integrated circuits, such as the TTL7400 or CMOS4000 families, and construct circuits on solderless breadboards. The handling of these circuits containing logic gates is more motivating than using a digital circuit simulator software or an FPGA, which looks like a black box for beginner students. To verify the built circuit's operation on the solderless breadboard, with a digital integrated circuit, it is necessary to generate input signals and display the output signals, as well as a probe in order to check the logic level at any point in the circuit. For this, there are two options: using didactic modules for experiments with digital circuits, or generating input signals with switches and showing the output signals with LEDs. The former has the disadvantage of relatively high cost. The latter has the drawback of inserting many other problems when building a digital circuit using breadboards. As a low-cost alternative, this paper presents a virtual instrument that consists of an Arduino and a software, which allows experiments using digital integrated circuits.

Keywords—computerized instrumentation; digital circuits; low cost;

I. INTRODUCTION

Practical experiments with digital circuits are very important for teaching computing and engineering because they act as a bridge between theory and practice, not only solidifying the concepts shown in class [1] but also being highly valuable to one's curriculum [2]. The first course for digital systems education becomes much more interesting to students when it involves practical experiments in the laboratory, which undoubtedly increase motivation in class and improve the extent to which students understand and remember the laid out concepts.

Conducting experiments using simulator software is much more interesting than teaching a class based only on the blackboard. However, the use of simulators does not arouse much interest in students due to their lack of physical components to be handled when assembling the circuits. In addition, many interesting problems arise when a project is implemented in hardware, and as such, these hands-on experiments are necessary to develop essential skills [2].

Currently, practical experiments involving physical components use two approaches. In the first one, the circuits are assembled on protoboards using logic gates (AND, OR, NOT, etc.) contained in SSI and MSI integrated circuits, such as the old TTL74 and CMOS4000 families. In the second approach,

the experiments are performed using hardware boards containing programmable logic devices (VLSI and ULSI), such as FPGA-based prototyping [3].

The second approach has several benefits, such as: the possibility of assembling more complex circuits; the student does not need to manage wires to interconnect the logic gates; no issues arise from bad contacts and shorts; the circuits are assembled more quickly; and more [3]. However, when considering the first course in digital systems—taught to beginners—it appears that these benefits are somewhat diminished, and the first approach that allows the handling and physical interconnection of logic gates becomes more appealing. In [4], it was found that discrete components are fundamental in the initial courses and the FPGA is an economical alternative to subsequent courses.

To verify the operation of the protoboard-assembled circuit using SSI and MSI integrated circuits, we need to generate input signals and display the output signals, as well as have a test probe to check the logic level at any point in the circuit. This may be accomplished using specific teaching modules for experiments with digital circuits, whereas this solution has the disadvantage of a relatively high cost, around US\$1000 per module in Brazil. Another much cheaper solution is to generate the input signals using switches, and display the output signals using LEDs and resistors. This last solution has the drawback of inserting several other problems in addition to those which already naturally occur when assembling a digital circuit using protoboards and wires. Besides, the increased number of wires—which will cause more bad contacts—plus the switch bouncing and LEDs with inverted terminals can complicate the experiment for the beginner student. For example, an LED connected incorrectly at the output of a logic gate (inverted anode and cathode terminals) will erroneously display the output level as always 0 (LED always off) to the student.

Given the above, and considering that currently the use of virtual instruments has received considerable attention in the literature [5, 6] and the great popularity and low cost of open-source platforms for electronic prototyping, such as Arduino [7]–[9], the objective of this paper is to develop a virtual instrument consisting of an Arduino and a computer application, which allows the realization of practical experiments using SSI and MSI circuits at low cost. The proposed system is a solution that does not present the problems associated with the use of switches and LEDs to generate and display the logic levels, respectively; and it does not present the inconvenience of the

high cost usually associated with the use of specific didactic modules for experiments with digital circuits.

II. METHODOLOGY

The system is designed to be simple to use at first, and so its requirements for running are just:

- connecting an Arduino Mega 2560 board to a USB port;
- opening the software and letting it detect the board automatically (Figure 1).

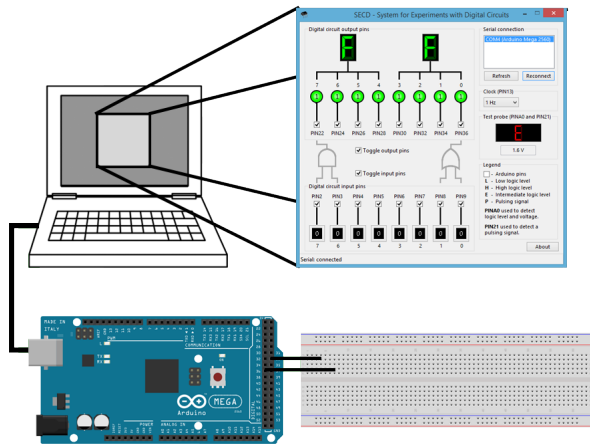


Fig. 1. How to set up and use the system.

By pressing the virtual circuit buttons in the program, the user sends LOW or HIGH digital state signals to the specified pins on the board. To receive signals, the user must use one of the available pin numbers shown in the program. For instance, a signal can be sent from button 7 to LED 7 by connecting a jumper from PIN2 to PIN22. This I/O system provides a method of manipulating real-life signal processing circuits without dealing with how to visualize the output states in hardware.

A. Hardware

The prototyping platform chosen for developing the system is the Arduino. The model used in this project is the Arduino Mega 2560¹, which has a proper pinout compatible with the system. Currently, this is the only model supported.

The Arduino platform has undergone a major refinement, becoming better, simpler, more accessible and cheaper for electronics students, generating a large number of possible projects. The Arduino Mega 2560 is based on the *Atmel AVR ATmega2560* [11] microcontroller, featuring 54 digital I/O pins (15 of these are used as PWM outputs) and 16 analog inputs. The major user base of this platform for the most part are beginner designers who, perhaps, would not be able to get more sophisticated prototyping controllers because of their price and/or complexity. Its accessibility associated with its great performance, plus its extensive community and

documentation, make the Arduino one of the main platforms used worldwide [12].

The role of the Arduino in the system is to perform the analysis and study of a particular digital circuit project through the signals that are generated by the Arduino, and the signals—not necessarily logical—which are generated by the circuit. The system can generate inputs with static logic levels according to a project specification, and can also analyze its output through the logical levels; all of this using the input and output pins from the Arduino. The system is also capable of generating square waves through the digital outputs, in certain pre-determined frequencies, using the built-in timers on the microcontroller.

A great strength of the system is that it is capable of making a more precise analysis of a digital circuit by measuring the voltage and signal type at any point in the circuit using the analog input and the interrupts system as a test probe. This probe checks whether a signal is low, high, indeterminate or pulsing. To determine whether a signal is high, low or indeterminate, the Arduino does the signal pre-processing using the built-in A/D converter, turning the signal into data that the software is capable of translating. If the analyzed signal has variations in a frequency equal to or above 10 Hz, our firmware will define this signal as pulsating. If the signal is below 10 Hz, it is expected to see the changes between LOW and HIGH on the interface. Every hundred milliseconds, the firmware checks whether there was any change in the signal's logic level. If there is more than one logic level change during these hundred milliseconds, the signal is determined as pulsing; if there was just one change, the firmware analyzes the time difference between each state. If there was no change in these hundred milliseconds, the signal is one of the other three types, but not pulsing. To identify a change in the signal's logic level, hardware interrupts are used as a feature within the microcontroller.²

B. Software

The software part is responsible for quickly exchanging messages with the Arduino board, using serial communication to automatically upload the firmware and to process input and output signals for the virtual buttons and LEDs.

We developed the software using C++ and *wxWidgets* for the graphical user interface (GUI). *wxWidgets* is a programmer's toolkit for writing cross-platform applications with GUIs and contains a large library for handling standard controls, events, databases, multi-threading and general communications [10]. Currently, the software uses two threads for its inner workings, the main one processing the window events and other general calculations, and the second for the USB-virtual serial port communication loop.

When performing a new serial connection, the program tries to identify the firmware and, if it is missing or else is not the same version, an automatic upload is done using the third-party uploader *AVRDUDE*.³ With the new firmware, the next connection attempt will succeed when an identifier string is sent to the program, which verifies it for authenticity, and

¹<http://arduino.cc/en/Main/arduinoBoardMega2560>. Accessed on Apr. 10, 2015.

²<http://arduino.cc/en/Reference/attachInterrupt>. Documentation for `attachInterrupt()` Accessed on Apr. 12, 2015.

then the user may fully use the interface and start physically prototyping the circuit.

C. Communication Protocol

The serial protocol used to communicate between the Arduino and the software is relatively simple. It is composed of a three-byte packet, for both sending and receiving data, which contains information about (Figure 2):

- the inputs which are provided from the Arduino to the digital circuit;
- the square wave frequency that the Arduino should generate;
- the data analyzed by the test probe (voltage or pulsing signal);
- a checksum/hash to detect communication errors.

The three bytes sent from the software to the Arduino contain information about the logical level of each input generated from the Arduino, the square wave frequency and a XOR (eXclusive OR) byte, which is essentially the XOR operation on all the other bytes. The response from the Arduino to the software contains information about the logical level of each output generated from the digital circuit, the test probe signal information and also the XOR operation on the other bytes.

This XOR operation is a method of preventing data loss. It is not the most secure means, yet it is very simple and effective for simple applications. The option for simplicity in this case is chosen because the system must process communication very quickly. The analysis for the pulsing signal, which requires a fast processing time, is done within the hardware initially, before the Arduino can pass the information to the software. Therefore, if any data loss or bit-swapping occurs during communication, this information should be easily retransmitted on the next packet without the user noticing any difference in behaviour on the interface due to its fast speed (which is set to 115200 bps).

To keep track of when a packet starts or ends—in case an error occurs during communication—all the bytes have their high-order bit set to 0, except for the first byte, which has its most-significant bit set to 1.

	7	6	5	4	3	2	1	0
$byte_1$	1	bt_6	bt_5	bt_4	bt_3	bt_2	bt_1	bt_0
$byte_2$	0	bt_7	$clock_index$					
$byte_3$	0	$byte_1 \text{ XOR } byte_2$						

	7	6	5	4	3	2	1	0
$byte_1$	1	ld_6	ld_5	ld_4	ld_3	ld_2	ld_1	ld_0
$byte_2$	0	ld_7	$probe_value$					
$byte_3$	0	$byte_1 \text{ XOR } byte_2$						

Fig. 2. Data packet format. (Top) Packet received by the Arduino. (Bottom) Packet sent by the Arduino. *bt₇–bt₀* are the bits generated by the Arduino and *ld₇–ld₀* are read bits. The *probe_value* contains the voltage mapped from 0 to 50. A pulsing signal is any value above 50 (limited to 63 due to the 6-bit width).

D. Graphical User Interface

The GUI design is shown and explained in detail for better understanding (Figure 3).

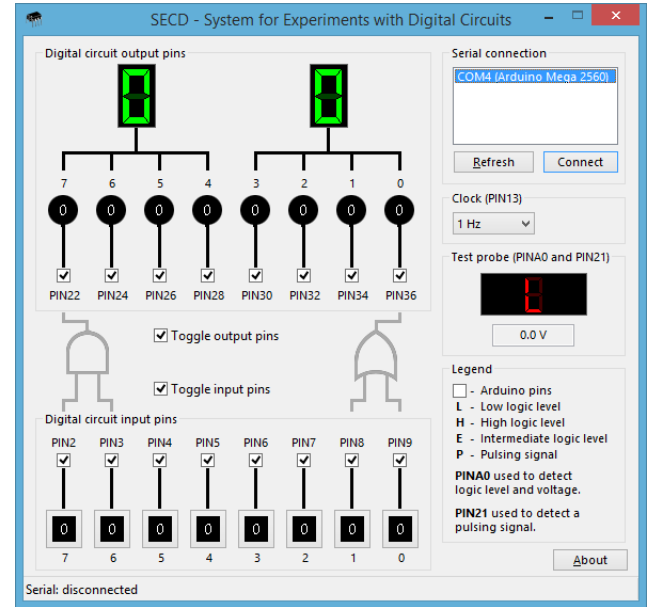


Fig. 3. The software when idle.

1) *Connection*: When the software is opened, it will check if an Arduino Mega 2560 is connected through the window shown in Figure 4. If an Arduino is connected or if the user connects the Arduino while the automatic search is executing, a dialog will ask if the user wants to do an automatic firmware upload if it is not already present, as shown in Figure 5. The user may cancel the automatic search and manually connect to a serial port, as shown in Figure 6.

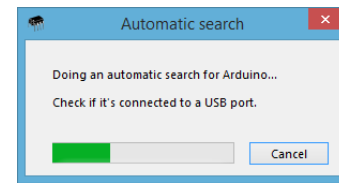


Fig. 4. The automatic Arduino search dialog.

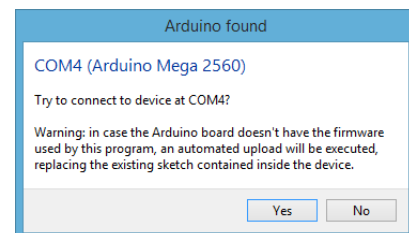


Fig. 5. The automatic firmware upload dialog.

³<http://www.nongnu.org/avrdude/>. AVRDUDE—AVR Downloader/Uploader Accessed on Apr. 12, 2015.

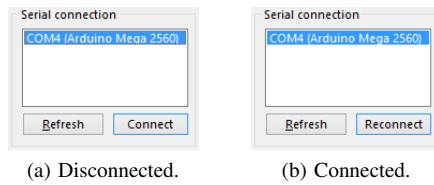


Fig. 6. The manual connection box.

2) *Digital Circuit Input*: These are the eight virtual buttons on the software as shown at the bottom of Figure 7. In this example figure, the button number '7' is pressed, sending a HIGH signal through PIN2 on the Arduino to the digital circuit. The user can toggle each pin to clarify which pins are being used in a project.

3) *Digital Circuit Output*: These are the eight virtual LEDs on the software as shown at the top of Figure 7. In this example figure, the LED number '4' is receiving a HIGH signal through PIN28 on the Arduino. The user can toggle each pin to not only clarify which pins are being used in a project, but also because the default state of every virtual LED is HIGH, so that it becomes less confusing. There are also two seven-segment displays for each four bits, showing an hexadecimal representation of these LEDs.

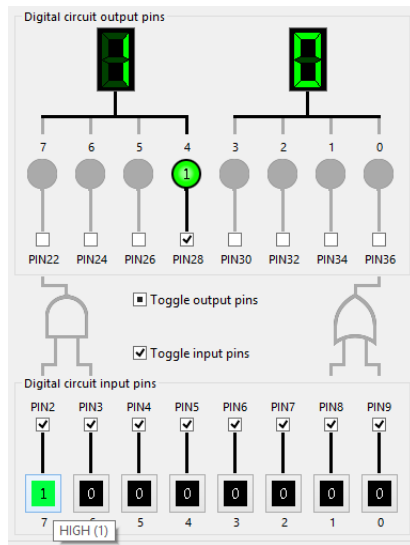


Fig. 7. The digital circuit inputs (bottom) and outputs (top).

4) *Clock Generator*: In Figure 8, the user can select an output clock frequency to be sent to PIN13 on the Arduino (0.5 Hz, 1 Hz, 10 Hz, 100 Hz and 500 Hz).

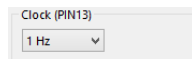


Fig. 8. The clock generator drop-down frequency list.

5) *Test Probe*: The test probe (Figure 9) can be used to read a voltage and to detect the type of signal anywhere in the circuit. PIN21 is used to detect a pulsing signal (displayed as P) and PINA0 to read a voltage and detect it as L for low, H for high, or E for indeterminate.

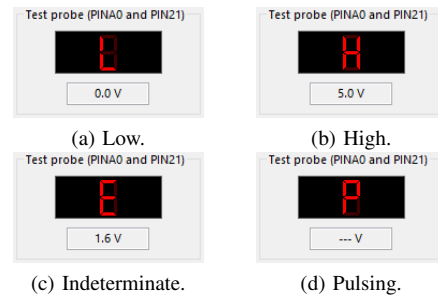


Fig. 9. The test probe box.

III. RESULTS AND DISCUSSION

The following subsections show the results obtained in the tests.

A. Signal Visual Delay

These two tests calculate the I/O visual delays using a *GoPro HERO3+ Silver Edition* video camera filming at 119.88 FPS (Frames Per Second). Note that this is a visual delay test—hence the decision to not only use a relatively high FPS camera but also to maintain simplicity and get a more practical and usable result.

The camera was set up to record both a computer screen and an *ATTEN ADS1102CAL+* oscilloscope in order to count the frames by a visual trigger between both devices.

To convert frames to milliseconds, the following equation was used:

$$delay_{ms} = \frac{1000}{119.88} \times delay_{frames}$$

1) *Software Output to the Arduino*: The values below are the delay length—in frames—for each output tested out of a total of 14. An output in this case is the change of a state button in the program, which sends a signal to the hardware part.

The delay counter starts when the software changes the state of a button after receiving a user command, and stops when the oscilloscope displays a change in signal.

LOW→HIGH	5, 9, 6, 2, 4, 9, 11, 9, 15, 9, 7, 11, 13, 12
HIGH→LOW	11, 6, 4, 5, 1, 3, 8, 15, 6, 10, 1, 8, 12, 15

It takes 72.6917 ms (8.7142 frames) on average to output a HIGH signal; and 62.5625 ms (7.5 frames) for a LOW signal. Therefore, the average output delay is approximately 67.6 ms.

2) *Software Input from the Arduino*: Once more, 14 tests were made for the input. 'Input' here is defined as the signal received by the software from the Arduino board.

The delay counter starts when the oscilloscope displays a change in signal, and stops when the software turns the respective virtual LEDs on.

LOW→HIGH	14, 4, 5, 16, 5, 6, 2, 6, 2, 4, 8, 2, 2, 1
HIGH→LOW	2, 8, 5, 6, 16, 6, 5, 2, 3, 3, 6, 1, 5, 1

It takes 45.8792 ms (5.5 frames) on average to receive a HIGH signal and 41.1125 ms (4.9285 frames) for a LOW signal. Therefore, the average input delay is approximately 43.5 ms. The largest value is 133.5 ms (16 frames), which is imperceptible to a human user.

B. Probe Measurement Accuracy

Using a *Hikari HF-3003S* adjustable DC power supply and a *Victor 88B* digital multimeter, we tested various voltage readings on 4 different Arduino boards. Knowing that our system was designed to display only one decimal place for the voltage, we set a resolution of 0.1 and obtained the results shown in Table I.

TABLE I. PROBE MEASUREMENT ACCURACY RESULTS. VALUES ARE MEAN \pm STANDARD DEVIATION.

Multimeter (V)	System's probe (V)	System's display
0.0	0.0 \pm 0.0	L
0.4	0.4 \pm 0.0	L
0.6	0.6 \pm 0.0	L
0.7	0.7 \pm 0.0	L
0.8	0.8 \pm 0.0	L
0.9	0.9 \pm 0.0	E
1.0	1.0 \pm 0.0	E
1.4	1.4 \pm 0.0	E
1.8	1.8 \pm 0.0	E
1.9	1.9 \pm 0.0	E
2.0	2.0 \pm 0.0	H
2.1	2.1 \pm 0.0	H
2.2	2.2 \pm 0.0	H
2.6	2.6 \pm 0.0	H
3.0	3.0 \pm 0.0	H

Considering the resolution of 0.1, it can be seen that the probe measurement error is negligible.

C. Probe Pulsating Signal Detector

Using a *Minipa MFG-4221* function generator and a *In-strutherm OD-275* oscilloscope to precisely measure the generated square wave, the system was able to detect frequencies starting from the 10 Hz mark. Below this mark, the test probe display periodically changes its state from LOW to HIGH, instead of detecting the signal as pulsating.

This is due to our detection code being used in the Arduino, as explained in section II-A. Therefore, it is a predetermined behaviour and limitation on the system. Any "pulsating" signal below 10 Hz is more likely to be a varying signal than a real square wave frequency.

D. Square Wave Generator Accuracy

Using an *ATTEN ADS1102CAL+* oscilloscope, for each square wave frequency the system can output and based on the readings of four different Arduino boards, the results obtained are shown in Table II.

TABLE II. SQUARE WAVE GENERATOR ACCURACY RESULTS. VALUES ARE MEAN \pm STANDARD DEVIATION.

System's clock (Hz)	O-scope's freq. (Hz)	O-scope's volt. (V)	Main time base (ms)
0.5	0.49725 \pm 0.000433	2.40 \pm 0.0	800
1.0	0.99600 \pm 0.0	2.40 \pm 0.0	800
10.0	9.87375 \pm 0.149389	2.46 \pm 0.034641	40
100.0	99.5500 \pm 0.0866025	2.46 \pm 0.034641	4
500.0	497.625 \pm 0.216506	2.46 \pm 0.034641	0.4

The average accuracy error for the measured frequency is 0.6275% with a standard deviation of 0.32117%, which is sufficient for this application.

IV. CONCLUSION

This paper presents a low-cost system, consisting of an Arduino (US\$ 45) and an application to be used in practical experiments with discrete digital components.

It is reasonable to assume that the main goal of a first course in digital circuits is to present important concepts and to fix them in the students' minds through experiments that motivate and spark interest in them, rather than presenting the latest technology in implementing digital circuits, such as FPGAs. Furthermore, a beginner student typically implements simple digital circuitry, and thus the main advantages in using FPGAs begin to diminish. Therefore, it is believed that the use of FPGAs is of great importance, but mainly so for more advanced courses on digital systems. For a first course, it is believed that the use of discrete components and the developed system shown here is a better solution.

The tests performed in our system showed satisfactory results, considering the application in question. The delays presented by the system are virtually imperceptible to a human user, who sees the changes in logic levels as instant changes, both in signal generation and reading.

Hopefully, this work has contributed to the teaching of digital systems in starter courses, with its advantage of being a low-cost alternative.

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The Exploration for Computer System Capacity Training in Experimental Teaching

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Abstract—Computer system capability is an essential capability for the computer professional undergraduate students, and the system capacity training becomes an important target for the computer professional education. Computer system design experiment is the key method to achieve this target. This paper introduces the exploration in training computer system capability of the Dept. CS&T Tsinghua University, which establish a series of course experiments to form a computer system experiment. This paper focuses on the experimental teaching, from the course contents adjustment to course experiments integration, to achieve an experimental teaching system for system capacity training. And this paper presents some key points for the computer system experiment, and gives a sample experiment embodiment of the computer system experiment for the computer system capability training.

Keywords—Computer System Capacity; Experimental Teaching

I. INTRODUCTION

For the computer professional students, the systematic view of the computer system becomes more and more important. In their eyes, the computer should be a completed organic whole which can work coordinately, not just the software or hardware part working separately.

In Computer Science Curricula 2013(CS2013), the System-level perspective becomes one of the expected characteristics of the computer science graduates. It requires the graduates of a computer science program think at multiple levels of detail and abstraction. This understanding should transcend the implementation details of the various components to encompass an appreciation for the structure of computer systems and the processes involved in their construction and analysis. They need to recognize the context in which a computer system may function, including its interactions with people and the physical world.[1]

In China, the Guidance Committee of Computer Professional Education of Ministry of Education also requires to enhance the system ability training in computer education and practice. It listed four main abilities of the computer professional, which are computational-thinking ability, algorithm design and analysis ability, program design and implementation ability and system ability. The system ability includes system cognition, system design, system application and system implementation.[2]

In order to meet these requirement, computer professional students are required to have the capabilities of the system design and system application. These capacities requires the students to master basic computer system knowledge, understand the interaction between computer hardware and software systems. It is just the computer system capacity training requirements.

The computer system capacity is a comprehensive ability, which includes the use of the system level view consciously, understanding the integrity, relevance, hierarchy, dynamic and opening of the computer system, and also requires the students be able to use a systematic approach to master the collaborate of the computer hardware and software, understand the mechanism of interaction between them[3].

In order to meet the needs of computer system capacity training, the core courses of the computer science undergraduate curriculum system should be adjusted to make the correlation between the course content closer, and let the courses connections smoother. Similarly, the experimental teaching of these courses should be carried out around the computer system capacity training. It requires the course experiments connected seamlessly, that is the course experiment should undertake the content of the previous course experiment and at the same time prepare for the subsequent course experiment. Thus all these experiments will eventually form an integral experimental teaching system.

In China, many universities have made attempt for system training target. Nanjing University and Zhejiang University reforms the curriculum to link the related courses content to form a system course, which has been carried out for several years. The students' system ability have been improved greatly.[4][5] And University of Electronic Science and Technology completed a demo computer hardware platform, which can support a simple educational computer with a monitor program. On it the student can design and implement a open CPU, and the student have made more deep understanding of the principle of the computer hardware.[6] But these reform only focus one aspect of the computer system, software or hardware, lack of whole computer systematic level consideration.

II. EXPERIMENTAL TEACHING IN SYSTEM

The experiment or practice training is an important method to help the student to understand the knowledge of the courses. In the CS2013 the Project Experience is listed as the characteristics of the computer science graduates. It mentions that all graduates of computer science programs should have been involved in at least one substantial project. Such projects should challenge students by being integrative, requiring evaluation of potential solutions, and requiring work on a larger scale than typical course projects. Students should have opportunities to develop their interpersonal communication skills as part of their project experience[1]. The experiment of computer system is a good project for this requirement, which need the students to complete by team work and is an integration practice of several courses in experimental teaching .

The current computer curriculum system includes a large number of computer systems related courses, such as Digital Logic Circuits, Assembly Language, Computer Organization, Computer Architecture, Compile Theory, Operating Systems, Embedded Systems, etc. Each of these courses has its own separated experiment contents, but these experiments are not good or enough for helping students to build systematic knowledge of the computer hardware and software systems. Through these courses learning and experiments practice, the students have in-depth understanding of the subsystem introduced in these courses, but they have not such understanding on the interaction between the various subsystems of other courses or on how these subsystems integrated to one computer system. That is the students have not really grasp the computer knowledge in systematic level.

The main reasons for this situation we think are the following two aspects:

(1) In the teaching process, these courses are planned and carried out independently. And these courses emphasize the integrity and systematic for their own self-knowledge system, thus it causes the redundancy of the knowledge, and meanwhile it also leads to insufficiency of the interconnection content between the consequent courses, so it is difficult to form a complete computer system knowledge system for the students.

(2) In the experiment process, these courses focus on the study of their own content, so the experiment is lack of the continuity of the leading course experiments, as well as the supports for the subsequent course experiments. And most of the experiments are mainly the simple verification of the principle, lack of the practice for complex integrated system design.

Computer experiment teaching is an integrated process, which need high correlation between the courses. The experiments need overall planning from the systematic level, in order to effectively develop and training students' ability in computer system capabilities[4]. Therefore it is demanded to adjust the experiment teaching system.

First of all, on the teaching principle, the courses should focus on how to improve the level of the system capability training. Based on the idea of "Focus system, Emphasizing

experiments, Building capacity", the related courses should adjust the courses' content to fit for the system level teaching.

Second, experiment teaching content need to be planned unified, in order to set up a complete knowledge system on systematic level for the students, from the underlying hardware to the operating system and the compiler, to form a complete experimental teaching system.

Furthermore, it is needed to establish a unified teaching experiment platform, thus each course experiment will be on the same implementation carrier, which is helpful for the coherence in these experiments, and also convenient to carry out the experiments.

Finally, the target of the experiments is that the students can design and implement an educational computer system, which is based on a certain instruction set, and on it they can run an operating system kernel and implement a compiler for this system. The computer hardware, OS and compiler are all implemented by the students themselves. Through the practice on this system experiment, the students will comprehend the computer on systematic view and the system capability will be improved greatly.

III. COMPUTER SYSTEM EXPERIMENT

In order to make up the deficiencies of the students system capacity in the teaching of computer professional courses, the Guidance Committee of Computer Professional Education suggests several universities to attempt the system experiment project, in order to explore an approach on the integration of course experiments using the methods of the engineering education, to form a systematic experiment of the computer professional. The computer departments of Tsinghua University, Beihang University, Zhejiang University, etc all joined this project, and have made some progress in the exploration process.

In Tsinghua university, the Computer Experiment Teaching center is the National Demonstration Center[7], in order to achieve the objectives of the system experiment, we made following changes in the system related courses and experiments: adjust and optimize the courses content, integrate the experiments, design the experimental system and develop the experiment platform. In the past three years, we continuously improve our system experiment, and gradually formed a prototype of the experimental teaching system for the goal of system capacity training.

A. Planning Experimental Teaching Unified

Based on the computer professional curriculum system, we analyzed the knowledge points of each courses related to the system experiment, and listed the overlapped teaching content in each courses, found back the connection content missed before between the consequence courses. In the teaching process, these courses are planned unified and cooperated with each other.

The computer system experiment mainly involves Digital Logic Circuit, Assembly Language, Computer Organization, Operating System, Compiler Theory, these five courses. In order to meet the requirements of the computer system

experiment, the experiments of these courses were analyzed and adjusted, focusing on the interconnections of the contents between the course experiments. The detail adjustment contents is shown in Table I.

These adjustment of the entire experiments is intended to link up the experimental teaching contents in each courses to form a complete computer system experiment. This system experiment will strengthen the training of computer system capability.

B. System Experiment Design

The computer system experiment is a complex system level experiment. The students need to design and implement a complete computer system. They should complete several stages in each course, and in the Computer System Design

TABLE I. ADJUSTMENT AND OPTIMIZATION IN EXPERIMENTS

Course Name	adjustment or optimization content
Digital Logic Circuit	<ol style="list-style-type: none"> 1. Strengthen the experiments of using programmable logic device, including gate level to component level design 2. Emphasis on the experiment of the computer component. 3. Learn how to use the corresponding EDA tool for complex system design.
Assembly Language	<ol style="list-style-type: none"> 1. Introduce the assembly language as the interface and connection of the hardware and software system. 2. Add MIPS instruction set experiments, including interrupt and exception handling, virtual memory management, etc. 3. Add the experiment of typical C code expressed in assembly language level and the disassembly experiment.
Computer Organization	<ol style="list-style-type: none"> 1. Design and analysis of instruction system based the MIPS instruction set 2. The design and implementation of a simple computer systems, in which the CPU at least supports the subset of the designed instruction set with Multi-cycle or pipelined. 3. The designed CPU should support interrupts, including soft interrupt and hardware interrupt. 4. Add the TLB experiment of the virtual memory management.
Operating System	<ol style="list-style-type: none"> 1. The designed instruction set / processor in Computer Organization course is the target platform of the operating system. 2. Strengthen the combination of operating system theory and experiment. Require to complete a simplified mini OS that can be able to work on the real hardware platform. 3. Emphasize that the core algorithms of each experiment can form an organic whole. The experiment will use its previous experiments code, and eventually form a complete small operating system.
Compiler Theory	<ol style="list-style-type: none"> 1. The designed instruction set / processor is the target platform of the compiler. 2. Implement a compiler that supports the experimental platform used in previous courses. 3. Add the experiment of optimization for the specific experimental system.

course they will eventually integrated previous experiments to form a complete computer system. So, the relevant courses should adjust the experimental system and experimental content, treat their own experiment as the module or base of the final comprehensive system experiment.

Assembly Language and Digital Logic Circuit is the experimental foundation courses, providing an experimental basis for other courses; the experiments of Computer Organization, Operating System and Compiler Theory will become the parts of computer systems. The experiments of Computer Organization will implement the basic hardware, and Operating System experiments will be the software parts. The following are the experiments of these two courses.

The experiments of Computer Organization will implement the hardware part of the system experiment, with three-level experiment contents: verification level, design level and comprehensive level experiment content. The final experiment is to design a computer hardware which can run an assembly program called monitor program that can manage the hardware resources of the experiment platform.

Lab 1 (Instruction Set Lab). This is a verification experiment, writing the assembler language programs in the simulator using the instruction set for the designed CPU. This experiment is in order to let the students be familiar with the instruction set and understand the function of the simulator and monitor program.

Lab 2 (Component Lab). Design and implement the ALU. Let the students learn the basic ALU design methods and data path, and to be familiar with the hardware experiment platform. The designed ALU will be used as important component of the CPU in the following experiments.

Lab 3 (Memory& IO Lab). Design a state machine to access the memory and IO on the platform. It is a design level experiment, which will help the students to comprehend the memory access timing and learn how the data exchanged on the bus.

Lab 4 (Hardware System Lab). Design and implement a complete computer hardware system on the platform, and the monitoring program can run upon the designed hardware CPU core. A data transfer program will load the binary code of the monitor program directly into the memory, and then the designed computer will run the monitor program, which will communicate with PC. This experiment is a comprehensive experiment that allows students to learn how to design an underlying hardware of the education computer, and this computer should support the OS in the Operating System course.

Operating system is the basic software in the computer system, and it is tightly integrated with the hardware[8]. In order to support the hardware designed in Computer Organization, Operation System course's experiments were based on ucore OS and transplanted to the new platform[9].

Lab 0 (experimental operating system environments and tools).It aims to let the students understand and become familiar with the tools and process in the whole course experiments, including kernel debugging, simulator, etc.

Lab 1 (startup process). It will implement the bootloader for loading and running the operating system, in order to understand the process of starting the bootloader, bootloader's files, the boot process of the ucore OS, and interrupt handling mechanism.

Lab 2 (physical memory management) & Lab 3 (virtual memory management). These labs will help the student to understand how the system manages the memory.

Lab 4 (kernel thread management)& Lab 5 (user process management)& Lab6 (scheduler)& Lab 7 (synchronous mutex). These labs will help the students understand the process of the kernel thread creation and execution, and understand how to implement the context switching.

Lab 8 (File System). It requires the students to understand the file system and its implementation technique.

After these labs, the students will grasp a simple operation system of ucore in the simulator, and in following course they will run it on their designed hardware.

C. Experiment Platform

The unified planned system experiment needs a unified platform to support the experiment deployment. This platform need to support each course experiments, and can support the comprehensive computer system experiment as well. The platform includes not only the actual hardware circuit board, but also the software tools, which contains the debugging tools, simulator, assembler, compiler and other tools. All of the platform should support a simple, standardized instruction set. So we choose about 50 MIPS like instructions as our instruction set, and designed the circuit board, named THINPAD(TsingHua mINi PAD)[10], as the hardware carrier. We also developed some software tools, including system simulator, assembler, compiler, terminal program and etc. And we have run the teaching operating system ucore on this platform. In addition, the corresponding compiler was developed. The program generated by this compiler can be run in the ucore. Thus the system experiment platform was established and has been used in the course experiment teaching.

1) Hardware platform.

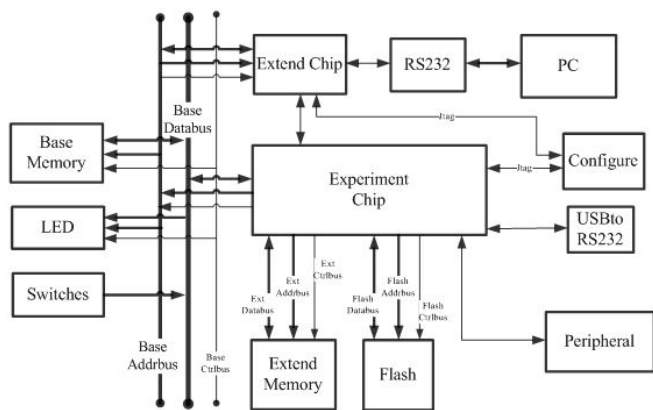


Fig. 1. Example of a figure caption. (figure caption)

The figure 1 is the composition of the hardware platform. The circuit board uses the programmable logic device as the experiment carrier. This programmable device is a FPGA, which is the experiment chip that will act as the CPU of the experiment computer system. The students need to design and implement a CPU using the EDA tools, and configure the design into the experiment chip. The platform provides two separate memory sections(Base Memory and Extend memory), act as the instruction memory and data memory. The flash is used to store the operation system and RS232 interface is the input/output of the experiment computer. And there are several peripherals to help debugging, such as LEDs, switches. these devices like SRAM memory, Flash memory and other peripherals are all connected to the experiment chips via several buses.

2) Software tools

For the system experiment and the hardware platform, we developed several software tools to help the students completing the experiment. The following is the main tools:

a) *Instruction simulator.* This simulator can help students complete software simulation and debugging. The students can use this simulator debug their assembly program, avoiding directly debug on the hardware platform.

b) *Assembler.* This assembler can convert assembly language to binary code of the hardware platform. This tool can help the student to write some simple assembly program for their designed computer system.

c) *Data communication program.* This program can load/store the data or program into the memory/Flash on the board.

d) *Monitor program.* Before running the operating system on the hardware, this program is a relatively complex program which can be a preliminary test on the hardware system implementation. It can work as a mini operating system to manage the platform's resources and testing programs.

e) *GCC compiler.* As the operating system is written in C, the GCC compiler can compile the operating system to the instruction set. Of course, this GCC compiler was modified for experiment platform, and it only used for the operating system (ucore) compilation.

f) *Hardware simulator:* This simulator is a hardware simulator which is specifically designed for our experiment CPU. In this simulator, the student can get the signal value of the designed hardware.[11]

D. Computer System Design Course

In order to integrate the experiments of system related courses, we add a new course in the curriculum called Computer System Design course, which is an experimental opening course. This course has been selected as the Challenging Courses of Tsinghua University.

After completion of previous courses, the students will use the knowledge learned in Digital Logic Circuit, Assembly Language, Computer Organization, Operating System and

Compiler Theory, etc. to design and implement an integral simple computer system independently in this course. It will improve the students' problem solving skills and the computer system capacity.

E. Experiment Process and Evaluation

The system experiment involves several courses' experiment. In each course, the students need to finish a part of experiment which will be prepared for the next course experiment. As the system experiment is very complex, so it need the students to complete in team work. They will keep working together in the whole system experiment, which will improve their communication and collaboration skills.

The final experiment evaluation contain two aspects:

One is on-site checking, the teams need to show their experiment to the teacher or TA, that is running their experiment computer on the platform. The teacher or TA will check whether they have implemented the basic function required and validate whether their computer can run the operation system (ucore) and the testing programs successfully. And if they have completed some additional functions, they will get some extra points on their scores. At last the teacher or TA will give an evaluation result of their experiment.

The other is presentation, each team will give a presentation to other teams, and these teams will give a evaluation result for this presentation. Because the students doing the experiment together, they will know each other more clearly. And the presentation will improve their express ability.

Thus, Combined these two evaluation result, our evaluation will be relatively fair.

IV. ACHIEVEMENTS

The computer system experiment has gradually carried out in the undergraduate teaching of the Department of Computer Science& Technologies, Tsinghua University. The teaching experimental platform has been used in the course experiments, and got good results. Some students has completed the system experiment: the ucore has run on their



Fig. 2. Computer system implemented in experiment

designed CPU, and some applications can be compiled by their own compiler and running successfully in the system. After complete the real first computer system, the students have an enormous sense of achievement. Figure 2 is a computer system implemented in the experiment course, which is running a slide shown program.

Through the computer system experiment, the students generally reflect that they understand the computer system more deeply and this experiment is good for their comprehending the knowledge in these corresponding courses. All courses use the unified experiment platform brings more convenient for the students experiments. The computer system experiment gave them a platform to use their knowledge and skills, and it helps them get more profound understanding of the mechanisms and principles of computer system.

V. SUMMARY

Computer system capacity training is an important target for computer undergraduate teaching, in which experimental teach plays an important role. Dept. CS&T Tsinghua University explored several years on it and established an experimental system, which has been deployed and got some achievement in the teaching process. Through this experimental system, the students' computer system capability has effectively improved.

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Helping Undergraduate Engineering Students Discover Their Interests (and Reduce Their Fear of Research)

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Abstract – In recent years, there has been an increased emphasis on undergraduate research. High tech companies need research to keep them competitive. This paper addresses the issue of getting engineering and computer science students interested in focused engineering and computer science areas so they are excited about these topics and want to learn more by doing research in that area. Our method is to encourage the student to research and write an interest paper as a first step to writing a proposal to seek and do organized research. In order to evaluate this approach, a survey was completed by 57 students in an Academic Success and Professional Development class who were assigned the writing of an interest paper in engineering or computer science. Results show that the assignment was successful for some students in leading them to an area of research in which they were interested and in other cases learning that they were not that interested in a particular area. Other students found a second interest. In this assignment, some students used an engineering data base for the first time.

Index Terms – Undergraduate Engineering and Computer Science Students, Research, Increasing Interest in Engineering Topics

I. INTRODUCTION

In the past, most undergraduate engineering and computer science students would earn a Bachelor's degree and go to work in industry without having interests in any particular subfields or having done any organized research. However, in recent years, there has been an increased emphasis on undergraduate research. Companies relying on good research to keep them competitive want students who are interested in their type of work and research. Although students used to use internships to help determine their interests, many company recruiters are now asking perspective interns about their interests. Some recruiters do not pursue students who do not know what interests them.

This paper is written in the context of an upper division Academic Success and Professional Development two

semester credit class with 66 students. The class is supported through an NSF S-STEM grant 1060226 and STEP grant 0856834. The course is taught within the Ira A. Fulton Schools of Engineering at Arizona State University (ASU) and includes all engineering majors, as well as computer science. Henceforth in this paper the term "ENGR" will include engineering and computer science. The students who attend this course are S-STEM and STEP scholarship students, transfer students directed by academic advisors, and students who have heard of the course from friends or by general word-of-mouth. The course credit does not count on a Program of Study, but the grade does count in the GPA.

The students are taught academic, professional development, and management-like (soft) skills that are often times left out of normal class sessions due to time constraints. These topics include: detailed time management, learning how to learn through the Guaranteed 4.0 Plan [1], career planning, how to prepare for and work a career fair, portfolios, internships, graduate school, and research. Although the authors are convinced that doing research is good for all ENGR students, it is difficult for many students to get involved in research because they do not know what really interests them, they do not understand what research is, and they believe that they will never have to do it. If a student is interested in a particular topic, it follows that s/he will be much more likely to want to learn more about that topic, schooling becomes more relevant, and the student is more likely to be retained. The Academic Success students are taught that "if you don't decide on an interest, someone else (industry) will decide for you, and you may not be too excited about their choice." Our emphasis on research is to help a student find a career doing something about which they are challenged and excited.

A majority of students in this class are upper division transfer students from local and rural community colleges. Many of these students only recently decided on engineering and do not have any particular interest areas. For most of these students, research is not in their background. For many, the transition to a large university is challenging and survival is on their minds, not particular engineering interests. Although talking about interests and research may motivate some students to pursue a research project, getting students actually

involved in research has proved to be difficult. Being able to come up with a new technique, a new idea, or an improvement on an idea seems overwhelming to most students. Encouraging students to talk with professors whose work interests them seems to be difficult since the student doesn't know what interests them. This is true even if they are instructed that just comparing two different ways of solving a problem can be "research." Along with a fear of not being able to do anything new, there is also a general attitude of "I did research once and I don't like it." Upon examination, the authors learned that usually the student was not really involved in research, but was merely a project helper and was not given anything meaningful to do. The authors have tried to engage the students in research by assigning them a research paper or proposal, with references, and giving them an outline on how to write it. [2] For some students this was overwhelming and they dropped the class rather than having to write such a paper. In fall 2014, a different approach to the assignment was tried by calling the assignment an "interest paper" and relaxing the requirement that the student propose a new research step at the conclusion of the paper.

A survey was given at the end of the semester to the students to determine if the new assignment was helpful. The survey asked if the assignment helped the student to learn to find engineering references and to find or to change a particular engineering interest. The students were also asked for suggestions on assignment changes that would help the student. As expected, the outcomes are mixed, but the majority of the class found the assignment to be useful and some students were able to find an interest.

A literature search to highlight work that has been done on undergraduate and graduate students doing research is included.

II. Background

A question that is commonly asked by students is why should I have to do research? I don't plan to go to graduate school. I plan to get a job in industry and I don't expect that I will ever do research. As an answer to these questions, we talk to them about research and why it is likely to be a part of their life someday as ENGRs.

Student involvement in research is good for ENGR and it is good for the individual student. It is good for ENGR in that students who become interested and involved in their major are more likely to stay in their major. [3] Research can be part of a retention strategy. If a student becomes involved in research in an area that is interesting, challenging, and fun, that student is very likely to stay in engineering and go on to graduate school.

However, our emphasis in the course and this paper is to help the student understand the advantages of learning how to do research and to actually do research.

For students going on to graduate school, research seems to be a reasonable activity in which to become involved as an undergraduate. Certainly students understand that if they seek a PhD, they will have to do original research. If students can become involved in research with a professor as an undergraduate, perhaps that research can continue into graduate school for the student and the research work can be funded and pay for graduate school. If the student finds an area in which they are interested, then this may take care of two major graduate school concerns: a topic and funding. Students doing a Master's degree with a thesis, report, or applied project, are ahead of the game if they have identified a research area before they begin graduate school. We recognize that doing research is not a prerequisite for a Master's degree. Many colleges and universities have a pathway to the Master's degree that requires some 30 hours of appropriate credit hours of classes and then a written comprehensive exam in lieu of a thesis or thesis substitute. Becoming involved in research early can also be very helpful for the Honors College student who writes an honors thesis. Knowing how to do research and finding areas of interest can make the writing of a thesis easier.

Another advantage of research is that there are research awards to help fund undergraduates and graduates. At ASU, for example, we have FURI (Fulton Undergraduate Research Institute) awards of \$1,500 per semester. Students find a faculty advisor (who advertise on the web that they are willing to work with undergraduate students in certain areas of research), write a proposal, and, if selected, obtain funding for approximately 10 hours of work per week during the semester. [4]

There are many other advantages of doing research. Having done research and having publications make a strong resume to help in obtaining an internship or job hire. Research and publications are considered minimum requirements for some graduate fellowships and scholarships. We have seen our students singled out for an interview and position because the research listed on their resume complements a research area of the industry or graduate school.

Having done research either as an undergraduate or as a graduate student should also help the student to be able to do more research in their career, if they desire, in industry, government, or a lab. Research is good training for industry. Companies are always looking for better ways to do things. When an engineer puts forth ideas on how something can be improved, he/she will need to do research to understand the status quo, what other ideas have been tried, and show that the suggested improvement is viable. Engineers may be given an assignment for which they do not have much background. They may need to do research to learn more about the project and to determine what solutions are already available.

Research is fun. The excitement of new discovery, of using your background to develop something new and helpful to

people, is fun and exciting. Our students give testimony to this over and over and make excellent role models for others students to follow.

III. Literature Review

Amekudzi and Meyer [5] develop research and information skills in Civil Engineering undergraduate students through a 300-level course that they teach. They emphasize the importance of students gaining information knowledge and skill sets through information structure, information access, and information integration. These skills are needed for the students to be able to write a paper on comparative systems analysis with project examples. The authors learned that students are eager to learn where and how to find scholarly or authoritative information if opportunities are provided for them. They also suggest that “to benefit every student, it is would be helpful for some students, especially transfer students, to attend a library basic introductory class before coming to the course-specific information workshops. [5] They note that their methods are applicable in any area of engineering.

Another paper along these same lines was written by Rockland. [6] “Because of the vast amount of data currently available, students need assistance developing an approach to gather this information. Without a proper plan on how to obtain information, they will waste countless hours, and become very frustrated at the process.” [6] The paper suggests a hierarchy in using various methods, depending on the type of search required. The author suggests that for general technical information, students check the *National Engineering Information Center*, which is part of the ASEE website (www.asee.org/neic). Additional sites are also recommended. Specific insights are given for product information, company searches, patents, mathematics, and biomedical engineering. [6]

There are several ways for students to actually get involved in research. One common way is through summer research programs such as the Research Experience for Undergraduates (REUs) sponsored by the National Science Foundation at universities across the nation. This is a great experience for the students, but may be an actual “brain drain” for minority-serving institutions. Summer research programs certainly benefit the host institutions in terms of research done at that time and the potential to bring the participants back as graduate students. On the other hand, for minority-serving institutes this may be an “erosion of the capacity to develop talent.” [7] It should be noted that, in general, there are many more applications than positions for these awards.

How to prepare students for engineering research is a problem of broad concern, without much research on the subject. For example, at a Software Engineering conference, a session was held entitled, “Preparing Students for Software Engineering Research.” The discussion included the needs of industry and

the preparation of graduates for professional careers, as well as how to support students who plan to do research in a particular area. [8]

Rogers and Goktas explored the research proficiency of engineering graduate students. In 2007, more than 25 percent of PhD students did not complete their program, suggesting that research for them was not a good experience. Although many reasons can be given for this attrition, lack of written and communication skills, inadequate mentoring, and barriers for certain underrepresented demographic groups, and little attention paid to the actual research experience are included. [9] They administered a survey for two years to both master’s and PhD students. Their primary conclusions were that “many students indicated that they lacked research preparation upon beginning graduate study and during the first year of study, lacked development in important research skills like statistics and communicating in writing, and were somewhat hindered in research organization and progress. Regarding academic motivations, students generally valued personal advancement and enrichment over paper publication. Doctoral students overall indicated more preparation with respect to several aspects of research and more value placed on paper publication than did master’s students.” [9]

A team of researchers looked at student’s beliefs about research, relative to sex differences, personality, and career plans. They were particularly interested in learning if understanding how students consider research could explain the low percentage of women in undergraduate engineering programs and academia. [10] Woodstock, Graziano, et. al looked at Person-Thing Orientation which has been shown to be a factor in gender differences of vocational interest. [11] In addition, Thing Orientation has been found to be a dispositional predictor of persistence in engineering. [12] Woodstock’s team surveyed 297 engineering major students. They found that there was no statistical difference between men and women in the percentage of Person Orientation. [10] However, there was a statistical difference between men and women in that a larger percentage of men had Thing Orientation. A second conclusion of their research was that “engineering students’ beliefs and expectations about research and researchers will be associated with their desire to pursue a research career” and that “Thing Orientation will influence students’ beliefs and expectancies about research.” [10]

Studies have also been done on the effect of research on the student including self-efficacy, satisfaction with the major, confidence, motivation, recruitment, and retention. For example, Ragusa and Lee [13] showed that focused degree projects resulted in increased efficacy in the area, as well as increased student satisfaction, and increased student retention. Seevers et al [14] showed that undergraduate research and internships increased student confidence and motivation. Further, Rabb, Nowicki, and Bristow showed that

early research experience had an impact on recruiting and retaining students in engineering. [15]

While these studies are related to our study, it should be noted that when we speak of a student with an interest area, we do not imply that the student is necessarily interested in a career in research.

IV. The Survey/Methodology

We built our survey using grounded theory. We have worked with upper division ENGR students for 13 years. During these years we have had many conversations with these students about their reasons for choosing and staying in ENGR. In addition, we have researched and surveyed ENGR students over these years. For example, we know that a third of our community college (CC) transfer students only decided on ENGR after they were at the CC. [16] We also know that next to lower tuition and proximity to home (to save money on room and board), not having decided on a major is the largest reason for attending a CC. [16] A major goal of our work with these students is to graduate them and to have them go right on to graduate school. Our efforts with both native and upper division transfer students have resulted in a current graduation rate of 95% and a rate of 50% for students going directly to graduate school in ENGR (rather than a 70% graduate rate and about a 12% graduate school attendance rate for upper division transfer students). A part of the success has been due to our stress on the importance of research and graduate school.

The students in the Academic Success and Professional Development class were asked to complete a survey in order to evaluate the assignment of writing an interest paper. Of the 66 students in the class, 57 (86%) of the students responded. The purpose of writing an interest paper was to help students define a special area of interest to help guide their career. The students were asked to research and to write a paper about an interest of theirs, but were not required to propose actual new work as in an actual research proposal. We note that writing an interest paper is not “doing real research” in the traditional sense, but it is hopefully getting students interested in new areas and to think about doing research.

We asked the students several demographic and background questions, including their participation in internships, research, and intent to go to graduate school, since this is an emphasis of the Academic Success Class. Relative to the interest paper, we wanted to know if the student had an area of interest before writing the paper, and if not, did the interest paper help to define an interest area. We also asked if the paper helped define an interest area for the first time, defined a new interest area, or the student discovered an area in which there was no interest. We also asked for suggestions on improving the paper assignment. The last two questions were how important the student thought it was to find at least one area of interest as soon as possible and how the student would

judge the interest paper assignment relative to their professional development.

V. Analysis of Survey

Some students did not complete each question, so the number of responses per statement varies. Of the 57 students who completed the survey, 10 (17.5%) of the students were females. Forty-five (78%) of the students were transfers. The distribution of students by academic level were: 11 sophomores, 25 juniors, 13 seniors, and 8 graduate students. Most of the “sophomores” were transfer students who were in at least their third year of college, but who were considered at the sophomore level in regard to engineering courses. The average age of the students was 25 with a range from 19-49 years. Twenty-seven (47.4%) or nearly half of the students had had an engineering or computer science-related internship, most of them during a summer.

We then asked the students how many semesters they had been at ASU and for how many semesters they had taken the FSE 394 Academic Success Class. Also included in this count were semesters spend in a similar one credit Academic Success Class for lower-division students, primarily native students. The results of this tally are shown in Table 1. It should be noted that most of the transfer students start this class in the fall which is their first semester at ASU, although a few postpone the Academic Success Class until their second semester at ASU. A few transfer students start ASU and the success class in the spring. For these reasons, there are fewer students at the second and fourth semester level. Note that only 23 of the students were in their first or second semester of the class and thus writing their first interest paper.

Semesters	1	2	3	4	5	≥6	Total
Number Students At ASU	13	2	12	2	14	14	57
Number Students in Class	17	6	15	0	8	11	57

Table I. Semesters at ASU and in Academic Success Class of Survey Takers

To the question, “Have you done Research?” Forty percent (23) of the 57 students said yes. Seven of these 23 students had published a paper (4 graduate students and 3 undergraduate students). Table II shows the type of research setting for the students. The WAESO research grants are offered regionally and each student team must include at least one underrepresented minority student (Black, Hispanic/Latino, Native American). It should be noted that several of the 23 students who did research had more than one research experience; hence the number of experiences is more than the number of students who had done research.

Type of Research	Number of Students
Fulton Undergraduate Research Institute (FURI)	10
Lab	8
Western Alliance Expanding Students Outreach (WAESO)	5
Research Experience for Undergraduates (NSF REU)	2
Other: Independent or based in Industry	7
Total	32

Table II. The Number of Research Type Experiences by the 23 Students Who Did Research

Next we looked at the number of students who did research according to the number of semesters at ASU and the number of semesters in the Academic Success Class. Table III gives these statistics.

Semester	No. Researchers per Students at ASU	Number Researchers per Students in Success Class
1	3/13	4/17
3	4/12	7/15
5	6/14	3/14
≥6	10/14	9/11
Totals	23/53	23/57

Table III. Number of Students Doing Research According to Semester at ASU and Semester in the Academic Success Class

There were no students doing research that were in either their 2 or 4th semester at ASU or in the Success Class. In general, we see that the longer the students are in the class, the more likely they are to do research. The students hear about getting interested in a topic, doing research, and going on to graduate school continually throughout the Academic Success classes.

As part of the class assignments, the students are told to visit an engineering librarian to learn how to access ENGR data bases if they do not already know how. For the interest paper assignment, they need to have 10 references. Using data bases will help the student find more appropriate references, but a student could find references through Google or other means. We asked the students if they knew how to access engineering data bases before they wrote the interest paper and if they knew how to do this after they had written the paper. Table IV shows the results.

Know how to access engineering databases?	Yes	No
Before interest paper	35	20
After interest paper	50	3

Table IV Number of Students Who Knew How to Use an Engineering Database to Find References “Before” and “After” The Interest Paper

Looking at Table IV, it is clear that we were successful in having almost all of the students understand how to access information through an ENGR data base. Only 3 of the students still did not understand this activity after the assignment. It is surmised that these students did not take the time to visit the engineering librarian. Two of the papers [5, 6] in the literature review emphasized that students need help in this area.

Next we wanted to learn if the assignment helped students find an interest area for the first time, or found an additional interest, or determined an area in which they are not interested. Seven of the students who said that had no area of interest in ENGR, said that they had an interest area after the paper assignment. Other good results from this exercise are that 21 students learned of a new area in which they are interested and 9 students learned of an area in which they are not interested. See Table V for details.

Have an area of interest in engineering or CS?	Yes	No	No Response
Before interest paper	41	15	1
After interest paper	46	8	3
Helped find an additional interest	21	35*	1
Learned of an area in which they are not interested	9	46	2

Table V. Number of Students Who Have Interest in One or More Areas of Engineering or Computer Science

*One of these students went into more depth in area of interest

As an additional check on the students’ interests, they were asked if, at the time of the survey, they had an area of interest in ENGR (independent of an interest paper). Only 6 students said they did not. Most of the students (87.5%, 49/56) intended to go to graduate school.

The students were asked if the interest paper assignments could have been better constructed to better help the student find an interest or additional interest area. See Table VI for the results.

	No	Yes	No Response
Better Constructed?	40	15	2

Table VI. Student Responses to the Question: Could the Interest Paper Assignment Have Been Better Constructed to Better Help Find an Interest or Another interest?

Although 70% of the students seemed satisfied with the assignment as given, it is interesting to note the suggestions for improvement given by the students. The students were also encouraged to give comments about the assignment at the end of the survey. Only a few had suggestions and they mostly related to making the assignment easier, although one student implied that they could have been asked to do more research.

The student suggestions for improvement of the Interest Paper Survey can be put into two categories as seen in Table VII. The comments in the two columns of the table are independent. The first category is changing the assignment. A first suggestion in this category is that students without an interest area be asked to do several smaller papers. It is not clear to the author how this would help the student to really explore the steps that are needed in research, but breaking the assignment up into smaller steps and cover more of the semester is certainly a legitimate suggestion. The suggestion of having the assignment be different for different students is valid. The instructions need to be clear that the second time a student does this assignment for this class, they should write an actual research paper or proposal.

The second suggestion of using only an outline may make it easier for the student, but again allows the student to go in less depth. Suggestions 3 and 4 under this category both have to do with making sure there are enough references for a topic, since the paper requires at least 10 references. If the students follow the instructions to use an ENGR database, they can quickly discover how many references are available. Usually the student will need to use this tool to narrow down their topic, since an inquiry, say into “solar energy,” can produce thousands of references.

Improvement Ideas for Interest Paper Assignment	
Alternate Form:	More Help with Paper
1.Allow those who haven't found an interest to do several small papers	1.Outline trigger questions
2.Writing an outline for a paper comparing several potential interests would be more beneficial and less mind numbing	2.Provide topics from which to choose
3.For first assignment pick 5 areas and do a brief search to see if there are plenty of references	3.Maybe a little clearer details needed. I ended up doing it wrong twice
4.Encourage a consultation with a professor about the topic; it would be very helpful to narrow on a topic and see if it relates fully to research I could be doing	4. Better instructions
5. If you have an interest, you have probably looked into it already; it should make you look at other things to expand horizons	

Table VII. Improvement Ideas for the Interest Paper Assignment

A goal of the assignment was to get the students to apply for a research grant such as the FURI, WAESO, or REU. If they have not done this, then we want the student to research their interest and to be able write about a contribution that they

could make in the field. The students were also told that if they were already doing research in an area and were interested in exploring another area, then this paper is a good opportunity.

The first two suggestions for making the assignment easier are asking for more directions. An outline of a research paper is made available to the students. Suggestion 2 is contrary to our intent to make the student think about their own interests, not follow someone else's. The two suggestions asking for better instructions will be noted. The paper is discussed in class, but perhaps a more detailed written description of the assignment is needed. In the instructions for these students, they were asked to first write an interest paper based on 5 references, then to add 5 more references and expand the paper. One student commented in the survey, that it would be easier to have the first assignment be to find at least 10 references and then to write the paper in a second assignment. This suggestion will be incorporated with the next assignment. We believe that if we can help a student write one research proposal, then it will be much easier for them to write a second one.

The students were asked how important they thought it was to find at least one area of interest as soon as possible. Table VII shows these results and suggests that the students understood the importance of the assignment.

How important is it to find at least one area of interest as soon as possible?					
Importance	Very Important	Some what	Neutral	Un Important	No Response
Number of Students	35	18	2	1	1

Table VIII. Number of Students by Level of Importance of Finding at Least One Area of Interest in Engineering or CS

A final question the students were asked was: “How would you judge the interest paper assignment relative to your professional development?” Their responses are in Table IX.

How would you judge the interest paper assignment relative to your professional development?						
Rating	Excellent	Very Good	Neutral	Not Good	Negative	No Response
Students #	12	27	14	1	2	1

Table IX. Ratings by Students of Interest Paper Assignment Relative to Their Professional Development

The positive responses in Tables VIII and IX would make it appear that most of the students understood the importance of the assignment and research, although some were not convinced.

Finally, the students were asked to comment. The comments in general corresponded to their rating. Those who felt the assignment was good for them stated: "It was insightful," "I would love to take my interest paper and put it into my portfolio," "It was interesting," "It was very helpful in further preparing me for my honor's thesis," "I like the assignment, it helped me really think about what I want to do," "Great, forces you to get out of comfort zone," "I enjoy the interest paper, it is a lot of great information," "I enjoyed learning about research and how to research topics, different topics that I am interested in," "It was useful to get interested in a topic in multiple ways, it was good for interview scenarios, and finding something to be passionate about," and "Thought it was great."

Those who had difficulty with the assignment were of course more negative: "I didn't really learn anything from the paper since my interests aren't very well defined," "It became an annoyance rather than something that excited me to action," "Just make sure it is more clear on Blackboard. No worries though," "I had no idea where to start and the instructions were unclear," and "Split up the assignment weighed the same each week."

The maturity shown by most of the students on this type of assignment is encouraging. Some students need to take the course a couple of times in order to be convinced that the assignments are all designed for their own good. The interest paper assignment is only given in the fall semester. Even though it is a difficult assignment for first semester transfer students, we want to get them involved in research as soon as possible in order to help them to get research funding, to strengthen their resume, and to help with interviews for internships. One student commented, "All of the assignments have been helpful."

VI. CONCLUSIONS AND FUTURE WORK

The "interest paper" assignment will be given again in the Academic Success Class next fall. Some changes will be made in the assignment. The students will again first be asked to visit an engineering librarian to learn about using ENGR data bases, if they do not already know. Their first assignment for the paper will be to find a list of 10 appropriate references.

The students will be encouraged to talk with the transfer students who work in the Transfer Center, who are available to help students, have taken the course, and have completed the assignment. They will also be reminded to talk to the course instructor if they are stuck or overwhelmed by the assignment. As a result of this survey, the instructor will make a point to talk more with the students about the interest paper assignment and try to determine if they need additional help. Sometimes new transfer students have a difficult time asking for help when they need it. The instructor will also review the assignment to make sure that the instructions are appropriate for students by how many times they have already done it.

For the students who want more help with choosing a topic, they will be reminded to look on the web for professors who are willing to work with students on a FURI grant proposal and whose area of research is listed. The students are also told to look up the research of professors that they are particularly interested in and to read about their research on the ASU web.

The conclusions drawn from the survey show that the assignment is working quite well in accomplishing its goals. Only 23 of the students in the class were doing the assignment for the first time. Before the assignment 20 students did not know how to use an ENGR data base. After the assignment, only 3 students in the class said they did not know how to use such a data base. Only 15 students did not have an interest area before the assignment; five of these students had an interest area after the assignment. Another nice result of the assignment was that 21 students, who already had at least one interest area, were helped by the assignment to find an additional interest. Nine students learned of an area in which they are not interested, which is good information when deciding on the type of industry in which they might have a career. Using some of the suggestions by the students should make the assignment even more effective.

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Developing an Ecosystem for Student Success in Engineering in Rio South Texas

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Abstract—The University of Texas-Pan American (UTPA) faces some unique regional challenges that hinder retention, success, persistence, and progression. These regional challenges include reduced college preparedness, a high incidence of poverty, low educational attainment, and a language barrier. In particular, first-year, first-term UTPA students are largely unprepared to take Calculus. This places an undue burden on the students, lengthens their time to graduation, and hinders their performance in many gatekeeper courses. The shortcomings that result in gatekeeper courses are especially acute and significantly hinder success in upper-division courses. To overcome these, the authors have identified four proven practices that will accelerate math-preparedness of incoming freshman, overcome misconceptions that hinder progression from lower to upper division, and enhance sustained student engagement throughout. Together these practices form a strategy intended to engender a sustainable ecosystem of student success in Engineering and Computer Science in the Rio South Texas Region.

I. INTRODUCTION AND BACKGROUND

Driven by the emergence of Rio South Texas as a leading manufacturing hub that requires increasing numbers of engineering graduates, the University of Texas-Pan American (UTPA) has established collaborations to increase participation of high school and college students in Engineering. It serves a population of students that present both challenges and enormous potential. To address both, faculty members from the College of Engineering and Computer Science, the College of Science and Mathematics, and the College of Social and Behavioral Sciences have devised a series of coordinated activities intended to instill a sustainable culture of student success in the College of Engineering and Computer Science.

UTPA is located in Edinburg, Texas, where it offers degree programs leading to professional careers, continuing education, and services designed to improve the quality of life in the seven-county Rio South Texas Region through research and community engagement. With a recent (Fall 2014) enrollment exceeding 21,000 including approximately 2,300 Engineering and Computer Science majors, the university is the eleventh largest in the state and the sixth largest in the University of Texas System. UTPA has the nation's fourth highest enrollment of undergraduate and graduate Hispanic students and is

ranked eighth in the number of Engineering bachelor's degrees awarded to Hispanics [1].

Three key challenges this project is designed to overcome are

- 1) Rio South Texas Region public school students lag behind in rigorous course-taking and accomplishment essential for success in postsecondary STEM coursework;
- 2) Rio South Texas has a high incidence of poverty and low educational attainment, which negatively impact persistence in postsecondary education, especially in STEM coursework; and
- 3) The Rio South Texas Region is predominantly Hispanic, a population severely underrepresented in STEM majors and careers.

High school students from Rio South Texas are significantly less likely (34.2%) to meet the criterion score of "3" on Advanced Placement tests than students across the state (51.2%) [2]. Significant gaps in average college entrance exam scores (SAT/ACT) also exist between the Region's schools and statewide and national outcomes. There is an even more pronounced regional (10.0%) and statewide (26.9%) performance gap for students scoring at or above the Texas Education Agency's "criterion" scores indicative of "college readiness" (an SAT of 1110 for Critical Reading and MATH or composite ACT of 24) [2]. Nationally, Hispanics consistently lag behind their white counterparts on standardized tests, which are used in Texas for first-year Math placement. Amongst the Fall 2010 and 2011 cohorts, 27% and 34%, respectively, of the first-time, first-term Engineering and Computer Science students qualified to take Calculus I or II. In recent years, approximately two thirds (or greater) of incoming students are not Calculus ready. Finally, the percentages of Class of 2009 graduates from the area schools who met both of TEA's "college readiness" standards (English Language Arts/Mathematics) are significantly lower at 35% compared to 47% statewide. These measures are predictive of the number of students entering postsecondary education needing remediation.

Rio South Texas includes two of the poorest Metropolitan Statistical Areas in the nation, but is also one of the fastest growing areas in the US aspiring to sustain a growing manufacturing sector. 34.8% of its residents are below the poverty level, more than twice the State and national rates. The percentage of economically disadvantaged public school students in the region is even higher, at 85.6% [2]. Low levels of educational attainment also characterize the region. 85.1% of residents over the age of 25 have education completion levels below a baccalaureate degree, as compared to the state (74.7%) and national rates (72.5%). This means that only 14.9% of the target area residents have earned a four-year college degree. However, 34% of the population is under the age of 18 compared to 27.8% statewide and 24.6% nationally. Many parents of school-age children lack first-hand knowledge of the American public school and higher education systems. 80.2% of the population principally speaks Spanish [3]. Language, cultural, and educational barriers prevent many parents from providing the support needed by high school students to successfully avail themselves of opportunities for rigorous mathematics and science coursework.

According to the 2010 U.S. Census, 91.0% of the Rio South Texas' 1,544,713 residents are Hispanic [4]. The Hispanic population of the area's public schools is even higher, at 95.2% [2]. UTPA and STC have been engaged in efforts to facilitate student engagement and success in STEM which has led to a steady increase in STEM majors and graduates over the past dozen years. These activities have resulted in a number of articulation agreements that facilitate the transition of STEM students from regional two-year institutions to UTPA, and have enabled more low-income and non-traditional individuals to pursue Engineering degrees. The regional population demographics have provided a unique environment for identifying and implementing strategies that support the success of students in STEM, and, in particular, the success of low-income, first-generation Hispanic students. There is still, however, a significant need for more extensive interventions to reach the levels of success in STEM participation that would constitute closing the gaps. For these interventions to be sustainable, they must leverage existing activities that target recruitment, retention, and persistence. Both UTPA and STC have several existing programs that target recruitment and success of STEM majors.

II. PROJECT OVERVIEW AND DESIGN

This project is establishing a sustainable ecosystem of success in Engineering and Computer Science in the Rio South Texas Region by targeting major barriers to student achievement and creating opportunities for enhanced student engagement. To do so, the project leverages existing programs and resources. It brings together these resources in a holistic manner previously lacking and builds upon this foundation through four interventions. The interventions include

- 1) A targeted, STEM-focused, concurrent-enrollment program;
- 2) An entering-first-year, summer-bridge program;

- 3) Just-in-time, inquiry-based, supplemental instruction; and
- 4) Peer-led, mentoring and teaching.

These activities are intended to attract a greater number of quality students into the Engineering and Computer Science majors at UTPA, accelerate the preparedness of entering students who are not otherwise Calculus-ready, reduce the bottleneck in existing gatekeeper courses, and establish a sustainable peer-mentoring structure to support all the interventions. This will serve as a model for establishing and sustaining STEM success at minority serving institutions.

Activity 1: Targeted Concurrent Enrollment Strategies for Potential Engineering Majors. This activity establishes a streamlined process for providing precollege students already participating in a summer Engineering and Computer Science camp – the Texas Prefreshman Engineering Program (Tex-PREP) – the opportunity to partake in the summers prior to their Junior and Senior years in an Engineering-focused, concurrent-enrollment program that includes a residential experience and an engineering design project. This program, dubbed UPREP, provides precollege students an opportunity to advance and/or enhance their preparedness for an engineering or computer science program while earning college credits. Two special courses were offered to U-PREP students (College Algebra and English I) that considered the needs and special interests of future engineering students. The College Algebra section offered to these students catered to engineering applications and focused on skills needed later in Calculus and beyond. The English I section was designed to help develop technical writing skills.

Activity 2: A Summer Bridge to Calculus. The purpose of this activity is to accelerate the Calculus readiness of incoming students who do not test into Calculus. During the spring prior to their first-year of college, based on their math placement, students are offered the opportunity to participate in a Summer Engineering Bridge Program that includes accelerated Math preparation, a specialized college-preparedness curricula, and engineering design projects. Many students who have high school credit for Pre-Calculus or even Calculus do not place into Calculus based on entrance or college readiness exams. To leverage their prior experience in these areas and reward them for those concepts they have mastered, a special section of Pre-Calculus employing an emporium approach was implemented.

Activity 3: Enhanced Student Engagement and Guidance in Engineering "Gatekeeper" Courses. To improve persistence and timely progression, the authors have established, for key "gatekeeper" courses, specialized online and in-person recitations that target common misconceptions and improve mastery of key fundamentals. During the first year of this project, the authors have worked with instructor for Calculus I, Statics, Circuits I, Engineering Statistics, Chemistry for Engineers, and Computer Science I. Each instructor was tasked with creating and implementing interventions and supplemental course material. This was based on work previously conducted in Statics which included

- Lectures developed to review prerequisite material,

- Online homework designed to review prerequisite material and prepare for a pre-test,
- A pre-test to assess mastery and recall of prerequisite material,
- The development of metrics to identify at-risk students, and
- The implementation of an online course inventory conducted at the beginning and end of the course.

Activity 4: Student Peer Mentoring, Recruitment, and Teaching. Each of the activities will be supported through the work of peer mentors. As students progress, they will be taught and mentored by specially trained, upper-division students, many of who previously partook in the activities. They serve to connect the activities and provide a shared link that supports long-term sustainability.

As Figure 1 illustrates, Activities 1 and 2 provide two precollege paths – one targeted at increasing the number of high-achieving students who enter Engineering and Computer Science and another aimed at those who declare an Engineering or Computer Science major but who are not Calculus ready. As both cohorts transition into the lower divisions, Activity 3 provides interventions to help them master the fundamentals. High performers entering the upper division can become mentors in Activity 4 and serve as role models. This activity is a “feedback” to each of the others closing the precollege-college loop and lower-division-upper-division loop. The mentors supports Activities 1-3 through peer teaching. The interaction of students involved in Activities 3 and 4 supports the transition from novice to expert or mentee to mentor.

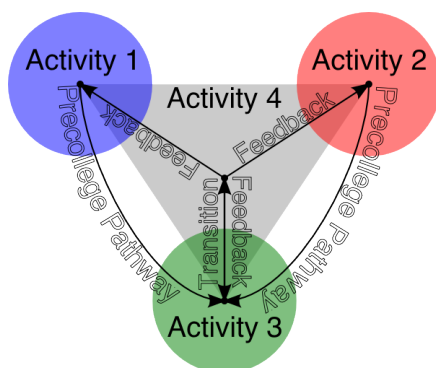


Fig. 1. Activity pathways and connections.

III. PRELIMINARY RESULTS AND OUTCOMES

The summer of 2014 was the first implementation of Activities 1 and 2. At this stage, it is rather early to gauge the longitudinal impact of Activities 1 and 2 on the matriculation and persistence of students in Engineering and Computer Science programs at UTPA. Nonetheless, participants are presently being tracked, especially those who completed the Bridge to Calculus.

Twenty two TexPREP students participated in Activity 1. Each completed six hours of college credit courses that contribute to a degree plan in Engineering or Computer Science. All but one of the students lived in the dorm for the duration of the program. The one student who opted out began staying at the dorm toward the end of the program as she recognized it was a comfortable and supportive learning environment. Six tutors, four mentors, and four resident assistants provided supervision, academic assistance, and social activities for the students. Eleven of the students were declared as engineering majors, four were undecided, and majority of the balance were other STEM majors. As we track these students over the coming years, we will determine how many remain or matriculate to Engineering and Computer Science majors. Additional details regarding preliminary results are presented [5].

Twenty two entering first-year students participated in the Activity 2 in the summer of 2014. All but five students successfully completed the course, four of which had significant job workloads. Of those that successfully completed, all but one went on to take Calculus I in the fall of 2014. The Calculus I pass rate – measured as the percentage of students who pass the course with a grade of “C” or above – for the Activity 2 participants was 63% compared to 49.3% in the general population. Still, the anticipated pass rate was higher. Hence, we are currently assessing what adjustments can be made to help the students optimize their performance in subsequent courses. Nonetheless, it should be noted that, based on their college readiness scores, most of the participants would have been placed into College Algebra fall of 2014. Instead, they successfully completed Pre-Calculus, and, as a cohort, performed comparably well in Calculus I relative to the general population. Additional details regarding preliminary results are presented [6], [7].

Regarding Activity 3, several key outcomes have resulted thus far due to the preliminary efforts conducted in Statics. A pre-test has long been used in Statics to assess students’ mastery of prerequisite material, and to identify students that may be at risk. However, historically, the average performance on these pre-tests has been poor, and there was little correlation between the pre-test results and general performance in the course. To better address the needs of this project, several co-authors experimented within interventions preceding administration of the prerequisite knowledge test (pre-test). These interventions include an online review and web-administered pre-test assignment and practice problems. This and careful design of the pre-test instrument has since led to a high correlation between the pre-test and final course grade. This was important because it serves as a key metric for identifying at-risk students who would most benefit from interventions include the supplemental instruction. Several other key factors for identifying at-risk students were also used. They include grades on the pre-test review assignment, GPA, performance in prerequisite courses, and class repetition due to failure or drop. Similar pre-test instruments are currently in development for Engineering Statistics, Electric Circuits I, Computer

Science I, Calculus I, and Chemistry for Engineers. During the summer of 2014, nine faculty members who have been involved with Activity 3 participated in a two-day workshop aimed at extending the practices adopted in Statics to the other courses previously mentioned. The practices used in Statics has resulted in improved pass rates. Previously the pass rate lingered around 60%. The pass rate in recent semesters has been around 75%. Details regarding related results can be found in [8], [9].

Peer mentors have been trained and imbedded in each of the previously mentioned courses. However, results show that while mentorship helps, it is not statistically significant due to small sample size. More results will be obtained in the coming semesters. Qualitative analysis has revealed, though, that more training is needed to teach the peer mentors best practices. All too often, the interaction between the mentors and mentees resorts to little more than tutoring. We have experienced challenges in recruiting and retaining well-qualified students as most are often being recruited into research assistantships and other opportunities. Hence, we are seeking ways to improving training and optimize the peer-mentoring model.

IV. CONCLUSION AND FUTURE WORK

We are currently reaching a critical mass of data in the various activities that will allow us to conduct more definitive analyses to better inform our practices and assess the success of our interventions. Some preliminary results are further detailed in [6], [5], [8], [9].

Based on experiences during the first summer of implementing Activities 1 and 2 we have made some adjustments to our strategies for recruiting participants and will soon be able to assess the influence of these changes. Additionally, we are planning to expand some of these practices in collaboration with regional community colleges. In particular, we are seeking to focus the efforts of these collaborations on facilitating the transition of transfer students into our Engineering and Computer Science programs. Though articulation agreements already exist that insure transfer of nearly all the students credits, other issues exists that would be well-served by adopting some of the activities we have implemented. The programs at the two-year institutions struggle to recruit and retain mentors for key gateway courses because many of those who are qualified have either transferred or are in the process of moving on to a four-year program. Thus, we are seeking ways of providing face-to-face and web-enabled peer mentoring sessions.

Currently, through Activity 3, we are already working with one faculty member at South Texas College in Engineering. Our hopes are to expand that into Mathematics and potentially Chemistry and Physics. It has been our observation that many transfers to the College of Engineering and Computer Science struggle integrating themselves into the preexisting cohorts and learning communities. Moreover, they are often unaware of or not acclimated to the supplemental resources at our campus. Hence, we plan to leverage extended versions of our existing activities to address these challenges. For instance,

the Bridge to Calculus model could readily be adopted by the Mathematics departments at the community colleges. Also, a similar model could be used to offer a Bridge to Engineering or Computer Science where transfer students come in during the summer and take a sophomore level course or junior level course not offered at the community college. We can embed or connect various extracurricular activities that better connect the students with the local student success resources and integrate them into existing cohorts and learning communities. In other words, the various activities can be adjusted to enhance the transition of transfer students from the lower to the upper division.

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Learning to Learn: Creating Engineering Classrooms for Deep Understanding

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Metacognition involves an ability to reflect upon a learning episode, understand what strategies provoked learning, and gauge one's current level of understanding. This paper details preliminary evidence regarding the University of Texas at El Paso (UTEP) Metacognitive Learners course, a pre-engineering course structured to develop metacognitive strategies and habits through scaffolded collaborative group work, small and large group discussions about learning, and guided writing exercises designed to support learner reflection. Course curriculum addressed metacognition and metacognitive skill development in three explicit ways: a) team problem solving, b) student goal setting, and c) reflective writing about group process, project progress, and individual learning. Following this course, student survey data across all 4 sections suggests initial success in creating a learning environment that supports developing metacognition—students considered how they learned best, described their knowledge to others, and were asked to check their own understanding and progress throughout the course via dialogue and reflective writing.

Keywords—*metacognition, introductory engineering courses, community of learners*

Metacognition involves an ability to reflect upon a learning episode, understand what strategies provoked learning, and gauge one's current level of understanding [1]. The research literature suggests metacognition may be vital to developing high-level expertise in a domain—studies of experts and novices indicate metacognition is a key difference between the two groups [2,3]. This paper details preliminary evidence regarding the University of Texas at El Paso (UTEP) Metacognitive Learners course, a pre-engineering course structured to develop metacognitive strategies and habits through scaffolded collaborative group work, small and large group discussions about learning, and guided writing exercises designed to support learner reflection. This course was developed as part of a United States Department of Education Minority Science and Engineering Improvement Program (MSEIP). Research questions this study addresses are the following:

Do students perceive the entry level general education course as a learning environment that supports metacognitive learning? If so, in what ways?

I. METACOGNITION IN ENGINEERING

Metacognition involves an ability to reflect upon a learning episode, understand what strategies provoked learning, and gauge one's current level of understanding. A related conception of metacognition is that it involves knowledge about how to learn, the skill and awareness needed to gauge what one has learned, and the ability to manage new learning opportunities for optimal learning [4]. The research literature suggests metacognition may be vital to developing high-level expertise in a domain—studies of experts and novices indicate metacognition is a key difference between the two groups [2,3].

Students with metacognitive abilities are more likely to be aware of their academic strengths and weaknesses and use feedback to improve future learning. This may be particularly important in a field like engineering, in which rigorous coursework in a fast paced higher education setting can overwhelm students who are less prepared. Studies of metacognition in engineering contexts suggest that inquiry based design experiences such as capstone courses may provide opportunities for developing metacognitive capabilities, yet it is unclear whether open-ended problem based learning alone can lead to greater self-regulation—as an example, Lewanto [5] found disciplinary differences in the development of cognitive self-appraisal and cognitive self-management during senior design courses.

A. Designing for metacognition-curricular supports for developing student thinking about their thinking

Metacognitive learners take time to reflect upon what they know and how they learn best, and consider strategies that would help them improve their knowledge. Metacognitive learners are reflective about what they are experiencing in learning contexts, and consider connections between what they learn in classes over time and how they might transfer to application in the engineering field. While some students seem to have innate abilities and inclinations to study their own learning, this is not evident across the undergraduate student body.

Traditional instructional and assessment in schooled settings do not tend to promote reflection, nor provide opportunities to learn in a variety of ways. However, evidence suggests that classroom practices that emphasize reflection, provide timely, specific feedback to learners, and promote

learning strategy development could heighten students' attentiveness to their own learning. Korgel [6] initiated journals in a course setting in which students developed personally relevant analogies to describe important concepts in chemical engineering, thus eliciting student reflection. Newell, Dahm, Harvey, and Newell [7] asked students to monitor in writing how their group was progressing and detail barriers they faced in their progress. Students stated they valued this activity, and that by monitoring their progress in group meeting, they were able to advance more quickly in their design work.

Reflective journals can promote deeper learning, particularly when students are prompted through carefully crafted journal assignments to reflect on their conceptual understanding, monitor their progress in learning key concepts, and consider a purpose for learning beyond the course grade [8]. Qualitative evidence details how students became more focused on conceptual understanding in the course, learned to assess themselves and their progress in learning content throughout the semester, and became more adept at connecting the content from the course to real world applications. The UTEP Metacognitive Learners effort draws on the work regarding written journals as a means to heighten metacognition and extends the premise that courses can be designed to promote metacognition. The theory of change regarding course design and implementation as well as the research methods for studying the impact of the course on participants are discussed in sections II and III.

II. THEORY OF CHANGE- DEVELOPING A LEARNING ENVIRONMENT THAT FOSTERS METACOGNITION

The Metacognitive Learners team at UTEP designed the course as well as data collection and analysis strategies with a sociocultural view of learning [9]. In this view, learning occurs in social interaction with others, and with tools and artifacts of the discipline. Learning environments such as classrooms afford learning to different degrees, based on the ways interaction is structured, or not structured, to provide all students access to experiences that promote learning outcomes. A goal of the Metacognitive Learners project is to create a community of learners [10], a collection of learners who work together to develop more advanced understanding of a profession, discipline, or content area. In this case, the Metacognitive Learners project aims to create student to student and student to faculty bonds that promote critical feedback mechanisms, reflection on conceptual learning and progress within a content area, and supportive team members poised to learn together throughout their undergraduate studies in engineering.

III. COURSE DESIGN AND INSTRUCTIONAL METHODS

In an effort to ensure all new engineering students had access to the metacognitive learners curriculum, program leadership chose the Engineering 1301 course for this initiative. All entering freshman are required to take a 1301 course at UTEP. The 1301 series of courses promote the following:

“All sections will▪ Strengthen your academic performance and ease your transition to UTEP.▪ Enhance your essential

academic skills.▪ Increase your interaction with faculty members and fellow students.▪ Encourage your self-assessment and goal clarification.▪ Increase your involvement with UTEP activities and resources.” [11]

Writing prompts and activities focused on thinking and reflecting about learning. Pre-calculus mathematics concepts and a robotics project served as focal content areas in this general education course. Pre-calculus was chosen as a focus area because the majority of UTEP engineering students begin their academic careers in preparatory mathematics courses until they are calculus-ready. Mathematics courses serve as a barrier to successful completion of engineering in many institutions—this issue is particularly prevalent in schools with inclusive admissions policies such as UTEP. Course curriculum addressed metacognition and metacognitive skill development in three explicit ways: a) team problem solving, b) student goal setting, and c) reflective writing about group process, project progress, and individual learning. Specific written assignments designed to promote metacognition were the online prompts for reflective writing and engineering notebooks used to document progress in the group robot project.

Some illustrative examples developed from interviews as well as classroom observations of practice appear below. The examples serve to depict implementation of this engineering course.

Example A: It is mid-October. Twenty eight students enter the classroom, which is set up with tables facing forward. Three peer leaders circulate, asking students in Spanish and in English about their weekend. There is light chatter before the class begins. The instructor walks towards the front of the room, and reminds the class that today is a math group day. Students reconfigure the tables in the room to accommodate groups of 4 or 5. Students begin working on becoming experts on their assigned math topic- they collectively solve sample problems, google youtube videos, and consult with the instructor and peer leaders. The instructor reminds them to answer the online reflection question related to their experience of learning math collaboratively in this course.

Example B: It is late October. Students are moving on to their culminating activity for math—a group Jeopardy game. In this game, teams that have worked on math topics together all semester are working together to solve precalculus questions. “Remember,” the instructor calls out, “make sure everyone on your team can reach the answer—we will call one of you from the group to the board.” As questions are read aloud, groups huddle around their tables, negotiating solving strategies. Students who have sketched out an answer on paper begin describing the main concepts to their teammates, walking them through the problem step by step. A team raises hands. “Miguel, pick someone from that team to go to the board.” The peer leader says. Miguel picks Jorge, a quiet student who sits on the periphery of the group. Jorge walks slowly to the board, picks up a marker, and pauses. “Go on Jorge, you got this,” calls Jamal, a member of another group. Jorge begins to sketch out the answer.

Example C: It is mid-November, a robot day. Groups gather their equipment from the storage locker in the classroom—

hardware, the engineering notebook, and the computer they will need to program the robot. “We said we would have the robot built out by now, so we are behind schedule,” says Roberto, reviewing the goals they set for the group the week before. “Right, but I have been practicing the code for making the robot navigate the room, so I think we can make up the time this week,” Marisel tells the group. They schedule a time outside of class to meet the following day, so they can be sure to get back on track.

IV. DATA COLLECTION AND ANALYSIS

The Metacognitive Learners project involves multiple methods of evaluation and research. Internal and external evaluators collect the following: observational notes from course meetings, artifacts of practice including journal entries, engineering notebooks, assignments, syllabi, video of project work, survey data from all students, interviews and focus groups with select participants, including faculty members and instructors. In addition, the evaluators have collected baseline student course outcome data for courses that cross all engineering disciplines- in this case, high level mathematics courses. Future work will involve comparing Metacognitive Learners’ outcomes in these courses following their Engineering 1301 course. This paper focuses on the external evaluation of the project, which to date included observations, interviews with faculty, and student surveys.

Given the sociocultural theory that drives this effort, it was important to gather data at the right level of abstraction. Taking into consideration the focus on social, collaborative, and collective practices, the classroom learning environment itself was considered the appropriate unit of analysis in this case.

TABLE I. CLASSROOM COMMUNITY SCALE RESULTS

Classroom Community (positive items) <i>Strongly disagree = 1; neutral = 3; Strongly agree = 5</i> <i>87% of students averaged more than 3 across items</i>	Mean	Std. Dev
I trust others in this course.	4.1739	.73950
I am given lots of opportunities to learn in this course.	4.1556	.99899
I feel connected to others in this course.	4.1304	.85916
Students in this course care about each other.	4.1087	.87504
I am confident that others will support me in this course.	4.0217	.88164
I am encouraged to ask questions.	4.0000	.94281
I can rely on others in this course.	3.9348	.90436
I receive timely feedback in this course.	3.9130	.98491
This course is like a family.	3.8444	1.10691
Members of this course depend on me.	3.7391	.95300

Rather than measuring students’ perceived metacognitive skills, skills that may or may not have derived from the course, we targeted the learning environment itself for study. We used the validated instrument developed by Thomas [12] called the Metacognitive Orientation Learning Environment Scale

[MOLES], which was developed with a social-constructivist approach towards metacognitively rich classroom learning, in which learning and knowledge building are collaborative, interactional efforts. This instrument best fit the goals of the instructors, which were to create communities of learners who were able to reason about their own learning and meaning-making.

A secondary element of the learning environment of interest to the Metacognitive Learners program was the extent to which the class members felt a sense of community in the course. The Metacognitive Learners project sought to develop strong social ties between students with the assumption that developed relationships would serve engineering in the future—they would gain a sense of community, feel supported in their academic efforts, develop study groups, and feel as though they had a confidante in future courses. To measure the extent to which students felt they developed a community, the evaluator implemented a modified version of Rovai’s classroom community scale [13].

In spring of 2014, initial data was collected from students to understand their experiences of the UNIV 1301 course. That data and analysis informed development of the survey completed by students in four sections of UNIV 1301, all receiving some version of the Metacognitive Learners curriculum. For example, all participated in math review in teams, all received the UNIV 1301 college readiness curriculum (e.g., time management, study skills), and all participated in a robotics project with various themes for their work.

V. RESULTS

Forty seven of the 98 students enrolled in Engineering 1301 in the fall of 2014 participated in the survey (48%). Details of the classroom community and Metacognitive Learners survey data are provided in this work in progress paper, along with qualitative responses to open ended survey items related to metacognition.

A. Classroom community

This report highlights the positively worded items from Rovai’s classroom community scale, as negatively worded items showed skewed and irregular patterns. Overall, Engineering 1301 students in the metacognitive learners program viewed their classroom as connected, caring, encouraging, and trusting. Average scores were all in the “agree” range, at or near 4.0. A closer look at each student’s average score indicated that 87% of survey participants had a mean greater than 3, or neutral. Evidence suggests that Metacognitive Learners courses were successful in fostering ties among students and other stakeholders.

B. Metacognitive opportunities in UNIV 1301

The research-based instrument is made up of 8 subscales that describe a classroom environment that is supportive of metacognitive learning. First, students must interact with “thinking about thinking” as part of the content of the course—in other words, students must consider the course do be one in which individuals model their learning processes (teacher

modeling and explanation) and where they view part of the learning objectives to be related to their metacognition (metacognitive demands). Secondly, metacognitive learning environments assume flat distributions of power and responsibility, in which student ideas are valued and discussed in the class openly (student–student discourse, student-teacher discourse, student voice). Learning objectives and experiences develop over time with input from students (distributed control). Finally, in a learning environment in which students are admitting to misunderstandings or disclosing a lack of learning strategies they must feel emotionally safe and supported by colleagues and peers (teacher encouragement and support, emotional support).

The following table indicates the results from the post test for MOLES in all 4 sections of Engineering 1301 engaged in Metacognitive Learners. No scale differences were statistically significant across gender, course section, or instructor. Each scale had at least 4 items, making each measure more robust than one item alone. Averages for all scales are in the “agree” range, in this case between 3.97 and 4.38. There were slight differences that did not reach statistical significance in this small sample by instructor. The emphases on encouragement, student voice, and emotional support were slightly higher for a professor who noted in an interview these were his/her goals in the Engineering 1301 course. Another professor who focused more on metacognitive demands and student-student discourse saw slightly higher scale means for those elements of the MOLES survey.

TABLE II. METACOGNITIVE LEARNING ENVIRONMENT SCALE RESULTS

Scale Name	Sample scale item Strongly disagree= 1; neutral = 3; Strongly agree = 5	Mean out of 5	Proportion of students who average 3 or above (neutral- positive)
Student-student discourse	“Students discuss with each other about how they can improve their learning.”	3.97	83%
Metacognitive demands	“Students are asked to think about how they learn.”	4.00	79%
Student voice	“It is OK for students to speak out about activities that are confusing.”	4.04	85%
Instructor encouragement and support	“My professor encourages students to try different ways of learning.”	4.19	83%
Emotional support	“Students’ efforts are valued.”	4.38	87%

C. Qualitative description of the benefits of Metacognitive Learners

Two themes emerged from the qualitative data regarding course experiences. One was that students felt they learned how to work together in this course. This is important in the field of engineering because early engineering courses are traditionally lecture based, and because engineering design courses often do not take time to describe or scaffold students’

cooperation. Engineering 1301 was unique in that it valued group work for freshmen and was designed to provide students specific roles in every group such that cooperation was supported. The first quote focuses on the structured preparation of learning to work in groups, the second quote highlights the intentional focus on collaborative practices, and the third mentions that learning occurs in teams, rather than just “work”—in other words, students talked about what they knew and how they learned it. The third quote also shows that students met many other peers in the group work.

“This class teaches you how to be successful working with other students.”

“Other courses are based on an individual but Engineering 1301 revolves around group work.”

“There is a lot of learning and discussing in teams, which is not something you do in every class; working in teams is very helpful and you get to know a lot of people.”

The second theme was related to reflection on learning and the ways in which the course was designed to support group reflective leaning practices supportive of metacognitive capabilities. The first quote indicates the class was perceived as one that was open to multiple ways of learning, the second quote shows how students had opportunities to consider their progress in the course before moving onto another set of learning objectives, and the third quote is indicative of a developing community of learners.

“I believe this course is very different from other classes because it does not really support any (specific) way of thinking but encourages you to explore other ways, other than your own.”

“There’s a reflection about how it is that we learn instead of just learning the material and not understanding it at times in other classes.”

“It gives us different ways of thinking and allows us to discuss which path we took to learn. They support group learning as we would learn from and teach each other.”

VI. CONCLUSIONS AND NEXT STEPS

Following this course, student survey data across all 4 sections suggests initial success in creating a learning environment that supports developing metacognition—students considered how they learned best, described their knowledge to others, and were asked to check their own understanding and progress throughout the course via dialogue and reflective writing. Students’ ratings of their course showed high marks. The majority of students rated the course with a 4 or 5 out of 5 across all scales. The metacognitively-focused curriculum provided student voice, an opportunity to build metacognitive skill, encouragement and emotional support for learning, and opportunities for rich student-student discourse. Longitudinal student data analysis with institutional records of course grades planned for summer 2015 will show whether this preparation has academic benefits beyond this course, specifically whether the students involved in the Metacognitive Learners program outperform other engineering cohorts in their mathematics course completion.

VII. ACKNOWLEDGMENT

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Agile Learning Through Continuous Assessment

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Abstract—This work explores the impact of teaching and learning if the rate of learner engagement outside the classroom is continuously measured and available to the instructor and students. We describe an ongoing implementation of a monitoring tool built within a software engineering continuous integration and testing (CI & Test) platform that integrates multiple streams of student activity and performance on yearlong junior software engineering projects. The CI & Test platform allows for continuous and instantaneous feedback, which we will use to inform student behavior change. In the work-in-progress we describe the technology, its impact on the teaching process for the instructor, and preliminary results observing impacts on student engagement behavior.

Keywords—agile; project learning; continuous assessment

I. INTRODUCTION

This work-in-progress is an application of agile process concepts from software engineering to learning assessment. *Agile* is the overarching theme, taken in the software engineering context (and derived from industrial engineering) of *empirical process control* [6]. In a forward-engineered, defined process model, the steps of a process are elaborated and arranged using tools such as task activity networks. Participants in the process execute the scheduled tasks, with expected process output if the tasks are completed within the specified constraints. Most courses are planned in this predictive, forward-engineered way. Learning outcomes are supported by learning activities (whether active or passive), and typically laid out on a course calendar or syllabus, which guides both the teacher and learner through the process. In contrast, empirical process control suggests that complex processes are not amenable to a predefined set of scheduled steps, as the environment is too fluid. Instead, the process should be driven by a feedback loop where small adjustments are constantly made based on continuous feedback.

The popular *agile* software engineering process models are based on this empirical process principle. In prevailing agile software engineering practice, processes are instrumented with continuous and visible feedback mechanisms. For example, *daily standups* are short (less than 5 minute) meetings to share individual progress and hurdles to success. *Scrumboards* are

information radiators [1] meant to provide a highly visible, continually updated representation of project requirements and associated tasks. *Continuous Integration and Test* (CI & Test) tools provide an instantaneous view of product quality, and reduce the risk associated with long gaps of development without validating system integration (“big-bang integration”). There are several other practices and extensions to mainstream agile practices (such as *Kanban*) that are beyond the scope of this work. Suffice to say this project is motivated by the potential for engineering an instrumented learning process for the purpose of providing visible continuous feedback to students and instructors. The hoped for result is behavior change in the manner in which students conduct long-term (semester or yearlong) projects.

II. BACKGROUND

A. Continuous Assessment

Continuous assessment refers to a field in educational research devoted to the practice of performing frequent assessments in a course context [6]. The concept has become somewhat popular with the rising popularity of constructivist approaches to learning, as frequent assessment provides a feedback mechanism ensuring students are properly aligned with a scaffolded learning process. It remains an active area of research, with an ongoing debate surrounding the utility of formative versus summative continuous assessment [2][6]. From a practice perspective, frequent assessments are becoming more common with the support of technology. Badges and micro-certificates used in some MOOCs are, in our view, examples relying on finer-grained and more frequent feedback mechanisms.

We do not present a new validated vehicle for continuous assessment nor do we have a specific perspective to advance in the debate over formative versus summative assessment. This work instead offers a specific instance of continuous assessment in the context of a project-centric student experience with the support technology-based tools.

B. Embedded Assessment

Embedded assessment is a concept related to continuous assessment, with an emphasis on the context in which the assessment is delivered. Typically the embedded assessment happens as part of the learning process, not as a discrete

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external activity. Some embedded assessment techniques obey similar principles to continuous assessment. Classroom assessment techniques and technologies (clickers, in-class polls, 1-minute papers, tablet-based activity monitoring etc.) support frequent assessment to give the instructor feedback on learner absorption of material. Automated online assessments not only ease grading workloads, they also offer the opportunity for instant feedback, remediation, and personalization of self-study outside a classroom. Embedded assessments within e-content or newer print textbooks give the student immediate feedback on the content just consumed.

C. Continuous Assessment from an Agile Perspective

Despite the rise in popularity of continuous and embedded assessment, the prevalent delivery model is to push students through a predefined amount of content and assess the student at the conclusion of that activity. Even descriptions of continuous or embedded assessments tend to follow a scaffolded, discrete event learning process, albeit at a much higher rate of frequency than traditional course-grained learning processes. What if we drive the time of assessment to time of learning gap limit to zero?

As discussed in the introduction section, agile software engineering methods derive from empirical process control, or simply put the ability to enact an heavily instrumented process so continual minor adjustments (“tweaks”) keep the process within desired control parameters. Active research and practice in agile methods attempts to drive the feedback loop to zero, thereby eliminating the need for process scaffolding such as frequent short iterations (or “sprints”).

Our work conveniently overloads the term *continuous* from both the educational and agile software engineering perspectives. Conceptually, our work is an example instance of continuous assessment. In practice, it applies mechanisms from agile software engineering, specifically continuous integration and testing, to engineer a learning process resulting in greater engagement in a yearlong project experience. This specific instance and its mechanics are described next.

III. PROJECT-CENTERED LEARNING AND THE SOFTWARE ENTERPRISE

A. Projects as a Professional Spine

Sheppard et al. [6] proposed an integrated development thread in undergraduate engineering programs called a *professional spine*. The professional spine is realized by the Software Enterprise as a *project spine* in the context of undergraduate and graduate software engineering degree programs [5] (see Fig. 1). Instead of traditional dedicated courses in each phase of the software engineering lifecycle (requirements, design, verification & validation), the Enterprise-as-spine promotes learning each of these phases as themes in a integrative project context.

The Enterprise pedagogy combines project-centric and traditional models for course delivery resulting in a just-in-time, contextual learning experience. Software Enterprise courses are a required part of the degree programs from the sophomore year through 1st year of the graduate program at

Arizona State University. The Enterprise is currently in its 10th year, and details of the pedagogy have been presented elsewhere [1][4]. In the context of this work, a short summary of the approach is needed, which we do in the context of the junior year project experience, as this is where we have piloted continuous assessment practices.

B. The Software Enterprise

In a Software Enterprise course, software engineering concepts are broken into discrete modules and sequenced over the course of a semester to synch up with project activities. In this *just-in-time* approach, students are exposed to a concept, practice it, apply it on a scalable project, and then evaluate the applied technique *all within a three-week project iteration* (see Fig. 2). The goal here is to avoid situations where students understand a solution *in the small*, and instead understand problems and their solutions *in context*.

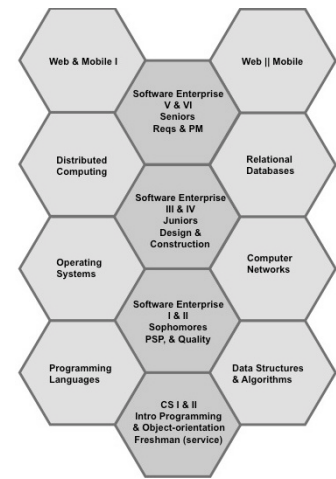


Fig. 1. Enterprise undergraduate spine

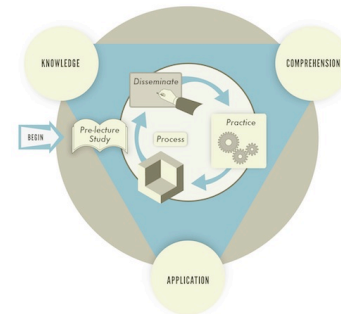


Fig. 2. Software Enterprise Pedagogical Model

Example modules in the junior year spring semester course include *source code control*, *unit testing*, *static analysis*, *code reviews*, *metrics*, *refactoring*, and *defensive programming*. Additionally, agile concepts such as *sprint planning with user stories*, *continuous integration and testing*, and *burndown charts* are covered. Again, for each of these concepts, students iterate through *preparation* (typically a reading), *discussion* (in a traditional lecture setting), *practice* (a lab or discovery activity), *learning-in-context* (put in practice in a scalable project), and *reflection*. The key to the Software Enterprise approach is that all of these stages happen at the point of discovery in a single three-week sprint.

C. Challenges and an Opportunity for Assessment

Perhaps the most challenging aspect of implementing the Software Enterprise pedagogy is the expectation that the

student constantly the integrate software engineering concepts (in the form of current modules) into their team's project workflow. This is antithetic to how students typically work on project coursework; projects are deadline-driven, with the majority of the work coming just before the project due date. There are a variety of reasons for this, from student time pressures to a simple inability to properly plan and estimate work over a long time period. Simple mitigation strategies include defining intermediate milestones, though this typically results in a microcosm of the larger problem; students do not pay attention to the milestone until it is almost due.

It is imperative in any project course that students make a consistent effort throughout the semester on the project. Students that defer work to the last minute usually shortchange the concepts they are to discover and apply in favor of just "getting it done". In agile software engineering projects, it is even more important to make consistent progress, the very nature of agile processes suggest developing a constant rhythm so constant feedback is available; without constant activity no work is completed, no feedback can be generated, so no adjustments can be made. The nature of empirical process control breaks down. Finally, in the Software Enterprise is it critical to have consistent activity so that concepts may be integrated in the project at the point of learning.

In the Enterprise, students are given the directive to work on their projects for 8 hours per week, and save 1 hour out of class for preparation activities. Students are asked not to go beyond 8 hours even if their project is falling behind, as the intent is to have the students rely on a team process, not heroic efforts, to complete the sprint goal. Students are assessed each sprint (4 times per semester) on their process-related activities, code-related activity, integration of modules into the project, and team process activities. Individual process activities include updating a scrumboard and participating in standup meetings (3 per week). Code activities relate to individual velocity measured by frequency and significance of commits to the source code repository. Module integration is determined by a student journaling evidence and presenting it as part of a sprint individual reflection. Team process activities are based on adherence to Scrum principles such as user story development, estimation and tracking on burndown charts, and sprint reviews and retrospectives. A student's final grade is the aggregation of each of the 4 sprint grades plus 20% reserved for the end-of-semester product deliverables.

IV. CONTINUOUS ASSESSMENT IN THE ENTERPRISE

A significant hurdle in the Software Enterprise is getting students to work in a constant rhythm. A phenomenon we observed is that students tend to do a burst of work at the beginning of a sprint and at the end of a sprint and not in-between. The burst at the beginning of a sprint aligned with when students received their prior sprint grade, while the end of the sprint is the milestone-driven mentality discussed above. Anecdotally, it seemed the students were more motivated just after receiving feedback (a partial course grade), and just before, but in-between fell into the same bad habits. The premise for this project then, is that continuous assessment, where the student always has visibility into her/his project grade, will motivate students to adhere to the

"consistent work rhythm" expectation, thereby increasing the student's ability to learn in context. The Software Enterprise provides a good vehicle for continuous assessment due to its highly modularized curricular organization, emphasis on highly iterative software development and pedagogical processes, and expectation of continuous, consistent work on the project.

We borrow from the concept of continuous integration and testing (CI & Test) in agile software engineering. CI & Test promotes continual integration and verification of software by performing a software build and regression test for each commit to a software repository, or at least on a nightly basis. This practice avoids the problem of infrequent integration testing and long build processes. CI & Test *dashboards* in tools such as TravisCI (travis-ci.org), Cdash (cdash.org), or Jenkins (jenkins-ci.org, see Fig. 3) provide pervasive visibility of product quality status. Used in conjunction with a *scrumboard* and a mature source code control platform like GitHub (github.com), the project team and all stakeholders have full visibility into the rate of product development, project activity toward requirements, and product quality.

S	W	Name ↓	Last Success	Last Failure	Last Duration
		Project F cubicCoins	20 hr - #106	27 days - #71	9.2 sec
		Project I Entrepreneur Sim	26 days - #30	26 days - #29	10 sec
		Project J Sports	8 hr 7 min - #98	15 days - #81	1 min 7 sec
		Project Team C Gamers	21 hr - #93	17 days - #72	48 sec
		Project Team D Gamers	1 hr 10 min - #68	N/A	1.2 sec
		Project X thefailedandthefurious	5 days 20 hr - #113	20 hr - #123	39 sec

Fig. 3. Example Jenkins dashboard. The traffic light and weather metaphors on the left provide a simple short-term and long-term feedback mechanism.

Our goal in this project is to create a dashboard similar to CI & Test platforms showing the continuous assessment view of a student's grade components – individual process activity, code activity, module integration, and team process activity. We have created a web-based tool that dynamically displays three of these perspectives (all but module integration) and made it available to Software Enterprise students in the Spring 2015 semester. The views this tool provides are shown Fig. 4.

The top chart in Fig. 4 shows team process progress. It measures, as a stacked area chart, the number of To-Do, In Progress, To Test, and Done tasks per day on the team's scrumboard. This particular chart shows good team process over the sprint, as the tasks are getting moved across the states of the scrumboard at a fairly consistent rate. The middle chart is an view of individual code activity. The grouped bar charts show frequency and significance of commits normalized to a common visual scale with a double y-axis chart. This particular student shows decent behavior, though in several cases there a number of insignificant commits, as shown by the blue bar being higher than the orange (commits outweighing code addition, meaning several trivial commits performed).

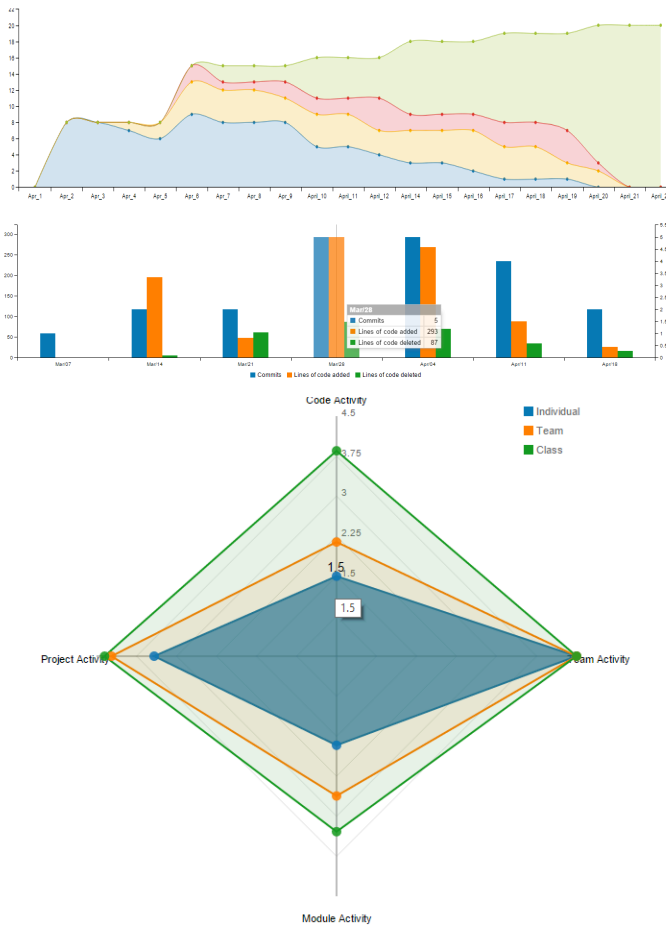


Fig. 4. Continuous assessment of team and individual project performance

The most important chart however, is the bottom chart, as it shows a view of the four components of the sprint grade, laid out on a radial chart. Further, the individual student's component scores (shown in the small dark area) are overlaid with the team's average component scores, and then the component scores of the entire class. The student is able to see, immediately, her/his performance with respect to the class.

These charts are worthwhile in that they show a rate of progress (the top two) and instant comparison to cohorts within the class. They are easily interpreted by the student, and are rendered in one place. This is better than going to the LMS gradebook for textual averages, a scrumboard, or a GitHub pulse diagram. We pull data from the source tools of each component, namely Scrumwise for the scrumboard and GitHub for the code activity, on a daily basis – and are working toward continuous streaming and integration of component data.

The web tool was deployed in Sprint 4 (the last full project sprint), so it was not available in time to use for multiple sprints. Students were asked, in the context of a larger course survey given by the instructor, how useful each of these three views are in the context of team projects. 22 students responded to the survey questions. For the top chart of Fig. 4, 15 students indicated the tool helped them understand team progress, while 1 said it did not help and the other 6 remained neutral. For the code activity (middle) chart in Fig. 4, 10

students indicated it helped, while 8 said it did not help and 4 were neutral. For the bottom (radial) chart, 7 said it helped, 5 said it did not, and surprisingly 10 were neutral. While the results overall were positive, particularly for the top chart, it was disappointing the radial chart did not generate stronger opinions among the students. Of course this is a small ad hoc survey, and we did not in fact have time yet to determine if availability of this data on a daily basis during semester-long project performance would incur the desired behavior change.

Of course, generating reports is useful but alone is of limited utility. We are more interested in behavior change; getting students to pay attention to their rate of progress and seek to work in a consistent manner so the learning process, guided by the pedagogy, has its maximum effect. To this end our technical design goal is to integrate rich views into daily activity through 1) automating assessment data gathering, 2) rendering views in the CI & Test project dashboard and/or in the LMS, 3) adding more and detailed views, and 4) using email, SMS, and/or mobile notifications to remind students as soon as they fall behind on their project expectations.

This project is in a preliminary stage as we prepare to mature the tools for use in the coming academic year. From a theoretical perspective, this project is one data point in agreement with Trotter [9] in that continuous feedback is a tremendous amount of work and sometimes stressful for students and instructors, but is on the whole worth it. Our motivation is to motivate behavior change in students toward consistent project activity, and prepare as instructors for larger project class sizes and a conversion of the Enterprise classes to online delivery. Automated continuous assessment tools is one way, we hope, to address these coming challenges.

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Amnesia: a Learning Object for Memory Hierarchy Teaching

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Abstract— The teaching and learning process of memory hierarchy is a not simple task. Many topics studied in theory may discourage learning due to its complexity. Resources have been developed to improve learning experiences, and learning objects are resources worth taking into account. This paper presents a learning object called Amnesia, which aims to facilitate the knowledge construction by simulating the structure, functionality and performance of the memory hierarchy in von Neumann architecture, specifically considering the cache memory module. Experimental studies demonstrated an increase in student learning when this object was used. In addition, the students' motivation to use learning objects also increased.

Keywords—education, learning objects, computer architecture, simulation in lab environments, cache memory, amnesia.

I. INTRODUCTION

Being a university lecturer is a great challenge. A university lecturer needs to simultaneously transmit a huge amount of information to students and also pay attention to how this knowledge is being conveyed. One of the factors that may discourage university students is the disconnection between theory and practice [5].

Aiming to bridge this gap, various resources have been developed to improve learning experiences in information technology courses, and learning objects are resources worth taking into account. According to the Learning Objects Metadata Workgroup, learning objects are: “Any entity, digital or non-digital, that may be utilized, reutilized or referred to in technology supported learning” [16]. Another definition, not as specific, says that learning objects are “Any digital resource that may be (re)utilized as a teaching support” [17].

This paper presents the cache memory module from the Amnesia project. The Amnesia project has transformed a tool, also called Amnesia, into a learning object to support teaching and learning in Computer Organization and Architecture courses.

The aim of Amnesia is to simulate the memory hierarchy structure and functionality, and analyze the impact of this hierarchy on the performance of applications. Amnesia is able to simulate internal registers in processors, caches, main

memory and also the use of disks considering virtual memory paging [8].

The practical study of cache memory content using simulations of the concepts presented in theory is an advantage in the learning process. By visual interaction, students can better comprehend the content of the subject, without being discouraged by the traditional teaching method. Furthermore, as the student has to observe the simulation process, it interacts with Amnesia, and actively participates in his/her own learning construction process [6, 15].

The aim of the learning object presented in this paper is not to replace the university lecturer. Instead, it must be used as a support in the teaching process, attempting a more active participation from the student.

This paper is structured as follows: Section II presents related work and Section III briefly describes the main characteristics of the Amnesia learning object. Section IV discusses two experiments conducted: the first, with undergraduate Computing students of a Computer Organization course; the second, with MSc/PhD students in Computing. Section V presents an evaluation of Amnesia considering two perspectives: the students' learning effectiveness, as well as their attitudes towards the use of Amnesia. Finally, conclusions are drawn and future work is recommended in Section VI.

II. RELATED WORK

Some memory hierarchy simulators, specifically cache memory simulators with different complexity and functionality levels, were compared in [12]: KSH [11], Multilevel and Split Cache Simulator (MSCSim) [2], Didactic Cache Memory Simulator (DCMSim) [1], Dinero IV [4], CacheSim [10], LBGCache [7] and SMPCache [14]. Among all of them, KSH, DCMSim, LBGCache and MSCSim performed better, as they had essential functionalities for cache memory learning, in addition to a friendly interface.

Table I shows that MSCSim is the closest to Amnesia. However, MSCSim does not make available lesson plans and tutorials, which are both of them also considered learning objects. MSCSim is also difficult to be reached, because it is not available in a Learning Object Repository (LOR), a place

where it is possible to locate and obtain educational resources for different educational levels and subjects. Amnesia is available in the MERLOT (<http://www.merlot.org/>) LOR. Amnesia has a textual and graphical interface that can simulate different and important concepts to the student learning process. Amnesia can also simulate the execution of a program in a previously configured environment; visualize main memory's contents, the allocation of word blocks in cache and the spread of address bits from each required block, showing byte-offset, word-offset, set and tag. Amnesia has associated learning object lesson plans and tutorials, which will be discussed in Section IV.

Table I contains the following characteristics used to compare the simulators:

- Split: indicates if it is possible or not to simulate split caches;
- Multilevel cache: shows if the simulator is capable of working with different levels of cache;
- Sequence and Parallel access: determines if it is possible to run parallel accesses to the cache memory in addition to sequential access;
- Access time: displays the access times on different levels of cache;
- Associativity: indicates if different levels of associativity can be considered;
- Memory trace: points out if the simulator is capable of generating new traces from each new execution;
- Statistics: indicate if there are metrics showing the performance observed by the execution;
- Graphical User Interface (GUI): determines if the software tool does not only have a user text interface; and
- Download: indicates if the simulator is available to download from a LOR.

TABLE I. TABLE OF THE MAIN CHARACTERISTICS IN THE SIMULATORS

Characteristics	Simulators				
	<i>KSH</i>	<i>DCM Sim</i>	<i>LBG Cache</i>	<i>MSC Sim</i>	<i>Amnesia</i>
Split		X	X	X	X
Multilevel				X	X
Sequence and parallel access	X			X	
Access time	X	X	X	X	X
Associativity				X	X
Memory trace		X		X	X
Statistics	X	X	X	X	X
GUI	X	X	X	X	X
Lesson plans		X			X
Tutorial					X
Download					X

III. THE AMNESIA LEARNING OBJECT

First, it is important to explain the origin of this learning object's name. It is a reference to a very common disease in humans that causes a memory deficit called Amnesia. Therefore, Amnesia, the learning object, is a memory hierarchy simulator in von Neumann architecture [9]. Its function is to demonstrate how registers (based on the MIPS processor), caches, main memory and virtual memory work together in a hierarchical view. Amnesia aims to facilitate and improve learning in Computer Organization and Architecture courses.

To start a simulation, the features of the processor, main memory, virtual memory and cache memory must be instantiated. These settings are kept in an xml file read during the Amnesia's startup. The processor setting is just the word size in bytes. Each cache level is set according to the following characteristics: unified/split, size in words, number of words per block, number of blocks per set (i.e., degree of associativity), number of cycles in each reading and writing access, each cycle's duration in time units, replacement policy (FIFO or LRU) and the write policy (write-through or write-back). For the main memory, the settings are according to: its size in words, the number of words per block and the number of cycles in each reading and writing access. Virtual memory settings will not be described here, as they are not in the scope of this paper.

Figure 1 shows that the simulation can be conducted in two ways: firstly (Figure 1a) from a binary code sequence, generated by assembling a MIPS code; and second (Figure 1b) directly from a DIN trace file. The results produced are the simulation statistics. In the first case, the simulation can also produce a trace file with accesses to the main memory in the DIN standard [4]. The simulation may be executed directly or step by step.

Figure 2 shows the output of a program's step by step execution, using a trace file as input. It also shows that this execution type generates a real time detailed log about main and cache memories. It is possible to observe how the bits in a requested address are divided in byte-offset, word-offset, set and tag.

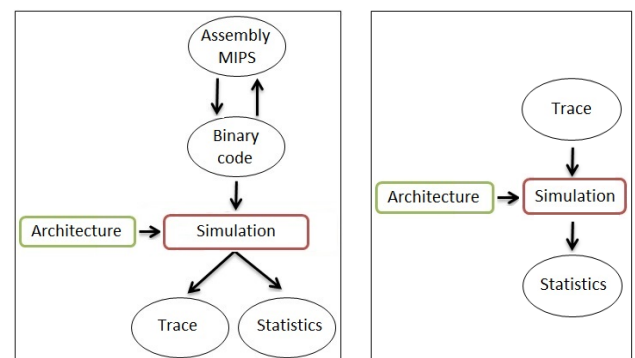


Figure 1. a) Amnesia operation from a binary code; b) Amnesia operation from a trace file.

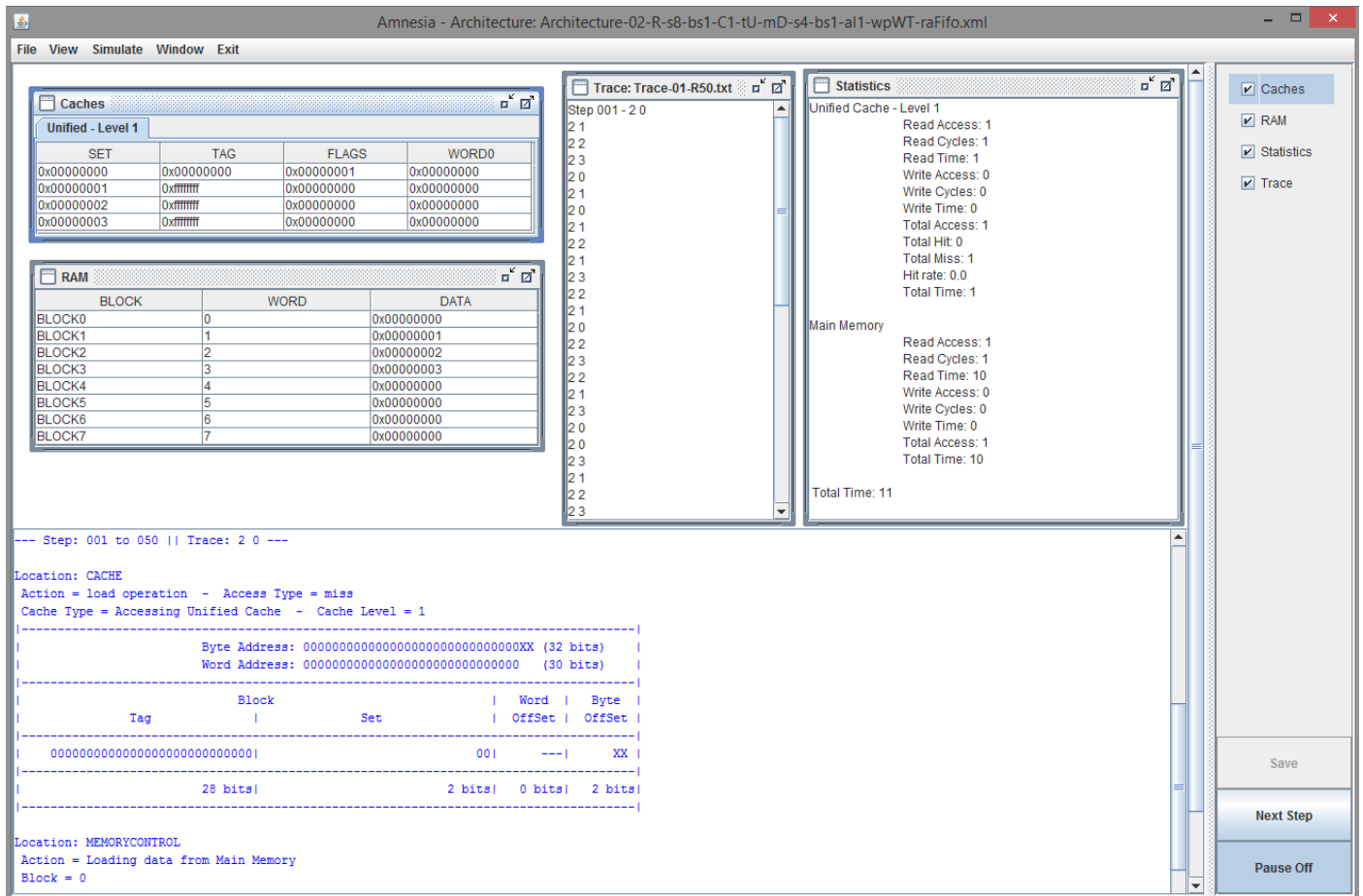


Figure 2. Step by step execution of a trace file.

In Figure 2, the following parts can be observed: program execution (trace), main and cache memory data, and performance aspects (statistics). The statistics are shown for each cache, considering the total amount of accesses, reading, writing and cycles, each cycle's duration (reading and writing), amount of hits and misses, hit rates and cache's total access time. In a main memory, the following information are considered: amount of accesses, total time spent for these accesses and the time spent for reading and writing.

A program can be executed in distinct settings regarding the processor, main and cache. This is important because students can execute a particular sequence of instructions in different environments and then compare the obtained performance.

Each simulation generates an information log containing data about the architecture and program used, the bits spread of each requested address, and the main and cache memories access statistics.

IV. EXPERIMENTATION

Two experiments were carried out using the cache memory module of Amnesia learning object. The aim was: (1) to evaluate whether Amnesia improves students' learning in

cache memory or not; and (2) to find out the students' attitudes toward the use of Amnesia.

Undergraduate students from the Computer Organization course took part in the first experiment. MSc/PhD students in Computing participated in the second experiment. The latter had not worked with cache memory concepts for a while.

In both experiments, two different tests were run, one before (pre-test) and one after (post-test) using the learning object. Both tests had similar complexity levels and consisted of two different sets of 15 questions, which cover all the theory content taught in cache memory during the Computer Organization course.

The pre-test lasted approximately 15 minutes and was it was done by all the students based only on students' previous knowledge. A group of students volunteered in using Amnesia to improve their knowledge. After this group had the practical class using Amnesia, all the students took the post-test, also lasting 15 minutes. The post-test was not applied immediately after the practical class; instead, there was a gap of a few days. If the post-test was run just after the practical class, the knowledge could be recent in students' memory and easy to be remembered, causing a positive influence in the post-test.

The practical class given using the Amnesia learning object was 2 hours long, and the main subjects of cache memory were taught. The subjects were developed with the students in 11 practical exercises, considering functional, structural and performance aspects of caches. More specifically, the following subjects were addressed: motivation and cache concepts, temporal and spatial location principles, mapping function (direct mapping, fully associative and set associative), hits and misses in the access, replacement policies (FIFO and LRU) and write policies (write-through and write-back), reading and writing accesses in caches, performance aspects, multilevel and unified/split caches, bits spreading in requested addresses (in byte-offset, word-offset, set and tag), multilevel cache and miss penalty vs miss rate. For all exercises, performance results were collected from the accesses, as the aim was to analyze and compare hits/miss rate and total duration of accesses, in order to help students understanding and reaffirm the concepts given in theory in a practical way. The exercises were done by the students with a monitor attendance.

Each student downloaded the Amnesia to their local machines and all the exercises were done individually, depending on the interaction of the student to complete it. Thus, the students actively participated in the his/her own knowledge construction.

Besides evaluating the learning effectiveness, the use of the Amnesia learning object was also assessed in these experiments. On the practical lesson day, students were asked to fill in two questionnaires. The first questionnaire asked about the Amnesia using expectation before using it. The second questionnaire was given at the end of the class, asking about the reaction of using it. Some questions are highlighted in Table II.

TABLE II. TABLE OF QUESTIONS IN THE EVALUATION OF USING AMNESIA

Answers: Very good – Good – Regular – Bad – Very Bad.

How was your knowledge on the content before using the object?
How is your knowledge after using the object?

Answers: Yes – Partially – No – Doesn't apply.

Did you increase the level of your knowledge?
Do you think the results obtained in the object were reliable?
Was the class more interesting when using the object?
Would you use the object again?
Are you interested in using any other objects?

V. RESULTS AND DISCUSSION

A. Evaluating the Learning Effectiveness

In the first experiment, conducted with undergraduate students who were taking the Computer Organization course, there were 102 students in the pre-test, 93 students in the post-test and 32 students in the practical class. Among all possible combinations, two scenarios were highlighted: (1) 23 students

who participated in the two tests and in the practical class; and (2) 52 students who took both tests and did not participate in the practical class.

Figure 3 shows the grades obtained by the students in pre-test and the post-test, considering both scenarios. The best results can be observed for Scenario 1, where students scored 165 points in pre-test, and 205 in post-test, showing a 24% improvement. Students in Scenario 2 scored 443 points in pre-test and 476 in post-test, showing a significantly smaller improvement of 7%.

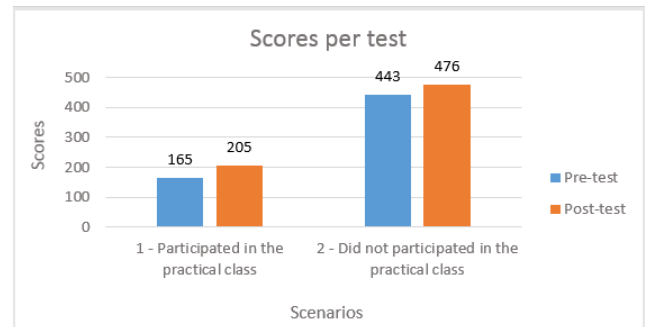


Figure 3. Scores per test in Experiment 1.

In the methodology used to analyze the results, firstly the difference between the grades of the students in the pre-test and the post-test was tested in order to observe if they follow a normal distribution. The normality test must be done to guide the choice of the test applied to compare the scenarios and to prove the influence of the Amnesia in the learning process.

The normality test used was the Shapiro Wilk test [13]. For Scenario 1, it was concluded that the differences did not follow a normal distribution (p -value = 0.01613) and for Scenario 2 the differences followed a normal distribution (p -value = 0.1595).

As the first scenario did not follow a normal distribution, a non-parametric test was used in order to test the difference between the two groups (pre-test and post-test) in each scenario, and the Friedman test [3] was chosen. This test compares evaluation methods considering dependent samples, and in this case the dependent samples are the results obtained in the pre-test and the post-test.

The result obtained when the Friedman test was run in Scenario 1 is a p -value equal to 0.001063, leading to a rejection of the equality of the groups. As the post-test grades are higher than in the pre-test, it can be affirmed that Amnesia improves the student's performance.

For Scenario 2, the Friedman test resulted in a p -value equal to 0.1011, leading to a value that did not reject the equality of the groups. In other words, the groups are statistically equals and the performance of the students in the post-test is the same to the pre-test.

Figure 4 shows a better analysis concerning the evolution obtained in each scenario. Figure 4a illustrates the evolution of knowledge obtained in Scenario 1 and it can be observed that the median score was improved, including a greater distribution of hits per student in post-test and eliminating the

outlier present in pre-test.. Figure 4b shows the progress of knowledge obtained in Scenario 2 and it can be observed that the median of the pre-test was almost the same as the post-test and values were more concentrated near the median. Considering this, the adoption of the Amnesia learning object in this experiment positively influenced the consolidation of knowledge obtained by the students.

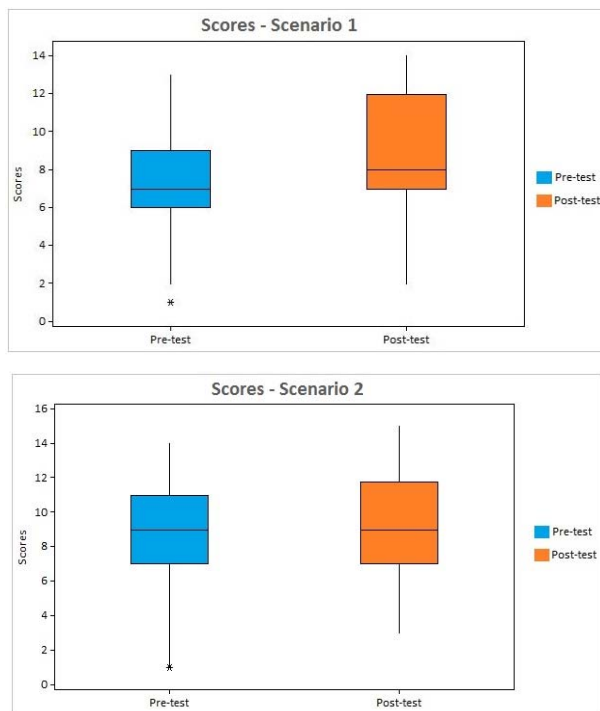


Figure 4. a) Scores in Scenario 1, Experiment 1; b) Scores in Scenario 2, Experiment 1.

Figure 5 and Figure 6 show the scores per subject in Scenarios 1 and 2, respectively. For most subjects, the students' knowledge developed in Scenario 1 increased, except for mapping functions and replacement policies. When this data is compared to data from Scenario 2, it can be observed that among the subjects that had a decrease in performance, mapping functions and replacement policies are also present.

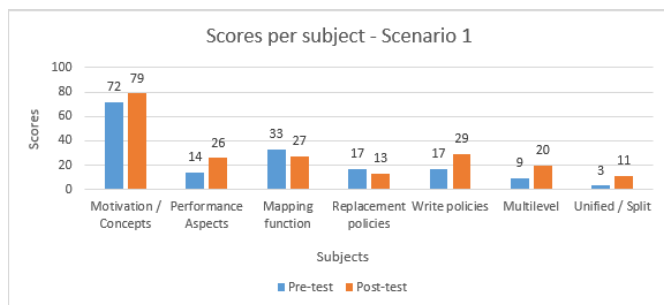


Figure 5. Scores per subject in Scenario 1, Experiment 1.

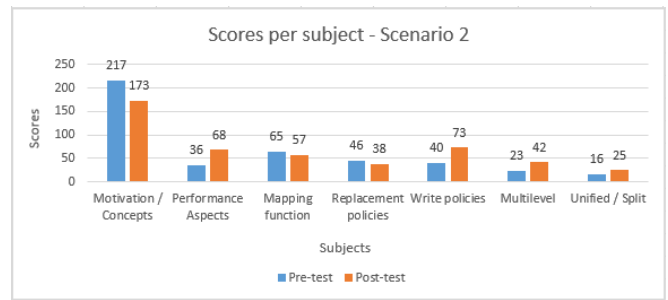


Figure 6. Scores per subject in Scenario 2, Experiment 1.

This information is important, showing that a decrease in performance is not related to the use of Amnesia. However, when investigating possible causes of this decrease, it was concluded that there was a lack of emphasis in these subjects in the practical class using the learning object.

Still comparing Scenarios 1 and 2 from Figure 5 and Figure 6, students using Amnesia considerably improved their performance in the subjects of motivation/concepts, multilevel and unified/split caches. As in this case the students participated in constructing their own knowledge, there was a larger concern regarding their understanding of concepts and exercises involved, which justifies their higher performance. The subjects on multilevel and unified/split caches demand complex concepts of cache memory architectures, and using the Amnesia learning object makes it easier to understand due to its practical simulation.

In the second experiment, conducted with MSc/PhD students, 15 students took part in the pre-test, post-test and the practical class. The practical class had a higher emphasis on the subjects of mapping functions and replacement policies due to the results in Experiment 1.

Figure 7 shows that the scores in the post-test were higher than in Experiment 1. Students scored 52 points in the pre-test and 135 points in the post-test, which was an improvement of 160%. The knowledge evolution obtained can be observed by the improved median score in the post-test, including a greater score per student.

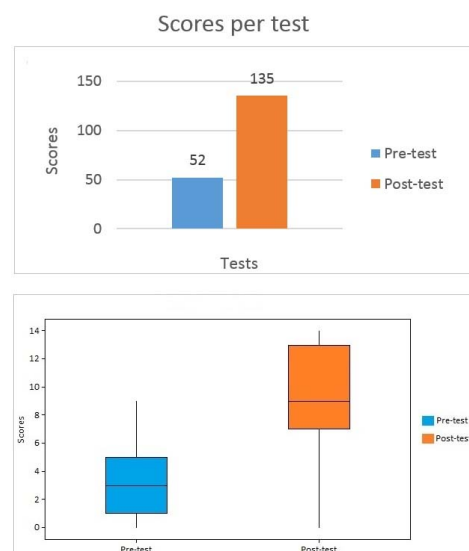


Figure 7. Scores per test in Experiment 2.

Figure 8 shows the scores per subject. Considering this, we noticed that knowledge was improved for all the subjects. Another important point to be highlighted is that even though the students in the experiments had not studied cache memory concepts for a while, the result was very positive.

Students' interest in the subject was noticeably better when using the Amnesia object, as they focused on the sequence of exercises and therefore consolidated more knowledge of each one, which justifies the significant improvement in learning. Furthermore, it could be argued that the adjustment made between Experiments 1 and 2 regarding mapping functions and replacement policies was also positive.

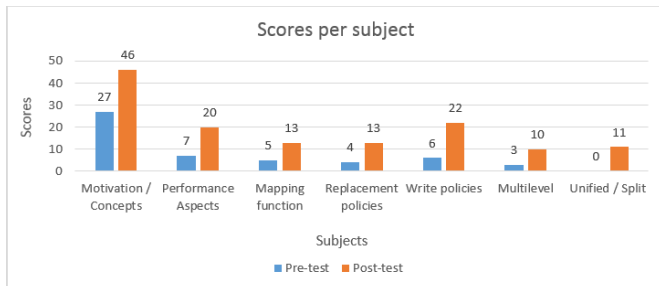


Figure 8. Scores per subject in Experiment 2.

Students were advised to do not answer the questions they were not sure, in both experiments. Therefore, another positive aspect concerning the two experiments was observed: the significantly fewer number of questions left blank in the post-test by students who participated in the practical class.

Figure 9 shows that the number of questions left blank by students in Scenario 1 of Experiment 1 was 57 in the pre-test, while in the post-test there were 28, which was about 50% less. Students in Experiment 2 left 96 questions blank in the pre-test, and 32 in the post-test, approximately 66% less. However, students in Scenario 2 Experiment 1, who did not take the practical class, left 100 questions blank in the pre-test and then 95 in the post-test, only 5% less. Taking this into account, the importance of the practical class can be highlighted when using the Amnesia learning object.

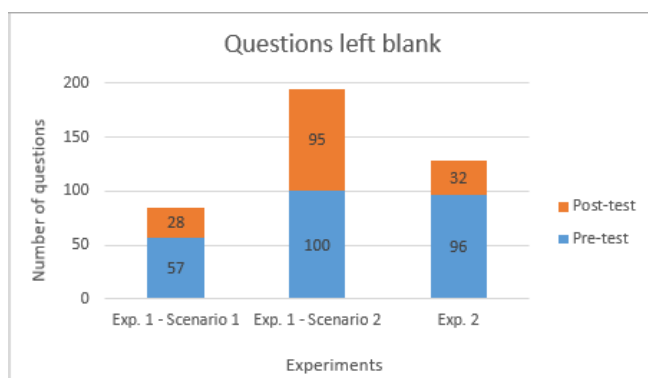


Figure 9. Number of questions left blank.

To emphasize the relevance of a practical class using a learning object, we analyzed the relation between the number of questions that were left blank in the pre-test and that were

answered correctly in the post-test. Figure 10 shows this relation considering both experiments and the topic Unified/Split, which had only one question in pre-test and also in post-test.

Considering the 23 participants in Scenario 1 of Experiment 1, 11 students correctly answered the question of this topic in the post-test, among which 8 had left the question blank in the pre-test (Goals). For Scenario 2 of Experiment 1, considering the 52 participants, 25 students correctly answered the question of this topic in the post-test, whereas 13 were participants who had left the question in the pre-test blank (Goals). For Experiment 2, considering 15 participants, 11 students correctly answered, among 9 who had left the question in the pre-test blank (Goals).

In terms of percentage, it can be observed that in Scenario 1, Experiment 1 and in Experiment 2, 73% and 82% of the students that were involved in the practical class were able to correctly answer the questions in the post-test that were left blank in the pre-test respectively. In Scenario 2, this value is 52%, which shows the importance of the practical class using a learning object.

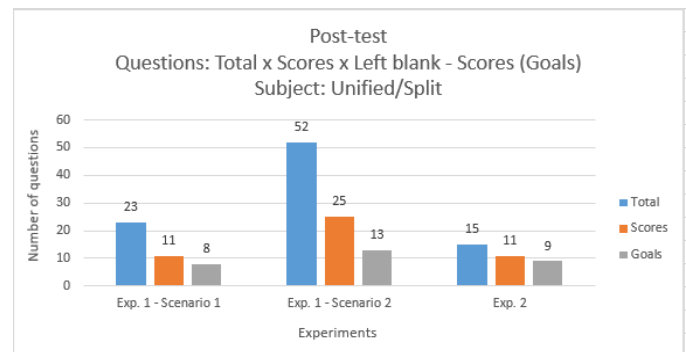


Figure 10. Number of questions left blank in pre-test and correct answers in post-test (Goals) per subject Unified / Split.

B. Evaluating Students' Attitudes

The first experiment conducted with undergraduate students had 32 participants. 37% were in doubt whether they would use Amnesia again in the future or not. 38.24% had sound knowledge of the subject before using the learning object. After using it, 97.06% said they would use the object again, and 88.24% felt confident with its results, 58.82% stated that their knowledge on the subject had improved and 29.41% said it had improved significantly. Furthermore, 85.29% of the students considered the subject more interesting after using Amnesia and 73.53% claimed they were motivated to use other learning objects in the future.

In the second experiment, carried out with MSc/PhD students, there were 14 participants. 57.14% of them already had sound knowledge on the subject before using the object and 92.86% stated that they had improved their knowledge significantly on the subject. While using the object, 71.43% felt confident with its results and 100% considered the subject more interesting and claimed they would use the object again. 78.57% said they were more motivated to use other learning objects again.

It is worth mentioning that the interest in using Amnesia again, as well as other learning objects, is a consequence of the importance of the practical class in the knowledge construction process.

VI. CONCLUSIONS AND FUTURE WORK

This paper presented the cache memory module of the Amnesia learning object. Its use as a support mechanism of the teaching and learning process was discussed, considering the memory hierarchy contents taught in Computer Organization courses.

In general, it could be observed that the simulation of cache memory theory concepts of helped students to learn, as discussed in Section V-A.

As the Amnesia object stimulates students' interaction, it was possible to hold their attention in class and they were able to construct their own knowledge. This makes the understanding of concepts and exercises easier for them. These conclusions can be supported by the 24% of the undergraduate students in Experiment 1 who improved their knowledge using Amnesia, compared to 7% who did not use it, and also by the 160% higher score reached by the graduate students in Experiment 2.

Furthermore, based on the Amnesia's object evaluation described in Section V-B, the high interest in using Amnesia (as well as other learning objects) again provides evidence on the importance of practical class in the students' knowledge construction process.

As future work, we point out the need of conducting a more complete evaluation of Amnesia. New experiments are being set up aiming to improve the evaluation methods. Moreover, new functionalities are being developed, tested and implemented on the object to make it easier to use.

The Amnesia learning object is available in the MERLOT LOR: <http://www.merlot.org/merlot/viewMaterial.htm?id=929863>.

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How Should We Estimate a Missing Exam Score?

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Abstract—In core engineering courses, instructors administer multiple examinations as major assessments of students' learning. When a student is unable to take an exam, the instructor must estimate the missing exam score in order to calculate the student's course grade. Using exam score data from multiple offerings of two large engineering courses, we compared the accuracy of several methods to estimate an exam score, including linear regression methods. The standard error of regression of the ordinary least squares (OLS) regression model was consistently about 0.5. For final exam scores, the standard errors of linear models with equal weights were nearly the same as the standard errors of the OLS regression models. For other exam scores, the equal weight model was somewhat less accurate. The results of this study provide practical guidance to instructors who need to estimate missing exam scores.

Keywords—examination, grading, assessment

I. INTRODUCTION

In large engineering courses that I (the first author) have taught, with hundreds of students, I usually schedule three examinations plus a comprehensive final examination. For the first three exams, I return exam papers to students within two or three days of the exam date. When a student misses an exam for illness or some other commitment, I try to give the same exam to the student on the next day, but for a prolonged illness, that solution is not possible. It would be unfair to give the student the same exam after papers had been returned, because the student would be able to obtain correct answers from other students during the interim time. Creating a makeup exam that has exactly the same difficulty as the missed exam would be impossible. How should I estimate the student's missing exam score, which I need to calculate the student's course grade?

There appears to be no previous research on estimating a score on an exam. In this study, building on the literature on imputing missing data, we investigate methods to estimate an exam score, using combinations of other exam scores as predictor variables.

Statisticians have developed several methods to impute missing data [1, 2]. In *mean imputation*, a missing value is estimated by the average of the other values of the variable. With mean imputation, if a student misses the second exam, the average of other students' scores on the second exam would be used. Mean imputation seems unfair because a student's academic performance would be determined by the performance of other students. In *interpolation imputation*, which is appropriate for time-series data, a missing value is

interpolated between neighboring values. With interpolation, a student's missing score on the second exam would be determined by fitting a line through the student's scores on the first and third exams. Although interpolation has the advantage of using the student's own scores, it does not use all of the student's scores. The practice of substituting the student's final exam score for the lowest exam score [3], in this case the missing exam score, has the same disadvantage.

In *regression imputation*, a missing value is estimated with a multivariate linear regression, using other variables as predictors. In a regression analysis, the variables are sometimes normalized so that each variable has a mean of 0 and a standard deviation of 1. Normalization of exam scores enables us to combine data on exams with different scale ranges and different levels of difficulty. For example, if the mean score is 72 and the standard deviation is 15, then a raw score of 69 is replaced by a normalized score of $(69 - 72)/15 = -0.20$. To estimate the normalized score on the third exam, a linear regression would determine coefficients $\beta_1, \beta_2, \beta_4$, to produce an estimate e_3^* of the normalized score on the third exam, using the normalized scores e_1 and e_2 on the first and second exams and e_4 on the final exam as predictor variables:

$$e_3^* = \beta_1 e_1 + \beta_2 e_2 + \beta_4 e_4$$

The *ordinary least squares regression* (OLS) calculates the β coefficients to minimize the sum of the squares of the residuals, i.e., the differences between the predicted scores and the actual scores.

Rather than OLS regression, I (the first author) have historically used a linear combination with fixed weights (β coefficients). To estimate the normalized score on the third exam, I used the equation above with $\beta_1 = \beta_2 = 0.25$ and $\beta_4 = 0.50$. Although I did not have any theoretical reasons for choosing these weights, the estimation with fixed weights was simple to calculate, easy to explain to students, and more "transparent" than an OLS regression: I simply disclosed the mean and standard deviation of the score on each exam. In the sequel, we call the linear combination with $\beta_1 = \beta_2 = 0.25$ and $\beta_4 = 0.50$ the *historical model* for estimating an exam score. Note that using the final exam score alone to estimate the third exam score corresponds to setting $\beta_1 = \beta_2 = 0$ and $\beta_4 = 1$.

Dawes [4] suggested that equally weighting the predictor variables produces better estimates than expert-chosen weights. To estimate the score on the third exam, Dawes would use the equation above with $\beta_1 = \beta_2 = \beta_4 = 1/3$. We call the linear

combination with equal weights the *equal weight model*. We can use the equal weight model to estimate any exam score.

Some instructors estimate a missing exam score by averaging the student's raw scores on all other exams. If all raw scores use the same scale, say 0 to 100, and they have the same mean and standard deviation, then calculating the straight average of the raw scores is equivalent to applying the equal weight model. For other methods of estimating student academic performance, see [5].

In this study we address the question of how the well OLS regression, the historical model, and the equal weight model estimate students' actual exam scores in engineering courses. To compare the quality of the estimates produced by these three different methods, we use data from actual offerings of core engineering courses with large enrollments.

II. METHODS

We gathered raw exam score data from multiple offerings of two core engineering courses taught each semester at the University of Illinois at Urbana-Champaign: ECE 110, Introduction to Electrical and Computer Engineering, and TAM 335, Introductory Fluid Mechanics. ECE 110 is a substantial, four-credit course with lectures and a design laboratory. The course covers electrical and electronic circuits, digital logic, and digital information systems. ECE 110 is required for first-year students who plan to major in electrical engineering or in computer engineering, and it is required for second-year students majoring in general engineering. TAM 335 is also a lecture-laboratory course that covers conservation, energy, and momentum principles via control volumes; the Navier-Stokes equation; laminar and turbulent boundary layers; and closed-conduit flow and open-channel flow. TAM 335 is required for third-year students majoring in agricultural engineering, in civil engineering, in engineering mechanics, and in general engineering.

In the table below, we summarize the semesters from which we obtained exam score data in ECE 110 and TAM 335. The data were completely blinded: they included no names of any students. Neither of the authors of this paper was involved in teaching these courses in these semesters. To develop the linear models, we used only data from the students with complete records, i.e., students who had taken all of the exams.

TABLE I. SUMMARY OF COURSES WITH DATA

Course Number	Semester	Total Enrollment	Students with complete records
ECE 110	Spring 2014	437	437
ECE 110	Fall 2013	416	416
ECE 110	Spring 2013	399	399
ECE 110	Fall 2012	352	339
ECE 110	Spring 2012	411	398
TAM 335	Fall 2014	213	206
TAM 335	Spring 2014	144	135
TAM 335	Fall 2013	218	204

Since Spring 2013, students who missed an ECE 110 exam were given a makeup exam. As a consequence, we have

complete records for all ECE 110 students for three semesters. In the Fall 2013 and Fall 2014 offerings of TAM 335, there was more than one version for most of the first three exams; students who sat in adjacent seats received different versions of each exam. For each student in TAM 335, we calculated each normalized exam score based on the version that the student took. Using Shapiro-Wilks test for normality, we concluded that the distributions of exam scores within each version were not normal. We used Levene's test to assess the equality of variances between different versions of the same exam because Levene's test is not as sensitive to normality as the F test. Based on the p -values of Levene's test (with significance level 0.05), we determined that the variances of exam scores from different versions were not significantly different. For Fall 2014, the p -values were above 0.70 for all three exams. For Fall 2013, the p -values were above 0.28 for all exams.

Using the statistical software package R, version 3.1.2 GUI 1.65 Mavericks build (6833), we calculated the coefficients for the OLS regression models for each exam in each course offering. For example, for ECE 110 in Spring 2014, we obtained the following OLS regression models for the estimates of the normalized exam scores e_1^* , e_2^* , e_3^* , and final exam score e_4^* , using the other exam scores e_1 , e_2 , e_3 , e_4 as predictor variables:

$$e_1^* = 0.21 e_2 + 0.04 e_3 + 0.56 e_4$$

$$e_2^* = 0.21 e_1 + 0.15 e_3 + 0.47 e_4$$

$$e_3^* = 0.05 e_1 + 0.19 e_2 + 0.47 e_4$$

$$e_4^* = 0.39 e_1 + 0.33 e_2 + 0.26 e_3$$

Notice that the coefficient of e_3 in the equation for e_1^* is relatively small, and the coefficient of e_1 in the equation for e_3^* is also small. The scores on these two exams were not highly correlated because they covered different kinds of material and required significantly different skills.

III. RESULTS

To measure the quality of the OLS, equal weight, and historical weight models, we calculated the standard error of regression for each estimated exam score for each of the three models. The standard error is the standard deviation of the predicted errors of a regression line. In the table below, we report the standard error for each model for estimating the score for each exam. A smaller standard error indicates higher accuracy. See Table II. We also found that using the final exam alone to estimate any of the first three exams always had a larger standard error than both the equal weight and the historical models. The standard errors for estimating scores using only the final exam were between 0.66 and 0.84.

IV. DISCUSSION

The standard error can be used to construct a confidence interval for the estimate. For example, suppose the standard error for the third exam is 0.60. If the standard deviation of the raw scores on third exam is 15 points, then we expect that the true score is within $0.60 \times 15 = 9$ points of the estimate with a confidence of 68%.

TABLE II. STANDARD ERRORS OF MODELS

Course	Semester	Standard Error			
		Exam	OLS	Equal	Historical
ECE 110	Spring 2014	Final	0.46	0.47	
		Exam 1	0.50	0.60	0.60
		Exam 2	0.50	0.59	0.59
		Exam 3	0.50	0.68	0.68
ECE 110	Fall 2013	Final	0.50	0.57	
		Exam 1	0.50	0.66	0.67
		Exam 2	0.49	0.54	0.57
		Exam 3	0.50	0.63	0.62
ECE 110	Spring 2013	Final	0.49	0.52	
		Exam 1	0.49	0.66	0.67
		Exam 2	0.50	0.62	0.62
		Exam 3	0.50	0.67	0.67
ECE 110	Fall 2012	Final	0.47	0.49	
		Exam 1	0.48	0.72	0.72
		Exam 2	0.49	0.56	0.56
		Exam 3	0.50	0.61	0.60
ECE 110	Spring 2012	Final	0.47	0.50	
		Exam 1	0.48	0.72	0.73
		Exam 2	0.50	0.64	0.66
		Exam 3	0.50	0.62	0.60
TAM 335	Fall 2014	Final	0.48	0.60	
		Exam 1	0.43	0.72	0.72
		Exam 2	0.46	0.67	0.69
		Exam 3	0.48	0.65	0.66
TAM 335	Spring 2014	Final	0.50	0.55	
		Exam 1	0.45	0.71	0.71
		Exam 2	0.46	0.70	0.70
		Exam 3	0.44	0.68	0.70
TAM 335	Fall 2013	Final	0.53	0.57	
		Exam 1	0.48	0.69	0.70
		Exam 2	0.48	0.67	0.69
		Exam 3	0.47	0.70	0.72

From the table of standard errors, we observe that the calculated standard errors for the Ordinary Least Squares models range from 0.43 to 0.53. The ordinary least squares model is always slightly more accurate than the equal weight model and historical weight model. This result is expected because the ordinary least squares model finds the linear model that minimizes the sum of the squared residuals.

The standard errors for the equal weight model and historical weight model are always within 0.03 of each other. This finding suggests that the equal weight model and historical model predicted very similar exam scores for our samples. We recommend that instructors use the equal weight model instead of the historical model to estimate missing exam scores. The theoretical reasoning behind the equal weight model is derived from Dawes [4]. As suggested by Dawes [4], we found that the equal weight model is almost as accurate as the OLS model in estimating final exam scores: for final exams, the standard errors of the two models are generally

close. An instructor could use the equal weight model to estimate students' final exam scores. The instructor could then offer students the option to use the estimated scores in calculating their course grades if they do not want to take the final exam. As an instructor, however, I (the first author) almost never excuse a student from a final exam, however, because students learn from repeated testing [5].

V. FUTURE WORK

To check the robustness of our findings, we plan to gather exam score data from other technical courses with large enrollments. Some courses schedule only two exams before a final exam. In these courses, if a student misses an exam, the missing score would be estimated from the scores on only two other exams. We will compare the quality of estimates from two other exams with estimates in courses that have three other exams. In addition, we will examine other models such as equal weight models in which the weights do not sum to one and models that use raw scores instead of normalized scores.

VI. CONCLUSIONS

When circumstances such as a medical emergency prevent a student from taking an exam, the instructor can use the student's scores on other exams to estimate the score that the student would have earned on the exam. From our empirical study, we conclude that the equal weight model is almost as accurate as the OLS regression model, especially for estimating the final exam score. Both linear models are always more accurate than using the final exam score alone as the estimate. Further, the equal weight model can be easily explained to students. Instructors are thus justified in using the equal weight model to estimate a missing exam score when they calculate a course grade.

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How to Take Into Account a Student's Degree of Certainty When Evaluating the Test Results

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Abstract—To more adequately gauge the student's knowledge, it is desirable to take into account not only whether the student's answers on the test are correct or nor, but also how confident the students are in their answers. For example, a situation when a student gives a wrong answer, but understands his/her lack of knowledge on this topic, is not as harmful as the situation when the student is absolutely confident in his/her wrong answer. In this paper, we use the general decision making theory to describe the best way to take into account the student's degree of certainty when evaluating the test results.

I. INTRODUCTION

A. Need to take into account the student's degree of certainty

On a usual test, a student provides answers to several questions, and the resulting grade depends on whether these answers are correct.

However, this approach does not take into account how confident the students is in his/her answer.

In real life situations, when a person needs to make a decision, it may happen that a person does not know the correct answer – but it is not so bad if this person realizes that his knowledge is weak on this subject. In this case, he/she may consult an expert and come up with a correct decision. The situation is much worse if a decision maker is absolutely confident in his/her wrong decision.

For example, we do not expect our medical doctor to be perfect, but what we do expect is that when the doctor is not sure, he/she knows that his/her knowledge of this particular medical situation is lacking, and either consults a specialist him/herself or advises the patient to consult a specialist.

From this viewpoint, when gauging the student's level of knowledge, it is desirable:

- to explicitly ask the student how confident he/she is in the corresponding answer, and
- to take this degree of confidence into account when evaluating the resulting grade.

Some tests already solicit these confidence degrees from the students; see, e.g., [4], [6], [8], [9]; see also [3], [8].

B. How can we take the student's degree of certainty into account?

Once we have the student's degrees of confidence in different answers, how should we combine these degrees of confidence into a single overall grade?

As of now, the existing combination rules are semi-heuristic. It is therefore desirable to come up with well-justified rules for such combination.

C. What we do in this paper

In this paper, we propose to use decision making theory to come up with a combination rule that adequately describes the effect of possible uncertainty and/or wrong answers on the possible decisions.

For that, we emulate a real-life decision making situation, when the decision is made by a group of specialists including the current student. In this setting, we estimate the expected contribution of this student's knowledge to the quality of the resulting decision.

II. HOW TO TAKE INTO ACCOUNT A STUDENT'S DEGREE OF CERTAINTY WHEN EVALUATING THE TEST RESULTS: CASE OF ONE QUESTION WITH TWO ALTERNATIVES

A. Need to describe how decisions are made: reminder

A natural idea to gauge student's uncertain knowledge is to analyze how this uncertainty affects the decisions. To be able to perform this analysis, we need to describe what is a reasonable way to make a decision based on the opinion of several uncertain (and independent) experts.

Decision making under uncertainty: general case. According to decision theory, decisions made by a rational agent can be described as follows:

- to each possible situation, we assign a numerical value called its *utility*, and
- we select an action for which the expected value of utility is the largest possible;

see, e.g., [1], [5], [7], [10].

B. Let us start with the simplest simplified case

Let us start our analysis with the simplest case, in which:

- we only have one question and
- for this question, there are only two possible alternatives A_1 and A_2 .

Let P_1 be the student's degree of confidence in the answer A_1 . Since we assumed that there are only two possible answers,

the student's degree of confidence in the other answer A_2 is equal to $P_2 = 1 - P_1$.

To gauge the effect of the student's answer on the resulting decision, let us assume that for each of the two alternatives A_1 and A_2 , we know the optimal action.

For example, we have two possible medical diagnoses, and for each of these diagnoses, we know an optimal treatment.

Let $u_{i,j}$ be the utility corresponding to the case when

- the actual situation is A_i and
- we use the action which is optimal for the alternative A_j .

In these terms, the fact that the action corresponding to A_1 is optimal for the situation A_1 means that $u_{1,1} > u_{1,2}$; similarly, we get $u_{2,2} > u_{2,1}$.

If we know the probabilities p_1 and $p_2 = 1 - p_1$ of both situations, then we select the action corresponding to A_1 if its expected utility is larger, i.e., if

$$p_1 \cdot u_{1,1} + (1 - p_1) \cdot u_{2,1} \geq p_1 \cdot u_{1,2} + (1 - p_1) \cdot u_{2,2},$$

i.e., equivalently, if

$$p_1 \geq t \stackrel{\text{def}}{=} \frac{u_{2,2} - u_{2,1}}{(u_{1,1} - u_{1,2}) + (u_{2,2} - u_{2,1})}. \quad (1)$$

If the actual situation is A_1 , then the optimal action is the one corresponding to A_1 . Thus, the above inequality describes when the optimal action will be applied – when our degree of confidence in A_1 exceeds the above-described threshold t .

C. How to estimate the probabilities of different alternatives under expert uncertainty

Let us denote the number of experts by n . Let us assume that for each expert k , we know this expert's degree of confidence (subjective probability) $p_{1,k}$ in alternative A_1 , and his/her degree of confidence $p_{2,k} = 1 - p_{1,k}$ in alternative A_2 .

In general, we do not have prior reasons to believe that some experts are more knowledgeable than others, so we assume that all n experts are equally probable to be right:

$$P(k\text{-th expert is right}) = \frac{1}{n}.$$

Thus, by the law of complete probability, we have

$$p_1 = \text{Prob}(A_1 \text{ is the actual alternative}) =$$

$$\sum_{k=1}^n P(k\text{-th expert is right}) \cdot P(A_1 | k\text{-th expert is right}),$$

hence

$$p_1 = \frac{1}{n} \cdot \sum_{k=1}^n p_{1,k}. \quad (2)$$

D. How to estimate the student's contribution to the correct decision

We started with the average of the probabilities of n experts. Once we add the student as a new expert, with probabilities $p_{1,n+1} = P_1$ and $p_{2,n+1} = P_2$, the probability p_1 changes to the new value

$$p'_1 = \frac{1}{n+1} \cdot \sum_{k=1}^{n+1} p_{1,k} = \frac{n}{n+1} \cdot p_1 + \frac{1}{n+1} \cdot P_1. \quad (3)$$

For large n , this addition is small, so in most cases, it does not change the decision. However:

- sometimes, the increase in the estimated probability p_1 will help us switch from the wrong decision to the correct one, and
- sometimes, vice versa, the new estimate will be smaller than the original one and thus, because of the addition of the student's opinion, the group will switch from the correct to the wrong decision.

According to the general decision theory ideas, the student's contribution can be gauged as the expected utility caused by the corresponding change, i.e., as the probability of the positive change times the gain minus the probability of the negative loss times the corresponding loss.

The probability of a gain is equal to the probability that $p_1 < t$ but $p'_1 \geq t$. Due to (3), the inequality $p'_1 \geq t$ is equivalent to

$$p_1 \geq t + \frac{1}{n} \cdot t - \frac{1}{n} \cdot P_1.$$

Thus, the probability of the gain is equal to the probability that the previous estimate p_1 is in the interval

$$\left[t + \frac{1}{n} \cdot t - \frac{1}{n} \cdot P_1, t \right].$$

For large n , this interval is narrow, so this probability can be estimated as the probability density $\rho(t)$ of the probability corresponding to p_1 times the width

$$\frac{1}{n} \cdot P_1 - \frac{1}{n} \cdot t$$

of this interval. Thus, this probability is a linear function of P_1 .

Similarly, the probability of the loss is also a linear function of P_1 and hence, the expected utility also linearly depends on P_1 .

E. How to gauge student's knowledge: analysis of the problem

The appropriate measure should be a linear function of the student's degree of certainty P_1 . So, if we originally assign:

- N points to a student who is absolutely confident in the correct answer and
- 0 points to a student who is absolutely confident in the wrong answer,

then the number of points assigned in general should be a linear function of P_1 that is:

- equal to N when $P_1 = 1$, and
- equal to 0 when $P_1 = 0$.

One can check that the only linear function with this property is the function $N \cdot P_1$. Thus, we arrive at the following recommendation:

F. How to gauge student's knowledge: the resulting recommendation

When a student supplies his/her degree of confidence P_1 in the answer A_1 (and, correspondingly, the degree of confidence $P_2 = 1 - P_1$ in the answer A_2), then we should give the student:

- $N \cdot P_1$ points if A_1 is the correct answer, and
- $N \cdot P_2$ points if A_2 is the correct answer,

where N is the number of points that the student would get for an absolutely correct answer with confidence 1.

G. Discussion

Let us show that if we follow the above recommendation, then we assign different numbers of grades in two situations that we wanted to distinguish:

- the bad situation in which a student is absolutely confident in the wrong answer $p_1 = 0$ and $p_2 = 1$, and
- a not-so-bad situation when a student is ignorant but understands his or her ignorance and assigns the degree of confidences $p_1 = p_2 = 0.5$ to both possible answers.

Indeed:

- In the first (bad) situation, the student gets the smallest number of points: 0.
- In the second, not-so-bad situation, the student gets $N \cdot 0.5$ points, which is more than 0.

Comment. Of course, if we assign the points this way, the fact that someone with no knowledge can get 50% means that we need to appropriately change the thresholds for A, B, and C grades.

III. GENERAL CASE

A. What if a question has several possible answers: analysis of the problem

In general, a question can have several possible answers corresponding to several alternatives. Let us denote these alternatives by A_1, \dots, A_s .

In this case, a student assigns, to each of these alternatives A_i , his/her degree of certainty P_i . Since we know that exactly one of the given s alternatives is true, these probabilities should add up to 1: $\sum_{i=1}^s P_i = 1$.

How does adding this student's knowledge change the decision of n experts? Similarly to the previous case:

- it may be that previously, the experts selected a wrong alternative, and the student's knowledge can help select the correct alternative A_1 ;
- it also may be that the experts selected the correct alternative, but the addition of the student's statement will lead to the selection of a wrong alternative.

Let us describe this in detail.

Similarly to the case of two alternative, we can conclude that a group of experts selects an action corresponding to the alternative A_{i_0} if the corresponding expected utility is larger than the expected utility of selecting any other action, i.e., if

$$\left(\sum_{j=1}^s p_j \cdot u_{i_0,j} \right) - \left(\sum_{j=1}^s p_j \cdot u_{i,j} \right) \geq 0 \quad (4)$$

for all i , where p_i is the estimate of the probability that the i -th alternative A_i is true. Similarly to the case of two alternatives, we conclude that

$$p_i = \frac{1}{n} \cdot \sum_{k=1}^n p_{i,k},$$

where n is the number of experts and $p_{i,k}$ is the estimate of the probability of the i -th alternative A_i made by the k -th expert.

When we add, to n original experts, the student as a new expert, with $p_{i,n+1} = P_i$, then the probabilities p_i change to new values

$$p'_i = \frac{1}{n+1} \cdot \sum_{k=1}^{n+1} p_{i,k} = \frac{n}{n+1} \cdot p_i + \frac{1}{n+1} \cdot P_i.$$

Thus, the left-hand side of the inequality (4) has a change which is linear in terms of the degrees P_1, \dots, P_s .

For each case when the addition of the student as a new expert changes the inequality between two expected utilities, the corresponding interval of possible values of the difference is small and thus, the resulting utility is proportional to the linear function of P_i – and is, thus, linear as well.

The probability of each such change is very small, so the probability that the addition of a student can change two or more inequalities – i.e., that two changes can occur at the same time – can be estimated as the product of these two (or more) small numbers and can, therefore, be safely ignored.

In this approximation, the overall utility can be obtained by adding the probabilities of all such cases and is, therefore, also a linear function of the probabilities P_i :

$$u = u_0 + \sum_{i=1}^s a_i \cdot P_i.$$

Let c be the index of the correct answer, then this formula can be reformulated as

$$u = u_0 + u_c \cdot P_c + \sum_{i \neq c} a_i \cdot P_i. \quad (5)$$

Usually, there are no a priori reasons why one incorrect answer is better than another incorrect answer. So, it is natural to assume that the utility c_i corresponding to each incorrect

answer A_i is the same. Let us denote this common value of the utility by f . Then, the above formula (5) takes the form

$$u = u_0 + u_c \cdot P_c + f \cdot \sum_{i \neq c} P_i. \quad (6)$$

Since the degrees P_i add up to 1, we have

$$P_c + \sum_{i \neq c} P_i = 1,$$

hence

$$\sum_{i \neq c} P_i = 1 - P_c,$$

and the formula (6) takes the form

$$u = u_0 + u_c \cdot P_c + f \cdot (1 - P_c).$$

Thus, the utility is a linear function of the student's degree of confidence P_c in the correct answer.

Let us denote by N the number of points that we assign to a correct answer in which the student is fully confident ($P_c = 1$). Naturally, a student gets 0 points when he or she is fully confident in the wrong answer (i.e., $P_i = 1$ for some $i \neq c$ and thus, $P_c = 0$). Thus, the desired linear function should be equal to N when $P_c = 1$ and to 0 when $P_c = 0$. There is only one such linear function: $N \cdot P_c$. So, we arrive at the following recommendation.

B. What if there are several possible answers: the resulting recommendation

Let A_1, \dots, A_s be possible answers, out of which only one answer A_c is correct. Let N denote the number of points that a student would get for a correct answer in which he or she is absolutely confident.

During the test, the student assigns, to each possible answer A_i , his/her degree of confidence P_i that this answer is correct. These degrees must add up to 1: $\sum_{i=1}^s P_i = 1$.

Our analysis shows that for this, we give the student $N \cdot P_c$ points, where P_c is the student's degree of confidence in the correct answer.

C. How do we combine grades corresponding to different problems?

In the above text, we describe how to assign number of points to a *single* question. Namely:

- Our idea was to assign the number of points which is proportional to the gain in expected utility that the student's answer can bring in a real decision making situation.
- Our analysis has shown that this expected utility is proportional to the probability P_1 of the correct answer.
- Thus, our recommendation is to assign the number of points proportional to the probability of the correct answer.

Real-life tests usually have *several* questions.

- In the traditional setting, a student provides answers to each of these questions.
- In the new setting, for each question, the student also provides us with his/her degrees of confidence in different possible answers to this question.

How do we gauge the student knowledge level based on all this information?

A natural idea is – similarly to the case of a single question – to use, as the measure of the student's knowledge, the expected utility that the student's answers can bring in a real decision making situation. Let us show how this idea can be applied.

The general decision making situation means selecting a decision for each of the problems. For example, on a medical exam, a student may be asked several questions describing different patients.

Usually, different questions on the test are independent from each other. It is known (see, e.g., [2]) that if a decision problem consists of several independent decisions, then the utility of each combination of selections is equal to the sum of the corresponding utilities.

We know the utility corresponding to each question – this is the value that we used as a recommended grade for this particular question. Thus, the overall grade for the test should be equal to the sum of the grades corresponding to individual questions.

Hence, we arrive at the following recommendation.

IV. RESULTING RECOMMENDATION

Let us consider a test with T questions $q_1, \dots, q_t, \dots, q_T$. For each question q_t , a student is given several possible answers $A_{t,1}, A_{t,2}, \dots$. For each question q_t , we know the number of points N_t corresponding to the answer which is correct and for which the student has a full confidence.

The student is required, for each question q_t and for each possible answer $A_{t,i}$, to provide his/her degree of confidence $P_{t,i}$ that this particular answer is correct. For each question q_t , these probabilities should add up to 1: $P_{t,1} + P_{t,2} + \dots = 1$.

To estimate the student's level of knowledge, we need to know, for each question q_t , the correct answer; let us denote this correct answer by $A_{t,c(t)}$. Then:

- for each question q_t , we give the student $P_{t,c(t)} \cdot N_t$ points;
- as an overall grade g , i.e., as a measure of overall student knowledge, we take the sum of the points given for individual problems: $g = \sum_{t=1}^T P_{t,c(t)} \cdot N_t$.

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The Academic Performance Index:

Creating a More Robust and Less Biased Measure of Student Academic Performance

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Abstract—This paper introduces an alternative to singular performance measures through the creation of a scaled index incorporating a variety of performance factors indicating overall student success as well as the creation of similar sub-indices for performances in the particular areas of math, English, and science. These indices have been used in two studies based on nationally representative college student data: the Sustainability and Gender in Engineering (SaGE) and the Outreach Programs and Science Career Intentions (OPSCI) projects. The Academic Performance Index (API) is a scale constructed out of students' weighted high school GPA, available standardized test scores (ACT/SAT), AP test scores (if any), highest levels of various high school coursework taken, and college credit hours earned prior to enrolling in college. Importantly, the API uses *any and all* available data in these domains, which can be up to 42 different indicators for an individual student in the case of the SaGE project. This index shows less bias regarding race and gender, when compared with commonly-used standardized tests scores. Additionally, this item is psychometrically better at indicating variation across students' performance.

Keywords—API; academic performance; measurements; controls

I. INTRODUCTION

Measures of academic performance are used in decisions about college admission and scholarships. Prior academic performance is also regularly used in educational studies to control for an individual's level of academic preparation, either overall or in particular subject areas. Many of these studies use a single measure, such as SAT/ACT standardized tests or Grade Point Averages (GPAs). However, there can be issues of consistency in the use of these measures. Standardized tests scores depend on a single performance in a testing environment that may not give an accurate picture of students' content knowledge or academic preparation. Additionally, GPA can vary significantly by school, district or state in the calculation of credit for scores earned in courses at different levels (e.g. college preparatory, advanced, Honors, or Advanced

Placement/International Baccalaureate) as well as the scores themselves. For example, in the state of South Carolina, each final grade in a course receives a distinct score on the GPA metric based on the Uniform Grading Policy implemented in 2006 (e.g. 94 in a college preparatory class corresponds to a 4.125 GPA, while a 95 corresponds to a 4.250, and a 94 in an AP course corresponds to a 5.125 GPA) [1]. However, in Indiana, the grading policy uses a more traditional +/- grading scale where an "A" is equivalent to a 4.0 and an "A-" is equivalent to a 3.667 [2]. Such variation can reduce the validity of GPA measures as controls or measurements of academic performance. Moreover, the traditionally used performance measures have been shown to be biased against historically-underrepresented groups in engineering – women and racial/ethnic minorities. With this focus, we present a more robust method of calculating academic performance that shows less bias.

II. BIAS OF TRADITIONAL MEASURES

Research has shown that traditional measures of scholastic achievement like the SAT or ACT required for college admissions show bias against women and underrepresented minorities [3-5]. Typically, test creators come from upper middle-class to upper class families. Because of homogenous backgrounds, items they put on these tests show bias towards language and culture that is associated to higher socioeconomic status [6]. Often, this bias directly affects underrepresented groups. The use of tests scores for college admissions is problematic because it creates barriers for entry based on unjust and factors favoring men, whites, and the affluent [4]. This trend has been noted by Haycock & Gerald [7, p. 7]: "...the 50 flagship universities now look less and less like America—and more and more like 'gated communities of higher education.'" Further (p. 5): "...the highest achieving students from high income families—those who earned top grades, completed the full battery of college prep courses, and took AP courses as well—are nearly four times more likely than low-income students with exactly the same level of academic

accomplishment to end up in a highly selective university.” In addition, standardized tests have not been shown to be particularly correlated with college performance [8]. Nonetheless, these measures continue to create barriers for underrepresented students to succeed in disciplines like engineering that require high admissions criteria.

Additionally, while average performance on standardized tests has increased for both men and women over time, a small but persistent gender gap favors men on both the SAT and ACT. The primary purpose of the SAT is to measure students’ potential for academic success in college. The current test, revised in March 2005, includes Critical Reading, Math, and Writing all scored on a range of 200 to 800 [9]. On the SAT, the largest gender gap is seen on the math section of the exam across all races/ethnicities and socioeconomic statuses. While, on the SAT math section, men outscore women across all of these demographics, Asian American, Hispanic, and white men have a gender advantage twice as large as that of their African American peers [10]. There is also a smaller advantage on the verbal section of the SAT as well. Some studies show that this advantage is on average 30 to 50 points [11]. Although, in general, the difference is small, and the distributions of male and female performance are overlapping, these differences can still have a significant impact on admissions and scholarships offered to students [12]. The average difference between males and females on the Math portion of the SAT has remained unchanged for over 35 years, despite the large increase in the number of females entering fields that require mathematics [13].

Similar to the SAT, the ACT is meant to predict first-year college grades. Unlike the SAT, the ACT questions are linked to curriculum and test students in English, math, reading, and science with a score for each subject area and total composite score ranging from 1 to 36. On the ACT, men have moderately higher composite scores, and there are gender differences on the individual sections. Men, on average, perform better on the math and science sections, whereas women perform better on the English and reading section of the ACT. While ACT scores have improved for Asian American and white test takers from 1995 to 2007, scores for African American and Hispanic students have either remained the same or declined. Additionally, Asian American and white students have outscored their peers on the math section over this period [10].

Several explanations have been offered for these persistent differences on standardized tests like the SAT and ACT, including test bias, purported biological gender differences, test anxiety (linked to stereotype threat), peer relationships, and differences in course taking [14,15]. However, recent trends point to self-selection as a reason for gender differences. Since 2002, all high school students in Colorado and Illinois are required to take the ACT. In both states, the male advantage on the composite scores has disappeared and a slight female advantage has emerged. Similarly in Maine, all students are required to take the SAT since 2007. These testing results have shown a reversal in the gender gap for the verbal section and a reduction in the math advantage for men from 38 points in 2006 to 12 points in 2007 [10].

Also, students on average are earning higher GPAs in high school with women performing slightly better than men. This trend does not reflect enrollment in easier coursework; in fact, women earn more credits than men in high school math and science and have a higher combined GPA in these courses [16]. Men still outscore women in the NAEP assessment in math, but only by a small margin. However, students’ family income level has a significant impact on student performance in these areas and the gap is not significantly decreasing [10]. With these potential biases in traditional measures of academic performance in mind, the Academic Performance Index (API) was created from a number of indicators to reduce bias and more accurately control for prior student preparation.

III. DATA FOR ACADEMIC PERFORMANCE INDEX

The two data sets used as examples in the construction of the API comes from two nationally representative surveys administered in two different contexts for separate research projects. The Sustainability and Gender in Engineering (SaGE) survey was administered in required, introductory English courses in Fall 2011 to collect data from a representative sample of engineering and non-engineering students (engineering.purdue.edu/ENE/Research/SaGE_survey_Godwin_2014). Drawing from a stratified, random sample of colleges and universities across the United States taken from the National Center for Education Statistics (NCES), the survey study collected data from 6,772 students attending 50 different 2- and 4-year post-secondary institutions. The SaGE survey included questions on high school science and math experiences, science enrollment and achievement (courses taken, grades, AP test scores, etc.) as well as their career goals, family characteristics and support, attitudes about sustainability, science and engineering, and demographic information.

Multiple aspects of validity and reliability of the SaGE instrument were assessed. To ensure content validity, hypotheses generated from a survey of NSTA members as well as from an open-ended survey of 82 first-year engineering and 41 non-engineering majors were included as items in the survey. Questions were further refined based on feedback from evaluators and the results of pilot-testing in a first-year freshman engineering course. An in-person pilot of the survey and focus groups were conducted with first-year freshmen engineering students. Thus, each item of the survey was further examined for face and content validity. Stability reliability of the items used in this analysis was assessed by a test-retest study of 62 students, with an acceptable-to-good average Pearson's correlation of 0.725 [17].

The Outreach Programs and Science Career Intentions (OPSCI) survey was administered in the fall of 2013 to incoming students at U.S. institutions of higher education that participated the Science, Technology, Engineering, and Mathematics Talent Expansion Programs (STEP) funded by the National Science Foundation. This program supports initiatives geared toward increasing the number of students receiving associate's or bachelor's degrees in STEM fields. The survey was administered in freshman English courses, typically required as a general education credit, to gain a representative sample of both STEM and non-STEM students at each

participating university. These responses included 23 four-year institutions and 4 two-year institutions. In total, 15,847 students completed and returned surveys.

Several items on the OPSCI survey were identical with an already developed and successfully used instrument, the “Persistence Research in Science and Engineering” (PRiSE - NSF GSE 062444) survey. Other questions were created specifically for the OPSCI survey by the project team. The OPSCI survey was pilot tested with students at a Southern university to ensure construct validity and to ascertain the time it took for survey completion. Test-retest reliability of the survey was established by administering the survey to 57 students at that same university twice in an interval of about two weeks. For continuous variables, the Pearson correlation coefficient serving as a measure of stability reliability had an overall mean of 0.73.

IV. CONSTRUCTION OF ACADEMIC PERFORMANCE INDEX

In each data set, a normalized API was created from the variety of performance measures to capture the wide spectrum of prior academic preparation into a single measure. Students’ self-reported many indicators on both the SaGE and OPSCI surveys including the math courses they took in high school (e.g. Algebra I, Geometry, Statistics, Trigonometry, etc.); the highest score earned on the SAT and ACT (total and individual sections); the high school science courses taken (e.g. Physical Science, Environmental Science, Earth Science, 1st Biology, 2nd Biology, 1st Chemistry, 2nd Chemistry, 1st Physics, 2nd Physics) as well as their most advanced math and English courses; the course level at which these courses were taken (e.g. regular, honors, AP, IB, other advanced); the year the courses were taken in high school; the final grade (e.g. A+, A, A-, etc.); and the AP exam scores for any AP tests taken. One difference between the two data sets is that the OPSCI survey did *not* ask students to report on the highest course level for English. (This resulted in the API-English having a higher mean and smaller standard deviation for OPSCI than for SaGE.)

First, the data were cleaned to remove any irregular student responses on the hand written SAT and ACT scores. Section scores below 200 or above 800 for the SAT and below 1 or above 36 for the ACT (all impossible) were removed. Additionally, total SAT scores below 600 and above 2400 were removed along with scores that did not conform to the ten point interval scoring scale for a total of 112 removed responses on SaGE (1.65% of the total respondents) and 444 responses on OPSCI (2.8% of the total respondents).

The data were normalized on a uniform 0 to 1 scale for each variable included in the index. For example, students’ science grades (reported in letter grades) were initially made numeric on a 4.0 GPA scale. Then, an “A” in a course (4.0) was interpreted as a one on the normalized scale, a “B” (3.0) corresponded to a 0.75, etc. Each of these scales was weighted by the level of course taken. For regular courses, students received no grade bump, for honors and advanced courses students received a 0.5 GPA increase, and for AP/IB courses

students received a 1.0 GPA increase consistent with GPA weighting for post-secondary students in the U.S. [1,2]. This weighting helped to reduce the inconsistencies typically seen in student’s GPAs from different high schools across the U.S., as discussed previously, by putting ALL students on the same GPA scale.

To obtain the most comprehensive amount of data and allow for simple comparisons across students, an overall SAT score and SAT section scores were created. Some students reported only the SAT, only the ACT, or both, or neither. We collected the available data and converted the highest scores into the SAT scale. For example, if a student did not report an overall SAT score, but reported individual section scores, these were summed to find the total. A similar process was used to combine ACT section scores into composite scores. The conversions of the ACT writing and math sections was a simple translation of the scores into the SAT scales [19]. For the ACT reading (ACTR) and English sections (ACTE), the concordance model appearing as (1) was used to combine these scores based on a conversion provided in an Education Testing Service (administrators of the SAT) report [20]:

$$SAT\ I\ Verbal = 7.52*ACTR + 8.76*ACTE + 156 \quad (1)$$

For students with only partially reported sections, each section was converted into an SAT scale using an ACT-to-SAT concordance [18] and the total score was left blank. Finally, all SAT scales were re-scaled from 0 to 1.

Once each of these data transformations was accomplished, an index for total performance, math performance, science performance, and English performance was created from any and all available data (on a case-by-case basis) using R [21]. For example, if a score was available for a given variable, then that score was added to a running total and the denominator (weight for the mean) was increased by one to appropriately incorporate that response for the index; otherwise, if there was a non-response on that question, the value was not added and the count remained the same for that student in the data set. Thus, the total performance index includes all available academic performance data reported by each student. Each of the subsections in math, science, and English was constructed in an analogous manner and includes the relevant information reported by students in each of those topical areas.

Some differences in the nature of the questions asked on the SaGE and OPSCI surveys resulted in a different construction of the API and subscales. Namely, the OPSCI survey did not ask for the level at which students took English courses, so a weighted GPA was not calculated for those courses. The result is that we would expect the AI-English index from OPSCI to have a higher mean and smaller standard deviation (which was, indeed, found – See Table I). Additionally, OPSCI not only asked for the highest level of math taken and the list of math courses taken, but asked specifically about students’ Pre-calculus and Calculus course taking. This fact means that for some students, their API-Math component might actually be weighted heavier because of additional details included about these class experiences.

TABLE I. COMPARISONS OF ACADEMIC PERFORMANCE INDICES BETWEEN SAGE AND OPSCI SURVEYS

Survey	Mean	Median	Std. Dev.
<i>API-Total</i>			
SaGE	0.54	0.56	0.19
OPSCI	0.69	0.69	0.12
<i>API-English</i>			
SaGE	0.48	0.46	0.21
OPSCI	0.77	0.75	0.13
<i>API-Math</i>			
SaGE	0.43	0.42	0.22
OPSCI	0.62	0.62	0.16
<i>API-Science</i>			
SaGE	0.56	0.57	0.18
OPSCI	0.67	0.70	0.14

The API-Science is very similar between the two data sets on the types of data collected, except that OPSCI did not collect information about students' Environmental Science courses. Additionally, a larger proportion of the students in the SaGE dataset attended two-year institutions (1548 out of 6772 or 22.9% of the sample) compared to the OPSCI dataset (2361 out of 15,847 or 14.9%). These differences could result in lower averages for the SaGE aggregate numbers on the four API measures presented in Table I.

Other minor differences include that OPSCI asked students about their Engineering and Computer Science course experience in high school. This difference affected the composition of the indices by including additional course information, but does not inherently suggest a significant difference in interpretation. OPSCI also asked for AP scores on Environmental Science and Computer Science. However, the OPSCI data set reported fewer than 200 students taking these classes in high school, or about 1% of the total population. Therefore, with the exception of English, we expect the index to be equivalent across to the two data sets.

V. EVALUATION OF THE ACADEMIC PERFORMANCE INDEX

The resulting indices combine a variety of academic performance and preparation information into a single index for both the SaGE and OPSCI data.

For the SaGE data, the API has a median of 0.56, mean of 0.54, and standard deviation of 0.19 with 5259 responses. The skew (-0.47) and excess kurtosis (0.03) indicate a fairly normal distribution that is slightly skewed negatively which is reasonable for a student population that has been admitted into a college or university. For the OPSCI data, the API has a median of 0.69, mean of 0.69, and standard deviation of 0.12 with 15,403 responses. The skew and excess kurtosis were -0.50 and 0.88, respectively indicating an almost normal distribution (slight negative skew and more peaked distribution

than Gaussian), similar to the SaGE data. Table I shows a comparison of the means and standard deviations of the indices from both SaGE and OPSCI. The results show the OPSCI with higher means and smaller standard deviations across all the indices. For English (and its contribution to the total index), the absence of a course level is a significant contributor to this difference. In addition, the OPSCI survey was administered only at four-year colleges and universities. As SaGE was administered in both four-year and two-year institutions it includes students with significantly different demographic backgrounds and academic preparation [22]. Thus, we are not surprised that the data which only includes students at four-year institutions to have higher academic performance indices.

When examining the relative bias of standardized tests in the SaGE data, the SAT math section and writing section show gender differences with the math section having a higher average for men, whereas the writing section has a higher average for women (see Table II). The ACT math and science sections have significantly higher averages for men than for women. In examining the performance indices in the areas of math, science, and English, only the API-Math shows gender differences. This result is not surprising since the API-Math index is created from standardized tests scores as well as high school course taking. However, when comparing the API-Math index with the SAT math section, the gender difference observed in the performance index is *smaller* than the difference seen in SAT math scores ($t(1023) = 1.87, p = 0.006, d = 0.11$). The API-Math is also significantly *less* biased against women than are the ACT math test scores ($t(1396) = 6.37, p = 0.006, d = 1.09$). While all of these indicators that may be used to control for prior academic performance show some gender differences, the developed API show significantly less differences between men and women than traditional standardized test scores. The fact that the API shows less bias while being constructed out of several factors, including those which show greater bias, is likely due sampling a students'

TABLE II. COMPARISONS OF THE ACADEMIC PERFORMANCE INDEX TO TRADITIONAL SAT/ACT SCORES BY GENDER – MEASURES WITH SIGNIFICANT DIFFERENCES

Standardized Measures	Women Mean	Men Mean	Significance ^a	Effect Size ^b
SAT Math (scale 200-800)	596	624	**	0.03
SAT Writing (scale 200-800)	596	556	***	0.06
ACT Math (scale 1-36)	23	25	***	0.04
ACT Science (scale 1-36)	23	25	***	0.03
API-Math (scale 0-1)	0.42	0.44	***	0.004

a. ** represents a p-value of statistical significance between 0.01 and 0.001, and *** a statistical significance of less than 0.001.

b. Effect size for Welch's t-test were calculated by using Cohen's *d* with 0.1, 0.3, and 0.5 indicating small, medium, and large effects, respectively.

TABLE III. COMPARISONS OF THE ACADEMIC PERFORMANCE INDEX TO TRADITIONAL SAT/ACT SCORES BY RACE – MEASURES WITH SIGNIFICANT DIFFERENCES

Standardized Measures	URM Students Mean	White Students Mean	Significance ^c	Effect Size ^d
SAT Total (scale 600-2400)	1611	1685	*	0.03
ACT Total (scale 1-36)	23	24	***	0.03
SAT Critical Reading (scale 200-800)	551	587	***	0.06
SAT Critical Writing (scale 200-800)	547	584	****	0.06
ACT Math (scale 1-36)	23	24	**	0.03
ACT English (scale 1-36)	23	25	**	0.04
ACT Science (scale 1-36)	23	24	***	0.04
ACT Reading (scale 1-36)	23	25	***	0.06
API (scale 0-1)	0.51	0.55	***	0.004

c. ** represents a p-value of statistical significance between 0.01 and 0.001, and *** a statistical significance of less than 0.001.

d. Effect size for Welch's t-test were calculated by using Cohen's *d* with 0.1, 0.3, and 0.5 indicating small, medium, and large effects, respectively.

performance across several domains, which will tend to “average out” testing bias on individual scores.

Additionally, the standardized tests in the SaGE data showed bias against underrepresented students. Students were grouped into either majority (white) or underrepresented minority (URM, consisting of self-reported racial groups: Black, American Indian or Alaskan Native, and Native Hawaiian or Pacific Islander. Note: Asian students are overrepresented in engineering and were not included in the URM measure [23]). White students had significantly higher averages on total SAT and ACT tests as well as higher averages on SAT Critical Reading, ACT science, and ACT Reading sections. The overall API measure also showed significant differences for underrepresented minorities (see Table III). When the difference for the overall SAT was compared to the API, a significant difference was found between the two measures ($t(1947) = 3.21, p = 0.0013, d = 0.23$). The API was not significantly different when compared with overall ACT scores ($t(4457) = -0.20, p = 0.84, d = 0.001$). These comparisons indicate that the API measure is no worse

and may even be less biased against URM students than traditional SAT/ACT scores.

Another advantage of using a performance index in controlling for or understanding students' prior academic performance is in utilizing the majority of data provided by students on self-report surveys can be included. For example, in the SaGE data only 954 out of 6,772 respondents reported a total SAT score, and 1651 reported a total ACT score. However, 1356 students reported individual sections scores on the SAT while 1669 students reported section scores on the ACT resulting in 2130 total SAT scores and 3320 total ACT scores when these measures were summed. By combining this information along with high school course taking, AP scores, and student performance, the API is estimated for 5,259 out of 6,772 total respondents. This technique uses the available data rather than resorting to missing data methods. While some forms of missing data methods, like multiple imputation, are highly robust and valid for handling these types of missingness, the efficiency of these methods are low for the extreme missingness of student-reported standardized test

scores (85.9% missing SAT scores). Our approach to this method used a variety of data sources to triangulate student academic performance without having to deal with the decisions involved in dealing with missing data methods in these kinds of extreme cases.

This approach allows for a comprehensive understanding of students' prior academic performance. Having more data incorporated allows the "data to speak for itself," instead of relying on unproven assumptions and weak correlations. It is also parsimonious, by allowing for the construction of simpler models with more easily interpretable results than those requiring complex data manipulations or numerous collinear controls within a model. In these cases, the standard errors of the affected predictors tend to be large and the Type II error rate may increase in the testing of various hypotheses. Redundant data (with independent variables that correlate highly with one another) can result in the over-fitting of a regression model. Such "high noise" models are less statistically robust and may not reliably predict the outcome across numerous samples drawn from the same statistical population.

The API subsections of math, science, and English also allow for a comparison of students' performances in specific areas in a more nuanced way than an overall performance measure, like standardized test scores or GPAs, could provide. For example, a student could be mediocre in their academic performance overall, but excellent in math. This is typical of many engineering students who score, on average, higher on the math sections of standardized tests than on the critical reading sections. The average math score of admitted students for the top 50 engineering schools in 2009 was 764 for SAT math sections and 655 for critical reading [24]. While overall performance is a useful indicator of prior academic performance, a closer examination of domain-specific performance can indicate differential effects of certain classroom performances on outcomes of interest. Use of the academic performance index

The API has been used as a control for prior academic performance in several published studies. For example, in a paper from the SaGE data set, published in the January 2014 issue of the *Journal of Engineering Education* [25], API-Math was used as a control in a logistic regression model predicting students' engineering career intentions as a binary dependent variable that was primarily concerned with students' sustainability-related outcome expectations (p. 146). This estimate had an odds ratio of 3.60 ($p < 0.001$) in predicting engineering choice and was the largest estimator within the included controls for the outcome of interest. API-Math and API-English were also included as controls in a logistic regression model predicting students' interest in an engineering career from sustainability issues that they wished to address in their career (p. 148). API-Math had an odds ratio of 7.58 for engineering choice ($p < 0.001$), and API-English had an odds ratio of 0.37 for engineering choice ($p < 0.001$). These results show that the API-Math has strong predictive power for outcomes of interest to engineering educators like students' choice of engineering as a career. Having a higher score on API-English reduced the odds of choosing an engineering career in college by over one-third. Additionally, these results

are a proof of concept in the use of the API and API subscales as controls in larger regression models.

This index was also used in a large block regression model predicting students' engineering choice in college based on background factors, critical engineering agency, career expectations, direct influences on student career choices, and students' experiences within their high school science classrooms as presented at the 2014 *American Educational Research Association Annual Meeting* [26]. This model revealed that students' prior academic performance (API) was non-significant in predicting students' engineering choice when a variety of other hypothesized independent variables about students' attitudes, self-beliefs, and pedagogical experiences were added.

This index has also been used with the OPSCI survey with similarly successful results. In a model of physics identity, the way in which a student describes themselves as a "physics person," as an outcome, API-Science was not a significant predictor because of co-linearity with high-school physics grades which were also included in the model. However, both API-Math ($\beta = 0.10, p < 0.001$) and API-English ($\beta = -0.04, p < 0.001$) were significant control predictors of physics identity [26]. Work currently underway has also successfully used these APIs as independent variables in regression models predicting interdisciplinary affinity – a construct measuring students' interdisciplinary interest and self-efficacy.

VI. IMPLICATIONS

The API and related subscales offer an alternative method for accounting for students' prior academic performance over traditional, singular measures of standardized test scores and high school GPA. These typical measures have shown bias against underrepresented groups and may skew findings in statistical modeling. The API and related subscales are less biased against these groups than other measures of performance. Additionally, this measure is a more robust accounting of academic performance than single, often highly collinear variables in a model. This method captures the maximum amount of information on student self-reported measures which are a typical way of gathering such data. Self-reported academic performance reduces the difficulty of obtaining student data under FERPA guidelines, but we acknowledge that it is not without limitations. Students' self-reported measure may be less accurate or more positive than actual student academic performance data from transcripts. However, normalizing all reported information together may mitigate some of the concerns.

Additionally, these data can be used as benchmarking tools to compare other students' prior academic performance with nationally representative values of college students' prior academic performance. Often, conducting a study with large-scale data is not feasible because of time and money restrictions. These data offer a picture of how students in studies with less variation may compare to a national sample of students in colleges across the U.S. The average values for the SaGE dataset are 0.46 for two-year institution students and 0.56 for four-year institution students. The average values for the OPSCI dataset are 0.62 for two-year institution students

and 0.70 for four-year institution students. These data are only nationally representative of *college-enrolled* students. This limitation would make comparisons to other groups (e.g. pre-college students or students who did not enroll in college) unfair.

Future studies using the API should include an external validation study of the measure by correlating students' self-reported API with actual high school performance and college grades. We would be interested in examining if the API and related subscales are better predictors of college performance than other measures.

While this method does provide opportunities to account for bias in traditional performance measures and to normalize prior academic performance across students from different schools, it does not address the root issues surrounding standardized testing procedures or the use of these scores in important decisions like college admittance or scholarship awards. This approach to providing a more robust and less biased estimate for prior academic performance works within the current system of national measurements rather than offering alternatives. Until the inequities in American society can be addressed, many minority students will be less likely than white students to attend well-financed, generously-staffed elementary and secondary schools, and many women will have the challenges of taking tests that under-measure their performance potential, and women of color will encounter the compounding of both of these issues. The use of this measure addresses the symptoms of measuring unequal educational opportunities with "standardized" assessment methods but does not change the underlying causes for bias in the evaluation of students. While we argue that the use of this measure is a step forward toward making research-based and less biased education and policy decisions, we acknowledge the long journey ahead to make education and access to engineering opportunities equitable for *all* students. The biggest issue in standardized testing is not the participating student population, but lies in how standardized tests are used to exclude specific groups from higher educational opportunities.

VII. CONCLUSIONS

In conclusion, we have delineated the process of developing the API for two large, nationally representative data sets. The API and related subscales have proven to be a successful way to control for prior academic performance in several published studies. In this paper, we demonstrated that the API and related subscales are a less biased estimate of prior academic performance than standardized tests scores for underrepresented groups in engineering such as women and minorities. This approach to operationalizing students' prior academic performance reduces the risk of Type II error in regression models by combining multiple collinear variables into a single measure and it maximizes the use of students' self-reported performance information.

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Evaluating Metrics for Automatic Mind Map Assessment in Various Classes

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Abstract—Over the past three years, we have been studying how automated evaluation of student mind maps (when compared to an expert map) shows student learning for a variety of metrics. The goal of this work is to build a system that would then allow students to evaluate their understanding of the terminology in a respective field. The weakness of our studies, so far, is that our focus group to study these metrics consists of a single course in the field of Computer Engineering, and though this class has been used over multiple years to demonstrate the feasibility of our approach in a longitudinal study, a broader study needs to be done. In this work, we show how our current metrics perform across three additional fields; specifically, we have collaborated with instructors in speech pathology, communications, and political science (in addition to our traditional class in computer engineering). We then use our methodology to determine if these courses and a term long mind map exercise have similar results than previously reported and are these results evidence of student learning. Our results show that our existing metrics have similar results for one of the three new courses. However, in the two other courses, the data shows no evidence of learning based on the mind map exercise. Each of the instructors of these courses describes their experience with the activity. Additionally, we evaluate the construction of the expert maps in each course to understand if there is a graph-based structural reason why the results might be different. We conclude by suggesting our methodology is good for courses where terminology is clearly defined and is used and studied throughout the semester, and describe some future directions for this research.

I. INTRODUCTION

The overall goal of this research is to investigate if machines can help provide students with feedback on their learning using mind maps. Mind maps are simple visual drawings that includes terms of interest (which we will call nodes) and lines connecting these terms (which we will call edges). We use the terms nodes and edges as they are common terms in for describing components of a graph, which is a structure under study in a mathematical field called graph theory. Based on this, we are examining if graph theory and

related algorithms can help us evaluate a student's mind map. This evaluation is achieved by comparing a criterion map to the students map, where the criterion map is the original mind map created by an expert (instructor). The criterion map determines the number of words and their connectivity.

To achieve this, we have proposed and studied a number of metrics in previous publications ([1], [2], and [3]) in terms of finding a set of metrics that show if a student is learning. The weakness in these works is that they have focused on a single course (Digital Systems Design) within a single major (Computer Engineering), and even though the results for some of our metrics (two in particular) have shown promising trends over each year of data collection, the bigger question is if our methodology shows similar trends over a range of courses.

The goal of this paper, then, is to present a broader range of courses and apply the same experimental method and evaluation to see how these metrics show learning. Specifically, we have enlisted the help of three instructors in speech pathology, communication, and political science and implemented our experimental method on some of their courses. The data collected over a semester in each of these courses was then analyzed using two of our most promising metrics, and the results are evaluated in this paper. In particular, we found that our favorite metric (a match metric) performed well in one case (speech pathology), showed some indication of learning in a second class (political science), and showed little evidence of learning in the third class (communication).

After presenting the methodology, a brief introduction to the metrics, and the results, we provide each instructors perspective on experiment, mind map activity, and their respective results. This discussion provides us with a conversational explanation for our results, and additionally, we look at aspects of the criterion maps to see if there is any difference that can further explain why in two out of four cases our preferred metric seems to be capturing student learning. This work provides us with one recommendation that our methodology

seems to be applicable to courses that introduce terminology with clear definitions and that terms are used throughout the semester. For courses that do not fit this model, we suggest some future work that might allow our techniques to be useful to students in their learning process.

The remainder of this paper is organized as follows: section II provides a background on mind maps and research into their use as measurement artifacts. Section III describes our methodology and measurement metrics. Section IV presents the results for two of our measurement metrics for the 4 courses we used in 2012/13, and describes these results in some details. Section V provides the three new course bases with a more personal description of their experience with the experiment and their respective results. Section VI discusses our overall results and concludes the paper.

II. MIND MAPS AS MEASURABLE ARTIFACTS

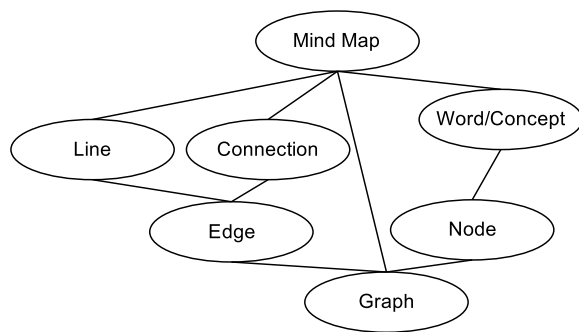


Fig. 1. Example of a mind map on the relationship between mind maps and graphs

Mind maps are simple visual representations of terminology and simple one-to-one relationships [4]. Mind maps [5] are a visual representation that are used in a number of settings including a Class Assessment Techniques (CATs) [6] which allows teachers to evaluate student understanding in class and provide feedback. Figure 1 shows an example mind map that expresses the main author's understanding of mind maps and how they relate to mathematical graphs. The words/concepts that are in a mind map are the nodes of a graph (circled bubbles), and the connecting lines between these words are edges of a graph.

There is continued interest in mind maps as a pedagogical tool that can help structure learning [7] as well as a vast and rich data set that can provide other insights [8]. Mind mapping tools are readily available and the technique is used in an wide number of areas. In our past studies we have provided background on mind maps in scoring. An updated one for mind maps includes:

- comparing the scores on tests to the technique [9]
- having two independent experts score (sometimes with a rubric) the mind map on a scale two times with one week delay and compare correlation of ratings [10]
- using structures and frameworks to identify redundancies and troubling portion of a map [11]
- using a large data-set of mind maps for deep fact finding of interrelated topics [12]

The type of mind maps we use in this study are called closed, which means they have a limited set of words (nodes) [13]. Our scoring technique that uses criterion maps is called *comparison with a criterion map* [14].

III. EXPERIMENT AND MEASUREMENT METRICS

To perform automatic feedback from mind maps to help students learn a field's vocabulary, our focus has been on semester long experiments that evaluate student mind maps with various metrics. In this work, we continue this experimental setup, but for a broader range of courses. In this section, we will describe the experimental setup and the measurement metrics that we have found to be most useful in showing that students have learned.

A. Experimental Method

We start with the assumption that *most* students learn about a particular area (course) over a semester, and this learning includes a better understanding of the technical vocabulary and terms as related to a class topic/field. Nation [15], Coxhead [16], and Chung *et. al.* [17] discuss the relevance of technical vocabulary in a field and quantify that their are approximately 5% technical, field-based the words used in related publications. However, the technical vocabulary is not necessarily the most important learning objective, and in terms of emphasis and assessment, the vocabulary might be a periphery outcome.

To measure the relevance of the vocabulary we will use Wiggins and McTighe's simple taxonomy [18]:

- 1) worth being familiar with
- 2) important to know and do
- 3) enduring understanding

where the importance of the learning objective is more important as the number increases. Each of our instructors in this experiment will give their courses technical vocabulary a 1, 2, or 3 rating depending on how important it is to their respective course and students.

The experiment is a semester based longitudinal experiment. First, the instructor picks twenty terms (closed mind map) that they then use to create the criterion map (expert map). Next, the students are briefly taught how to make a mind map using an example that is not part of their class. For example, a list of countries is provided and the instructor shows how different mind maps could be created depending on the context; for example, countries organized by trading partners versus geographical location versus immigration paths will each make a very different mind map. Then over the semester the students will be given the 20 terms (unorganized) and will create an in class mind map.

In terms of controls, we have attempted to control the following:

- Each in class activity is kept to 10 minutes
- There are twenty terms to create a mind map and those terms stay the same each time
- The activity is done at least twice, but preferably three or more times spread somewhat evenly throughout the semester

Students create their mind maps on paper, and therefore, the mind maps need to be electronically encoded to allow the measurement metrics to be calculated. This process takes some time, but until we have a flexible electronic tool this is part of our methodology. The conversion of paper mind maps is done once the semester is completed and grades have been submitted. Research consent forms are opened and students that gave permission for their mind maps to be included in the experiment are kept and non-participants mind maps are shredded and removed from the data set.

Once the criterion maps and the student mind maps have been converted into an electronic format, we run our data analysis tools to generate the respective metrics as will be presented in the results section.

B. Metrics to Measure Mind Maps

In our past papers ([1], [2], and [3]) our goal has been examining different metrics that measure how similar the criterion map is to a student mind map. Over these studies, we have found two metrics that seem to strongly show differences and a third one that is pretty good at showing graph similarities. In this work, we will use one of the strong metrics (the second metric was being evaluated) and the okay metric; these metrics are called *match metric* and *RGF-distance*, which we will describe below. These two metrics are the best performing metrics in our 2013 paper [2], which has additional description of why these metrics seem to better capture similarities and differences as related to learning.

The *match metric* is an edge by edge comparison between the student mind map and the criterion map. The nodes in our graphs are uniquely identified by a label (the term written in the bubble), and this allows us to compare the two graphs in linear time. During this comparison a number of statistics are recorded about the differences including missing nodes (*MissN*), extra edges (*ExtraE*), and matching edges (*MatchE*) where the comparison is the student map as compared to the criterion map. The *match metric* is a combination of these statistics:

$$MatchMetric = \frac{MatchE}{MissN + ExtraE + MatchE} \quad (1)$$

This equation results in a number between 0 and 1. The number is interpreted where as it approaches 1 indicates there is more similarity between the two graphs.

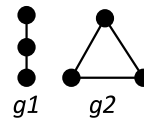
The second metric is *RGF-distance*. This metric is a little more complicated and relies on what are called, graphlets, which, are “a connected network with a small number of nodes” [19] and these small graphs are non-isomorphic induced subgraphs of a larger graph. Figure 2 shows all the graphlets of size 2, 3, and 4.

The existence of graphlets is used to analyze the structure of a graph. The procedure developed by Przulj *et. al.* [19] is to search for all graphlets of size 3, 4, and 5 in a given graph. Based on the count of each type of graphlet, a signature is constructed in the form (g1, g2, g3, g4, g5, g6, g7, g8, ..., g28, g29), where g1 is number of the first type of graphlet of size 3 shown in figure 2 and g29 is the count for the last graphlet of size 5. This signature can be compared to another graphs' signature to get a measure of similarity, and Przulj

2-node graphlets



3-node graphlets



4-node graphlets

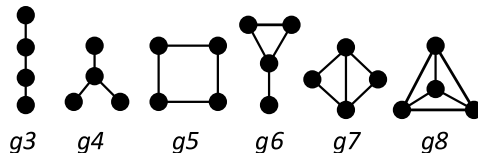


Fig. 2. Graphlets of size 2, 3, and 4

et. al. used their technique to compare graphs representing biological structures such as proteins.

RGF-distance is a measure of the difference in frequency of graphlets of g1, g2, g3, ..., g28, and g29 appearing in the two graphs being compared. A tool called GraphCrunch II will calculate this metric, and as this value approaches 0 the more similar the two compared graphs are, however, this is an approximate measure since the specific labels of the nodes are not used.

IV. RESULTS

In this section, we show the results for all four courses (computer engineering, communication, speech pathology, and political science) for both metrics (Match Metric and RGF-distance). Additionally, we provide a table that summarizes some of the differences in each courses experimentation, some parameters of each criterion map, and a percentage of metric results that align with evidence of learning. Our key assumption in this exploration is that we assume that on average the students are learning the technical vocabulary in the course as the course proceeds and if a metric is capturing this in the mind maps we should see the majority of the the students metrics trend a certain way (towards 1 from 0 for the *match metric* and towards 1 from larger numbers for the *RGF-distance*).

Table I includes a summary of a number of pieces of data for our experiments. Column 1 shows the course area. Columns 2 and 3 report the percentage of students included in the experiment that have a measured metric (RGF-distance and Match Metric, respectively) that trends better in a student's final mind map as compared to their initial mind map (for example, the match metric would be closer to 1 in an upward trend and the RGF-distance metric would be closer to 0 in a downward trend). Column 4 shows the number of students that gave permission to be included in the experiment and participated in all the mind map activities, and column 5 shows how many mind map activities were performed for the

TABLE I. DETAILS FOR EACH COURSE EXPERIMENT

Course Area	Metric Summary		Experimental Parameters		Criterion Map	
	Percent improved Match Metric	Percent improved RGF-distance	Population	Mind Map Activities	Average Degree	Density
Computer Engineering	100%	69%	32	3	2.85	0.30
Communication	27%	73%	51	4	0.95	0.10
Speech Pathology	91%	59%	34	3	1.68	0.18
Political Science	55%	57%	42	2	2.95	0.31

respective course. Finally, columns 6 and 7 report the average degree and density of the criterion mind map and these graph parameters will be used to describe differences in the criterion map.

Figure 3 shows each of the four courses and includes students metric if they participated in all the mind map activities. In terms of our assumption of learning, we hope to see an upward trend (from values of 0 towards values of 1) for the match metric. We see this upward trend in two cases - computer engineering and communication. Since there are many students in each of these courses, the data is a little noisy and is hard to interpret, but the summary of the “Percent Improved Match Metric” in Table I suggests that these 2 upward trending courses are clearly showing student learning. Conversely, both the graph and the summary data show that the communication course is not trending upwardly. The political science course is not showing clear results, and unfortunately since only two data points (mind map activities) were performed it is hard to make strong conclusions from this result.

Figure 4 shows each of the four courses and includes students metric if they participated in all the mind map activities. In terms of our assumption of learning, we hope to see a downward trend (from values tending towards 1) for the RGF-distance metric. The results here are much less pronounced compared to the match metric, and the summary data in Table I for “Percent improved RGF-distance” shows that all courses have over 50% of the students demonstrating improvement. On closer examination of the results, it is clear that RGF-distance and its estimation of graph similarity is a poor comparison metric since there can be false positives. For this reason we used these results to look at creating a new metric that mixes graphlets with the match metric in our paper [3].

We performed additional analysis on this data set including evaluating our previous experimental graph metrics and checking if there is any correlation between grades and the metrics. As reported previously with computer engineering and with these new courses, we saw little correlation between grades and any of our measurement metrics. No other metrics seemed to show trending as match metric and RGF-distance metric have.

V. INSTRUCTOR EXPERIENCES AND DISCUSSION

In this section, each of the three instructors (additional courses beyond our traditional computer engineering course) provide their experiences with the mind map activity and the respective results for their class.

A. Amber Franklin - SPA 334 Clinical Phonetics and Articulation Disorders

Clinical Phonetics and Articulation Disorders (SPA 334) is a required junior level class for students majoring in the department of Speech Pathology and Audiology. The majority of majors in this department plan to apply to graduate schools where they will be trained as Speech-Language Pathologists or Audiologist. The SPA 334 course addresses the fundamental aspects of phonetic transcription and articulatory phonetics. Students are taught to transcribe spoken English using the International Phonetic Alphabet. Other topics include English dialectal variation, and clinical phonetics as it applies to normal speech development and articulation disorders. The course quizzes and exams assess knowledge of terms and concepts as well as phonetic transcription ability, which is an applied skill. Some students excel in conceptual knowledge but do not perform well in transcription tasks. The mind map exercise corresponds to the conceptual and technical information taught but does not address the applied skill of phonetic transcription, which constitutes a significant portion of students’ final grades. This distinction may partially explain why there was no correlation between mind map performance and final grades. The terminology as a learning outcome is rated as “2 -important to know and do” based on the taxonomy discussed earlier.

The SPA 443 course builds gradually on a foundation of terms and concepts. Each quiz in the course is cumulative, thereby encouraging students to retain information introduced earlier in the semester. Twelve of the 20 concepts on the list were introduced before the midterm (2nd data point) and the remaining eight concepts were introduced after the midterm. Additionally, several of the terms introduced before the midterm were revisited in the second half of the semester and linked explicitly to new concepts. It is likely that the cumulative nature of the course was reflected in the improved match metric and decreased RGF distance over time. The students understood that their maps were going to be compared to my criterion map once the course was done. However, they also knew that mind map performance would not affect their course grade, making this a very low-stakes activity. The students demonstrated focused attention when generating mind maps at each time point in the semester. I believe the low-stakes nature of the activity facilitated student engagement and allowed them to interact with the material in an authentic way rather than worrying about the “right answers.” The technical vocabulary in this course is rated as “2-important to know and do” based on section III-A.

I observed several differences in the visual representations of student maps. One map was arranged in two distinct columns. Terms within a column were connected using curved

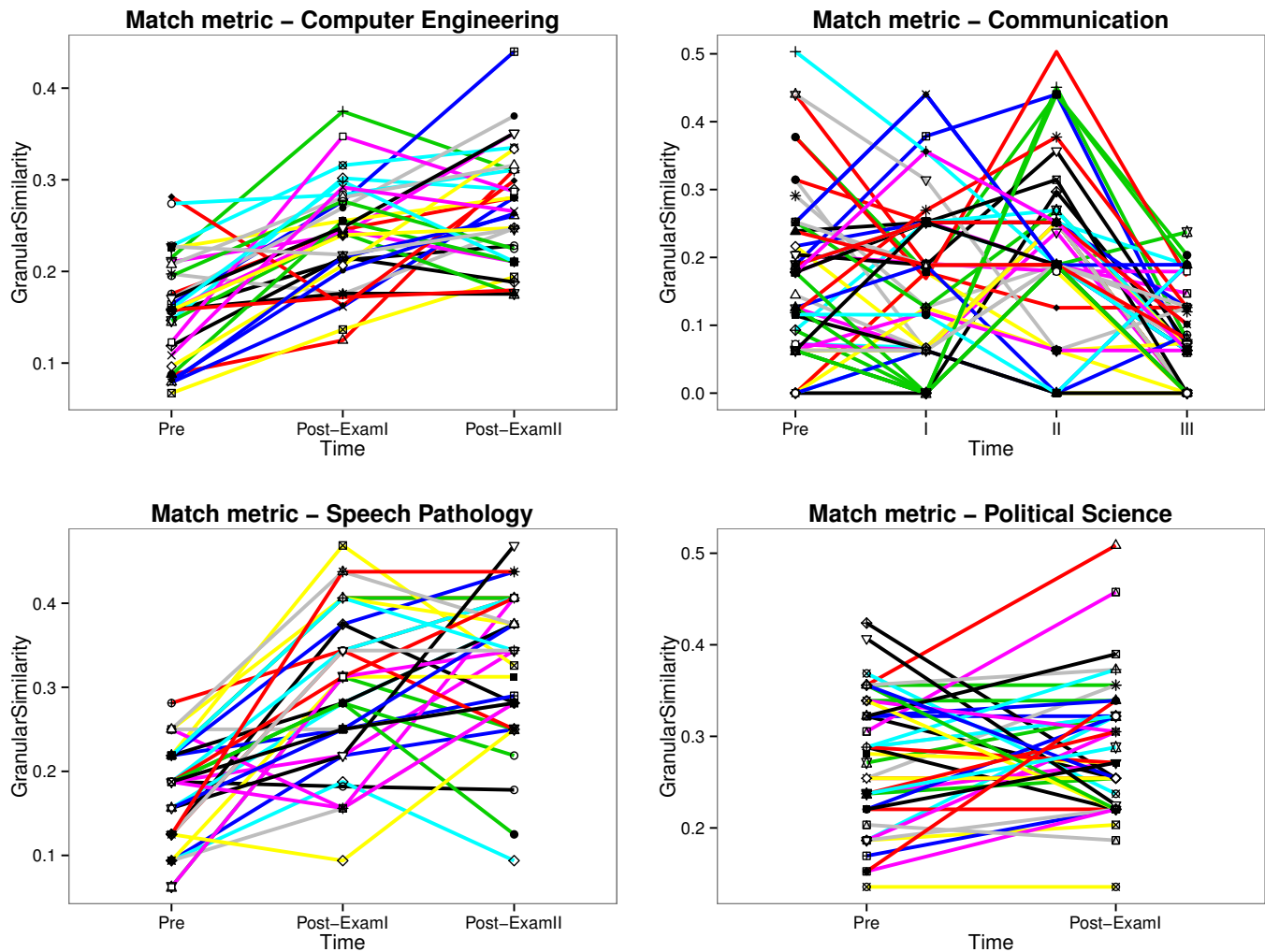


Fig. 3. Match Metric results for each of the four courses

lines and terms between columns were connected with straight lines. Other maps demonstrated a hierarchical structure, with a key concept at the top of the page and related concepts branching below it. Several other maps had a central concept in the center of the page with related terms and concepts branching like spokes from the center. Students were given a general example of a mind map at the beginning of the semester. However, they were not given specific directions regarding the visual structure of the map (e.g. "Start with a key concept in the middle of the page"). The electronic encoding of the maps removes the visual texture from the students' paper representations. Though not within the scope of the present study, I found it interesting to consider how the variation in written map representation may further reflect students' conceptual knowledge.

B. Walter Vanderbush - POL 101 Politics and National Issues

Political Science 101 is a course that fulfills a Liberal Arts social science requirement at Miami but does not count toward the political science major or minor. The primary goal of the course then is not to prepare students with the conceptual knowledge and analytical skills necessary in upper

level political science classes, but rather to expose those who major in Engineering, Accounting, or Zoology to social scientific analysis of political issues and debates. In this version of the course, just over half of the students were in their first year of college; only one of the students was a political science major, and one other student was majoring in public administration, which is housed within the political science department.

Before the first map exercise, I did an exercise on the board with a list of countries and attributes, suggesting various ways that one might link them depending on the context. The concepts chosen for the mind map assessment range from democracy, capitalism, and freedom (which all students will have some familiarity with on day one of the semester) to pluralism, libertarianism, and judicial review (which students may have heard before but were not universally likely to fully understand) and a couple of concepts that only students following politics pretty closely were likely to have familiarity with (self-deportation, e.g.). Over the course of the semester, the expectation was that the relatively unfamiliar concepts would become familiar. On the other hand, the definitions of the familiar ones such as democracy and freedom are

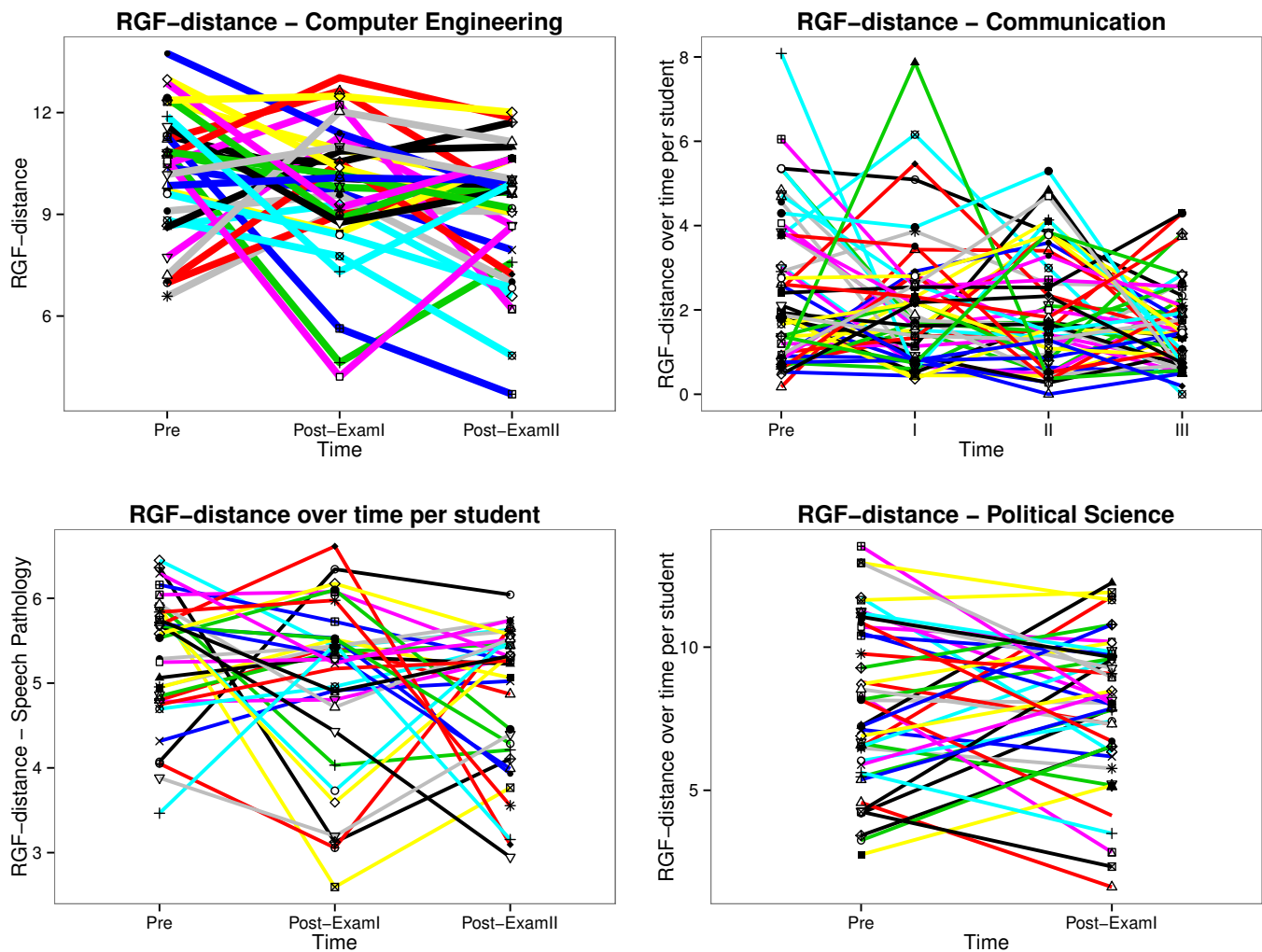


Fig. 4. Match Metric results for each of the four courses

challenged throughout the semester, as students are asked to think of them as contested concepts. To take another concept, separation of powers, one lesson students should learn during the semester is that some democracies have explicit separation of powers such as are laid out in the US Constitution, but other democracies do not see that sort of separation as necessary. On his or her mind map, a student is likely to have made a clear link between separation of powers and democracy at the beginning of the semester, thinking that all democracies had the separation of powers like the U.S., but by the end of the class might reasonably still make that link or might decide not to. The terminology as a learning outcome is rated as “2-important to know and do” based on the taxonomy discussed in section III-A.

I expect that the mix of concepts contributed to the mixed results for the metrics in this study. I tried to make the list reflect the variety of discussions that the class would have during the course of the semester. To that end, there were big philosophical concepts such as democracy, freedom, and individualism; traditional political science concepts such as pluralism, separation of powers, and judicial review; and reflecting some of the contemporary policy debates, terrorism,

American exceptionalism, and even self-deportation. The second of those groups is the closest to the idea of a technical vocabulary that made up a larger percentage of lists in other classes studied here. In a course intended to prepare students for more advanced political science classes, that technical vocabulary would have been more central. This initial use of mind maps, as well as pre-course discussions with my colleagues did lead me to think more about the ways that my twenty concepts might be interrelated. My criteria map tended to make more linkages than those of nearly all of my students. Many of them seemed to look for 2 or 3 strong relationships before moving on to the next concept. In my “expert” map, several concepts had five or six connecting lines, and others even more.

C. Julie Semlak - COM 135 Introduction to Public Expression and Critical Inquiry

The communication course used for this study, an introduction to communication theories course, is a survey course intended to provide communication majors with a foundation of metatheoretical issues, as well as a survey of communication theories they may encounter throughout their studies. The

terms used for this study were metatheoretical terms exploring the philosophy of theory development. Although these terms are utilized and reinforced throughout the semester, they are emphasized much more at the beginning of the course, and were likely most salient to students Post-Exam One, as these terms are the primary focus of exam one. Although the terms do appear on exam two and three, the content emphasized for these exams is specific to the individual theories taught during the semester.

Before students completed the mind map activity for this project, I introduced the definition of mind maps, and as a class we generated a mind map on the board, using pizza as the topic, and the word at the center of my sample mind map. I think this example prompted many of my student to want to put one of the concepts they had to work with at the center of their mind maps, which lead to some frustration when I told them they could choose any of the 20 words for the center. Similar to Dr. Franklin, although I also emphasized this activity was not graded, many students were concerned about completing their map correctly, and asked me if their mind map was correct. Also, after the second data point, several students asked to compare their second map to their first map. Those who did compare remarked at how different their respective maps were, and commented on the errors they had made in their data-point one map. The technical vocabulary in this course is rated as “1-worth being familiar with” based on the ratings in III-A.

When using mind maps as a pedagogical tool, one should take into account the overall goals of the course. The communication course used for this study’s goals focus on students being introduced to a variety of communication theories, students being able to apply individual concepts or theorems from individual theories to their experiences, and to identify the advantages and disadvantages of specific theories. While these skills are important for effective communication, they are skills, which are often assessed different from knowledge or understanding. When considering mind maps as a pedagogical tool, the overall intent of the course should be considered, as mind maps may not be the best assessment tool for a skills-based course.

VI. DISCUSSION AND CONCLUSION

From our results and discussions we find that our study, which expanded the number of classes studied with automated mind map evaluation, shows that there are more details in achieving a successful automated feedback metric(s) for students. In particular, from this study we can see how the nature of the ideas, words, and concepts used within the CAT has significant impact on the quality of the results. Second, this study provides further evidence that our best metric *match metric*, because of its more direct comparative feature, is still the best metric we have to analyze students maps and provide detailed feedback of what they are and aren’t connecting as compared to the expert.

Our mixed results on the *match-metric* groups the four courses into two sets. In one set, which includes computer engineering and speech pathology, the chosen words for the CAT have very clear definitions and relationships to other words, and these terms are introduced and used throughout the class. Conversely, in the other set, which includes political

science and communication, the words used either do not have clear definitions that are to be developed over time, or the terms themselves are introduced early and are used sparingly throughout the term. It makes sense that the first set when analyzed by our metrics shows student improvement because the terms are easier to classify and continually used over the semester, which follows the experimental design. Therefore, if courses have terms that are clearly defined and consistently used then this methodology seems strongly applicable.

Still with the second set, we wonder if there is still potential for automated feedback. In particular, we think the methodology has potential for those courses where term definitions and relationships to other terms is more ambiguous. In this case, our match metric could be used to find similarity over a set of experts and learners. For example, instead of a single criterion map, one could imagine a number of instructors creating maps and similarly students creating mind maps. In addition to these maps, the creator might write a paragraph or two describing why they created the map the way they did. With this database of mind maps, we could run a comparison to a new map and provide that student with a weighted match and show why and how the map they created relates to other learners and experts. This might even be a more meaningful form of feedback than a simpler yes/no response that indicates if you’re making a particular mind map relationship.

Looking back at table I the last two columns looked at some simple graph properties for the criterion map. In particular, another question we have is should the words in the criterion map be selected in such a way to manipulate the density or degree of a graph. In simpler language, if the criterion map is simpler (as in less connections between words) is that better for our automatic feedback methodology compared to a more heavily connected criterion graph. Our results, are unclear at this time, but we believe this is an interesting direction to pursue, where, currently, we hypothesize that a simpler graph will produce better results, but too simple a graph might be detrimental. A follow on question for this hypothesis, is how does an instructor create a criterion map that is appropriate for this methodology, and we leave this as future work.

Overall, in this study we took our early ideas on automatic feedback for student created mind maps to a larger and more diverse set of classes. This study concludes that our approach seems to be useful for courses that use a set of terms that are clearly defined and are used throughout the class. Our future work will focus on refining these techniques by focusing on how to create the criterion map, which in turn determines the subset of terms that will be used in the exercise. The summary data and mind maps are included in a compressed file and can be downloaded at: www.users.miamioh.edu/jamiespa/data_sets/fie_2015_mind_map_data.zip.

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Student Led Curriculum Development and Instruction of Introduction to Engineering Leadership Course

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Abstract— Identifying and tapping into what is intrinsically motivating has been touted as a key to true learning. Educators, therefore, are attempting to focus on instructional tools that tap into intrinsic motivation in order to excite students about learning and encourage them to become self-taught, lifelong learners. Finding the optimal tools to produce intrinsic motivation, however, can be challenging. Since what is intrinsically motivating is individualistic and can be challenging to identify for instructors, a course at The University of Texas at El Paso (UTEP) has been redesigned in an attempt to better align with what motivates students in the program. In order to create a paradigm shift in engineering education and focus on what students find motivating, Engineering Leadership (E-Lead) students at UTEP stepped up to help take ownership of, not only their own education, but also the education of future students. Under the assumption that students understand what motivates their peers best, the current Introduction to Engineering Leadership course has been developed and taught by second year Engineering Leadership students. Held once a week for three hours, this zero credit course is required for all students interested in the Bachelor of Science in Engineering Leadership at UTEP

Keywords—engineering leadership, first year course, innovation, intrinsic motivation, student taught course, curriculum development

I. INTRODUCTION

Intrinsic motivation has been noted to be a fundamental key to education in today's society. Institutions have been required to adjust to the technological era in which we are living today; hence their teaching methods are being modified to meet the company's expectations of the graduating students. As a result, educators are being encouraged to find new and innovative ways to inspire their students to take ownership of their education and to be intrinsically motivated to continue with their studies.

According to a research conducted at the University of Rochester, intrinsic motivation is defined as the drive to do something for one's own comfort [1]. The goal of numerous professors around the world is to get their pupils to motivate themselves and each other to become life-long learners. In an attempt to achieve this goal The University of Texas at El Paso (UTEP) has redesigned one of their seminar courses for the

Bachelor of Science in Engineering Leadership (E-Lead), which seeks to empower their students to turn their ideas into reality.

In order to develop a new curriculum for this seminar, a group of second year students from the program, alongside several UTEP faculty members, worked with Franklin W. Olin College of Engineering in an effort to redesign the course and its objectives. The goal of the course was to create an immersive learning environment that was also social, relatable, and inspiring to the instructors and the students. In order to achieve that goal, the second year students, also known as Mavericks, were given the opportunity to act as instructors for the course. The curriculum that was developed aimed its attention on three major aspects: leadership identity development, innovative thinking, and hands on skills, which were taught in a studio environment with collective and individual activities.

As a result of this experience, the hypothesis is that the Mavericks and incoming students would be intrinsically motivated to directly impact the Engineering Leadership program. Intrinsic motivation would be enhanced in the Mavericks through mentoring the incoming class during this teaching and curriculum development opportunity. Due to this student centric peer-taught course, student retention in the course (and therefore the program) would also improve. If this course instruction method proves effective, this pattern of allowing a group of students to redesign and teach the course each year will be maintained for future incoming classes.

II. BACKGROUND

In developing The University of Texas at El Paso's Bachelor of Science in Engineering Leadership (BSEL), a blend of effective leadership development philosophy and innovative pedagogy was sought. To this end, a partnership was strategically formed with the Franklin W. Olin College of Engineering for its progressive pedagogical approaches to teaching engineering. Although the program seeks to develop itself by learning from the collective knowledge and experience of these institutions, it also seeks to create its own identity and set of values appropriate for its student population while using a pedagogical approach that is transferrable.

A. Motivation

To begin mentoring incoming students in the style of learning expected during their BSEL and to start building intrinsic motivation in them, an Introduction to Engineering Leadership course was first developed and piloted in the fall of 2013. Unfortunately, having relied too heavily on traditional teaching styles, a lack of structure and synthesis of all of the subjects rendered the class unsuccessful. Retention rates in the course were poor and most students had strong negative feedback on the course. Several students, however, provided viable suggestions for modifying the course in their feedback. In an effort to improve on the shortcomings of the first class and develop leadership skills and motivation in students, the Engineering Leadership faculty decided to cede a majority of the control of the class to the students for the following fall 2014 course. This included curriculum design and the teaching of the course.

These second year students, also called Mavericks, worked closely with Engineering Leadership faculty, as well as faculty from Franklin W. Olin College of Engineering (Needham, MA), throughout the summer in order to develop curriculum for the incoming cohort of students in the fall of 2014. Upon being given the opportunity, the a group of Mavericks were hired to work closely with faculty to identify the three main focus areas they wished to address in the course as well an overall goal for the course. One of the major objectives set by the Mavericks while developing the curriculum was to indirectly create intrinsic motivation for the incoming students to take charge of their own education - meaning that they would be able to motivate themselves and have an intrinsic reward when their goals were achieved.

B. Pedagogical Approach

Engineering Leadership's pedagogical approach is the result of close collaborative efforts with Olin College. Olin is a small, private engineering-only college with a progressive perspective on engineering education with an admission rate of 16.8%[2]. In contrast, the University of Texas at El Paso, with an admission rate of 99.8%[3], is an urban, commuter based, and minority-serving university [4]. Questions were raised as to how translatable would the Olin pedagogical approach would be to a completely different institutional setting.

A method commonly employed in Engineering Leadership program to build intrinsic motivation is experience-based learning [5]. As such, students in the program are often placed in situations where they are encouraged to take a leadership role or actively participate in a group that is working on a project designed by the faculty but where the students are able to pick a topic of their interest. This approach to education is evident even in the classroom, where students are encouraged to take initiative and an active role in their education. Using a flipped classroom approach, or one in which students are tasked with learning the material on their own and are given an opportunity to synthesize and apply it in the classroom, is one of the many ways the program pushes the student to become intrinsically motivated.

III. METHODS

In order to start building the intrinsic motivation of the students mentioned earlier, the methods employed in this research relied heavily on the development and assessment of students' motivation. To this end, a process to craft the curriculum for the course and an assessment plan was developed. The Mavericks got together with three of the faculty members who designed the pilot course and started from scratch a new plan with different objectives and a more innovative initiative. The curriculum's main objective was to create activities that will allow the students to expand their creativity with an ample margin for decision-making were they would be able to choose topics of their interest, this way they would develop intrinsic motivation to finish the course and continue on the program.

A. Curriculum Development

During the summer, Mavericks collaborated with faculty to work through a series of curriculum development workshops. The goal of the workshops was to allow the Mavericks to develop an improved, student-driven introductory. Engineering Leadership and Olin College faculty facilitated the workshop to teach pedagogy as needed and ensure adequate scope for the course and that assessment measures were appropriate. Over the course of two workshops, the Mavericks took their past experience in the pilot introductory course and worked with the faculty to develop the new curriculum.

The first of these workshops was specifically focused on the curriculum for the new introductory course. The Mavericks, along with the faculty, first outlined the strengths and weaknesses of the pilot course. To isolate key themes, individual strengths and weaknesses were written on sticky notes and then grouped. Mavericks then took the emerging themes and brainstormed methods for maintaining or improving each part of the pilot version of the course. Taking a step back, the Mavericks and faculty also worked to generate a list of the key skills with which the degree, as a whole, should equip students. These broad skills were distilled down to the fundamental skills that the incoming students would need in order to lay a foundation for excellence in the E-Lead program. The key skills that remained became the new focus of the introductory course: leadership identity development, innovative thinking, and hands on skills.

To further develop the curriculum, Mavericks brainstormed ways to provide incoming students experiences through with to grow in the three focus areas. These ideas were grouped into three different categories: needs development, can be implemented, and blue-sky ideas. The Mavericks then took the ideas, especially the blue-sky ideas, and worked on making them into implementable ideas. Blue-sky ideas were the creative ideas in which the possibility of implementation was not a limit. From there, the two main projects for the course were developed. The first was the Identity Sculpture (focused on leadership identity development) and the second was the

Entrepreneurship Project (focused on the innovative thinking and business acumen).

As an engineering *leadership* degree, leadership identity development was a key skill to develop in the incoming students. To help students begin to articulate their own identity, the Identity Sculpture project focused on identity development and the use of common tools. To complete this project, students were instructed to create a sculpture of their choosing that they believe best tells the story of who they are and who they want to become. During the creation of their sculpture, students were trained on how to use tools in the machine shop and were required to manufacture at least one part of their statue in the machine shop. In the Entrepreneurship Project, students were introduced to innovative thinking, teaming, and business skills while developing a product prototype and pitch for their own small startup company. (Additional details on other course activities provided in the Results.)

Having ideas for the two main projects for the course, the Mavericks then considered the reactions of at an important stakeholder: the students who would be taking the course. To do this, hypothetical student profiles were created, using the current demographics of UTEP and Engineering Leadership population. With these profiles, the Mavericks assessed how each student might react to and feel in the new course. This activity helped the Mavericks better identify ways to enhance the learning environment for a broad range of students and further refine the course projects and activities. By the end of the first workshop, the backbone of the new course was established but still needed to be better connected to the overarching goals of the Engineering Leadership degree plan.

In a second workshop, Mavericks worked with the entire Engineering Leadership faculty to connect the goals of the course to the goals of the degree. The Mavericks presented the curriculum developed to this point and the faculty gave feedback to help further advance the curriculum. Once the curriculum was finalized and classes started, the Mavericks were presented with different challenges that limited some of the activities and lessons that were planned, this caused the curriculum to evolve as the course went, but thought out it maintained its main purpose and overall structure.

Although the Mavericks were more successful in relating to the students in the course, they did lack the authority and experience in being a professor and had no upperclassmen to seek assistance from. Although progress was made, future iterations of the course should ensure that the leadership abilities of student instructors is passed down in order to perpetuate the continuous improvement of the course. In fact, the intent for this course is that each year, the students that took the course the prior year would become the new Mavericks. Lessons learned by the student-instructors the prior year would be handed down, creating a cyclic pattern of leadership in the program. In addition, this is hoped to maintain a relevant and ever evolving culture in the Engineering Leadership program. Each summer, a group of students finishing their first year in Engineering Leadership will be hired to repeat this process of iterating on the course design and content before taking

responsibility for teaching the course to the new incoming students.

B. Interviews and Observations

To assess achievements and the deficiencies of the course, interviews were completed with each of the Mavericks at the end of the course by a faculty member in the Engineering Leadership program (also an author of the paper) not overseeing the course. The interviews were a blend of open-ended and structured questions requesting students rate their agreement to a given statement based on an ordinal scale from 1 to 5, with 1 being strongly disagree and 5 being strongly agree. Each Maverick was individually interviewed at the conclusion of the course for approximately 30-45 min. Questions in the interview covered the following topics:

- Demographic data: age, gender, year in college, and role in the course.
- Course design, classroom setting, and meeting time
- Likes and dislikes about the course
- Leadership development in the 3 C's

IV. RESULTS

As a result of being empowered by the faculty in the Engineering Education and Leadership department at UTEP, the Mavericks were able to experience the other side of education and overhaul the Introduction to Engineering Leadership course. By reflecting on their own experience in the pilot course the prior school year, the Mavericks were able to identify the strengths and weaknesses of the previous course design. They then developed the new introductory experience for the incoming Engineering Leadership students. Following the completion of the course development and subsequent instruction of the course in the fall of 2014, the Mavericks were interviewed as described above. In addition, observations about the response of the incoming cohort of students are also shared.

A. Participant Demographics

a) *Demographic data was collected for each of the Mavericks interviewed "Table 1".*

TABLE I. MAVERICKS DEMOGRAPHIC DATA

Gender	Number	Average Age	Ethnicity	Classification
M	3	20.0(0.0)	2 Hispanic, 1 Caucasian	2 nd year students E-Lead
F	3	19.33(0.58)	3 Hispanic	2 nd year students E-Lead
Total	6	19.67(0.52)	5 Hispanic, 1 Caucasian	2nd year students E-Lead

B. Introduction to Engineering Leadership Course Outline

The semester was split into three main leadership development goals, which were leadership identity development, hands on skills, and innovative thinking. Using these goals, course content was laid out to fit the development of these skills. To help in the implementation of these skills, two main projects were created for the course. These projects were designed to touch on at least one of the main course goals. The rest of the course was structured around these two projects and smaller activities were chosen to supplement what the students were learning to be able to use those skills for their projects. For leadership identity development, a group project was created that would allow students to further their understanding of themselves and start viewing who they were as leaders. This project included the creation of a identity sculpture that helped them learn about themselves and each other. The Mavericks were also able to learn more about the students and create a more comfortable environment than would be more difficult to reach with a regular college professor. After the students were encouraged to learn more about each other, the transition began from the individual to the group. Small group activities and discussions were integrated that would introduce the topics of group work and leadership. These topics prepared the students to begin to get comfortable with group work since the second project was a group project. The second project was chosen to the innovative thinking part of the course and also ties in the hands on skills. Students were put in groups in order to come up with a new and innovative product for which they had to have a prototype by the end of the course. Instructional time and discussions were used to develop innovative thinking in the students. Smaller activities and projects, like machine shop and circuit building, were also introduced to develop hands on skills that could be implemented in the major project.

5	Innovative Thinking	Introduce the students to innovative thinking	Second project introduction: improve on an object that already exists
6	Identity Development	Reflect on Project One and the Course	Project 1 Reflection Discussion
7	Young Entrepreneurs	Introduce Entrepreneurship and its role in Engineering	Professional sales pitches on their up and coming ideas
8	Leaders Have Fun	Help students apply a couple of group dynamics understanding, and have fun!	Lego Mindstorm robotics development
9	Hands-on Skills	Students will understand the basics of circuits	Students will use breadboards to make a circuit with a LED that blinked at faster or slower rates depending on temperature.
10	Hands-on Skills	Introduce machine shop	Complete requirements to enter machine shop and use tools.
11	Innovative Thinking Application	Understand how to apply an innovative mindset	Group discussion on previous war, tech, and everyday products: how have they evolved? Why?
12		Address final concerns and last minute adjustments to project two	Last Minute Feedback Session
13	Communication Skills, Identity Development	Present final Project and give an understanding of the skills and knowledge they have gained	Final Project Presentation
14	Reflection	Get feedback from students about the course and their experience	Course Evaluation

TABLE II. ACTIVITIES AND DISCUSSION TOPICS FOR REDESIGNED COURSE

Week	Course Goal	Outcome Statement	Course Activity
1	Leadership Identity Development	Show students how their identity is going to be developed along their college life and beyond.	Identity Sculpture - students designed a sculpture that they believe best tells the story of who they are and who they want to become.
2	Group Dynamics	Gain insight to the overall "personality" of a team.	Lecture and discussion about leadership through TV and movie clips
3	Leadership Introduction	Demonstrate to students what leadership truly means, and how great leaders achieve greatness.	Discussion and group activity on past 'leaders'
4	Invention and Innovation	Understand the difference between invention and innovation	Group discussion on various everyday items

Using the methods described above, the Mavericks developed the materials outlined in Table 2. A required zero-credit course for all students pursuing the Bachelor of Science in Engineering leadership, the class met on Friday afternoons from 3-5pm in a studio style setting with movable tables and chairs and ample whiteboard space. On an average week, the Mavericks met twice with the teaching team: once to prepare the material for the week and again to receive feedback from the supervising faculty member. While all Mavericks attended the class each week, smaller sub-teams shared primary material delivery responsibilities in order to share the teaching and perpetration load.

Summarized in Table 2, specific activities were designed to enhance leadership identity development in the three C's, innovative thinking, and hands-on skills.

To develop *Character*, the primary activity was an 'Identity Sculpture'. For this project, incoming students had to reflect on their own personality and identify what made them unique. They then were to create a statue to visually communicate who they are and who they want to become to their peers. These sculptures not only helped the students learn more about themselves, but they also served as an icebreaker at the

beginning of the course. To follow up on this exercise, students also took the Myers-Briggs Type Indicator (MBTI) self-assessment to help them discover and better express the type of person they identify with and want to be, as well as possible strengths and weaknesses.⁶ MBTI results were also used in pairing students when doing group work. Since group projects were more about further personal identity development rather than outcomes focused, students were paired with others of the same MBTI personality type hoping to make them comfortable in a group setting and allow them to see their own personality type mirrored in their peers. When working on group projects, student interactions and habits were closely observed to see their interactions with others in a group setting. Each group also had at least one Maverick with the same MBTI personality type as the incoming students to help in facilitating discussion. Students were also encouraged to interact with the Mavericks that were teaching the course in social settings. The frequency and depth of these social interactions were monitored consistently. Mavericks also kept track of their individual growth, confidence, and ability to relate to their audience and communicate information. Through this character and identity development process, students were to become more self-aware in order to become better leaders.

The *Capacity* of the students was also developed in and outside of the classroom. Students were given opportunities through the program to be part of extracurricular and volunteer activities. In these volunteering opportunities, the students got to expand their leadership skills by being part of running Innovation Session, an event to introduce high school students to the degree. In order to track the students involvement, Mavericks checked which students were attending Innovation Sessions, were involved in student organizations, had a job, or where participating in other activities. The main group project that was designed for the course was also designed to improve student capacity. Relying on the skills students had learned throughout the course, the final project they were given was to apply these skills in a project that made them think about different areas of new product design and development. Being given control of the class allowed the Mavericks to also grow with the students taking the class. Mavericks had to learn to manage their regular course schedules and prepare for the course.

Opportunities to expand their *Competence* were offered through the lessons given in class and the projects were a reflection of what the students were learning. However, Competence was rather tricky to measure mainly due to the fact that it encompasses more than just technical knowledge. To a greater extent, competence is demonstrated when students are able to take what they have learned and apply it in a tangential application in another course, at work or at home. One semester was insufficient to fully understand how much they grew in their learning and in what areas they subsequently applied this knowledge.

Besides the two main projects, smaller activities and projects were created alongside the main projects to help students connect what they were learning to real applications and practice the *hands-on* skills necessary for completing the

major course projects and equip them for future Engineering Leadership courses. These activities included, but were not limited to, working in the machine shop and building circuits. The students could then take those skills and use them to create items for their sculptures or build their product for the final project. In order to successfully teach the course, Mavericks developed their individual capacity as leaders by going through these different topics and gain the skills necessary to teach to the incoming students. While the class itself encouraged students to gain a variety of competencies, from presentation skills to business practices and engineering principles, student teachers too had to become educated on pedagogical practices as well as the material in the course.

While the lessons given to the students introduced the idea of innovative thinking, the true measure was the final Entrepreneurship Project. The objective of the project was to take an already existing product and/or materials and bring new value by creating an entirely new purpose for it. The idea was that the new product must solve a current issue using products/materials of their choice, given those materials were not originally intended to solve the issue. The students were paired in teams and given the freedom to choose anything they would like to use and the project was left very open ended to allow for creativity. This idea of not being told specifically what to do or specifically what to deliver was discomfoting to the students. They were expecting to be told what they had to deliver, but that does not capture the process of innovatively thinking and producing. Over the course of the project and the class time they became more comfortable with the idea of owning their own project and delivering something that would be completely different and presented differently than their peers. This helped encompass the notion that being innovative involves overcoming the fear of doing something different and better.

C. Observed Impact on Incoming Students

While the primary focus on leadership development in this research was focused on the Mavericks, leadership growth was also observed in the students taking the course in the areas of character and capacity (competence was more difficult to observe as the time limit of one semester did not allow for observation of the students applying their gained competence in a tangential application). At the beginning, the expectations for the course, as voiced by the incoming students, was that of "concern", "uncertainty" or expecting "traditional lecture". However, the majority were surprised by their experience and pleased with the outcome. One of the trends observed was the incoming students consistently commenting about the "welcoming environment" in the course. This seemed to indicate a growth in *Character* for some students. For example, several shy students that never talked in class were making jokes with their peers and the student-teachers. As one student shared, "This class has really helped me break out of my shell and open up." For students who claimed it was hard for them to meet new people, they felt that they were able to quickly made friends and were thankful for the introductory course. One student, on the other hand, claimed, "I got along with my classmates but not really made friends. It is not something that

I can easily manage.” It appears that as a result of the course structure and environment, a majority of the students showed greater confidence in themselves, increased efforts in the course, and elevated interaction with student teachers and peers; this improved their team dynamics during group participations. These results will require further study.

The *Capacity* of the incoming students was observed based on their change in involvement throughout the class. From the beginning, incoming student involvement ranged from being highly involved on campus (as members of student organizations for example) to having little or no involvement outside of the classroom. In an effort to build community, the Mavericks consistently invited the students to organized social events, such as going to a movie, playing Frisbee, or going out to eat. Often, one or more faculty members also attended these extracurricular events. Participation in the after class hangouts was optional. Most students, once they attended an after class hangout, were regular attenders with few new students joining the hangouts later in the semester.

Incoming students in the Intro to E-Lead course also demonstrated growing leadership capacity and personal ownership of the Engineering Leadership program. During the semester, Mavericks held recruitment events, called Innovation Sessions, at local high schools. These three hour Innovations Sessions required continuous development, iteration, and improvement by the students running them in order to create an effective method of spreading awareness about engineering, engaging with the high school students, and provide future college students an opportunity to learn about the Engineering Leadership degree. Though not a requirement of the course, several first year students volunteered to help host the Innovation Sessions and took responsibility for leading portions of the day. These first year students had to presenting material, organizing activities, and interacting with the high school students. In fact, of the first year students that volunteered, none had previous history of being highly involved on campus. Many of these students however remained engaged and active in the Engineering Leadership program and continued to volunteer to the end of the semester. A preliminary review of current enrollment in the second course in the BSEL degree plan taught in the spring of 2015, shows a trend indicating that students that attended these organized social events often also volunteered and were more likely to remain in the program. Every student who attended socials went on to become a part of the next course (16 out of the 25 that continued the E-Lead course sequence participated in these social events). It was observed that community produced a willingness to step into leadership positions in incoming students. They also developed an understanding of the importance of their leadership development and the importance of inspiring the next group of incoming students.

D. Maverick Leadership Development

Although allowing Mavericks to teach incoming students was a step forward in the development of their leadership, the student instructors did lack the educational experience and authority that is often given a faculty member. This, at times, took away from the credibility of the class, as the enrolled

students often questioned Maverick credentials, and inquired as to the experiences that qualified them to teach the course, especially in the area of leadership. On the other hand, the student instructors were seen as ‘experienced peers’ who were able to connect on a deeper level and provide feedback to the incoming student. This allowed them to share relevant experiences in addition to technical information; such as mistakes that second year students made so incoming students would not have to repeat the same mistakes. Allowing student to be instructors seemed to encourage the incoming students to become more engaged in the classroom activities due to the fact that the student instructors were able to better relate to the incoming students. In the future, an improved balance of faculty involvement could help to lend credibility to the Mavericks while also mainlining the incoming student’s perspective of them as experienced peers.

E. Retention Rates

The student retention rate – measured as the number of students to complete the course that were enrolled as of the university census day – in the Engineering Leadership program as a result of the redesigned introductory course was 92% (Table 4). This was higher than the retention rate when it was piloted the year prior (60%). An even greater number of students were retained from the first class day in the redesigned course (70%) than in the pilot course (30%).

TABLE III. STUDENT RETENTION

Number of Students	2013	2014
Number of Students at First Day of Class	50	34
Number of Students Enrolled at Census Day	25	26
Number of Students that Completed the Course	15	24
Retention Rate	60%	92%

The resulting improvement in retention rates (from 60% in 2013 to 92% in 2014) of the first semester of the Engineering Leadership program is largely attributed to the improved community and course designed by the Mavericks. Based on feedback from the Mavericks, the pilot year took much more effort and time to build community amongst the students as well as with the faculty. When the Mavericks were given the opportunity to teach the Introduction to Engineering Leadership course, they developed relationships with the incoming students and created a safe, inviting, and friendly environment that bridged the gap between the incoming students and faculty. As a result, the incoming students in the redesigned introductory course benefitted from the program in ways that were not present the year before and the Engineering Leadership retention rate greatly improved. To date, several of the incoming students continue to come by the Engineering Leadership department on free time and say hello to faculty, student-teachers, and other students from their course. It is also prudent to note that this retention rate may have been influenced by the fact that this course and the program was in its inaugural year and this may have also influenced the differences in retention as the popularity of the program was still growing.

However, most efforts to promote the program did not occur until the second year was well underway. Therefore, initial recruitment of students in the redesigned course mimicked those of the pilot course.

V. DISCUSSION

A. Curriculum Outcomes

Overall, students felt that they were able to achieve strong improvements in their leadership skills and knowledge. In particular, due to their unfamiliarity with curriculum design and any new material to be covered in the course, Mavericks developed the ability to learn thing on their own and then communicate that information to their peers. Not only did they learn about different engineering fields and create the interdisciplinary connections for themselves, but they also had to communicate this knowledge to the incoming students. Further, they not only learned basic theory of leadership, they also applied it. The position these student instructors were put in required them to become leaders - becoming more responsible, accountable, and meticulous. The Mavericks had to prepare content before classes, be ready to deliver content, and answer questions. These second year students also became role models and mentors for the new incoming students, guiding them through their first year of college. This experience helped develop a higher understanding for the Mavericks of what it takes to lead and effectively develop future leaders.

B. Study Limitations

As this research covers a single course, a single redesign iteration, and a single group of six student-teachers, one major limitation of this research is its small sample size. An additional limitation is that a subset of the Mavericks and faculty member that did the interviews are co-authors on this paper and therefore some objectivity in the reporting is lost. Further, the students teaching the redesigned course, while second year students in E-Lead, were third year students by credit. Therefore, it will be interesting to see if the above trends continue with the next group of student-teachers that will be second year students both in the program and by credit hours. Further, no formal interviews were completed with incoming students, but informal interviews and observations were completed throughout the semester to record their experiences. Future iterations of this research should include interviews of the both the incoming students and the current student teachers. However, this research demonstrated the feasibility and effectiveness of allowing students to develop their leadership skills through taking on the role of instructor in an introductory engineering course.

VI. CONCLUSION

In the fall of 2013, an Introduction to Engineering Leadership course was piloted with the inaugural class of students in the Engineering Leadership Program. After getting numerous ideas for improvements to the course for the following 2014 year, these same students were hired to take

over the redesign and implementation of a new Introduction to Engineering Leadership Course. This redesign effort by students not only resulted in a new curriculum for the E-Lead program, but also improved the course by increasing the feeling of community for incoming students and thereby increased. More importantly, this experience of being placed in the curriculum development driver seat, also served to help the student-teachers develop intrinsic motivation in themselves and in the incoming class. The mavericks also agreed that the experience helped them increase their innovative problem solving and thinking skills and develop their identity. Overall, this research demonstrated the feasibility and effectiveness of allowing students to become intrinsically motivated by taking on the role of instructor in an introductory engineering course.

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Enhancing the Experience of First-Year Engineering Students with an Entry-Level STS Course

Science-Technology-Society

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Abstract— Engineering and Society, a course designed for first-year engineering (FYE) students and non-majors, was introduced in spring 2011 and most recently (F2014) became part of the required FYE core curricula. In addition to traditional elements of an FYE course such as the study of engineering disciplines and a team-based design project, students explore the various ways non-technical factors influence the development and integration of technology within our society, aligning with many of the learning outcomes specified by ABET General Criterion 3. Student outcomes were measured with a relatively simple pre-test/post-test study that uses a self-constructed on-line survey. Relative to the control group, students who enrolled in the course showed significantly greater gains in self-confidence, most notably with respect to engineering problem solving and design; sense of fit within the engineering profession; and understanding of the broad nature of engineering, including the importance of creativity, ethics, and societal influences to engineering design and decision making. Changes in academic self-confidence and satisfaction with the decision to study engineering were somewhat mixed, yet students in the course expressed a significant increase in their confidence of remaining in an engineering major throughout college, while students in the control group expressed a slight but not significant decline.

Keywords—First year engineering course, science-technology-society, student attitudes)

I. INTRODUCTION

Engineering and Society is a course designed for first-year engineering (FYE) students with a small number of seats open to interested non-majors (NM). The course was developed and implemented at Clarkson University, a small, technologically-focused research university comprised of three schools – Engineering, Arts and Sciences, and Business. Prior to its introduction all FYE students were enrolled in a 2-course sequence in Calculus, Physics, and Chemistry, two humanities/social science/writing courses, and a two-credit computing course. Now, approximately half of all incoming FYE students delay Physics I, largely by virtue of their performance on a pre-enrollment math readiness exam. These students are scheduled into a fall section of Engineering and Society, while the remaining FYE cohort enrolls in spring semester. Students receive credit toward university-established Common Experience course requirements in communication, technology, and science-technology-society [1].

In addition to meeting curricular requirements for the university, Engineering and Society strives to enhance the first year experience for engineering students by engaging them with engineering faculty and the field of engineering in general. The broad goal of the enhanced experience is to improve students' overall understanding of the field of engineering and, ultimately, their own identity and sense of fit within the scholarship and profession of engineering. These efforts go hand in hand with other curricular efforts to improve engagement and retention of first and second-year engineering students at the University [2, 3]. National retention data for engineering education indicate that 40 to 50% of all students who enroll in engineering programs either leave engineering or the university entirely before graduation, and that roughly half of that attrition happens after the first year [4-7]. Engineering student retention at Clarkson University is slightly above the national average, with roughly 10% to 15% of FYE students changing their majors or leaving the university entirely after the first year.

Contrary to popular belief, academic difficulty is not the main reason students leave engineering [8, 9]. Several studies have investigated factors that contribute to student attrition from undergraduate engineering degree programs and the findings have indicated that, while academic ability often plays a role, the reasons students leave engineering are actually much more complex and include students' background, lack of peer group support, loss of confidence, lack of motivation, poor teaching practices and/or inaccessible faculty, the competitive culture of the programs, class size, and poor fit within the institution [e.g., 10-14]. In fact, with respect to women and minority students in particular, the science and engineering gap may have more to do with perceptions and beliefs than with academic achievement levels [15-19]. For a thorough literature review on engineering retention and the individual and institutional factors that contribute to student attrition, see [9, 19].

An effort has been underway since the mid-1990's to increase participation in engineering by attracting a more diverse group of students [20]. Framing engineering concepts, studies, and careers within a broader context to demonstrate societal relevance is one way to dispel negative perceptions of engineering among women and minorities, who are shown to be more sensitive to the broader context of engineering design

[21] and are generally drawn to the careers that involve working with and helping people and communities [16, 18, 22]. Similarly, adapting evidence-based, student-centered teaching and learning strategies, known for improving student learning, achievement, and knowledge retention [23-27], may engage a broader range of students in the learning process [28, 29]. Other efforts to improve retention include unifying programs to minimize compartmentalization [30, 31], and broadening the curriculum to better prepare students with 21st century skills [32]. At the freshman level, introductory courses have been developed to bridge the gap between students' perceptions and expectations of engineering and engineering curricula, as well as dispel many of the generalizations students carry with them into the start of their engineering degree [4, 6, 7, 14]. Use of collaborative and project-based learning [4, 6] and supportive pedagogies [4], were shown to improve retention of students within engineering paths, particularly students from underrepresented groups such as women and minorities [4, 6]. These findings support the assumptions of a GE foundation report [33], which proposes that student success in the quantitative disciplines relies on three factors: engagement (interest), capacity (content mastery), and continuity (institutional support). In fact, the importance of student attitudes, engagement, and feelings of self-efficacy to their academic motivation and success is well documented [13, 34-36]. A relatively small number of studies have investigated the relationship between these phenomena specifically for engineering students [e.g., 13, 19]. Building on these findings, a better understanding of the effectiveness of learning experiences on student attitudes, values, self-confidence, and sense of fit within engineering will help us move forward with strategies to support student engagement and success.

This paper provides a descriptive case study analysis of the new Engineering and Society course outcomes, including those aligned with ABET criteria as well as our objectives related to improving students' understanding of and attitudes toward engineering. We have specifically looked at the changes in students' feelings of self-confidence, self-efficacy, and sense of fit within engineering, as they progress through the one-semester course. The course content and pedagogical approach, briefly summarized, highlight the importance of student engagement, specifically in learning activities that demonstrate the broad and complex nature of engineering, to achieving the intended course outcomes. Although our findings are constrained to the student population at our relatively small research university, the course's value is indeed demonstrated with a combination of summative and cumulative assessment results, with recommendations for future research.

II. COURSE CONTENT AND PEDAGOGY

Although it has elements typical of an FYE course including a survey of the origins and characteristics of various engineering disciplines and the engineering profession, as well as a hands-on design project, Engineering and Society uniquely focuses on the non-technical aspects of engineering and addresses the connections between engineering, technology, and society. When synthesized in this manner, engineering ethics and engineering design content/experience naturally dovetail with the technology and society content. Our

approach, supported by the work of, for example, [37], [38], and [7], allows us to introduce FYE students to engineering topics and content from a perspective that aligns with many of the learning outcomes specified by ABET (Accreditation Board for Engineering and Technology, Inc.) General Criterion 3 [39]. The course allows us to address societal context and contemporary issues alongside engineering topics in a manner that, unlike most of the rest of the engineering curriculum, emphasizes the former. In particular the role of societal forces shaping technology is emphasized; while most students broadly accept the notion that our society has been shaped by the development and implementation of various technologies, the role of societal forces in shaping technology, and the complex interplay between engineering, social science, business and economics, are generally less apparent.

Core learning objectives of the course meet the needs of a technology-focused engineering class as well as a science, technology and society (STS) course within the University's common curriculum requirements [1]. Learning outcomes are shown in Table 1 with reference to ABET Criterion 3 program outcomes. With the STS focus of this class as well as the in-depth analysis requirements, many of ABET's program outcomes are addressed. Most notably, the course addresses at length and in various contexts the topics of engineering design [ABET 3(c)], ethics [ABET 3(f)], impacts of engineering solutions in a global/societal context [3(h)] and contemporary issues [3(j)]. As shown in Table 1, students are assessed on their ability to engage in course activities and to successfully demonstrate their understanding of concepts orally and in writing.

TABLE I. COURSE LEARNING OUTCOMES AND ABET CRITERIA

Course Learning Outcome – Students will demonstrate:	ABET ^a	Assessment
An understanding of and an ability to use the engineering design process.	a, b, c	design project
An understanding of value systems and ethics and be able to relate these concepts to professional problems.	f	HW, exams
The ability to recognize and analyze environmental, social, political, ethical, health and safety, and sustainability considerations and impacts of engineering design.	c, f, h, j	HW, discussion, exams
An appreciation of the need for critical assessment of the sources of information, including computational tools, used to solve engineering design problems.	c	HW, discussion, design project
An understanding of the major engineering disciplines and be able to identify the core scientific disciplines underlying these. They will demonstrate an understanding of how the engineering profession intersects with the sciences and mathematics.	d	HW, exams
The ability to effectively communicate their ideas in written and oral formats.	g	class activities, design project

^aABET criteria c: (a) an ability to apply knowledge of mathematics, science, and engineering; (b) an ability to design and conduct experiments, as well as to analyze and interpret data; (d) an ability to function on multidisciplinary teams; (e) an ability to identify, formulate, and solve engineering problems; (g) an ability to communicate effectively; (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context; (i) a recognition of the need for, and an ability to engage in life-long learning; (j) a knowledge of contemporary issues; (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Engineering and Society has been offered each semester since the initial one-section pilot in Spring 2011, and has most recently (Fall 2014) become a required course for all FYE students (roughly 500/year). Eight to ten closely-coordinated sections are offered each semester by a team of three to four instructors, who have adapted many evidence-based, student-centered instructional practices [23] in an effort to engage students in a non-traditional learning experience. Course topics align with the following categories: (i) The Engineering Professions; (ii) The History of Engineering and Technology; (iii) The Design Process; (iv) Value Systems and Engineering Ethics; and (v) Engineering and Society. Topic (iii) is covered largely through a semester-long team-based design project challenge, which students accomplish primarily outside of class time. Past projects have included the construction of a prosthetic arm [40], a bench-scale solar water heater, a bench-scale wind turbine, and a portable pedestrian bridge [41].

The majority of class time is spent on topics (iv) and (v). Students explore various concepts and case studies through extensive readings (primary texts include [42] and excerpts from [43-45], as well as supplemental assignments related to current events), interactive class discussions and activities, and written composition. Students practice role play, risk assessment, and value conflict resolution; they debate the benefits and risks associated with emergent technologies and conceptualize creative approaches to inherently safe and sustainable designs; and they approach ethical dilemmas through the lens of different ethical theories and from the perspective of various stakeholders, applying ethical problem solving techniques to analyze decisions associated with a number of historical and contemporary case studies. For an in-depth description of course structure and content see [2] and [46].

III. COURSE OUTCOMES

Course level outcomes assessment focuses on ABET General Criteria 3(c), (f) and (h). Summative assessments are conducted annually using student design project deliverables [ABET 3(c)] and specific exam questions that target [3(f)] and [3(h)]. Scoring rubrics are used for the design projects and specific criteria are used to grade the exam questions. Data collected since Spring 2012 demonstrate that students consistently meet expectations for these key outcomes and, by extension, for the course. The most recent analysis in Spring 2014 indicates that, for ABET 3(c), design, students are meeting (94.9%) or exceeding (37.7%) expectations; for ABET 3(f), ethics, students are meeting (89.3%) or exceeding (44.3%) expectations; and for ABET 3(h), societal context, students are meeting (86.4%) or exceeding (34.3%) expectations. Anecdotally, by inviting students at the freshman level to consider the complexities of ethical and societal questions in relation to engineering decision making and design, our intent is to equip them with skills that they will continue to use as they revisit these ideas throughout their undergraduate education, which is quite different from the traditional path that provides them with a first exposure to engineering ethics, for example, in their upper level design classes. Our hope is that, as upper classmen, they will draw on these experiences to

develop a deeper appreciation of the intricate relationship between engineering and society.

IV. STUDENT OUTCOMES:

UNDERSTANDING OF AND ATTITUDES TOWARD ENGINEERING

A. Methods

Student understanding of and attitudes toward engineering were measured with a relatively simple pre-test/post-test study that uses an online survey to elicit a combination of Likert-type and open-ended responses from students enrolled in the course. Students in the course ('treatment') are administered surveys at the beginning and end of each semester. Pre- and post-surveys are administered simultaneously in fall semesters to a control group consisting of freshman engineering students enrolled in Physics I (Introduction to Physics) who, by virtue of their schedules, are not enrolled in Engineering and Society. The anonymous questionnaires are coded to enable matching of pre/post student responses. All components of the survey procedures have been approved by Clarkson University's Institutional Review Board (IRB).

The questionnaire we use was developed as part of this project. Most of the attitude items were adapted from existing questionnaires [47-50], while original items were created to measure course objectives related to students' understanding of the breadth of engineering and interactions with society. The questionnaire contains 22 items that use a Likert-type format with five options ranging from strongly disagree (1) to strongly agree (5). The items are specifically intended to measure students':

1. Self-confidence (general performance, within engineering problem solving and design, and team work)
2. Confidence in the engineering curriculum
3. Satisfaction with the decision to study engineering
4. Comfort level or "fit" within engineering
5. Understanding of the broad nature of engineering and engineering problem solving (creativity, teamwork, ethics, and society context)

The post-survey contains 4 additional Likert-type items that ask students to broadly self-assess the degree to which the course has helped them learn about engineering and design, as well as 10 mixed-format questions that provide formative feedback for adjusting the course pedagogy. The complete survey is available from the author.

Student response data collected over seven academic semesters, fall 2011 through fall 2014, have been pooled by semester for analysis, yielding three sample groups: fall semester treatment (n=500), spring semester treatment (n=221), and fall semester control (n=735). Students in the course were separated into the two treatment groups to enable a more realistic comparison between treatment and control groups (using fall only), and also to enable us to investigate potential variations between the fall and spring student cohorts. By way of design, many students in the fall control group were part of the spring treatment group; as of yet there has been no

effort to identify these students for special analysis, although this has been identified as an area for future research.

All data were compiled into Excel and analyzed through different methods within SPSS (Statistical Package for the Social Sciences). Likert-type rating scales were converted to numerical values (1 to 5) according to a predetermined preferred direction of response in order to calculate summated rating totals for each item. Items were subsequently grouped into the five topics or categories defined above, and average mean responses for each student were calculated as simple means based on their responses to each item in the category. Post-pre changes in student responses for each cohort were analyzed by comparing students' matched pre/post average mean scores using the Wilcoxon signed rank test, a nonparametric statistical procedure equivalent to the paired-sample Student t-test. Between-group comparisons (fall treatment vs. fall control; fall treatment vs. spring treatment) were analyzed by comparing post-pre differences using the Mann-Whitney U Test.

B. Quantitative Outcomes – Results and Discussion

The pre/post matching procedure resulted in sample sizes of 500 (fall treatment), 221 (spring treatment), and 735 (control). Results are summarized in Table II and Figure 1. Figure 1 shows pre and post mean values for each of the five above categories, for the fall treatment and control groups. Table II presents a more detailed look at mean student responses on the post survey (ranging from 1 to 5), and the post-pre differences, for the five categories and for a few selected items within each category, for all three student cohorts. Also shown are the significance level of between-groups comparisons, which were performed between the fall treatment v. control, and fall v. spring treatment groups. Bold values in the table indicate a significant difference ($\alpha=0.05$) between the pre and post survey mean response, or between the pre/post change of the two comparison groups, respectively. Parenthesis indicate negative post-pre changes, within-group, and post-pre changes for the fall treatment group that were less than (if positive) or greater than (if negative) the control; that is, parenthesis indicate changes in the treatment group that were 'worse' than changes in the control.

In general, there were significant pre/post improvements in responses from students enrolled in the course to items relating to students' *self-confidence*, *sense of fit within the engineering profession*, and *understanding of the broad nature of engineering and engineering problem solving*. These changes were significantly more positive than the control group, who declined significantly in all three of these categories overall. In particular, after taking the course students felt more confident about problem solving and team work, a stronger sense of 'belonging' in an engineering career, and a better understanding of the role of ethics and societal factors to engineering design and decision making. While the control group showed similar gains on some of these items, overall the changes were much more pronounced and widespread among the students who took the course. Also, while the emphasis of the comparison is between the control group and the fall treatment group, these changes were generally consistent

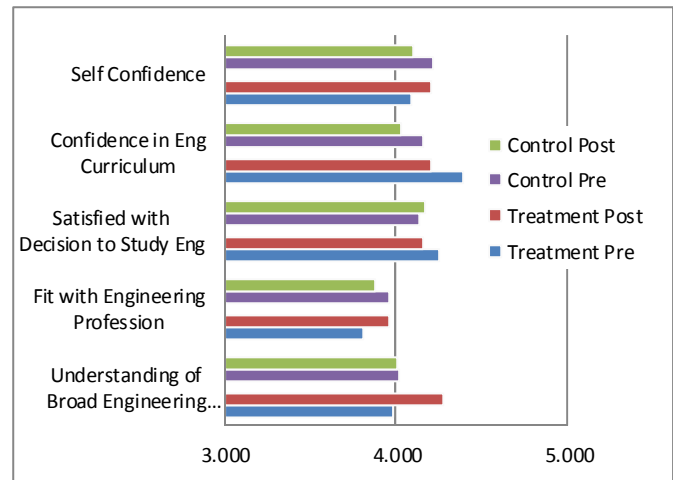


Fig. 1. Pre/post changes in student responses (scale of 1 to 5) to the 5 question categories, fall treatment group vs. control. Gains were significant for treatment group, and significantly greater than control, in 'Self-Confidence', 'Fit with Eng. Prof.', and 'Understanding'. Both groups showed significant decline in 'Conf. in Eng. Curriculum'. Treatment group showed significant decline and control a significant increase in 'Sat. to Study Eng.' Details provided in Table II.

among students enrolled in the course in both fall and spring semesters, at least in terms of the students' increase in self-confidence and understanding of engineering problem solving (Table II). Unlike the fall treatment group, students in the spring cohort did not indicate that they increased their feelings of fitting in with the engineering profession, with their overall post mean response remaining roughly stable, and lower than the post-mean for the fall treatment group, over the course of the semester. Thus, it appears that students' appreciation for the broad nature of engineering problem solving, and their feelings of self-confidence, are more malleable in general than their sense of belonging within the engineering profession. Another possible explanation for the significant changes in fall semester among both treatment (positive) and control (negative) groups compared to the relatively stable response in the spring is the idea that first semester freshmen are adapting to change at many levels, academically and socially, as they integrate into university life. This is certainly a phenomenon that warrants further study, yet the findings here of the positive influence the Engineering and Society course had on students' understanding of engineering problem solving, self-confidence, and – for fall semester – students' sense of fit within engineering, bodes well for the course.

Results for the remaining two categories are somewhat mixed. Students in both the fall treatment and control groups expressed a roughly equivalent, significant decline in their *confidence levels with respect to the engineering curriculum*. This decline in academic self-confidence was noted in an earlier study [46] and was posited to reflect a combination of students' overconfidence when first arriving on campus (pre-scores were on the order of 4.2-4.4 for these questions) followed by the realization, after first semester, of the difficulty level of these courses. The lack of change in academic self-confidence among the spring cohort seems to confirm this hypothesis, although this, too, warrants future investigation. Moreover, while both fall groups showed a drop in confidence

TABLE II. STUDENT RESPONSES TO PRE/POST ATTITUDE SURVEY

	Fall Treatment		Control		Fall v. Control	Spring Treatment		Fall v. Spring
	Mean Post	Post-Pre ^b	Mean Post	Post-Pre ^b	Mann-Whitney P ^c	Mean Post	Post-Pre ^b	Mann-Whitney P
Self-confidence	4.21	0.13*	(4.03)	-0.07***	<0.001	4.23	0.15***	0.91
I feel confident about applying a systematic design process to an unfamiliar problem	4.16	0.47***	3.85	0.11**	<0.001	4.15	0.36***	0.09
I have almost no understanding of how to approach solving a new problem or challenge ^a	4.22	0.20***	(3.88)	-0.17***	<0.001	4.27	0.20***	0.71
I feel confident working as a member of a team	4.33	0.09*	4.26	-0.01	0.01	4.27	0.10*	0.99
Confidence in engineering curriculum	(4.21)	-0.18***	(4.03)	-0.13***	0.53	4.15	-0.06	0.15
I will succeed (earn an A or B) in my math/chemistry courses (2 items combined)	(3.73)	-0.31***	(4.14)	-0.11***	(<0.01)	4.07	0.04	<0.01
I will succeed (earn an A or B) in my engineering courses	4.12	-0.03	(4.14)	-0.16***	0.006	4.14	-0.01	0.62
Satisfied with decision to study engineering	(4.16)	-0.10**	4.17	0.06**	(<0.001)	(4.03)	-0.18***	0.07
At the present time, I am satisfied with my decision to study engineering	(4.27)	-0.13***	(4.30)	-0.17***	0.17	4.31	-0.07	0.05
At the present time, I feel confident that I will keep my chosen engineering major throughout college	4.09	0.09*	4.08	-0.03	0.02	4.15	0.15	0.98
At the present time, I am exploring other non-engineering majors at Clarkson University ^a	(3.89)	-0.25***	3.92	0.60***	(<0.001)	(3.35)	-0.78***	<0.001
Fit within engineering profession	3.96	0.15***	(3.88)	-0.09**	<0.001	3.83	-0.02	0.06
I will feel "part of the group" if I get a job in engineering	3.96	0.15**	(3.88)	-0.09**	<0.001	3.83	-0.02	0.06
Understand the broad nature of engineering	4.28	0.30***	(4.01)	-0.01*	<0.001	4.29	0.36***	0.12
Creativity is important to the engineering process	4.56	0.08*	4.38	-0.05*	0.004	4.48	0.08	0.78
Ethical problem solving is an important part of engineering design	4.44	0.42***	4.14	0.04	<0.001	4.32	0.36***	0.34
Engineering design is influenced by the societal context in which it takes place	4.34	0.34***	4.05	0.12***	<0.001	4.31	0.31***	0.50
I understand how engineering decisions are made	4.21	0.93***	3.56	0.20***	<0.001	4.14	0.82***	0.04
I understand the relationship between engineering and the society in which it is practiced	4.35	0.94***	3.71	0.09**	<0.001	4.25	0.92***	0.90

^aThese negatively worded items have been reverse-scored for analysis.

^b**Bold** values indicate that pre/post gains for this student group, or differences between designated groups, are significant. Parenthetical values () indicate a negative pre/post change. **Bold** values are significant:

* $\alpha=0.05$

** $\alpha=0.01$

*** $\alpha=0.001$

^cP-values in parenthesis indicate that post-pre changes for fall treatment group were less than (if positive) or greater than (if negative) control.

in math/chemistry (2 questions combined), the drop was greater among students in the course, which makes sense given that students are enrolled in the fall semester of Engineering and Society because of their lower performance on pre-enrollment math readiness exams. Students in spring semester showed a slight but significant increase in their confidence in math and chemistry, again confirming the suspicion that freshmen in general may come to university with inflated confidence in their academic abilities, and that confidence is swiftly thwarted during their first semester as they experience the difficulty of university-level courses. Such misconceptions of introductory engineering courses have been found by others [e.g. 51, 52]. However, as shown in Table II, confidence specifically in *engineering* courses dropped for the control group but remained level for students in the course, both fall and spring semesters. These findings suggest that, by engaging with engineering faculty and educational opportunities related specifically to engineering, students' confidence in their ability to study engineering may be preserved.

Finally, as shown in both Figure 1 and Table II, *satisfaction with the decision to study engineering* declined significantly among students in both fall and spring treatment cohorts, and increased significantly among the control group. This finding may partially result from inflated satisfaction levels at the beginning of the semester among the fall treatment group (pre response mean was 4.3), since the post scores at the end of fall semester were essentially the same for both treatment and control. Also, although responses continued to decline throughout the spring, post values were still relatively high at 4.0. Both fall groups showed equivalent declines in response rates to the individual item 'satisfaction to study engineering' (no change in spring), still with high post values despite the decline (4.3). There is also some level of inconsistency among the results for individual items in this category. For example, students in the fall treatment group simultaneously expressed an increase in their confidence about staying in engineering, and an increase in exploring other non-engineering majors (item negatively worded and reverse scored). This

inconsistency was also present, although not as pronounced, for the spring treatment group. These inconsistent responses may be an artifact of the detrimental effects of a negatively worded survey item noted by others [53, 54].

Nevertheless, despite inconsistencies among this particular group of questions, the results clearly indicate that in general, both the treatment and control student cohorts finished out their semester with relatively high levels of satisfaction with their decision to study engineering, and – most importantly – students in the fall semester course were significantly more inclined to stay in engineering than students in the control group. This result, together with the finding discussed previously regarding the stable confidence of students enrolled in the course toward succeeding in their engineering coursework, indicates overall that the course is having a positive impact overall on students' attitudes toward engineering.

C. Self-assessed Course Impacts

Student responses to questions on the post survey that asked them to self-assess the impacts of the course on their attitudes generally confirmed the positive pre/post changes described above with respect to their improved understanding of engineering. After taking the course, 86% of the students agreed or strongly agreed that they have a better understanding of what engineering is (mean=4.2); 90% agreed/strongly agreed that the course helped improve their understanding of the engineering design process (mean=4.2); and 75.2% strongly agreed/agreed that the course helped improve their understanding of the differences between the various engineering disciplines (mean=3.9).

Students responded overwhelmingly positive to the classroom format, with 371 out of 488 students (76%) selecting 'activities/discussions' as their preferred learning environment, as opposed to 117 selecting 'lecture'. A total of 723 FYE students provided qualitative feedback regarding the most valuable aspects of the course. Since we first began collecting information, students have consistently cited most frequently their experiences with the design project (297 students) and teamwork (136 students) as most valuable. They also appreciate learning about the relationship between ethics and engineering (136 students) and the exposure to engineering in general, the various disciplines, the real-life case studies, and the relationship between engineering and societal factors (323). Students appreciated 'learning how things are connected [with engineering];' 'applying things we learned to real scenarios (role play and design project);' and that the course 'changed my perception about engineering.' Students consistently write that the course helps them 'think differently about the world' and 'see the bigger picture.' One student wrote that through the course, they were 'able to notice connections among the way we got to where we are today and how to analyze where we need to go from here.'

In the words of one student: "I think the course overall was valuable because it teaches you that as you become an engineer you will not just be developing products but also playing a role in society development. It helps show that you have a responsibility to society as an engineer to create products that

will not only be beneficial but also be safe." Taken as a whole, the qualitative feedback supports the value of exposing students at the freshman level to engineering 'in context', as found by the work of Kilgore et al. [21].

V. CONCLUSIONS AND FUTURE WORK

A course has been developed for first year engineering majors that engages students with engineering faculty and the field of engineering in general. Students explore engineering through an STS lens that uniquely focuses on the non-technical aspects of engineering and addresses the connections between engineering, technology, and society. The course content aligns with many of the learning outcomes specified by ABET General Criterion 3, most notably 3(c), 3(f), 3(h), and 3(j). Course instructors have used a variety of evidence-based, student-centered instructional techniques to create a supportive, inviting, and engaging learning environment. Aside from satisfying ABET criteria, a major goal of the course is to improve students' attitudes toward and understanding of the broad field of engineering, and their sense of belonging within engineering studies and careers. Results from a relatively simple pre-test/post-test survey study administered over seven semesters show that, relative to a control group, students in the course experience positive changes in their self-confidence regarding problem solving and teamwork, their sense of fit within engineering, and their understanding of the broad nature of engineering, including the importance of creativity, ethics, and societal factors to engineering decision making and engineering design. Although the findings regarding students' academic self-confidence and satisfaction with their decision to study engineering are somewhat mixed, students in the course have relatively stable confidence levels toward their ability to succeed in their engineering courses, and indicate a clear positive trend in their confidence about keeping their engineering major throughout college. The study has uncovered a general decline in academic confidence among freshman students in the fall semester, which seems to be pervasive among both the study and control groups and is not present in spring.

Future work will include a closer look at qualitative results collected from the study, to better elucidate the decline in academic self-confidence as well as the conflicting findings noted in this paper regarding the change in students' levels of satisfaction with their decision to study engineering. We also hope to work toward a more consistent survey administration methodology that will include testing each incoming freshman engineering student at three points: prior to enrollment, and following fall and spring semesters. This will be possible now that the course is required as part of the regular freshman engineering curriculum. As this methodology is developed, the survey will undergo major revisions as we attempt to create more detailed questions that probe nuances that may be connected with students' identity as an engineer, sense of fit within engineering studies and careers, and their intent to continue with studies in their engineering major. Simultaneously, a system will be developed to engage a subset of freshmen in focus group interviews following their participation in the course. We hope that future research will garner findings that will both (1) deepen our understanding of

the nature of our own students and the impacts of the course on their own sense of belonging; and (2) enable us to broaden our findings to a more generalizable population.

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Assessing Student Views of Traditional, Free, and Interactive Modifications for an Introductory Networking Course

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Abstract—Common questions faced by instructors in their course designs are how to incorporate interactive technologies to increase student motivation as well as limiting the costs associated with education, contributed predominantly through course textbooks. We describe two course changes from a baseline scenario for a networking course, which aim at making the course no-cost using public domain content or, alternatively, focus on making the course highly interactive. We find that course cost benefits were offset by shortcomings in the open-source material replacing the textbook, but that the additional course costs of an interactive course are offset by increased course and learning perceptions reported by students. The focus on instructional interactivity, however, left the hands-on components up to students, with a potentially negative impact on the perceived quality of instruction.

Index Terms—Computer science education, Communication engineering education, student perceptions

I. INTRODUCTION

The interconnected world of today requires a thorough education of students in different fields, such as engineering and computer science, to attain at least a basic level of mastery concerning underlying mechanisms at play. In turn, introductory networking concepts oftentimes are integrated into the curriculum in a dispersed manner or covered in a dedicated course. This paper explores the self-reported student perceptions for such an initial “funnel” course. Independent of their selection of several specialization areas within the Information Technology (IT) track offered by the Department of Computer Science at Central Michigan University, students are required to take the introductory course in communications networks. As the IT track offers a more hands-on approach to the underlying concepts, students typically experience a combination of lectured content and hands-on networking exercises. Common choices that educators preparing these types of courses face are (i) the affordability of materials to students, especially when considering institutions with high ratios of financial aid receiving students as well as (ii) the fashion in which courses are delivered when considering an in-classroom setting. For three consecutive semesters, we evaluated student progression through this introductory sophomore-level course. We gathered the student feedback

employing anonymous survey instruments at the beginning, middle, and end of each considered semester targeting how student perceptions about the course focus changed over time with modifications from (i) traditional over (ii) no-cost to (iii) interactive, but not “flipped.” The remainder of this paper continues with a description of the underlying changes between semesters on a high level and the survey instrument. We follow in Section III with a discussion of dominant findings before we conclude in Section IV.

II. IMPLEMENTATION

Throughout the three semesters under evaluation, we performed several modifications to the course’s instructional methodology, which reflect some common choices faced by today’s educators:

- The baseline semester featured a traditional course setup, delivered employing a standard networking textbook paired with hands-on instructional laboratory units as part of the class meeting times.
- The first change was a replacement of the traditional textbook with an open-source book, which was supplemented with materials and hands-on instructional laboratory units as part of the class meeting times, i.e., the focus was on a no-cost course.
- The second change combined a traditional textbook paired with classroom response systems for feedback (“clickers,” which students had to purchase) and laboratory units now performed as homework, i.e., the focus was on increased interactivity resulting in significant costs for required course materials.

The accessible Kurose/Ross textbook [1] was adapted for the course and typically, each chapter in the textbook was flanked by a hands-on experience for students, related homework problems, and a quiz administered through the Learning Management System (LMS). For the interactive class, all quizzing (graded and ungraded) was performed using the clickers [2], with immediate feedback to foster resolution of wrongly retained answers. Throughout each course offering, announcements within the LMS and in-class were used in the beginning (first two week time frame), middle (after

the first mid-term examination), and end of the semester (before the final examination) to make students aware of the anonymous survey. The survey itself was modeled after the one presented in [3], combining persistence in engineering [4] and motivational tendencies [5], with questions presented in Table I.

III. RESULTS

We performed a multi-variate analysis on the 86 total responses we received for survey items incorporating persistence in engineering and motivational components, with an overview of results for all semesters provided in Table II. Throughout, we consider a two-factor design (semester or instruction mode \times time within) and employ significance levels of $\alpha=0.05$ in the univariate analyses of variance (ANOVA). Due to space limitations, we focus our discussion on (i) program continuation or persistence, (ii) quality of instruction, (iii) perceived course value and enjoyment, and (iv) self-perceived learning, which are items that were found to exhibit the highest significance by semester, time within a semester, and the interaction of both. We furthermore note that in some cases, significant variability differences exist between groups, which in an overarching manner can be explained through the survey feedback rate differences throughout semesters.

We initially note that the persistence of students to continue taking courses within the discipline exhibits a significant difference by semester. Students in the traditional course setting indicated the lowest level of continued interest ($M=2.06$, $SD=0.79$), followed by the free semester ($M=4.35$, $SD=0.88$), while the highest interest in the program was indicated in for the interactive instruction group ($M=4.7$, $SD=0.68$). These results indicate a significant main effect with $F(2, 83)=108.51$, $p<.001$, $\eta_p^2=.723$. Students overall indicated as they progressed throughout the semester in the traditional and interactive course formats an increasing likelihood of remaining with the department's programs, while a slight reduction can be observed for the free course approach. The interaction between these semester and surveying time factors was also found to be significant $F(4, 77)=7.99$, $p<.001$, $\eta_p^2=.3$. We note that effect sizes indicate that a larger contribution stems from the overall instruction mode (semester), which exhibits a large effect size, while the time during a semester features a medium effect size. Comparing the joint effects, we again note a larger effect size.

Next, we evaluate the perceived instruction quality, which was found to exhibit a significant main effect by semester $F(2, 83)=18.44$, $p<.001$, $\eta_p^2=.308$ and is illustrated in Fig. 1a. We note that while variances between groups vary significantly, a Welch evaluation of means indicates significance ($p<.001$). Specifically, students in the traditional course rated the instructional quality highest ($M=4.58$, $SD=0.61$), followed by the interactive group ($M=3.39$, $SD=1.03$), and trailed by the free course ($M=3.2$, $SD=1.20$). As indicated, this finding is corroborated by the large effect size. As all three course variations were taught in the same manner with the

outlined adjustments, it seems that the overall student perception leans towards employment of the traditional textbook and lecture style combining slides and whiteboard together with instructor-guided hands-on exercises. However, we did not find a considerable main effect for the time within the semester $F(2, 83)=.444$, $p=.643$, $\eta_p^2=.011$ or the interaction of both $F(4, 77)=1.78$, $p=.141$, $\eta_p^2=.085$. This indicates that students overall perceived the instructional quality highest in the traditional textbook-based lecture paired with hands-on laboratory settings most, while the free textbook approach did not meet student instructional needs. The interactive course format falls somewhere in the middle and results could be interpreted in the context of laboratory units being conducted in a self-guided manner, which might overload students not familiar with self-scheduling. Indeed, an additional evaluation indicates that student ratings by semester for the homework difficulties show a significant main effect with an effect size approaching medium $F(2, 83)=3.811$, $p=.026$, $\eta_p^2=.084$.

We noticed a significant main effect between the semesters when students were to value the course $F(2, 83)=12.514$, $p<.001$, $\eta_p^2=.232$ with a medium effect size. While a Levene test indicates variances between groups vary significantly, a Welch evaluation of means indicates significance ($p<.001$). Students in the traditional course overall indicated the lowest perceived value ($M=3.18$, $SD=1.16$), followed by the free course format ($M=4.1$, $SD=0.79$). Students in the interactive class, however, exhibited the highest level of appreciation for the course with the lowest deviation of ratings ($M=4.18$, $SD=0.53$). While no significant main effect was determinable for within a semester $F(2, 83)=.42$, $p=.658$, $\eta_p^2=.010$, the evaluation of the interaction indicates a significant main effect $F(4, 77)=3.823$, $p=.007$, $\eta_p^2=.166$. (We note that for the combination of semesters and times within, the variances are non-homogeneous.) The overall differences become more apparent when viewed graphically, as in Fig. 1b. While students in the interactive course agree to the course being worthwhile on a stable level, students in the free course reduced their course rating over the time of the semester. The traditional course students increased their class valuation towards the middle of the semester and kept their rating afterwards on the same level. Some of this increased valuation could be attributed to the increased hands-on practices in the laboratory times. Some problems became apparent with the free course text selection, which students mentioned in class. Amongst those referenced were writing styles, illustrations, and spelling errors. In turn, the increased usage of the free text with generated slides could be a significant contributor to the lower ratings.

When asked if they enjoyed the course, students in the traditional setting provided the best marks ($M=4.15$, $SD=0.62$) followed by the interactive course delivery ($M=3.76$, $SD=0.94$) and the free format ($M=3.5$, $SD=1.15$). With a significant main effect $F(2, 83)=3.643$, $p=.03$, $\eta_p^2=.081$, this indicates that overall, students enjoyed the course, but the delivery format

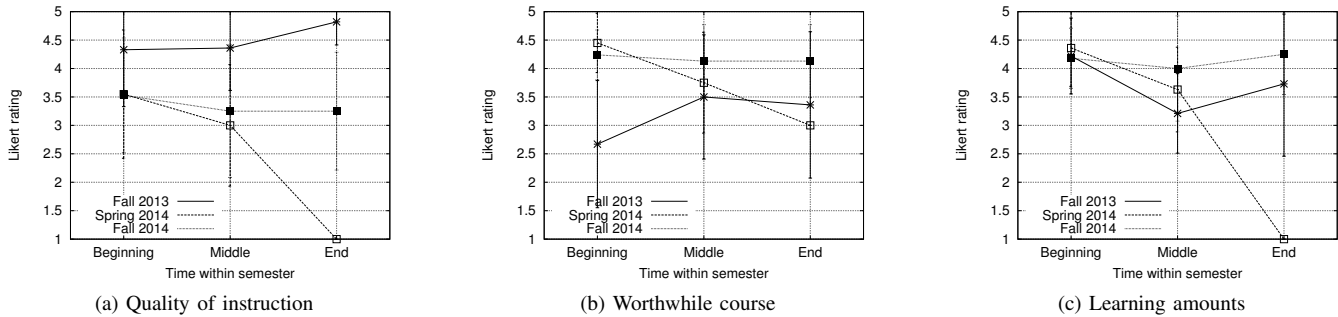


Fig. 1. Visual representation of means observed for quality of instruction, considering the course worthwhile, and self-perceived learning.

and potential problems with materials can have a significant impact. This result has to be regarded with caution, however, as the variability difference between groups is significant. While the traditional and interactive course versions remain at a fairly stable level, the free course shows a continuous slide of student course enjoyment as surveyed. When the time within a semester is considered, however, we do not observe significant differences $F(2, 83)=1.324, p=.272, \eta_p^2=.031$, which indicates the initial observation is corroborated on a steady level during semesters. The interaction main effect, in turn, can be explained by this individual course format's content problems can be regarded as culprits for the reduced ratings $F(4, 77)=3.104, p=.020, \eta_p^2=.139$.

Finally, we describe the self-perceived learning as reported by students in the survey, illustrated in Fig. 1c. An increase can be noted from traditional ($M=3.67, SD=0.99$) over free ($M=3.9, SD=1.02$) to interactive ($M=4.15, SD=0.67$) course formats. The visible order can be noted by semester, which, however only approaches significance $F(2, 83)=2.463, p=.091, \eta_p^2=.056$. Due to a lack of variance homogeneity, a Welch test was employed to confirm ($p=.074$). The significant main effect within the semesters $F(2, 83)=6.491, p=.002, \eta_p^2=.135$ showcases how student rating progress throughout the semester from (i) high to (ii) reduced and return to (iii) higher for the course versions. We note, however, that due to in-between group variability, we corroborated our observation with a Kruskal-Wallis H test, which showed a statistically significant difference, $\chi^2(2)=12.374, p=.002$. This finding is further corroborated by the significant interaction main effect $F(4, 77)=4.679, p=.002, \eta_p^2=.196$, noting that again inter-group variability is significant.

We note in conclusion that the individual submission for the Spring 2014 semester could be a significant outlier, potentially submitted by a student that was fully dissatisfied with the course and/or grade earned during the semester. In turn, response number variations significantly impact the between-group variabilities and assumptions for ANOVA, which, however, can be considered more a call for caution in the interpretation of results rather than their invalidation [7].

IV. CONCLUSION

We find that overall, student responses vary greatly with the course implementation, but less within a semester. The interactive course results in the highest motivation to continue with the department's offerings while students report challenging lectures and reading assignments. Their valuation of the course as worthwhile and enjoyable can be seen as a result of the right challenge level, see, e.g., [6]. Compared to the free textbook offering with material shortcomings and the traditional textbook-only approach, we note that a replacement of the designated supervised laboratory time with the increased in-lecture activities results in a higher level of the students' need to keep up with materials and self-organize (based on general feedback we received). Thus, we conclude that a traditional, edited textbook can aid to keep learners abreast in self-studying, while adding interactivity and immediate resolution of misconceptions significantly fosters the perceived value of the course offering by helping to balance challenge levels for learners. Future works will investigate supplemental video instructions to help students in the initial phases of assignments and replacing the current traditional textbook in the interactive course with another free or low-cost alternative.

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TABLE I
OVERVIEW OF THE EMPLOYED SURVEY FOR A SUBSET OF THE PERSISTENCE IN ENGINEERING [4] AND MOTIVATIONAL TENDENCIES [5] SURVEYS
BASED ON LIKERT-TYPE QUESTIONS.

Item	Text
1	I want to continue taking Computer Science courses.
2	After graduation I want to become a computer scientist or IT professional.
3	I think that I am doing well in this course.
4	I have good math skills.
5	I have good science knowledge.
6	I am good at applying math and science to real world problems.
7	I like working in teams.
8	I perform well on teams.
9	Creative thinking is one of my strengths.
10	I am skilled at solving problems that can have multiple solutions.
11	Math skills are important for computer scientists and IT professionals.
12	Science knowledge is important for computer scientists and IT professionals.
13	An ability to apply math and science principles to real-world problems is important for computer scientists and IT professionals.
14	An ability to perform on teams is important for computer scientists and IT professionals.
15	The quality of instruction by faculty is good.
16	There are enough opportunities to interact with faculty.
17	The computer facilities at the IT sites are good.
18	The classroom facilities are good.
19	The library services are good.
20	The academic advising is good.
21	I feel stressed about the course load for this class.
22	This is an enjoyable course.
23	I learn a lot in this course.
24	The team projects require a lot of effort.

TABLE II
OVERVIEW OF THE MEAN AND STANDARD DEVIATIONS OBTAINED FROM SURVEYING STUDENTS AT THE BEGINNING, MIDDLE, AND END OF THREE
SEMESTERS EMPLOYING DIFFERENT INSTRUCTIONAL AND MATERIAL SUPPLY APPROACHES.

Item	Fall 2013				Spring 2014				Fall 2014			
	Beg. (N=8)	Mid. (N=14)	End (N=11)	Tot. (N=33)	Beg. (N=11)	Mid. (N=8)	End (N=1)	Tot. (N=20)	Beg. (N=17)	Mid. (N=8)	End (N=8)	Tot. (N=33)
1	1 (0.00)	1.93 (0.27)	3 (0.00)	2.06 (0.79)	4.55 (0.93)	4.13 (0.83)	4 (0.00)	4.35 (0.88)	4.47 (0.87)	5 (0.00)	4.88 (0.35)	4.7 (0.68)
2	4.5 (0.93)	4.07 (1.39)	4 (1.27)	4.15 (1.23)	4.36 (1.03)	4.25 (0.71)	4 (0.00)	4.3 (0.86)	4.47 (0.80)	4.88 (0.35)	4.5 (0.76)	4.58 (0.71)
3	4.25 (1.03)	4 (1.41)	4 (1.27)	4.06 (1.25)	4.09 (0.30)	3.25 (0.89)	2 (0.00)	3.65 (0.81)	4.41 (0.51)	3.75 (1.28)	3.75 (1.17)	4.09 (0.95)
4	4.5 (0.54)	3.29 (1.07)	3.64 (1.21)	3.7 (1.10)	4.09 (0.70)	3.5 (0.93)	4 (0.00)	3.85 (0.81)	3.53 (0.80)	2.88 (0.83)	3.5 (0.93)	3.36 (0.86)
5	3.88 (1.25)	4.14 (0.54)	4.09 (0.94)	4.06 (0.86)	3.64 (0.81)	3.63 (0.74)	4 (0.00)	3.65 (0.74)	3.71 (0.77)	3.88 (0.64)	4 (0.76)	3.82 (0.73)
6	3.75 (1.17)	4.14 (0.54)	4.27 (0.47)	4.09 (0.72)	3.82 (0.60)	3.75 (0.89)	4 (0.00)	3.8 (0.70)	3.35 (0.70)	3.5 (0.54)	3.63 (0.74)	3.45 (0.67)
7	4.13 (0.83)	4.14 (0.66)	4.18 (0.75)	4.15 (0.71)	3.45 (0.93)	3.25 (0.71)	4 (0.00)	3.4 (0.82)	3.53 (0.94)	3 (1.07)	3.25 (0.71)	3.33 (0.92)
8	3.88 (1.25)	3.71 (1.33)	3.82 (1.17)	3.79 (1.22)	3.73 (0.47)	3.75 (0.46)	4 (0.00)	3.75 (0.44)	3.88 (0.86)	3.75 (0.89)	4 (0.54)	3.88 (0.78)
9	4.38 (0.52)	4.21 (0.58)	4.27 (0.65)	4.27 (0.57)	3.73 (0.91)	4.13 (0.64)	5 (0.00)	3.95 (0.83)	4.12 (0.78)	4.25 (0.46)	3.75 (0.71)	4.06 (0.70)
10	4.25 (0.71)	3.71 (0.82)	4.27 (0.65)	4.03 (0.77)	4 (0.78)	3.75 (0.89)	5 (0.00)	3.95 (0.83)	4.12 (0.78)	3.88 (0.99)	4 (0.76)	4.03 (0.81)
11	4 (0.93)	3.86 (0.86)	4.27 (0.65)	4.03 (0.81)	4 (1.00)	3.75 (1.03)	4 (0.00)	3.9 (0.97)	3.82 (0.88)	3.38 (1.06)	4 (1.07)	3.76 (0.97)
12	4.5 (0.54)	4.43 (0.51)	4.36 (0.92)	4.42 (0.66)	4 (0.63)	3.63 (0.92)	3 (0.00)	3.8 (0.77)	3.71 (1.05)	3.5 (1.20)	4.38 (0.52)	3.82 (1.01)
13	4.25 (0.71)	4.14 (0.66)	4.55 (0.52)	4.3 (0.64)	4.36 (0.81)	3.88 (0.99)	4 (0.00)	4.15 (0.88)	3.88 (0.93)	3.88 (0.99)	4 (1.07)	3.91 (0.95)
14	4.63 (0.52)	4.57 (0.51)	4.73 (0.47)	4.64 (0.49)	4.18 (0.75)	4.25 (0.71)	4 (0.00)	4.2 (0.70)	4.35 (0.86)	4.38 (0.74)	4.5 (0.54)	4.39 (0.75)
15	4.63 (0.52)	4.36 (0.74)	4.82 (0.41)	4.58 (0.61)	3.55 (1.13)	3 (1.07)	1 (0.00)	3.2 (1.20)	3.53 (1.01)	3.25 (1.17)	3.25 (1.03)	3.39 (1.03)
16	4.25 (0.89)	3.86 (0.86)	4.09 (1.22)	4.03 (0.98)	3.55 (0.82)	3.13 (1.13)	2 (0.00)	3.3 (0.98)	3.65 (0.49)	3.38 (0.74)	3 (1.31)	3.42 (0.83)
17	3.13 (0.83)	3 (0.68)	2.82 (0.98)	2.97 (0.81)	3.55 (0.93)	3.38 (0.92)	2 (0.00)	3.4 (0.94)	3.24 (1.20)	3.25 (1.17)	3.25 (1.49)	3.24 (1.23)
17	4.13 (0.83)	4 (0.88)	4 (0.78)	4.03 (0.81)	3.73 (0.65)	3.38 (0.92)	3 (0.00)	3.55 (0.76)	3.59 (0.71)	3.63 (1.06)	3.63 (1.51)	3.61 (1.00)
18	3.88 (1.13)	4.29 (0.61)	4.18 (0.87)	4.15 (0.83)	4 (0.78)	3.75 (0.89)	2 (0.00)	3.8 (0.89)	4 (0.79)	3.63 (0.92)	4 (0.76)	3.91 (0.81)
18	3.25 (1.03)	3.29 (0.99)	3.09 (1.04)	3.21 (0.99)	3.45 (0.69)	3.75 (0.71)	2 (0.00)	3.5 (0.76)	3.53 (1.01)	3.63 (0.92)	3.88 (0.83)	3.64 (0.93)
20	4.13 (0.83)	4.07 (0.73)	3.91 (1.30)	4.03 (0.95)	3.18 (0.87)	3.25 (1.03)	5 (0.00)	3.3 (0.98)	2.65 (0.86)	2.88 (1.25)	2.88 (1.46)	2.76 (1.09)
21	4.38 (0.52)	4 (0.56)	4.18 (0.75)	4.15 (0.62)	4.09 (0.83)	3 (0.93)	1 (0.00)	3.5 (1.15)	3.82 (0.81)	3.75 (1.03)	3.63 (1.19)	3.76 (0.94)
22	4.38 (0.52)	3.21 (0.70)	3.73 (1.27)	3.67 (0.99)	4.36 (0.67)	3.63 (0.74)	1 (0.00)	3.9 (1.02)	4.18 (0.53)	4 (0.93)	4.25 (0.71)	4.15 (0.67)
23	3.38 (0.74)	4.21 (0.97)	4.09 (1.45)	3.97 (1.13)	4.18 (0.75)	3.25 (0.46)	4 (0.00)	3.8 (0.77)	3.35 (0.93)	3.75 (0.71)	3.25 (1.03)	3.42 (0.90)

A Pedagogical Model for Introducing 3D Printing Technology in a Freshman Level Course Based on a Classic Instructional Design Theory

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Abstract—This paper presents a seven-step pedagogical model for introducing 3D printing technology to students with different levels of technological literacy in a freshman level course. The model was derived from a classic instructional design theory on the development of intellectual skills, the Conditions of Learning, with consideration of the technical requirements of 3D printers. It aimed to tackle the practical problems arose when course instructors adopted 3D printing as learning activities in classes, such as the diversity of students' technical backgrounds, the low throughput of 3D printers and the difficulty in integrating 3D printing into learning task. The model was piloted for two years in a General Education course under the engineering domain that opened to all freshmen. Most of the students had no prior experience in 3D printing and all of them agreed that they have had a good understanding of the technology after completed the course. They reported that the learning task supported the development of their innovative ideas and enhanced their learning motivations. However, their perceptions of the workload vary.

Keywords—3D Printing; Educational technology; Pedagogy

I. INTRODUCTION

3D printing technology, also known as rapid prototyping technology, is identified as one of the key emerging educational technologies to support student learning and to stimulate innovations. The technology is likely to have a major influence on higher education [1-3] in the coming years. It is even being heralded as “Industrial Revolution 2.0” [4]. While the technology is not new to the higher education community, academics have been using 3D printers (or rapid prototyping machines) for more than 20 years in research and teaching. However such equipment is very expensive and is usually housed in department or research laboratories. It is often available only to students in certain professional disciplines [5,6], wide adoption of 3D printing technology across disciplines as teaching and learning activity is rare. In the recent year, the cost of the 3D printers dropped significantly and the higher education community is eager to integrate the now inexpensive technology into regular classes for enhancing student learning. Instructors begin to incorporate 3D printing technology in their courses [7-9], but very often they encountered practical problems during the implementation, such as students may have different levels of CAD and 3D printing technology knowledge, the slow printing speed and low throughput of 3D printers which handicapped the adoption of the technology in large class, and no proven teaching

strategy in adopting 3D printing in learning task. These pedagogical and technical issues can hold back the adoption of the technology and discourage passionate teachers from developing innovations in teaching. Thus a working pedagogical model is needed for instructors to integrate 3D printing into their courses.

II. ISSUES IN ADOPTING 3D PRINTING TECHNOLOGY IN LEARNING TASK

Issues in adopting 3D printing in learning activities have been reported by early adopters [7-8,10]. Also course leaders who wished to incorporate the technology into their courses at City University of Hong Kong have been consulted and their practical concerns during the instructional design process are documented. In general, issues related to adopting 3D printing in learning task can be grouped into two categories:

1) *Students' diverse technical backgrounds*: Students from different disciplines who enrolled in the same course poses a challenge to the instructor in adopting 3D printing technology in class. Although it is reasonable to assume the majority of students do not have any hands-on experiences on using 3D printers, as the technology is still not widely available to general public, some students do possess a higher level of technological literacy to begin using the technology, such technical skill in CAD and proficiency in comprehending 3D objects. These skill sets can be acquired by students during their studies in high schools, through technical courses offered by vocational colleges, or by self-learning before entering University. This group of “advanced” students may find that the introductory materials of the 3D printing technology are redundant knowledge and may lose motivation in learning. On the other hand, this fundamental knowledge (refer to skill in CAD and comprehension of 3D objects) is essential for the rest of the class to learn and use the technology.

2) *Low throughput*: As the majority of the 3D printers are using additive manufacturing process, the sequential deposition of materials limited the printing speed, resulted in low throughput. For example, it is commonly to find that a 5 x 5 x 5 inch object requires at least 10 hours of printing time and another hour for post processing (removing supportive material). It basically consumed a day's work on printing just one item. Using the same formula, a 25-student class will take 25 working days to accommodate all student works for

sequential printing. It is not cost effective to support teaching in this way, thus limited the adoption of 3D printing technology in large class. Purchasing additional 3D printers can certainly increase the throughput if budget and space were available. 3D printer manufacturers attempt to increase the overall speed by putting multiple printing heads in one 3D printer and extrude building material simultaneously, however most of 3D printers available on the market at affordable price are still single-head model. This technical barrier is unlikely to be solved completely, thus the pedagogical model has to work around this issue.

III. THE PEDAGOGICAL MODEL

A pedagogical model for integrating 3D printing into learning task is developed. It is derived from a classic instructional design theory, the Conditions of Learning by Robert Gagne [11], with consideration of 3D printers' throughput and students' differences in technological literacy.

A. The Conditions of Learning

Gagne's theoretical framework is based on the development of student's intellectual skills and is first used for military training purpose in the 60s' [12]. Since then it has been applied to the design of instruction in different domains [13]. According to the theory, Nine Instructional Events are the basis of instruction design. Each instructional event corresponds to a specific cognitive process. The nine-event provides the necessary conditions for learning in any discipline. Table I shows the Nine Instructional Events and the corresponding cognitive process.

TABLE I. NINE INSTRUCTIONAL EVENTS AND THE CORRESPONDING COGNITIVE PROCESS OF THE INSTRUCTIONAL DESIGN THEORY: THE CONDITIONS OF LEARNING [11]

	Instructional Event	Cognitive Process
1.	Gaining attention	Attention: Alertness
2.	Informing learner of the objective: activating motivation	Expectancy
3.	Stimulating recall of prior knowledge	Retrieval to working memory
4.	Presenting the stimulus material	Selective perception
5.	Providing learning guidance	Encoding: Entry to long term memory storage
6.	Eliciting performance	Responding
7.	Providing feedback	Reinforcement
8.	Assessing performance	Retrieval
9.	Enhancing retention and transfer	Generalization

B. Pedagogical Model for Introducing 3D Printing Technology

Although the theoretical framework of the Conditions of Learning can be applied to all aspects of learning, including 3D printing, practical implementation issues have to be addressed. A seven-step pedagogical model is developed based on the theoretical framework with practical solutions to address the two aforementioned problems in adopting 3D printing

technology in learning task. Staff requirements for the model are the course instructor, tutors (senior year students) with 3D printing skills and a laboratory manager (technician) to provide technical support and feedbacks. These are typical resource available to a freshman level course with laboratory session. The pedagogical model is described below and its association with the Nine Instructional Events and the cognitive processes is presented in Table II step-by-step.

- First (Step 1) students are grouped into team-of -three to -six followed by (Step 2) an introductory seminar on 3D printing technology conducted by the instructor or the laboratory manager. The adoption of collaborative learning in the model is proven to be effective in enhancing creativity [14-16] and also enable large class to adopt the technology. The two steps correspond to the cognitive processes of attention and expectancy. Students are alerted about the use of 3D printing in their learning tasks. It stimulates their motivation and also informs them the expectancy of the performance to be achieved in the course.
- Then (Step 3) each team is coached by a senior year student, who acts as tutor in class, on creating printable 3D designs using CAD. "Advanced" students with good technical background in CAD within the team can help to teach other teammates, providing additional peer learning element in the learning process. This step corresponds to the retrieval, selective perception and encoding processes. The action of demonstrating CAD by the tutors helps students to recall any prior knowledge or subordinate skills to their working memory, setting up their mindsets to receive the stimulus material. The new knowledge then can be encoded and transferred to students' long term memory.
- Afterward (Step 4), students work together to create their own team designs within a specific time period (i.e. two weeks). These collaborative learning approaches help to draw out expertise from students with different backgrounds and contribute to the design. While science and engineering students can lead the technical aspect of the product, art students can advise on the outlook design and business students can contribute to the marketing feasibility. Whenever they encounter technical difficulty (Step 5), they can visit the on-duty tutors who are stationed in the 3D printing laboratory for troubleshooting their design problems and also to conduct a preliminary design rules check (DRC) as a formative assessment of their designs. Students with weak technical skills can receive extra help from the tutors, by repeating Step 4 to 5, and to catch up with the rest of the class referenced to the Mastery Learning approach [17]. This self-learning process provides flexibility to suit individual student's learning style and need. Step 4 to 5 correspond to the cognitive process of encoding, responding, and reinforcement. Encoding of new knowledge to long term memory continues in this step, but instead of learning under the instructions of tutors, students collaboratively work and learn together. The

shift from passive to active learning is particular important for students to create innovative designs. To ensure students develop in the right direction, their performances are elicited according to the DRC. This timely feedback helps students to gauge their works and allow them to improve on their designs and reinforce their learning.

- Students then (Step 6) submit their final designs to the laboratory manager by the end of the design period for a detail DRC and receive technical feedbacks from him. Multiple designs then combine together (Step 7) into one design file for printing simultaneously. The batch printing eases the pressure on long printing time, as compared to serial printing. Finally students receive the printed objects and conduct a summative assessment on their designs in physical form under the guidance of instructor (cognitive processes: retrieval and generalization). Students receive an overall evaluation of their works and appraisal in a formal way. It enhances the retention of their newly acquired

knowledge and enables them to apply/transfer the intellectual skills to future projects.

The proposed model not only adopted the classic instructional theory in designing learning task using 3D printing technology, it also provides the flexibility to accommodate different settings and budgets (for 3D printers) and can be scaled up with class size. As the laboratory manager can select suitable 3D printers based on the resource available, such as professional 3D printer versus desktop model, the only requirement is to have a sufficient building volume that can print multiple student designed items (combined into one object) all together. Low cost, desktop version, 3D printers with build volume larger than 12 x 10 x 10 inch are available on the market. Additionally the course instructor can adjust the student team size to meet the resource requirement. The model can easily accommodate a 60-student class by dividing them in to 12 team-of-five. Six items, each with a size of 4 x 5 x 4 inch, can be printed in one batch and only two batches of printing are needed (approximately 2 days of printing time). However the maximum item size that each team can use is dictated by the 3D printer's building volume.

TABLE II. PEDAGOGICAL MODEL FOR INTRODUCING 3D PRINTING TECHNOLOGIES

	Pedagogical Model	Nine Instructional Events	Cognitive Process	Staff Involve	Remark
Step 1	Instructor explains the adoption of 3D printing technology in learning task and groups all students into team-of -three to - six.	1. Gaining attention	Attention: Alertness	Instructor	Collaborative learning approach is proven to be effective in enhancing creativity and also it enables the adoption of the technology in large class size
Step 2	Instructor explains the objectives of the learning task and conduct a brief introductory seminar on 3D printing technologies	2. Informing learner of the objective: activating motivation	Expectancy	Instructor and Laboratory Manager (optional)	Activate students' motivation using real examples and applications
Step 3	Tutors coach individual team on creating printable 3D designs using CAD	3. Stimulating recall of prior knowledge 4. Presenting the stimulus material 5. Providing learning guidance	Retrieval to working memory Selective perception Encoding: Entry to long term memory storage	Tutors	"Advanced" student within the team can help to coach his/her teammate
Step 4	Students create/revise their own designs in computer lab at school or at home		Encoding: Entry to long term memory storage		Self-learning approach to provide flexibility to suit individual student's learning style and need
Step 5 (Repeat step 4 if need)	Whenever students encounter technical difficulty, they can visit the on-duty tutors for troubleshooting their design problems and also conduct a preliminary design rules check (DRC)	5. Providing learning guidance 6. Eliciting performance 7. Providing feedback	Encoding: Entry to long term memory storage Responding Reinforcement	Tutors	Students with weak technical skills can receive extra help from the tutors and to catch up with the rest of the class (the Mastery Learning approach)
Step 6	Students submit their final designs for a detail DRC and receive technical feedback from the laboratory manager	8. Assessing performance	Retrieval	Laboratory Manager	
Step 7	Laboratory manager combines multiple designs into one file for printing Students receive the 3D objects and assess the products with the instructor	9. Enhancing retention and transfer	Generalization	Laboratory Manager and Instructor	The batch printing eases the pressure on long printing time, as compared to serial printing

IV. IMPLEMENTATION

The pedagogical model was piloted for two years (2013/14 and 2014/15) in a General Education course, GE1324 Creating Your Smart Home, under the engineering domain that opened to all freshmen at City University of Hong Kong. The course aimed to introduce students a creative approach to smart living and to inspire students to adopt technology innovatively for a healthier and more environmental friendly living environment. It was taught by an academic staff from the department of Mechanical and Biomedical Engineering. In the year 2013/14 and 2014/15, there was 89 and 28 student enrolment respectively. About half of the class came from the College of Science and Engineering and the other half is from different Colleges and Schools (Table III) in both years. Thus it created a learning environment with diverse student backgrounds, similar to the issue #1 mentioned in section II, to evaluate the pedagogical model. The key assessment task was to develop a concept of a smart home appliance and to visualize the idea by building a prototype using 3D printing technology followed by a final presentation. The assessment weighted 35% of the course grade. Approximately 15% of student work hour was dedicated to learn and use the technology for their prototype development. Students were grouped into team-of -five to -six and only one design per team is allowed. They were expected to complete their CAD designs within two weeks of time. The maximum object build size for each team was 4 x 4 x 4 inch. The allowed build volume was sufficient for printing scale prototypes for presenting and demonstrating their designs/ideas. The course instructor followed the seven-step pedagogical model for introducing 3D printing technologies to students during the tutorial sessions, in parallel with the lecture sessions where subject contents were taught. Five tutors and a laboratory manager provided the technical support during the 3D printing tutorial sessions. Three packages of CAD software, Tinkercad, SolidWorks and Rhino 4.0, were available to students. Most of them selected the cloud version of Tinkercad, an easy to use 3D CAD design tool that was available online. A Stratasys Fortus 400mc 3D printer from the Gateway Education Laboratory [18] was used to print all the items. Every six designs were combined in one file for batch printing.

TABLE III. GE1324 STUDENT ACADEMIC BACKGROUND

	2013/14		2014/15	
College of Business	21	(24%)	10	(36%)
College of Liberal Arts & Social Science	14	(16%)	2	(7%)
College of Science & Engineering	42	(47%)	15	(54%)
School of Energy and Environment	7	(8%)	0	(0%)
School of Creative Media	4	(4%)	0	(0%)
School of Law	1	(1%)	0	(0%)
Exchange student	0	(0%)	1	(4%)
Total	89	(100%)	28	(100%)

V. STUDENT FEEDBACKS

Quantitative feedbacks from two questionnaires and qualitative feedback were obtained from students at the end of the course to evaluate the effectiveness of the pedagogical model.

The first quantitative feedback is an institutional Teaching and Learning Questionnaire (TLQ). It is a 7-point Likert-type questionnaire to gather student feedbacks on the overall course teaching and learning experience. TLQ was sent to all GE1324 students with 51% and 43% response rate in the 2013/14 and 2014/15 classes. Results of the learning experience from GE1324 TLQ are compared to the University Norm in the respective year (69,490 responses in 2013/14 and 66,954 responses in 2014/15, both with 48% response rate). Results are summarized in Table IV.

TABLE IV. GE1324 TEACHING AND LEARNING QUESTIONNAIRE DATA COMPARED TO THE UNIVERSITY NORM*

Item		2013/14			2014/15		
		GE 1324	U Norm	% Diff	GE 1324	U Norm	% Diff
TLQ1	I found the learning experience well designed.	5.60	5.58	0.4%	5.83	5.62	3.7%
TLQ2	I was encouraged to be creative/innovation.	5.98	5.47	9.3%	6.17	5.50	12.2%
TLQ3	I was encouraged to think critically	5.60	5.56	0.7%	6.00	5.60	7.1%
TLQ4	I found the course difficult.	4.93	4.93	0.0%	4.58	4.95	-7.5%
TLQ5	Overall, I consider the learning experience provided by the teacher in this course as valuable	5.71	5.69	0.4%	5.83	5.73	1.7%

*7-Point Likert Scale: 1 (Strongly Disagree) to 7 (Strongly Agree)

The second quantitative feedback is a 3D Printing Experience Survey (3D-PES) specifically designed to seek each team's collective perspective on the use of the 3D printing technology in class, that included learning and usage experiences. It is a 5-point Likert type questionnaire and each team is allowed to provide only one response. The 3D-PES was administered only to the 2014/15 class and all 5 teams have responded to the survey. Four out of the five teams indicated they have no prior experience in 3D printing technology and one student reported that he has less than 6 month experience in using the technology. Results are shown in Table V.

TABLE V. 3D PRINTING EXPERIENCE SURVEY*

	Item		Mean	Std Dev
Learning Experience	ES1	After completing the course, I have a good understanding of the 3D printing technology	4.2	0.40
	ES2	The use of 3D printing technology in the course supported the development of my innovative idea	4.4	0.49
	ES3	The use of 3D printing technology in the course enhanced my learning motivation	4.4	0.49
Usage Experience	ES4	After completing the course, I am comfortable in using the CAD software to design a simple 3D object	4.4	0.49
	ES5	Workload related in using 3D printer/CAD software in the course is appropriate	4.2	0.75
	ES6	Support from the GE Lab staff/tutors in using 3D printer/CAD software is appropriate	4.6	0.49

	Item		Mean	Std Dev
	ES7	The overall learning experience related to the use of 3D printing technology is well designed	4.6	0.49

*5-Point Likert Scale: 1 (Strongly Disagree) to 5 (Strongly Agree)

Qualitative feedbacks from students are obtained through an anonymous online platform and are summarized into three categories: 1) Learning experience; 2) Usage; and 3) Area for Improvement. Six statements are identified:

Category 1) Learning experience

- *The course provide a chance for students to use the 3D printing technology and learn to design their 3D objects by using online software, it is a really useful experiences to students as some of them may not have an opportunity to touch those things in their 3/4 years university life.*
- *Earning the experience to have lab visit, and do 3D model drawing and printing.*
- *Amazing experience to use this technology.*

Category 2) Usage

- *The software for 3D model development is easy to use.*
- *The product is printed as expected.*

Category 3) Area for improvement

- *Something may be too difficult for other areas' students to learn (e.g. BBA/CLASS)* because it involves technical things in the course.*

*(BBA = Bachelor of Business Administration; CLASS = College of Liberal Arts and Social Sciences)

VI. DISCUSSION

From the TLQ results, it is evident that students believed the course provided a good learning experience for them to be creative/innovation (TLQ2). The score in this item is significantly higher than the University Norm by 9.3% and 12.2% in the two years, while other items are on par with the Norm. It is an encouraging result that students agreed with the course aim that a creative/innovative learning environment was provided to them. Since the TLQ is an institutional instrument that provided an indication of the overall learning experience of the course, which involved lecture, tutorial, 3D printing task and other hands-on activities, the higher that Norm score on innovation was an integrated result of all the learning tasks of the course. While task related to 3D printing consisted of 15% of student work hour, one can suggest that the 3D printing pedagogical model has contributed to the development of student innovations. This assumption is supported by the 3D-PES and qualitative feedback (Category 1) and is discussed subsequently.

The team responses from the 3D-PES indeed provided a clear indication of student learning experience specifically on 3D printing from their perspectives. They overwhelming agreed that the adoption of 3D printing technology in the learning task supported the development of their innovative ideas (ES2) and enhanced their learning motivation (ES3). They indicated that they had good understanding of the technology after completing the course (ES1) and have received positive learning experience on using 3D printing in

learning task (ES7). Students also explained in written form that they have received a very good learning experience in using the 3D printing technology (Qualitative feedback - Category 1). As for the usage experience, students also agreed that the CAD software was easy to use under the coaching of tutors (ES4 & ES6), supported by their qualitative feedback (Category 2). However, students' perceptions on workload related to the learning task vary (ES5) with a high standard deviation value (0.75). This result agreed with the qualitative feedback (Category 3) where student pointed out that technical material was more difficult for art and business students to learn as compared to science and engineering students. It is reasonable to assume that students outside the science and engineering areas, whom have weaker technical backgrounds in general, may require more study hours to master the technical skills.

Overall, students provided very positive comments on their 3D printing technology learning experience under the piloted pedagogical model. They have learnt to use the technology in a relatively short period of time with good results. It is believed that the collaborative learning approach helped students in learning the new technology effectively. The complex 3D printing learning task, for intellectual skill, was introduced to students in a teaching sequence corresponded to the well-established Nine Instructional Events proven to be successful. A portion of the learning steps in the model relied on student's ability in self-learning and their own initiatives to seek assistance; at the same time, this approach provided the flexibility for students with lower level of technological literacy to catch up and mastery the skills. Nevertheless, students' own learning motivation and willingness in spending efforts in learning were always the vital keys for their successes, and the piloted model provided a good and supportive learning environment for them.

The piloted pedagogical model essentially provided structured instructional steps that can be easily adopted to different settings and course contents. It provided a practical solution to scale up the technology adoption in a large class, by using the collaborative learning approach, forming teams and relying on batch printing, and handled the teaching challenge of having students with diverse backgrounds through the self-learning and mastery learning approaches. The instructional steps of the model helped students to clearly identify their objectives and guided them to reach the learning outcomes step-by-step.

VII. CONCLUSIONS AND FUTURE WORK

A seven-step pedagogical model for introducing 3D printing technology based on the classic instructional design theory, the Conditions of Learning, was developed. The model adopted the collaborating learning, self-learning and mastery learning approaches to tackle the two major practical issues, students with different levels of technological literacy and low 3D printer throughput. The pedagogical model was applied to a freshman level General Education course for two years. Students' feedbacks were analyzed and the results shown that the model has supported the development of their creative ideas with good learning and usage experiences. However,

students had different perspectives on workload in learning the technology.

To further study the effectiveness of the pedagogical model across disciplines, courses in different subject areas should be considered. Comparison of results from different General Education and major courses can reveal the disciplinary dependency of the model. Furthermore, student profile has not been considered in the current study, it is valuable to evaluate whether the model has the same pedagogical effect to all students in terms of gender, major and level of study in the future.

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Outcomes of Accepting or Declining Advanced Placement Calculus Credit

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Abstract— Students who qualify for Calculus credit via the Advanced Placement (AP) exam often have the choice of accepting the credit, and starting in Calculus II or III, or declining the credit, and retaking Calculus I in a university setting. This study investigates and reports success metrics for students who make a choice of accepting or declining AP Calculus credit. The 2014 College Board National Report states when compared to similar peers, students who receive a score of 3 or higher in an AP exam tend to earn higher college grade point averages (GPAs), have higher graduation rates, and have the opportunity to take more discipline course work in college. This report is based on all the AP courses offered by College Board. It is not certain what the outcomes are for an individual course, i.e. AP Calculus, or how the markers of success translate to engineering students and engineering programs. By analyzing 3,600 engineering students academic records from Fall 2012 and 2013 (i.e. gender, ethnicity, residency, grade received in Calculus I course, AP Calculus exam score, High School GPA, SAT/ACT Math and Verbal score), this study seeks to describe patterns of success in students' subsequent Calculus courses from those who accepted AP Calculus credit, skipping Calculus I, as opposed to those who did not accept their AP Calculus credit and took Calculus I. Students ask for recommendations from their first year engineering advisors on whether to retake Calculus I in college or accept their AP Calculus credit, which consists of a score of 4 or 5 at this university. As research in this specific topic is absent, advisors in a first year engineering program must advise in the absence of concrete data. This paper offers insight based upon previous student academic records, which may inform advisors and incoming first year students on whether or not to accept AP Calculus credit.

Keywords—Engineering Education; mathematics; calculus; engineering students; qualifications

I. INTRODUCTION

While much research has been done showing who has access to Advanced Placement (AP) Calculus classes and the benefits associated with enrolling in them [1][2][3][4], little research has been done to look at the consequences of the choice to accept or decline credit for one or more calculus classes for those who qualify. Some of these students retake the course they received credit for, whereas others move on to the next course in sequence. Typically, incoming students seek counsel from their advisors on whether to retake Calculus I in college or accept their AP Calculus AB credit. University policies vary in what AP score qualifies a student to receive college credit- many offer credit for a score of 3 or higher

[5][6], whereas more selective institutions require a score of 4 or 5, or do not offer credit based on the AP at all [7]. Currently, advisors in the FYE program at Purdue University offer advice based on anecdotes and prior experience with students. This study seeks to identify key factors that may predict students' success in the first Calculus course by analyzing 3,600 engineering students academic records, some of whom accepted AP Calculus AB credit, skipping the introductory Calculus course, while others did not accept it and took the introductory course. We studied academic records for the Fall 2012 and Fall 2013 cohorts of First-Year Engineering students who enroll at Purdue University who qualify for credit in either Calculus I or both Calculus I & II. The data drawn from academic records includes gender, ethnicity, residency, AP Calculus exam score, high school GPA, SAT math and verbal scores, first math course taken at Purdue, and the grade received in that course. These data were chosen for their relevance in observing any racial or gender biases in advising or outcomes and based on relevance of these variables in earlier studies [8][9][10]. By evaluating these data from First-Year Engineering students, we hope to better equip advisors to inform incoming students about whether they should accept or reject the AP Calculus credit for which they qualify.

II. BACKGROUND

Previous research highlights the significant impact AP courses have on a student's academic trajectory (i.e. college grade point average and graduation rates) by focusing only on students who accepted their AP credits [1]. There has been little research focused on the outcome of students who reject AP credits and retake the introductory course.

Research has shown that students who take AP courses in high school have an academic advantage over those who do not [2][11][12]. In the admissions process, universities have traditionally used Advanced Placement (AP) courses as determining factors for academic success. The 2014 College Board National Report states that when compared to similar peers, students who receive a score of 3 or higher on an AP exam tend to earn higher college grade point averages (GPAs), have higher graduation rates, and have the opportunity to take more discipline course work in college [4]. The Advanced Placement Calculus AB curriculum in high school is designed to be equivalent to a first-semester college course. A student passing the AP Calculus AB exam with a score of three or higher is considered to be capable of passing Calculus I as a college freshman[13]. When compared to non-AP students,

those who scored a 3 or higher perform better in college courses within their disciplines as opposed to those who took introductory courses[13] . Yet the report does not separate AP courses, rather it pertains to AP courses and test scores in the aggregate. A longitudinal study conducted on students with AP credits at Georgia Tech revealed an association between AP score, college GPA, and graduation rate. Across the cohort of students being studied, those who did not complete any AP exams graduated at a rate of 72.7 percent, while the graduation rate increased 8.9 percentage points for students who took one or more AP exams regardless of scores [14].

First semester GPA has been shown to be a good predictor of graduation success. Budny, et al. concluded that for engineering students, the first semester math grade can be used as a predictor of graduation success, in place of the entire first semester GPA [15]. Therefore, placing students in the correct first math course may be critical to their success. This study will look at what the best placement is for a student to be successful in their first math class while obtaining as much college credit upon arrival as is prudent to accept.

III. DESCRIPTIVE STATISTICS

A. Eligibility to Receive Credit

Data from two Fall cohorts (Fall 2012 and Fall 2013) of incoming First-Year Engineering students were collected. This data included both performance and demographic data. Race/ethnicity, gender, and residency were demographic factors, and high school GPA, SAT scores (verbal and math), AP Calculus AB or BC scores, and grade in first math class taken were performance data. Of the approximately 2800 students entering in Fall of 2012 and 2013, just over 1300 had received a 4 or higher on the AP Calculus AB or BC test, giving them a choice on whether or not to accept college credit for their AP score. Breakdowns of these scores by gender are shown in Figures 1 and 2.

As seen in the graphs, gender differences are slight. Females appear to have more scores in the lower AB and BC levels compared to males. When a t-test was run, the difference in means was significant, but with only a 0.37 difference in the actual mean AP scores. Means for both male and female were between 4 and 5, using a scale from 1-7 with values of 6 and 7 representing BC scores 4 and 5. An F test was done and showed no difference in variances for the two samples. A proportion test on the two distributions showed no significant difference.

B. Choosing to Receive Credit

We next looked at the choices made by the students as to whether or not to accept the AP credit received. At Purdue, credit for Calculus I or II is only given for a score of 4 or 5. Scoring a 4 or 5 on the AP AB test gives a student possible credit for Calculus I. For a 4 or 5 on the AP BC test, students

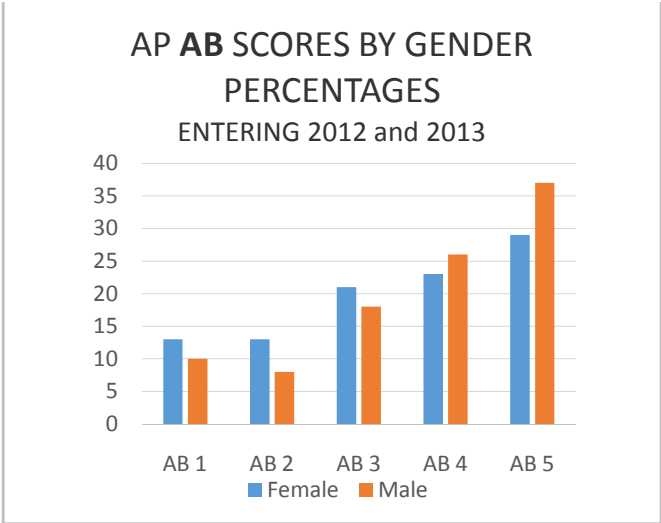


Fig. 1. AP Calculus AB Scores by Gender, Fall 2012 and 2013

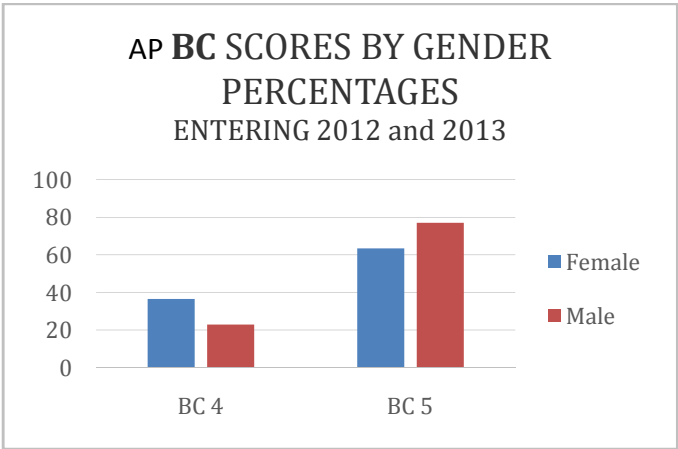


Fig. 2. AP Calculus BC Scores by Gender, Fall 2012 and 2013

can receive credit for both Calculus I and Calculus II, if desired. Those who took the AP BC test also receive an AB subscore. A 4 or 5 on this subscore will allow them to receive credit for Calculus I. Table 1 shows the breakdown of how potential credit was chosen for those students entering in the fall of 2012 and 2013 aggregated, disaggregated by AP score. The data are further disaggregated by gender and race/ethnicity. White and international students were aggregated as these populations tend to be privileged. Black and Hispanic students were aggregated as underrepresented minorities for comparison purposes. Due to low numbers, American Indian/Alaskan Native, Native Hawaiian/Other Pacific Islander, 2 or more races, and unknown groups were not included in the breakout groups. Asian populations were not used in either breakout category.

TABLE I. CHOICE BY AP SCORE FOR ENTERING 2012 AND 2013

# STUDENTS	NO CREDIT TAKEN	HALF CREDIT TAKEN	ALL CREDIT TAKEN
BC 5	25 (6%)	94 (24%)	268 (70%)
WHITE/INT'L Female	4	18	41
BLACK/HISP. Female	2	2	1
WHITE/INT'L Male	14	60	171
BLACK/ HISP. Male	2	4	11
BC 4	14 (10%)	73 (54%)	49 (36%)
WHITE/INT'L Female	2	19	14
BLACK/HISP. Female	0	1	0
WHITE/INT'L Male	9	39	25
BLACK/ HISP. Male	0	2	2
AB 5	86 (30%)	----	201 (70%)
WHITE/INT'L Female	29	----	63
BLACK/HISP. Female	0	----	0
WHITE/INT'L Male	94	----	223
BLACK/ HISP. Male	1	----	11
AB 4	169 (50%)	----	171 (50%)
WHITE/INT'L Female	42	----	35
BLACK/HISP. Female	0	----	1
WHITE/INT'L Male	108	----	108
BLACK/ HISP. Male	5	----	4

The column for 'half credit taken' only applies to students who had BC scores of 4 or 5. They had the choice to either take credit for both calculus classes, just one class, and no credit at all.

For students who received a score of 5 on the BC test, credit for both Calculus I and II was available. Overall, close to 70 percent of those students took credit for both courses and started in Calculus III at the university. Of the remaining 30 percent, only 6 percent chose to retake both courses in the university and not receive any credit for math. These ratios are also seen in the gender and race splits, with the exception of black/Hispanic females. For this group, only 20 percent took the credit and the remainder was split evenly between no credit and half credit. Although the sample size is small, this might be explained by the fact that this group is the minority group in both race/ethnicity and gender, and therefore may have less confidence in their ability to succeed at the university level (regardless of their actual ability to succeed).

Students who received a 4 on the BC test also had the choice of taking all, half, or none of the credit afforded them by their AP score. For this group overall, the majority (54 percent) chose to only take half of the credit offered. Just over a third chose to take all of the credit, and similar to BC 5, only 10 percent started out in Calculus I, not accepting any credit. Due to the fact that these students did not score the maximum on the BC test, they may have felt that they should not accept all the credit but start in a class that would partially be a review

for them. The only subgroup not following this breakdown were the Black/Hispanic males. Everyone in that group took at least some of the credit offered. The sample size was small, so it is difficult to assert that this represents a general trend in those populations.

Students receiving the highest possible score on the AB test followed a similar path to the BC 5 students. Two-thirds chose to take the credit for Calculus I and start in Calculus II, with one-third repeating the Calculus I course. These students did not have the choice to only take half of the credit. Considering that they received the highest score possible on the test, it is again reasonable that the majority chose to take the credit instead of repeating the course. The one subgroup who didn't follow this split was again the black/Hispanic males. A full 92 percent of this group took the credit for Calculus I, with only one student retaking Calculus I. Given the fact that this subgroup is more likely to be socioeconomically disadvantaged, the decision could in part have been made with financial reasons involved. As there were no black/Hispanic females to compare the trend with, this is only a possible idea to explain the discrepancy.

As with students receiving a 4 on the BC test, students who received a 4 on the AB test were a bit less likely to take the credit with half choosing to take the credit and half deciding to retake the class. The white/int'l females were a bit less likely to take the credit, again possibly due to confidence.

C. Grades in First Math Class

After looking into the choices made by the students, we looked at the grades received in the first math class taken at the university. As mentioned earlier, grade in the first math class correlates with student graduation, therefore it is important that a student does well in that first class. After the choice was made by the student, grades in the first math class are shown in Figures 3 through Figure 7 below for each group of students that had a choice to make.

Figure 3 shows the grade distribution of Calculus 1 grades for students who either did not take the AP Calculus exam or did not earn a 4 or 5 on the exam. All of these students were required to begin in Calculus 1. The average grade for these students was a 2.44 (C) and the median score was a 2.3.

As would be expected, students who came in with credit for both Calculus I and II by receiving a 4 or 5 on the BC test, performed well at all levels, whether retaking the class or accepting the credit and moving on. Very few of these students earned grades below a C- , the minimum grade to proceed in the math sequence and the first-year engineering curriculum. Based only on this descriptive data and given the fact that students who scored a 4 or 5 on the BC test did well in whichever math class they decided to begin in, it would be safe to tell students who make a 4 or 5 on the BC test to take all of the credit for which they are eligible, unless there are mitigating circumstances. The fraction of students earning each grade does not seem to be a function of whether half or all eligible credit is accepted. If these students are particularly concerned about earning a high grade in their first math course, the grade distribution for the students in this group that accept no credit is particularly favorable.

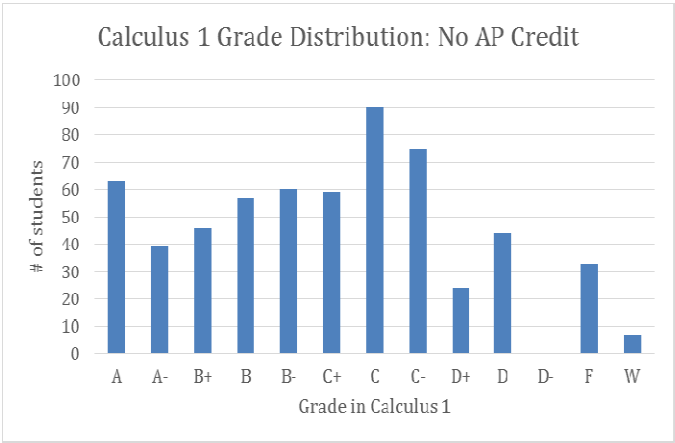


Fig. 3. Grades in first calculus class for students without AP Calculus credit (Fall 2012 & 2013)

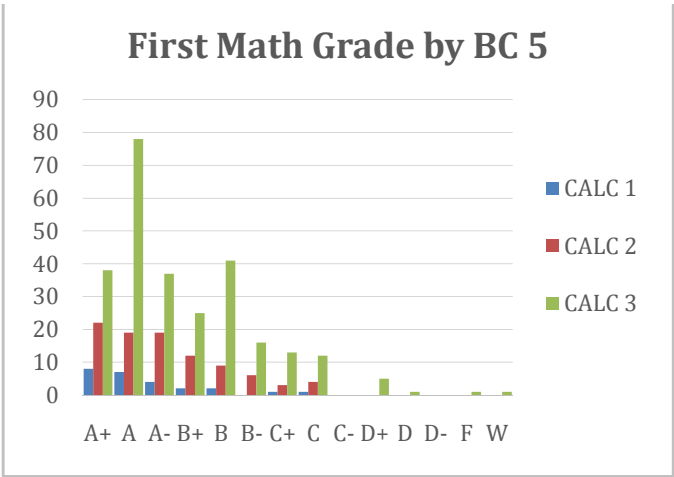


Fig. 4. Grades in first calculus class for students with a BC score 5 (Fall 2012 & 2013)

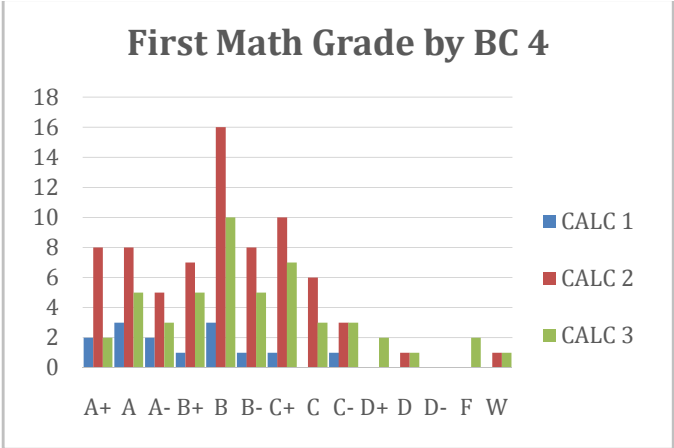


Fig. 5. Grades in first calculus class for students with a BC score 4 (Fall 2012 & 2013)

For students earning a 4 or 5 on the AB test had the choice to start in Calculus II or retake Calculus I. The data as shown in the graph below for students with an AB 5 score appears to a distribution that favors high grades in Calculus I, whereas the distribution of grades in Calculus II appears to be a normal distribution centered on a grade of B. Therefore, accepting the credit would seem to be reasonable in the absence of mitigating circumstances for students most concerned with making forward progress, whereas students concerned about maintaining a high GPA should be advised to retake Calculus I. The importance of the grade in the first math course documented in the literature may support the latter recommendation to retake Calculus I even for students with an AB score of 5. There is very little likelihood of receiving below a C- in Calculus II.

IV. REGRESSION ANALYSIS

A. Predicting the Choice to Accept Credit

SAS 9.4 was used to run systematic, stepwise regression analysis on the data. The first analysis was designed to identify factors affecting the choice made by the students to accept or decline AP credit for calculus. For entering and exiting variables, a significance level of 0.15 was used in the model. Research has shown this to be the best level for identifying and retaining significant covariates in regression [16]. For students who scored a 4 on the AP AB test, the significant factors were high school GPA ($p=.0567$) and verbal SAT score ($p=.0837$). Yet these two factors explain only 3 percent of the variation in choice and no other factors were significant. The relevant factors were different for students who scored a 5 on the AB test. Here, the only significant factor in their decision was their math SAT score ($p=.1406$). Again, the explanatory power was low; less than 1 percent of the variation was explained.

For BC students who scored a 4, the only significant factor in the choice was gender ($p=.1313$), explaining 3 percent of the variation. While this might be explained by research that women are less confident in math than men [17][18], this same effect was not found for students with an AB score of 4. Finally, for students who scored the highest possible score of 5 on the AP BC exam, the significant factors in their decision on how much credit to accept proved to be high school GPA ($p=.0088$) and math SAT score ($p=.0220$), explaining only 4 percent of the variation. This last relationship seems to indicate that the highest academic performers accept the credit and students whose GPAs and math SAT scores are lower are more likely to choose to retake at least one Calculus course.

The regression was run again, pooling the data and treating AP score as a continuous variable. The model for choice included two significant factors. These were AP score ($p<0.0001$) and math SAT score ($p=0.0015$). These two factors accounted for 7.5 percent of the variance in choice.

B. Predicting the Grade in the First Math Class

Next, another systematic stepwise regression analysis modeled the grade in the first math class, using the same factors used earlier but adding choice (all, half, or none) as a new factor in the regression (with values of 0, 1, and 2). At first the regression was separated by first calculus class taken, and then the data was pooled into one group. For Calculus I, the factors affecting the math grade were AP score ($p<0.0001$), math SAT score ($p=0.0166$), and gender ($p=0.0297$). All of these factors were significant and together accounted for almost 11 percent of the variation in math grade.

For grades in Calculus II, gender dropped from the model but choice was significant. The significant factors were choice ($p=0.0479$), AP score ($p<0.0001$), and math SAT score ($p=0.0001$). These three factors together accounted for 12.5 percent of the variation in grade in Calculus II.

Grades in Calculus III were significantly affected by AP score ($p=0.0115$) and math SAT score ($p=0.0012$), consistent with the high-performing factors affecting the choice to accept credit for Calculus II. These two factors accounted for 9 percent of the grade variation.

First Math Grade by AB 5

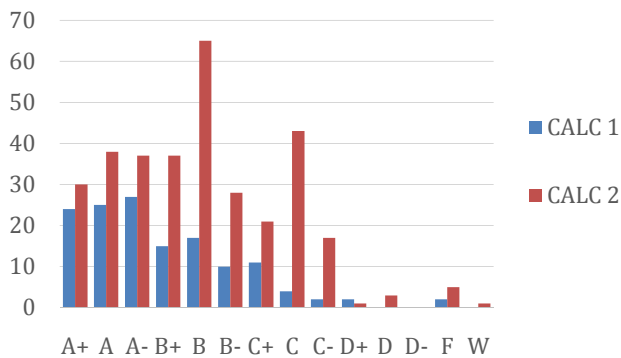


Fig. 6. Grades in first calculus class for students with an AB score 5 (Fall 2012 and 2013)

First Math Grade by AB 4

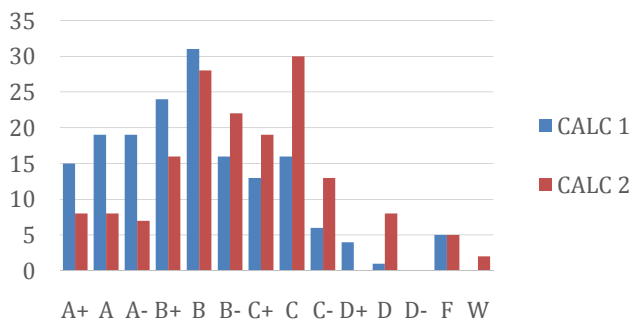


Fig. 7. Grades in first calculus class for students with an AB score 4 (Fall 2012 and 2013)

For students who received a 4 on the AB test, the choice was split evenly between whether or not to take the credit for Calculus I. The grade distributions for these students are shown in Figure 6. At this level of AP, both grade distributions are normal, but the average grade is a bit lower for students. This may suggest that AB students who retake Calculus I are overconfident and underperform their ability, resulting in a grade distribution that is very similar to students who take Calculus II. Thus, the advising in this case might be that students who retake Calculus I should be cautioned to complete all their work and study to ensure they receive a higher grade. Students who are either focused on making rapid progress toward their degree or who will not keep up with the work if they are not challenged should proceed into Calculus II. Particularly because this choice seems ambiguous, we looked closer into all the student factors we had to see if there were any statistically significant factors that may affect the math grade based upon a student's choice.

When the data were pooled and calculus level was coded as an independent variable, the model for grade in the first math class had three significant factors: AP score ($p < 0.0001$), math SAT score ($p < 0.0001$), and calculus level ($p < 0.0001$). All three of these factors were significant and together explained over 12.5 percent of the variation in math grade. Whereas AP score and math SAT score correlate positively with math grade, Calculus level has a negative correlation. The parameter estimate for calculus level was -0.3139, so for every increase in calculus level, students would expect to see their grade lowered by 0.3 of a letter grade. All other factors in every model run were positively correlated with both choice and math grade.

V. CONCLUSIONS

Females tended to have slightly lower scores on the AP Calculus test, which may be due to self-efficacy and confidence issues more than ability issues. When looking at the choices made by the students to accept or decline the AP credit for which they qualified, 70 percent of students who earned the top BC score of 5 chose to receive all credit for which they qualified. The only exceptions to this trend came for the black/Hispanic females who received a BC 5. Only 20 percent of them accepted full credit, with 40% taking half credit. This may again be a result of confidence issues for females, but more research needs to be done to back up that claim. For black/Hispanic males who scored an AB 5, 92 percent chose to receive full credit, as compared to 70 percent overall. This choice may be the result of socioeconomic factors, but more research would need to be done on this issue.

For students who scored a 4 on either the AB or BC test, the percentages who chose to accept all credit declined to around 50 percent. It may be that the fact that they didn't earn the top grade kept them from accepting full credit, thinking they still needed to learn some of the material.

The effect of the choice made was shown in graphs of grades in the first math class taken. For students who received a 4 or 5 on the BC test, the grades in calculus 2 and 3 were equivalent. Taking all of the qualifying credit would appear to be advantageous. Students who received the top AB score did well in either class but if a student needs to keep a high GPA, retaking Calculus I gives them a better chance at an A. There is little chance they would not receive credit for Calculus II if they enrolled, however. For students who received an AB 4, the chance of receiving a D or F in Calculus II goes up, but the grades in Calculus I are also lower than might be expected for a student who could have accepted credit for it. Overconfidence or boredom may come into play in this case.

Regression analysis was run to find the significant factors in both choice and in math grade. The math SAT was a significant factor for students who scored a 5 on either AB or BC. Choice was affected by different factors for those who received a score of 4. For BC 4 students, gender was significant as was mentioned earlier with the black/Hispanic female population. For AB 4 students both GPA and SAT verbal were significant. This may be representative of harder working students who believed that their hard work would allow them to succeed in an upper level course.

When the regression analysis was run with math grade as the dependent variable, AP score was a significant factor in all three calculus levels. The SAT math score was also significant for those who took Calculus I or II. Choice was significant only for those who started in Calculus II, and gender was a significant factor only in those who chose to retake Calculus I. Advisors should use this information to especially help students who are thinking of beginning in Calculus II as that appears to be the place where lower grades have been earned.

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TecEval: An on-line dynamic evaluation system for engineering courses available for web browsers and tablets

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Abstract— The assessment process *in* engineering courses is an arduous task. It requires a lot of effort from teachers. In Mathematics and Physics courses, there are additional issues related to the evaluation of questions with numerical and symbolic answers. In this project, an on-line dynamic assessment system called *TecEval* was developed. It is a web platform that can be accessed via desktop and mobile browsers. This system enables the management of mathematical equations, and it can randomize the order of the questions and the values of the coefficients in them within certain parameters. Consequently, every student will have to answer a different test every time he/she uses the platform. *TecEval* allows professors to generate dynamic tests for engineering courses, which are graded automatically. *TecEval* can create tests with 4 types of questions: i) numerical questions, where the answer is a predetermined number, ii) multiple choice questions (including multiple answers), iii) dynamic questions, where the response is based on a equation, and iv) dynamic-equation questions, where the response is a mathematical equation that may contain dynamic variables. During the evaluation process *TecEval* performed successfully with students and it obtained positive comments from surveys applied to professors.

Keywords— *Assessment process, eLearning tests, Online evaluation, Object oriented Architecture, Virtual learning environments.*

I. INTRODUCTION

Thanks to the development of technology, it is more frequent to find tests or exams that are applied on computers or mobile devices. In this kind of exams, it is common to find question catalogues with static questions and static answers, mostly with multiple choices. Although in some occasions the question order can change each time the exam is opened, static question catalogues makes student evaluation more difficult to determine. The main issue with this static catalogue is that the student knowledge is not always congruent with the grade generated by the system. This is caused by a variety of reasons. One of them is that students can get the right answers by using

a trial-error method (after several attempts to answer), or the presented question has been seen before and the answer is already known (even without knowing the justification for it) [1].

In Mathematics and Physics this problem is even greater due to numerical and symbolic resolution in problems. Questions with multiple choices also have the inconvenient that the student might choose the correct answer by guessing, without following the appropriate procedure to solve the problem.

To overcome these difficulties, this paper proposes the development of an online dynamic evaluation system that provides suitable handling of mathematical equations. In this system the order of questions changes each time an exam is presented and the equation coefficients may also change according to certain parameters, in such a way that each student has a different exam each time he/she accesses the system.

The main goal of this project is therefore to design an online system, called *TecEval*, which allows:

- Elaborating, managing and applying different kinds of questions that can be graded automatically in exams, including open questions.
- Making the writing of mathematical symbols easier.
- Including dynamic questions (algorithmically).
- Generating statistics for the teacher and for the system improvement.

In addition, the system has to be Mobile/tablet friendly and compatible with Android or iOS.

This project is innovative because it permits accessing the resources (questions and exams) not only from a computer, but also from mobile devices with the most common operative

systems. On the other hand, *TecEval* considers both content management by the teacher and statistical analysis of the content use by the students (few current systems offer this last functionality). This feature can help teachers to adjust their contents based on students' performance and necessities that may appear. *TecEval* uses trees for the computational representation of mathematical expressions [2].

II. RELATED WORK

As related work, four commercial tools were analyzed.

- A. *MyMathLab* [3]. This is an application developed by *Pearson Publishing*. This tool provides students additional online resources to improve their learning, but questions and materials are restricted only to textbook content. There is functionality so that the teacher can create their own independent resources. However, the price of the license is already included in the cost of the textbook, i.e. when a textbook is purchased, it contains an access code to create an account on the Web application.
- B. *Aleks*[4]. This application was developed by McGraw Hill. The content of materials ranges from elementary mathematical concepts to advanced undergraduate topics. It provides different types of feedback (hints and explanations). *Aleks* has an interesting feature that provides practice exercises in the application. The functionality is called "worksheets", which generates a pdf for printing with a series of exercises. *Aleks* is a robust application to practice and learn mathematical themes. However, this system does not include sophisticated assessment tools and lacks an appropriate functionality for the teacher, because their approach is to link it to other products (textbooks) where the main goal is learning, not assessing.
- C. *Hawkes* [5]. *Hawkes* is a desktop tool that runs on Windows platforms and for some courses on Mac platform. *Hawkes* was developed by the company *Hawkes Learning Systems*. Although this platform has no graphical tools it provides appropriate calculation tools and functionality to display answers in the form of equations. *Hawkes* presents on its web page a case study with 14 US universities, where a improvement in students' grades, savings in the cost of the course, and a study on the relation between classwork and work time out of class are reported.

- D. *ReadyMath* [6]. The *ReadyMath* application was developed by *iLearn* and *Ed2Go* companies and it is only available in English. The focus of this application is to support mathematics learning for undergraduate students. If a question is not answered correctly the system provides students an easier question. On the other hand, if the question has been answered correctly *ReadyMath* delivers a question with a higher difficulty level. The application displays immediate feedback to students showing the correct solution for wrong answers.

Additionally, it is also convenient to mention that some major publishers have provided robust online systems to their textbooks in order to enrich their learning resources. Most of them include tools to assess and give online feedback to students and to deliver performance statistics for teachers. Examples are: *Connect*, *WebAssign*, *MasteringPhysics* and *CengageNOW*, among others ([7], [8], [9], [10]). Nevertheless, the formats or syntaxes provided to write mathematical equations are usually rather limited, so students have first to learn how to write down their results in the system before solving the problem. Therefore, it can happen that even if the answer is mathematically correct, the system considers it as wrong. This could produce an unwanted and counterproductive effect on students, who could become confused and disappointed because they do not can find the origin of their mistakes.

Due to the fact that the main objective of the commercial tools or systems presented above is to support learning themes contained in the textbooks provided by these editorials, they do not include functionality for student assessment or only provide rather basic versions to this purpose. Nor are teachers allowed to create their own questions that are aligned to the particular curriculum or knowledge they want to evaluate. On the other hand, these systems do not always provide functionality to create diverse kinds of questions that teachers consider the most appropriate (multiple choice, open, etc.).

III. PROCESS

The development of the project was divided into 6 big steps, shown in figure 1: 1) definition of the characteristics and requirements of the system, 2) development of the system software, 3) elaboration of questions of diverse types, 4) testing of the system with teachers and students, 5) results gathering and analysis, and 6) discussion and conclusions.

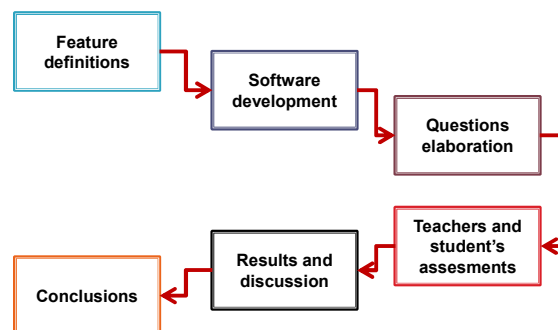


Figure 1. Main Phases of the project

A. Definition of TecEval's features

To define the characteristics and requirements of the system, several work sessions with expert teachers on Mathematics and Physics were organized. The main characteristics that were identified in these meetings are described next.

Services

It was defined that the system had to provide services to four types or main users:

- *Administrator*
- *User teacher*
- *Author teacher*
- *Student*

The *Administrator* takes care of the basic catalogues and information of the academic department (School, departments, semesters, assignments, topics, teachers and groups), and also of the security module for access control.

The *User teacher* functionality includes the management of his/her account to modify data, create exams, reopen exams and obtain reports.

The *Author teacher* has the option to add more questions, sections and themes to the course, in addition to the functionality of a User Teacher.

The *Student* has the functionality to select an exam already created, configured and activated by the teacher, to answer questions and to consult grades from current and past academic terms.

Types of questions

It was requested that *TecEval* should be able to create the following types of questions.

1. **Numerical questions:** This refers to questions whose answer is a number that is calculated from a specific formula, and lies within a given range of values.
2. **Multiple choice questions:** This refers to questions where the right answer or answers must be selected from multiple options. These options are provided when the question is designed. The question may have more than one correct answer. In this later case the level of difficulty of the question increases.
3. **Dynamic questions:** This refers to questions that depend on a formula whose variables can take values within certain specific ranges. In this way, each time a user solves a problem the value or values of the question change in a dynamic way within the specific range, although the formula for the general solution remains the same.
4. **Dynamic-equation questions:** This refers to questions whose answer is a mathematical equation. It has the additional possibility of posing questions including variables that can take values in certain ranges. These variables can change

dynamically. This possibility includes up to four dynamic variables.

A very important requisite of the system is that it has to be capable of grading questions of any kind automatically. Nevertheless, it also includes the option of allowing the teacher to manually grade questions whenever he/she may consider there were other possible answers.

Tools for representing equations

It was identified the necessity of having a tool to represent mathematical equations in two ways:

- A. Visual representation: It was required a visual representation of the equation for Web and tablets in a clear and elegant way, as shown in Figure 2. A control was defined that would allow teachers and students to write equations from a web browser (Desktop and tablets) [11]

$$\int_1^3 \sqrt{\frac{2x^9+1}{x^2+9}} dx \quad (1)$$

Figure 2. Example of the representation of a complex equation.

- B. Computational representation: In mathematical equations there is a problem when there are multiple equivalent ways of representing the same answer. For example: $3x + 2$ equals $2 + 3x$. Therefore, it has been established the necessity of generating a tree for the equation based on a lexicographic analyzer (it is a program that receives as input the source of another program (string) code and produces an output consisting of tokens or symbols), with the following rules:

- The priority order for basic operations is: addition, subtraction, multiplication and division.
- Fractions are transformed into divisions.
- Parenthesis, braces and brackets are deleted, and when appropriate, they're expressed in a multiplication form.

B. Software Development

During the investigation process to develop a computational platform for the automatic evaluation of exams, using the requirements described before, several difficulties and challenges were found. Among them the following are distinguished:

- a) *The functionality to evaluate automatically questions for Physics and Mathematics assignments.* In the case of

Physics a parser had to be used to allow answer computing based on formulas created by the teacher, which contains dynamic variables that change for each student. In the case of Mathematics the system should evaluate if a mathematical expression corresponds to a correct or to an incorrect answer.

b) *The challenge of creating a scalable platform that could be used from desktop computers, tablets, and/or a web browser.*

c) *The development of user-interfaces that are attractive to students and teachers alike.* They are interfaces designed to allow writing mathematical symbols in a practical form. Instructors can create questions and exams easily. The format for students is equally easy to use. The system can be used in both web and Android and iOS tablets.

TecEval's Platform consists of 3 main components (Fig. 3):

- Core:* Shared classes generated with EMF on Rails and Database
- Service Providers:* Spring MVC Web application and Service Server where all functionality and business rules exists.
- Clients:* Web and mobile browser using the services and business rules from the Service Server. Only UI/UX functionality exists here. More clients can be added over time.

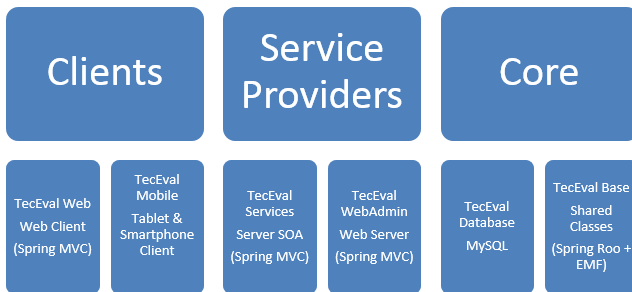


Figure 3. *TecEval's platform components.*

One of the core processes in *TecEval* is to get a mathematical expression from a web control and to save it as a tree data structure [11]. The process is done following the steps (Fig 4):

- Enter the mathematical expression in the web application.*
- Using Javascript the expression and the image of the expression are sent to TecEvalServices.*
- The image is saved in the server.*
- The expression is translated to MathML.*
- The MathML expression is translated in a tree.*
- The tree is saved to the database.*

The tools, models and technologies used in the development of *TecEval* were: Modelling with Unified Modelling Language (UML), Object-oriented language (Java) in a Service Oriented Architecture (SOA), EMF on Rails,

Spring MVC, Security Aspects, Web Technologies (HTML5, CSS, Javascript + JQuery), MathML, Mathematical Equations representation trees and regular expressions.

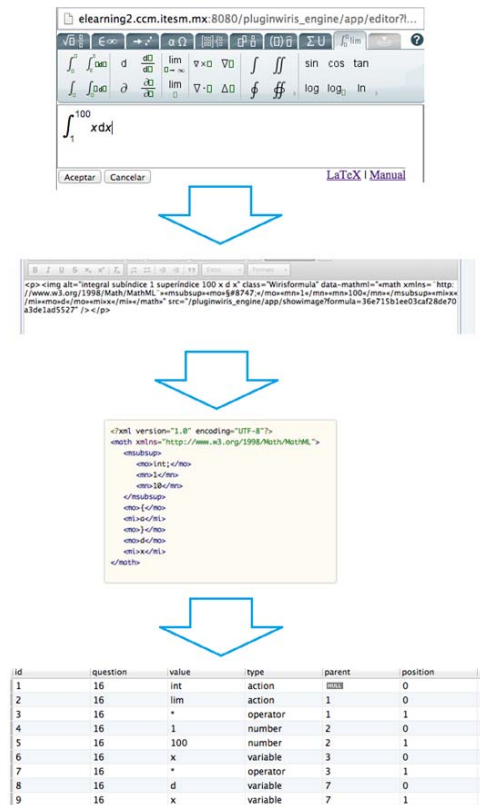


Figure 4. Workflow of a simple equation from the web application to the database.

Finally *TecEval* Services implements a 3-way security system to avoid reading or saving questions and answers without authorization [12].

IV. *TECEVAL* MAIN INTERFACES

The main interfaces of *TecEval* are presented next.

A. SYSTEM ACCESS

Students and teachers can access the system in the site (Fig. 5): <http://elnovus.ccm.itesm.mx:8181/TecEval/>

Figure 5. System login interface

When entering the username and password, *TecEval* activates the allowed functionality that corresponds to the type of user.

B. ADMINISTRATOR INTERFACE

In Figure 6 the administrator user view is shown. The administrator controls the Access to users, in addition to the functionalities described in section III.

Figure 6. Administrator interface example

The administrator also has the functionality of updating (Adding, removing, changing, and consulting) the following catalogues: institutions, schools or divisions, departments, terms, assignments, topics and groups.

Additionally, the administrator is responsible for the security module with the following specific functionalities: creating new users with any role, blocking/unblocking user accesses, consulting user information (except their passwords), and activating/deactivating users.

C. QUESTION CREATION

As it was mentioned in section III, *TecEval* allows the creation of different types of questions. These are briefly described next.

Numerical questions. In these questions the result is a number. *TecEval* allows defining a value range for the correct answer. In figure 7 an example is shown.

Figure 7. Example of a numerical type question.

Multiple-choice questions. When designing a multiple-choice question there are two modalities: questions with just one right answer or questions with more than one right answer. The system indicates to users the corresponding modality: for the one right answer modality *TecEval* displays small empty circles preceding the question options, while for a question

with more than one right answer the system displays small squares. In figure 8 an example of this kind of question is shown.

Figure 8. Example of a multiple-choice question

Dynamic questions. This kind of questions is particularly useful for Physics-like problems, in which up to 4 parameters in a given formula change each time a student enters the system, displaying problems with different data. The parameters take values randomly within certain specified ranges and the answer is a numerical value. In figure 9 an example of this question is shown.

Figure 9. Example of a dynamic question.

Dynamic-equation questions. The answer for these questions is a mathematical equation. The system allows teachers and students to write mathematical symbols in an easy way. This is accomplished using the WIRIS equation editor [13]. Teachers may represent the answers up to three different ways and the system can grade them automatically. In this kind of questions it's possible to change up to 4 parameters, so they appear in a different way to each student each time an exam is presented. In Figure 10 an example is shown.

Figure 10. Example of a Dynamic-equation question.

D. EXAM CREATION

A model to facilitate the teacher the creation of exam was developed based on questions previously created by other teachers. Exams are organized by assignment and topic. The functionality is described below.

To create an exam its name, timespan to solve it, the corresponding course, and the topic(s) that the exam covers have to be defined. The teacher is allowed to define whether the student can see or not the correct answers at the end of the exam, the number of allowed attempts to solve it, and the question order. The teacher can also indicate some general instructions and select the appropriate questions the exam will contain. This selection can be done in several forms:

- From a tree of previously created questions, the root is taken to add questions and create the exam.
- From a list of questions previously created.
- The teacher can create questions during the allowed timespan assigned to solve the exam.
- The teacher can ask the system to randomly select questions previously created.

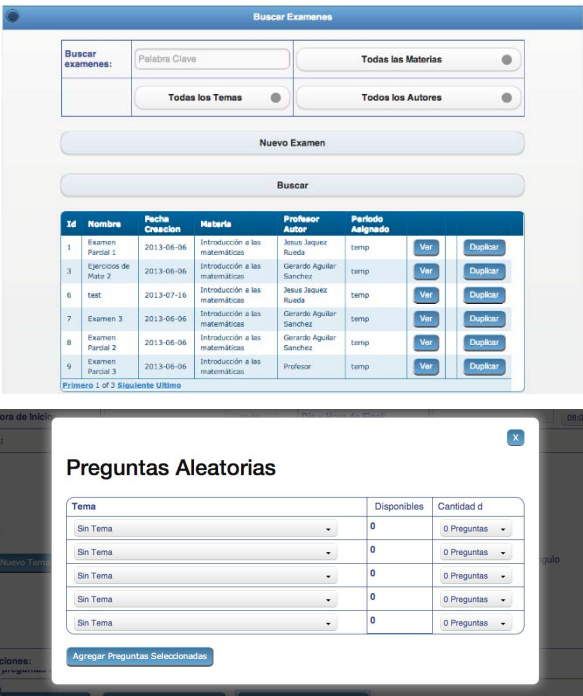


Figure 11. Example of an exam creation.

In Fig. 11 an example of an exam creation is shown.

The questions and exams created by a teacher can be shared with other colleagues. However a teacher cannot directly edit questions or exams created by another teacher in the main database. For this purpose, he/she should first create a copy of the selected resources in a new entry and afterwards edit and adequate them to his/her courses.

E. SOLVING EXAMS

To answer an exam, the student must enter the assignment section and select the exam that he/she has to solve. In the test *TecEval* displays the time given and the number of attempts that the student has to solve it. The student has the option to hide the chronometer during the exam. Due to the structure of *TecEval*, the writing of Mathematical symbols is simple for the student. In case of disconnection, the system registers the precise place where the student left the test at that moment, and *TecEval* will allow him/her to continue solving the exam just in that place. The interface for solving exams is illustrated in figure 12.

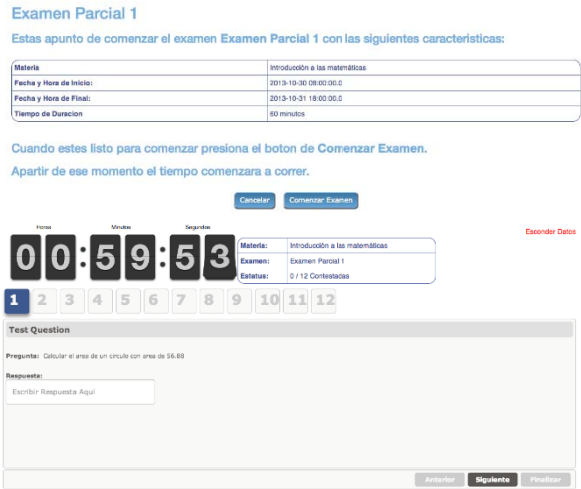


Figure 12. Student interface during an exam.

F. SCORES

The teacher can consult the students' grades by question, exam, group, student, or topic, as seen in figure 13. This allows them to provide appropriate feedback to students. On the other hand, the system also allows students to consult their performance immediately after completing the exam and check their grades in previous exams. Additionally, the head of the department can monitor student performance by assignment or group. All these reports can be downloaded in PDF format.

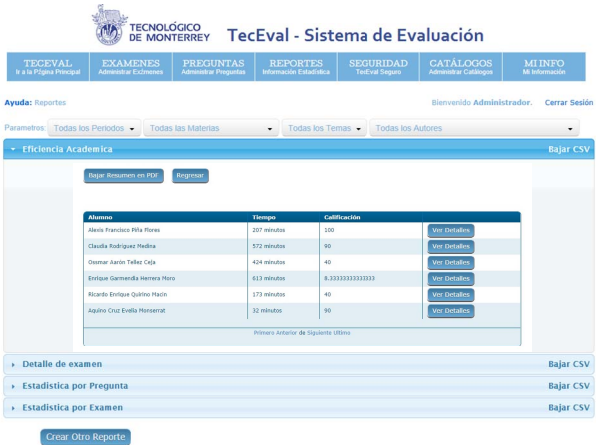


Figure 13. Example of the interface to consult grades

V. EVALUATION, RESULTS AND DISCUSSION

Testing sessions for the system were carried out during two weeks in the January-May 2014 term, where 9 teachers of Physics, Mathematics and Computing used the system in their courses. During this period some adjustments and improvements to *TecEval* emerged. In general, the perception on *TecEval* provided by teachers was good. Indeed, most professors found it easy to use this system (88%), and 89% of them felt that the system would be useful in their academic areas. On the other hand, 67% of them stated they would use *TecEval* in their courses, while the remaining 33% indicated that they would also use it once it incorporates some suggested modifications. Additionally, the results for specific questions of a survey applied to teachers regarding the functionality of the system are presented in Fig. 14.

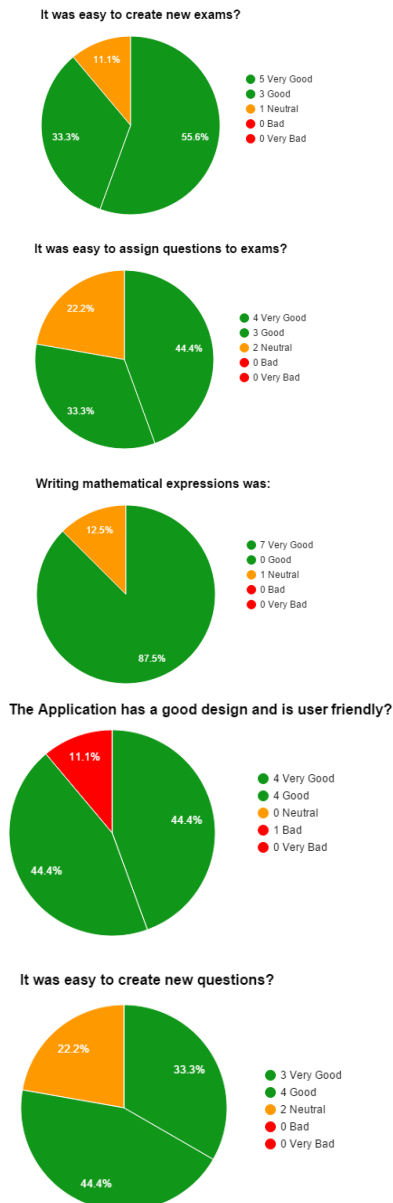


Figure 14. Results of the survey questionnaire applied to teachers

Tests were also conducted with 26 students of the Engineering area during the same term. Students worked in assignments of their courses using *TecEval*. After the assignment, they were asked to answer a survey questionnaire. The corresponding results are presented in figure 15. In general, the perception of the students was good: 62% said that it was easy to use the application, and 64% said that it was easy to do assignments and tests in *TecEval*. A comparison of opinions between doing exams in *TecEval* against doing them elsewhere resulted to be divided: 31% of the students think it is better, 31% think it is worse, and the remaining 38% had a neutral opinion. Finally, we found that 73% of the students and the teachers said that the platform has a nice design and it was easy to use, and some students even asked for a smartphone version of *TecEval*.

An additional feature of the system is the possibility of including open questions to be graded automatically. Although the kind of questions included so far in *TecEval* were designed for Mathematics and Physics, the system can also be adapted to be used in other disciplines.

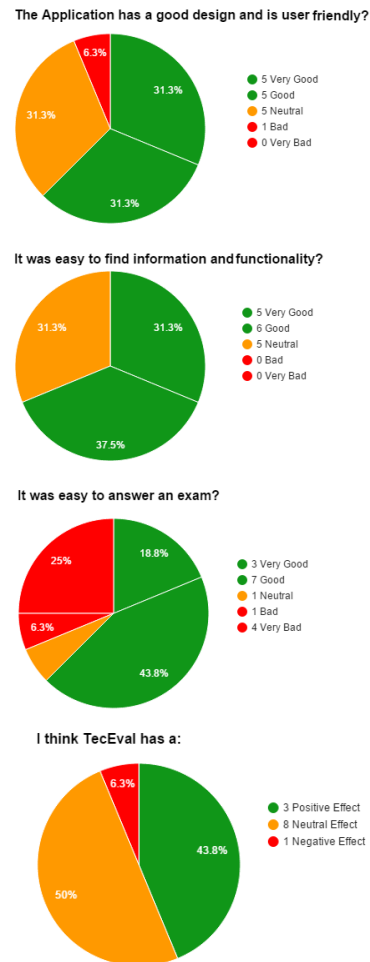


Figure 15. Results obtained in the students' perception questionnaire

Finally, the following points describe the main advantages and disadvantages of *TecEval*:

A. Advantages for teachers

Creation and management of appropriate questions and exams that correspond to specific curricular material. The teacher can add his own questions, share quizzes and questions with other teachers, and carry out analysis and evaluation of students' performance.

B. Advantages for students

It is an additional tool to self-evaluation for curricular material. Students can access the exams through mobile devices, with optimal security measures.

C. Possible disadvantages

Server failures would affect the presentation of the quizzes.

V. CONCLUSIONS

TecEval system allows the creation of diverse types of questions and tests in engineering areas that need an appropriate mathematical notation, in a simple way for the teacher. The system allows teachers to design their own questions according to the learning needs of their students. Writing mathematical symbols is simple for both teacher and students, even for complicated formulae and specialized mathematical symbols. The system also permits adding figures to complement the questions.

In a test of the system performance both, teachers and students, expressed a favorable opinion on the usability of *TecEval* when compared to other assessment systems.

Additionally, *TecEval* allows the collaboration and synergy between colleagues of the same or different areas, who can share both questions and exams. It has also a great flexibility in content management. An important feature of the system is that it can be accessed via web or from tablets. The system can deliver appropriate statistics that facilitate the administration of the course, and also can provide teachers and students with timely and group feedback. This feedback leads to a better learning of subject topics. Finally, it is important to note that *TecEval* also permits users to carry out searches by subject and

group. As future work, more tests of the system will be conducted with students and teachers of Mathematics and Physics courses in order to improve its performance.

VI. ACKNOWLEDGMENTS

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SEED-PA. A Practical Instrument for Assessing Individual Ethics Initiatives

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Abstract—This Work In Progress describes a NSF funded project to revise/simplify our research instruments used to measure ethical development of engineering undergraduates and make them useful for practical applications. Results of this project will provide a way for institutions, programs, and faculty to assess the impact of ethics initiatives at the, course, co-curricular, or single intervention level. As such, it has the potential to transform the way in which undergraduate engineering education is delivered by allowing individual institutions, programs, and faculty to assess and improve on their own ethics initiatives. In this paper we describe the method for reducing the full instrument to a more practical tool and initial steps at pilot testing.

Keywords—ethics, assessment, moral reasoning

I. INTRODUCTION (HEADING 1)

The work described in this paper is an outgrowth of the Survey of Engineering Ethical Development (SEED) project. Here we describe the refinement of the SEED survey to a tool that is more practical for use in assessing the impact of individual curricular or co-curricular interventions. Development of the SEED-PA (Survey of Engineering Ethical Development – Practical Assessment) is guided by four goals: Goal 1: create a practical instrument for assessing individual ethics initiatives (SEED-PA); Goal 2: use the SEED-PA to conduct four separate studies addressing important research questions and demonstrating the utility of the instrument; Goal 3: develop the SEED-PA User's Guide to assist in research design, administration, data analysis, and interpretation of results; Goal 4: broadly disseminate the SEED-PA instrument and the SEED-PA User's Guide.

To date, the researchers have created the SEED-PA (Goal 1) and pilot tested the instrument at our four institutions (Goal 2). The researchers have also begun to work on a User's Guide (Goal 3) including documenting the process for online administration, describing how the survey can be adjusted to measure what was taught in a course, and explaining how student data can be used to understand how students interpret faculty interventions. The researchers have also addressed limitations of what can be evaluated given that we are not using controlled experimental conditions in this analysis.

Overall, the SEED-PA will be a useful tool for assessing learning and evaluating innovations related to students' ethical development. The project spans multiple institutions and involves the creation and adaptation of an assessment tool that may contribute to our understanding of engineering students' ethical development. Thus, it will allow the researchers to learn how new strategies for ethics instruction are transferred to diverse settings and how they impact student learning. Finally, the researchers expect to bring about the widespread adoption and implementation of the SEED-PA. Thus, the user's guide will be designed in such a way to assist the community in transferring its use.

II. THE SEED INSTRUMENT AND THE SEED-PA

A. The SEED Instrument

The focus of the 2010 SEED study was to assess the state of ethical education in engineering programs nation-wide. Consequently, it included 227 items related to students' past and current experiences with ethics interventions in and out of

the classroom. Results from the SEED survey and the instrument have been published elsewhere [1-5].

B. Reframing the SEED into the SEED-PA

The first step in reframing the SEED instrument into the SEED-PA instrument was to remove all items not related to the new purpose of testing the efficacy of a single ethics instruction or intervention. These included the majority of items serving as explanatory variables, including past curricular and co-curricular experiences, specific engineering major, and high school grade point average.

The next step in reframing was to test a new set of items intended to measure whether students' pro-social and anti-social behaviors were pre-planned or spontaneous. In order to do so, we conducted three pilot test sessions with 24 undergraduate engineering students at a doctorate-granting, very high research institution. Each session was 50 minutes and all participants received a \$20 Amazon.com gift certificate as an incentive. The test functioned in an iterative manner, with each group viewing and being asked about a set of items which were then rewritten based upon their feedback and tested with a subsequent group. The final versions of the altered items are shown in Table I.

Two other items were tested related to students' potential reluctance to cheat or potential to ignore reluctant thoughts. These items were ultimately discarded when students could neither appropriately interpret the provided items nor suggest suitable alternate language.

The final step in reframing was to create two instruments which could be used in tandem and be administered prior to and after an ethics intervention. Items measuring demographics were removed from the post-intervention survey because data are collected on the first instrument and because the two response sets are intended to be merged together by a unique identifier. For most items the language was simply adjusted from plans and intentions in the pre-intervention survey to actual experiences and behaviors in the post survey. We also created items to measure students' satisfaction with and perception of value of the intervention just experienced, as well as a measure of the types of pedagogy they perceived were used, which was intended to be matched against the instructor's description of the actual pedagogical techniques. A comparison of the initial SEED instrument to the SEED-PA pre- and post-intervention surveys is provided in Tables II and III.

TABLE I. COMPARISON OF SEED AND SEED-PA PRO-SOCIAL AND ANTI-SOCIAL ITEM WORDING

Pre-Intervention Survey	Post-Intervention Survey
Do you intend to volunteer for a service project during the current term? <ul style="list-style-type: none"> Yes No 	During the past term were you part of any volunteer service projects? <ul style="list-style-type: none"> Yes No
How will you figure out the details of volunteering? <ul style="list-style-type: none"> I already have a plan for how I will volunteer I don't have a plan yet, but figure one out ahead of time I won't have a plan, I'll just volunteer when an opportunity arises 	Did you create a plan for volunteering for a service project? <ul style="list-style-type: none"> Yes, I had a plan ahead of time for how I would volunteer No, I just volunteered when the opportunity arose
Do you intend to cheat on homework (in any course, not just this one) during the current term? <ul style="list-style-type: none"> Yes No 	During the past term, how often did you cheat on homework? <ul style="list-style-type: none"> Every time I had a homework assignment Almost every time I had a homework assignment About half of the times I had a homework assignment A few of the times I had a homework assignment One time Never
How will you figure out how to cheat? <ul style="list-style-type: none"> I already have a plan for how to cheat I don't have a plan yet, but will figure one out ahead of time I won't have a plan, I'll just cheat when an opportunity arises 	Did you create a plan for cheating? <ul style="list-style-type: none"> Yes, I had a plan ahead of time for how I would cheat No, I just cheated when the opportunity arose

III. RESULTS OF SEED-PA FROM PILOT STUDIES

Over the course of a single academic year, four pilot studies were conducted as part of the development of the SEED-PA instrument. Two schools participated in the survey – School A and School B. Three sets of data from School A (Spring 2013, Fall 2013, and Spring 2014) and one set from School B (Fall 2013) are presented here. A total of 35 students were surveyed at School A and 26 at School B. Respondents from School A were enrolled in a senior level course on ethics in civil engineering, while students from School B were enrolled in a first-year engineering course. For each set of data, both a pre- and post-intervention survey were administered.

Explanatory Variables			
	SEED		SEED-PA
<i>Formal Curricular Experiences:</i> <ul style="list-style-type: none"> • Nine pedagogical methods by seven settings in which they might have occurred • For the most influential experience, an item about Bloom's Taxonomy and an item about likelihood of that experience influencing a future decision • An item about overall satisfaction with ethics instruction 	66 items	<i>Formal Curricular Experiences:</i> <ul style="list-style-type: none"> • Items about overall satisfaction with ethics instruction to date and the importance of professional ethics to engineering education • Items about the specific ethics intervention: satisfaction with instruction, value of instruction, type of pedagogical method experienced, and perception of value when used to confront future professional ethical dilemma 	Pre-survey: 2 items Post-survey: 1 item
<i>Co-Curricular Experiences</i> For each of five engineering activities (e.g. engineering design team, professional engineering student society) and ten non-engineering activities (e.g. student government, varsity athletics), items measuring: <ul style="list-style-type: none"> • Frequency of participation • Status as an elected or appointed leader • Participation in volunteer service sponsored by the group 	45 items	<i>Co-curricular Experiences</i> A multiple-response item about participation in a range of student organizations	1 item
<i>Student Characteristics</i> Class level, transfer status, age, gender, citizenship, race, ethnicity, full-time/part-time status, specific engineering major, final high school grade point average, current college grade point average, primary language, political orientation	13 items	<i>Student Characteristics</i> Class level, transfer status, age, gender, citizenship, race, ethnicity, full-time/part-time status, current college grade point average, primary language, political orientation	Pre-survey: 11 items Post-survey: None

Outcome Variables			
<i>Knowledge of Ethics</i> Ethics questions from Fundamentals of Engineering Exam	5 items	<i>Knowledge of Ethics</i> Ethics questions from Fundamentals of Engineering Exam	5 items
<i>Ethical Reasoning</i> DIT2 Scores calculated by the Center for the Study of Ethical Development including P score, N2 score, Personal Interest score, Maintaining Norms score [6]	85 items	<i>Ethical Reasoning</i> DIT2 Scores calculated by the Center for the Study of Ethical Development including P score, N2 score, Personal Interest score, Maintaining Norms score [6]	85 items
<i>Pro-social ethical behavior</i> Items about course-taking due to a community service component, participating in K-12 outreach, and participation involunteer service	5 items	<i>Pro-social ethical behavior</i> Items about participation in volunteer service in college and high school, intent to volunteer in the current term, plan for accomplishing volunteer service Items about participation in volunteer service in past term and creation of plan for accomplishing volunteer service.	Pre-survey: 4 items Post-survey: 2 items
<i>Anti-social Ethical Behavior</i> Items about frequency of cheating in high school and college	8 items	<i>Anti-social Ethical Behavior</i> Items about frequency of cheating in college and high school, intent to cheat in the current term, plan for accomplishing cheating Items about cheating in past term and creation of a plan for cheating	Pre-survey: 4 items Post-survey: 2 items

Over the course of the four pilot studies it was clear that the response rate varied considerably depending on what incentives were used. We attempted several pilot studies without incentives in relatively large courses at two universities other than School A and B. In both cases, the lack of incentives resulted in low response rates. The response rate for the pre-intervention tests was 3-10%, causing us to cancel the post-intervention tests as there would be insufficient data to analyze. At School A two incentive strategies were used. In the first case, we offered respondents a chance to win a \$100 Amazon.com™ gift card if they completed the pre-intervention test and an added \$20 Amazon.com™ gift card if they completed the post-intervention test. In this case the pre-intervention response rate was 50% and the post-intervention response rate was 86% for a net response rate of 43%. For the second intervention strategy, respondents were told that

participation in the SEED-PA pilot study was required for course credit. In this case, the pre- and post-intervention response rate was 100%, resulting in a net response rate of 100%. Finally the pilot study at School B used a different incentive strategy. Respondents were given two bonus points on the final exam if they completed both the pre- and post-intervention SEED-PA instruments. In this case the pre-intervention response rate was 85% and the post-intervention response rate was 52% for a net response rate of 44%. From these data it seems apparent that students are unlikely to complete the SEED-PA unless some form of incentive is provided. This incentive need not be financial, as the School A and School B pilot tests resulted in good response rates with promises of course credit or extra credit.

B. Explanatory Variables Other Than Demographics

For formal curricular experiences both School A and B respondents viewed the importance of ethics instruction as "Important" with a total of 50% of respondents choosing this response. Responses differed between the two institutions with respect to satisfaction with prior ethics interventions. School A students reported that "I haven't had any" (65%) while School B students were generally "Satisfied" (58%). From the post-test survey we are able to determine what pedagogy students experienced in formal curricular settings. From this multi-response item we can discern that respondents from School B indicated "Presentation by a professor", "Movie or film", and "Small groups or class discussion". School A respondents indicated similar experiences, but rather than a movie or film indicated that they experienced a "Presentation by a speaker".

C. Outcome Variables

Outcome variables are grouped into three categories: knowledge of ethics, ethical reasoning, and ethical behavior. Results from the knowledge of ethic items were compared for both pre-test and post-test surveys using a paired sample t-test with a 95 percent confidence interval. For the School B respondents only one item showed a significant difference between the pre- and post-test results, while for the School A respondents there were no significant differences in the before and after results. Thus we can conclude that there is no apparent change in the ethics knowledge of the participants as measured by the SEED-PA from pre- to post-intervention regardless of the nature of the intervention. This lack of significance may well be due to the fact that the sample sizes for the pilot studies were relatively small.

Ethical reasoning was measured using the DIT2 questionnaire and resulted in four scores that define an individual's moral reasoning capacity: N2 score, P score, Personal interest score, and Maintaining norms score [6]. No significant differences were found between the pre- and post-test survey results for any of the four scores with respect to either the School A or School B respondents.

Ethical behavior was assessed using pro-social and anti-social items focused on either volunteering or cheating. No statistically significant differences were observed in respondents self-reported pro-social or anti-social behaviors.

IV. CONCLUSIONS

From an analysis of four pilot studies at two institutions, the following conclusions about the SEED-PA instrument can be offered:

- We have generated a simplified and specific instrument (SEED-PA) from a larger research tested instrument (SEED) for measurement of ethical development in engineering undergraduates.
- Use of an incentive is necessary to assure sufficient response rate to the instrument for data analysis. However, the incentive need not be financial as academic incentives were found to provide sufficient response rates.
- The SEED-PA was unable to find significant differences in any of the measured outcome variables which may be a result of the short time interval between pre- and post-intervention or the relatively small sample sizes of the pilot tests.

ACKNOWLEDGMENT

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Automatic Fill-the-blank Question Generator for Student Self-assessment

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Abstract—Today's educational systems require students to recall and apply major concepts from study material to perform competently in assessments. Crucial to achieving this is practice and self-assessment through questions. The crafting of such questions can be time consuming for teachers while questions from external sources, e.g. assessment books, might not be tailored to suit students' study materials. As such, we present RevUP: an automated system for Gap-Fill Question Generation (GFQG) from educational texts. Example GFQs generated by RevUP from a high-school biology textbook are as follows.

- *Endocrine signals generated by the hypothalamus regulate hormone secretion by the _____.*
(a) posterior pituitary (b) anterior pituitary
(c) thyroid gland (d) pineal gland

Our system factors the problem of generating good questions into 3 parts:

- 1) Selecting topically important sentences to ask about
- 2) Identifying which part of the resulting sentence to choose as the gap
- 3) Crafting effective distractors to be part of the set of options to confuse the learner

The immediate advantage of this service is that it provides the tools that make it easy for teachers to quickly generate and edit questions for pop quizzes and worksheets from their lecture notes. In the paper, we will provide a detailed description of the methodology used to generate questions. We will also provide preliminary usability statistics from high school students where they qualified the usability and the negative aspects of the application.

I. INTRODUCTION

Knowledge acquisition is central to educational systems today. This requires a student to be able to recall and apply major concepts from study material to perform competently in assessments. Crucial to this is practice and self-assessment through questions. Questioning has been found to be an effective method of helping students learn better [1]. However, such questions are not easily accessible to students leading them to solely depend on teachers for practice material. On the other hand, continued crafting of varied questions is extremely time consuming [2]. Furthermore, learners are increasingly moving from the traditional classroom setting to an independent learning setting online [3]. The Internet is a treasure trove of texts, some of which could match the educational needs of students.

However, much of these texts do not come with instructional content that conventional classroom material provide. Here, there is a need for leveraging upon online educational texts to provide practice material for students.

Automatic Question Generation (AQG) shows promise for both these use-cases. AQG can provide extra practice material to students, for self-assessment to help reinforce concepts learnt during lessons. On the other hand, AQG can assist teachers in the laborious task of setting questions which could help free time and resources. Furthermore, AQG can be valuable in generating questions from arbitrary text for online learners.

However, most contemporary AQG systems have focused on generating grammatically and syntactically correct questions with little attention given to the semantics and educational relevance of the questions. To overcome these problems, we built a system, harnessing cutting edge computer science techniques, for automatic Gap-Fill Question Generation (GFQG) from educational texts such as lecture notes. In this Work-In-Progress paper, we will first provide a description of the application and examples of some questions generated by the system. This will be followed by a high-level description of the methodology used to generate questions. Finally, we will provide results of a very preliminary evaluation with 15 students where we requested participants to rate the questions generated by the system, the negative aspects of the application and ideas to improve the application. The study validates the promise of the system and also provides a set of future directions to pursue for the completion of the system.

II. SYSTEM DESCRIPTION

Our system generates gap-fill multiple choice questions from educational texts such as lecture notes. Example questions generated by our system from a high school biology textbook are as follows. The correct answers are in bold.

- 1) Endocrine signals generated by the hypothalamus regulate hormone secretion by the _____.
(a) posterior pituitary **(b) anterior pituitary**
(c) thyroid gland (d) pineal gland
- 2) _____ also use their hydrolytic enzymes to recycle the cells own organic material, a process called autophagy.

- (a) Endosomes (b) Organelles
(c) **Lysosomes** (d) Golgi Apparatus
- 3) Ribosomes facilitate the specific coupling of tRNA anticodons with mRNA codons during _____.
(a) DNA Replication (b) DNA Synthesis
(c) RNA Splicing (d) **protein synthesis**
- 4) NaCl diffusing from the ascending limb helps maintain a high osmolarity in the interstitial fluid of the _____.
(a) juxtamedullary nephron (b) **renal medulla**
(c) collecting duct (d) peritubular capillary

Throughout this paper, we will refer to the question sentence as the *sentence*. The correct answer to the blank in the sentence will be referred to as the *gap*. The wrong options will be referred to as *distractors*.

III. METHODOLOGY

Our system factors the problem of generating educationally relevant gap-fill multiple choice questions from educational texts into 3 parts:

- 1) **Sentence Selection:** Selecting coherent and important sentences from the text to ask about
- 2) **Gap Selection:** Identifying which part of the resulting sentence to choose as the gap. The gap essentially represents the concept being tested
- 3) **Distractor Selection:** Crafting effective distractors to be part of the set of options to confuse the learner to ensure that he has a good grasp of the concept being tested

Our system builds upon and proposes accurate techniques spanning the fields of Artificial Intelligence, Machine Learning and Natural Language Processing to solve each of the above-mentioned problems. We do not delve into the details of the algorithms used but a high-level description of the methods used are provided in the following subsections.

A. Sentence Selection

Here, we aim to select sentences that are coherent (express a few core ideas) and contain important information. Such a task requires domain knowledge. As such, we trained a neural network based topic model to discover concepts and topics from a high school biology textbook ???. These topics and concepts served as the basis for selecting important and coherent sentences.

Since the topics and concepts discovered were biology-related, questions generated by our system, as described in this paper, will be biology related. However, extension to other subject domains is trivial and only text covering most of the key concepts is required.

B. Gap Selection

We found that selecting an educationally relevant gap was one that depended on qualitative human judgement. As such, we collected human judgements (good/bad) on about 1200

gaps through the Amazon Mechanical Turk platform. This data was used to train a machine learning model. The specific model chosen was a Gaussian Kernel Support Vector Machine. After training, the machine learning model was able to distinguish between good and bad gaps. Validation of the model yielded an accuracy of 81% ??.

C. Distractor Selection

Our method selects distractors that fulfill the following properties best.

- *Semantic Similarity:* Distractors need to be similar in meaning to the gap. To do so, we use the word2vec tool. Word2vec learns and obtain distributed representations of words, from input texts, in a vector space which spatially encodes the semantic information of these words. As such, to find semantically similar distractors, we search for words that are closest to the gap in the vector space ??. To train the word2vec, we used texts from Wikipedia.
- *Syntactic Similarity:* Distractors that often look similar to the gap can be good. For e.g., t-phase is probably as good distractor for g-phase. We captured such syntactic similarities by computing the Dice Coefficient for the gap-phrase and each candidate distractor ??.
- *Contextual Fit:* Distractors need to fit into the question sentence. To do so, we used a language model to calculate the probability of a candidate distractor occurring in the question ??. The higher the probability, the greater the context fit.

IV. PRELIMINARY STUDIES

In this section, we will provide and analyse some preliminary statistics we have collected using the proposed system with students. The goal of the preliminary study is to provide metrics that could provide insights into the effectiveness of the system and also its efficacy in fulfilling students' needs.

A high school biology, *Campbell Biology, 9th Edition* textbook was used as the domain knowledge for the question generation system in the experiments. **15** students from NUS High School, whom had taken at least 4 years of high school biology, were recruited for the study. The students were aged between 15 and 18. We requested all the students to complete 3 main tasks. The description for each task and the results are presented in following paragraphs.

A. Question Rating

In the first task, our goal was to assess the educational relevance of the questions generated by our system. To do so, each student was tasked to provide us with a high school biology text of his/her choice. A list of questions were generated for each text and the students were asked to rate each question on a scale of 0 to 3. A cascade rating scheme was used as illustrated in Table I. From the texts that the **15** students sent, **495** questions were collectively generated. Figure 1 shows the number of questions that belongs to each rating band.

In terms of sentence and gap selection, our system performed

Rating	Requirements
0	Sentence is bad; Does not matter whether gap and distractors are good or bad.
1	Sentence is good, gap is bad; Does not matter whether distractors are good or bad.
2	Sentence and gap are good but distractors are bad.
3	Sentence, gap and distractors are all good.

TABLE I. QUESTION RATING SCHEME

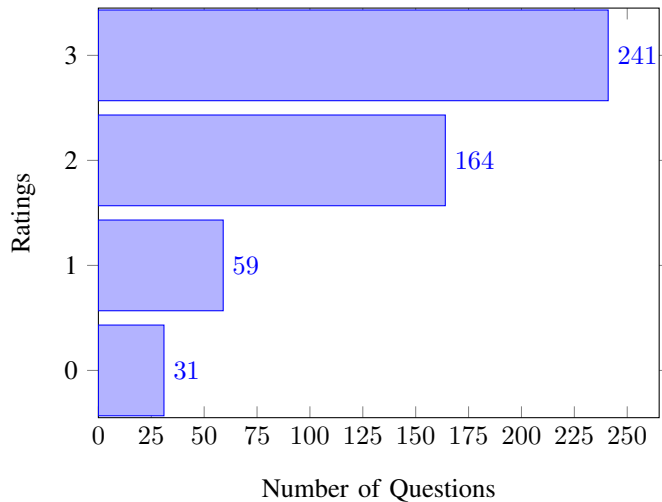


Fig. 1. Number of questions in each rating band

very well. 94% of sentences 87% of gaps were considered good. However, this was not the case of distractor selection where only 60% of the distractors were considered good. This can be mainly attributed to the fact that our algorithm, in its current state, is not able to reject distractors that could be correct answers to the question. More work is needed to build complete the question generation system.

B. Efficacy of System

The students were also posed the following question: "Do you think these questions serve as an effective memory tool to help you remember concepts learnt from notes". The aim of this question was to gain an understanding on how effective students perceive this tool to be. We found that **14** out of the **15** students answered "Yes" to the above question. The student who said "No" felt that the questions should require more critical-thinking. Nevertheless, this result is encouraging and serves as a reaffirmation of our approach.

C. Improvements

In the final task, students were posed the following question: "Do you have any suggested improvements?". our aim was to gather information on certain improvements students wanted to see in our final system to focus our efforts on the right areas.

- **Better Distractors:** One of the main concerns was the lack of good distractors. Apart from the fact that certain distractors were correct answers to the question, students expressed a need for more "confusing" distractors.

- **Question Variety:** On the other hand, a few students noted that there were repetitive questions tested on the same key concept. As such, we have to look into ways on increasing the variety of the questions generated. The re-wording of questions to make them more comprehensible to the reader was also proposed. We also hope to look into generating questions that test higher order thinking skills.
- **Tuning Difficulty:** Another interesting suggestion brought up included the addition of a feature to tune the difficulty of questions.

V. CONCLUSION

In this paper, we presented the preliminary version of our proposed automatic question generation system for student self-assessment by leveraging . The immediate advantage of this service is that it provides the tools that make it easy for teachers to quickly generate and edit questions for pop quizzes and worksheets from their lecture notes. These questions, as compared to those from practice books, etc. would be more relevant to the notes uploaded. Preliminary testing was also done with students. First, the quality of the questions generated was assessed. 94% of the question sentences, 87% of the gaps and 60% of the distractors were considered to be educationally relevant. Second, we found that 14 out of the 15 students surveyed found the system to be effective in helping to reinforce concepts. Finally, we gained insights into improvements they want to see implemented in the final system. The results obtained have been encouraging have given us clarity on the direction to be henceforth pursued.

VI. FUTURE WORK

To complete the system, we would be working on the improvements suggested by the students surveyed. Thereafter, we would like to take a more teacher-centric approach to the system. We feel that it would be useful if our system could pinpoint the certain topics that students make the most errors in, based on their answers to the auto-generated questions. This would allow tutors to re-emphasise those concepts in class whilst enabling students to focus on the concepts that they lack knowledge in. Furthermore, studies with teacher-participants to assess the effectiveness of our system could be useful. We also plan to assess how the system can contribute to preparing students for examinations.

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Pluggable Reputation Systems for Peer Review: a Web-Service Approach

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Abstract—Peer review has long been used in education to provide students more timely feedback and allow them to learn from each other's work. In large courses and MOOCs, there is also interest in having students determine, or help determine, their classmates' grades. This requires a way to tell which peer reviewers' scores are credible. This can be done by comparing scores assigned by different reviewers with each other, and with scores that the instructor would have assigned. For this reason, several *reputation systems* have been designed; but until now, they have not been compared with each other, so we have no information about which performs best. To make the reputation algorithms pluggable for different peer-review system, we are carrying out a project to develop a reputation web service. This paper compares two reputation algorithms, each of which has two versions, and reports on our efforts to make them "pluggable," so they can easily be adopted by different peer-review systems. Toward this end, we have defined a Peer-Review Markup Language (PRML), which is a generic schema for data sharing among different peer-review systems.

Keywords—educational peer review; reputation system; web service

I. INTRODUCTION

Online peer-review systems are now in common use in higher education. They free the instructor and course staff from having to provide personally all the feedback that students receive on their work [1]. However, if we want to assure that all students receive competent feedback, or even use peer-assigned grades, we need a way to judge which peer reviewers are most credible. The solution is to use a *reputation system* [2]. Reputation systems may take various factors into account:

- Does a reviewer assign scores that are similar to scores assigned by the instructor (on work that they both grade)?
- Does a reviewer assign scores that match those assigned by other reviewers?
- Does the reviewer assign different scores to different work?
- How competent has the reviewer been on other work done for the class?

Any or all of this information may be factored into a reviewer's reputation. Not only does this help us determine what grade to award student authors; it also helps students see how effective they are as reviewers.

In the past, with small size classes, reputation systems were seen as an ancillary function of peer-review systems. However, in a large class they are essential, and in a MOOC, they are indispensable [3]. There is simply no other way to assess large volumes of work that cannot be automatically graded.

The same reputation algorithm can be used by many different peer-review systems. We have a multi-campus NSF-funded project to develop web services for peer review. Our project will develop pluggable reputation systems that can be deployed in many different peer-review systems. These reputation systems can assign grades calculated as a linear combination of student-assigned grades, with competent reviewers' scores weighted more heavily.

Once reputation systems have been deployed as web services, peer-review researchers will be able to use them to calculate scores on assignments, both past and present (past data can be used to tune the algorithms). This will yield the following benefits: (1) peer-review systems that lack reputation systems may use one of ours without coding it in their system; (2) instructors will be able to experiment with different reputation systems for their own classes, without implementing them locally; and (3) the information that we gather from this experimentation will help us recommend reputation systems appropriate for different kinds of assignments and courses.

II. ALGORITHMS SUPPORTED

Inputs of reputation algorithms vary, but a common way to represent review scores is to use an adjacency matrix. In this matrix, each row represents an artifact and each column represents a reviewer. The values of the matrix are the scores given to each artifact by each reviewer. Reputation algorithms use the matrix to generate two quantities: the reputation values for each reviewer and the weighted grades for each artifact.

It would be simplest to assign reputations based on agreement with expert (instructor) grades. But, in practice, instructor grades are not always available, so reputation algorithms need to calculate reviewer reputations and weighted scores for artifacts recursively till they reach convergence.

To give a precise definition of the algorithms supported in our web service, let a be an artifact; A be the set of all the artifacts; r be a reviewer; R be the set of all the reviewers; g_a^r

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be the grade that r assigned to a ; R_r be the set of artifacts reviewed by r ; A_a be the set of reviewers who have reviewed a ; W_r be the weight for reviewer r ; G_{expert}^a be the expert grade for artifact a ; $G_{predict}^a$ be the grade that the algorithm predicts for artifact a based on current reputations; and G^a be the temporal grade for artifact a in the algorithm.

In the Hamer algorithm (we call it Hamer-peer in this paper) [4], $G_{predict}^a$ is the weighted average of the grades assigned to a :

$$G_{predict}^a = \sum_{r \in A_a} g_r^a \times W_r / \sum_{r \in A_a} W_r \quad (1)$$

$G_{predict}^a$ is then used to update the reviewers' weights since the expert grades are not considered available: $G^a = G_{predict}^a$.

The variances in the scores assigned by each reviewer are calculated based on how close their grades are to the predicted weighted grades:

$$\Delta_r = \sum_{a \in R_r} (G^a - g_r^a)^2 / |R_r| \quad (2)$$

With the Δ_r for all the $r \in R$, we can tell whether a reviewer's variance is higher or lower than average:

$$W_r' = \text{mean} \Delta_r / \Delta_r \quad (3)$$

So the higher W_r' is for $r \in R$, the "better" a reviewer r is. The range for W_r' is $(0, \infty)$.

To avoid having the reviewers with higher W_r' "dominate" the grade aggregation, Hamer used a "log-damping" approach to calculate the W_r :

$$W_r = \begin{cases} 2 + \log(W_r' - 1) & W_r' > 2 \\ W_r' & W_r' \leq 2 \end{cases} \quad (4)$$

W_r and $G_{predict}^a$ are calculated iteratively till they converge.

However, if expert grades are available, it is unnecessary to calculate $G_{predict}^a$; instead, G_{expert}^a can be used as G^a : $G^a = G_{expert}^a$. With this modification, we can use similar processes to derive an implementation of the Hamer-peer algorithm with expert grades (Hamer-expert). The difference is that this algorithm does not need to be run multiple times because G^a does not change from one round to the next.

The ranges for both Hamer-peer and Hamer-expert are $(0, \infty)$. If a review's reputation score is greater than 1, this reviewer is considered to be above average.

In contrast to the Hamer algorithms, the reputation range calculated by the Lauw algorithm (we call it Lauw-peer in this paper) [5] is $[0, 1]$. A reputation score close to 1 means the reviewer is credible.

The main difference between the Hamer-peer and the Lauw-peer algorithm is that the Lauw-peer algorithm keeps track of the reviewer's leniency ("bias"), which can be either positive or negative. A positive leniency indicates the reviewer tends to give higher scores than average.

Let l_r be the leniency of r . After $G_{predict}^a$ is calculated for each $a \in A$, l_r can be updated:

$$l_r = \sum_{a \in R_r} (G^a - g_r^a) / g_r^a / |R_r| \quad (5)$$

The difference between (2) and (5) is that in the Lauw-peer algorithm, the variance is not squared, which results in higher reputation scores for the weak reviewer. More results and analysis are provided in section 4.

Similar to the Hamer-expert algorithm, if expert grades are available, a new algorithm (Lauw-expert) can be defined by using G_{expert}^a as G^a . This algorithm also does not need to be run recursively because expert grades are already available.

III. DESIGN OF THE WEB SERVICE AND PRML

A. Design of reputation web service

Our web service is designed to make different reputation algorithms available for peer-review systems. As in any web service, the inputs and outputs will follow a pre-defined format. Our design goals were to—

- minimize data transactions;
- minimize the effort needed to plug the web service into the clients;
- minimize the knowledge that the web services need to have about the clients.

Fortunately, no personal information needs to be passed to the web service; personal IDs and names are not needed for calculating reputations. The web service can keep track of each reviewer using the primary keys from the clients, or a one-way hash, for example. Nor does the web service need to store any information used to calculate the reputations. However, client systems may choose to allow it to save anonymized score information to, for example, calculate reputations for a whole semester, or to make it available in a learning-analytic database.

To make use of all the algorithms provided by our web service, client systems simply need to implement a web-service interface module for their systems. This module will (1) transform and send data to the web service and (2) receive the reputation data and use it in calculating grades. We are open to helping potential clients to implement this module. Since this interface is on the clients' end, clients can set up security rules to guarantee data integrity and security. The clients will be able to adapt this web service interface module to make use of our other web services (such as visualization and rubric improvement).

The data that the web service receives from the pluggable interfaces will be in a common format, regardless of how the client systems represent it. A common format also simplifies the design of reputation web services, because they do not need to have any knowledge of the development languages, the designs and the purposes of the client systems.

B. Design of PRML

In order to interface this reputation web service to a wide variety of peer-review systems, we have defined a Peer-Review Markup Language (PRML). This language will provide a standard format for representing data structures common to peer-review systems, such as assignments, users, rubrics, and reviews. It will allow different peer-review systems to interface to our reputation web service (and our other web services) without needing to change their databases.

PRML is a generic data schema for collecting and sharing numeric and textual data. The reputation web service uses only a subset of PRML. The full PRML contains other entities, such as textual feedback provided by students. This paper only presents the portion of PRML used for reputation services.

PRML is an JSON-based markup language which encapsulates data and metadata generated by peer-review tasks. The entities of data used in the reputation web service are clients, assignments, tasks, reviewers, reviewed entities and scores. Each of these is explained in Table I.^a

IV. DATA SET AND EXPERIMENTAL RESULTS

The data set that we used in experiments was generated in CSC 517 (Object-Oriented Design and Development) at NC State University in 2014. This is a graduate-level course, which peer-reviews two programming and three writing assignments. All of these are team assignments with 2- to 4-member teams. In the review phase, students select artifacts to review. Peer reviews are done using the Expertiza system [6], which is a system developed to review student-generated course content. In the peer-review phases for each assignment, reviewers were asked to fill out a review rubric. They were expected to give textual feedback and Likert-scale scores for the various rubric criteria.

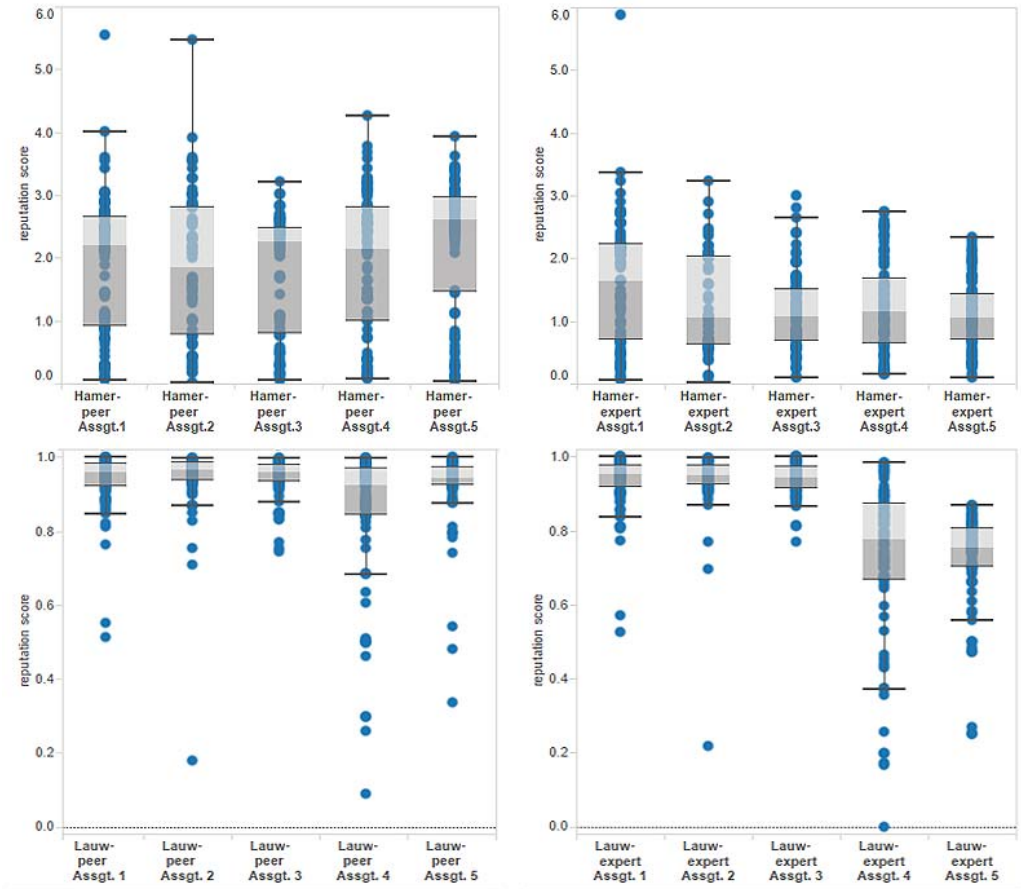


Fig. 1. Distribution of reputation scores calculated by each algorithm.

TABLE I. ENTITIES NEED BY THE REPUTATION WEB SERVICE

Entity name	Explanation
Client	A client system that uses the reputation web service.
Assignment	An assignment is what an instructor creates to prompt students to create artifacts.
Task	A task is an activity within an assignment. To incorporate peer-review systems that support multiple rounds of reviews, we consider each round as a task, and the web service calculates reputations for each task instead of for each assignment.
Reviewer	A user who submits one or more reviews for the current task.
Reviewed entity	The reviewed entity in the current task can be an essay, a video, a program, etc. Since we do not do content analysis in the reputation web service, we only need identifiers for the entities.
Score	The mapping table between reviewers and reviewed entities. Each instance represents a peer-review record, consisting of {reviewer, reviewed_entities, task, score assigned}. The instances of this entity should also contain the expert grades if they are available.

a. Class diagram of these categories can be found in : <http://www4.ncsu.edu/~ysong8/FIE2015/class%20diagram.jpg>.

Example of PRML can be found in:

<http://www4.ncsu.edu/~ysong8/FIE2015/json%20sample.xml>.

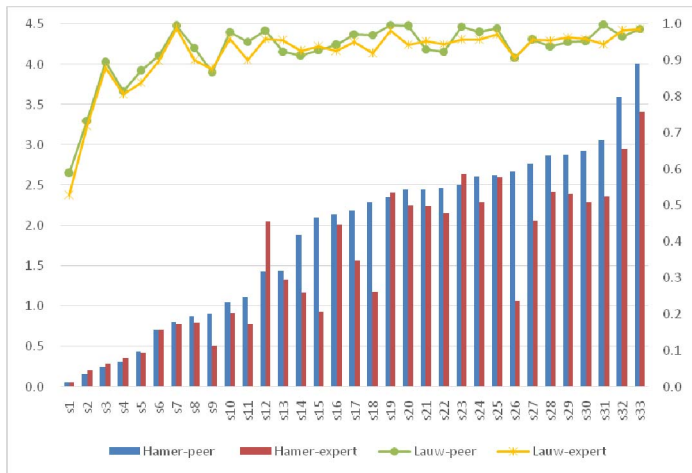


Fig. 2. Distribution of reputation scores calculated by each algorithm. We sampled 33 students (s1-s33) from assignment 1. The barchart shows the reputations calculated by Hamer-peer and Hamer-expert algorithms, with scale on the left side; the line chart shows the reputations calculated by Lauw-peer and Lauw-expert algorithm, with scale on the right.

Eighty-four students finished the course, and 2852 peer reviews were collected. We used the peer-review scores and computed aggregated scores on a 0-to-100 scale. Some of the artifacts received more than 100 because of bonus points, but bonus points are ignored in our experiments.

The web-service code calculated reputations for all students. Fig. 1. shows the distribution of all reviewers' reputation for all the assignments. The distribution of the reputation scores show that the Hamer algorithms have wider ranges, and that weak reviewers can receive reputation scores which are close to 0. By contrast, the Lauw algorithms give decent reputation scores to most of the students, but accord less weight to peer grades from credible reviewers.

One question that may interest instructors on client systems is, Do the reputation algorithms give consistent results? To answer this question we sampled 1/3 of students from assignment 1. Their reputations are presented in Fig. 2. It shows that even though the ranges of those algorithms vary, the result are consistent: the reviewers found to be credible by one algorithm are also deemed credible by the other algorithms. This is because all the algorithms are based on the degree of consistency between the scores given by one reviewer versus the scores given by the other reviewers on the same artifact. Another observation from Fig. 2 is that the students who received reputation scores close to 1 from the Hamer algorithms (meaning peer reviews skills are average) may receive 90% reputation scores from both Lauw algorithms, which shows that Lauw's tends to give higher reputation scores.

Another piece of information that the instructors using the client systems may want to know is, Which algorithm works best for my course? Since in this case the experts grades are available, the client can calculate the cosine values between the predicted weighted grades and expert grades for each assignment. We sample three assignments from the data set, namely assgt. 1 (writing a wiki page) assgt. 3 (writing a design document) and assgt. 5 (programming). We also computed the

TABLE II. COSINES BETWEEN PREDICTED AND EXPERT GRADES

		Hamer-peer	Hamer-expert	Lauw-peer	Lauw-expert
Assgt. 1	<i>Cosine</i>	0.999	0.999	0.999	0.999
	<i>Overall bias</i>	1.627	-0.773	1.082	-0.755
	<i>Max. absolute bias</i>	7.9	12.2	15.6	12.1
Assgt. 3	<i>Cosine</i>	0.997	0.997	0.997	0.997
	<i>Overall bias</i>	4.824	3.210	2.533	2.405
	<i>Max. absolute bias</i>	23.8	22.5	22.6	22.5
Assgt. 5	<i>Cosine</i>	0.999	0.999	0.998	0.998
	<i>Overall bias</i>	-16.583	-16.489	-18.539	-18.022
	<i>Max. absolute bias</i>	23.2	23.5	26.9	26.3

overall bias and maximum bias of predicted grades, relative to expert grades. The result is shown in Table II.

All the algorithms perform well on assignment 1: the Hamer-peer algorithm has the lowest maximum absolute bias and the Lauw-peer algorithm has the lowest overall bias. This indicates, from the instructor's perspective, if there are further assignments of this kind, expert grading may not be necessary. From assgt. 3, the overall bias is a little bit higher, but the max. absolute bias is very high (more than 20). This indicates that for future similar courses, the instructor can trust most students' peer grading, but should be aware that the students may give inflated grades. Therefore spot-checking is necessary. For assgt. 5, however, overall bias is quite low, as the students gave grades at least 16 points lower than expert grades. This may because either more training is needed, or the review rubric is inadequate. The results on assgt. 5 also suggest that for future courses of this kind, the instructor cannot trust the students' grades; expert grades are still necessary.

V. CONCLUSION

Reputation systems are a necessary part of peer-review systems, especially when they are used by large classes. We have designed a reputation web service which makes reputation systems "pluggable" into any peer-review system. It provides several algorithms that allow client system users to test different reputation algorithms without the need of implementing them locally. Instructors using the client systems can use reputation scores as weights in aggregating student-assigned scores into grades for each artifact.

The reputation web service is based on our Peer-Review Markup Language (PRML), which is designed as a generic schema for sharing peer-review based educational data. PRML isn't just useful for communicating with web services; it also facilitates development of more advanced peer-review systems by giving the community a common language for talking about peer review. With the plug-in interfaces that support PRML, researchers can also (1) share data with each other, and (2) build a centralized data repository. This means that, PRML can serve as a bridge to bring together isolated peer-review systems into a single research community.

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Architectural support for non-expert deployment of remote laboratories

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Abstract—In addition to the domain and pedagogic knowledge required to design the laboratory experience, the development and maintenance of the current generation of remote laboratories typically requires a relatively high degree of technical expertise. This has resulted in long development timelines, a lack of engagement from teachers, and limited exploration of new laboratories. This paper explores the feasibility and requirements of a laboratory architecture that simplifies the development of remotely accessed laboratories. The intent is that a non-expert user with limited technical knowledge (typically a STEM teacher) can readily configure an experiment so that it is able to be both monitored and controlled remotely. The solution incorporates a dynamic interface that can detect and configure components automatically. We believe that the result will be a much wider and more rapid exploration of possible remotely accessed experiments - in much the same way that science teachers readily explore variations in hands-on laboratory experiments.

I. INTRODUCTION

Laboratory environments have always been essential components in the education of Science and Engineering. They enhance learning through the direct exploration of a student's field of study and develop the experimental skills and methodologies required for the practice of those fields. Whilst rarely intended as a direct alternative for conventional hands-on laboratories, remote laboratories have garnered increasing interest as an additional resource due to the opportunity they provide for more flexible access [1], sharing of facilities and for augmentation of the student interaction with the equipment.

Unfortunately, the current generation of remote laboratories require a high degree of technical expertise and dedicated resources to develop, deploy and maintain. Some attempts have been made to create flexible architectures or streamline the creation of remote laboratories (see, for example, [2], [3], [4]), these generally still require a degree of customisation that is beyond a typical teacher. This has resulted in long development timelines, a lack of engagement from teachers, and limited explorations of new laboratories. These difficulties ultimately affect the viability of remote laboratories as a cost effective alternate laboratory experiences. However, allowing teachers to create, deploy and maintain remote laboratories with minimal assistance and technical expertise at a low cost will promote new remote laboratory endeavours and innovations.

To solve this problem, we have designed and implemented of a remote laboratory architecture that would allow non-expert users to quickly create their own remotely accessible experiments with ease. The motivation of this solution is

to provide teachers with the ability to quickly create and share remote laboratory experiments with their colleagues and students with a goal of building a community of practice where people can share their designs and creations. The simplicity and ease of use of this solution would also allow teachers to design remotely accessible experiment rigs that would keep up with new content and the changing syllabi that existing remote laboratories cannot cover or support.

The paper is organised as follows: Chapter 2 presents the background and literature review of remote laboratories and existing architectures. Chapter 3 introduces the proposed remote laboratory architecture design and implementation. Chapter 4 discusses and analyses the feasibility and results of the architecture, and Chapter 5 concludes the paper.

II. BACKGROUND

A. Remote Laboratories

Laboratories are an important aspect of education, in particularly with Science and Engineering. It enhances the learning of students, whilst allowing them to develop experimental skills and methodologies in their respective field of study. Although the right to education is universally recognised, limitations in the resources quite often exist in the form of a lack of funding or support to procure equipment and facilities. Concerns for a cost effective solution increases as a result of (claims/reports) that laboratory utilisation can be quite low, despite a lack of evidence to the fact (see, for example [5]). The emergence of remote labs offers a feasible solution to these issues by the cross-institutional sharing of resources to offset costs and labour. With further improvements made to current generation architecture and design, as is the aim of this paper, remote laboratories become an increasingly viable and attractive alternative [1].

Remote laboratories first appeared in the Engineering Education literature in the mid 1990's[6] and have developed considerably over the last two decades. These systems allow students and teachers to conduct scientific investigations using real lab apparatus via the Internet. This enables students and teachers from different organisations to access a wider range of equipment that would be too expensive or difficult for the individual schools to support. These remote laboratories are usually set up with cameras, data acquisition instrumentation and switching mechanisms to its allow users the ability to control and monitor experiments through either a web based or native application.

B. Benefits and Opportunities

Unlike conventional lab sessions, access to remote experiments can be 24 hours, 7 days a week. This allows students the flexibility to carry out experiments during their own time as well as repeating experiments for better understanding and clarifying doubtful measurements. In turn, it supports autonomous learning and enhances the educational values of the laboratory.

Remote laboratories have the potential to serve as assistive technology[7], allowing students with disabilities to complete experiments without being physically present in a laboratory. This also applies for students who are taking distance education or remote courses.

Although most groups developing and researching in this field acknowledge that this form of laboratory is not expected to replace traditional physical laboratories [8], remote laboratories do however present valid alternatives for some laboratories and serve as useful complements to others[9].

C. Existing Architectures of Remote Laboratories

Over the last decade, numerous remote laboratories have been created with varying architectures and technologies. In earlier iterations, remote labs were often accessed via remote desktop software such as Windows Remote Desktop or Log-MeIn. Although this method served its purpose, allowing users to access the experiment, it raised issues with scheduling, reliability and scalability.

With the emergence of web development, remote labs have gradually leaned towards web applications. Although there are many different implementations, most web-based remote labs have adopted the 3-tier web architecture[5]. This architecture consists of the application client which the users accesses, the lab server which manages the experiment and apparatus, and a service broker which manages the communication between the application client and the lab server. The 3-tier web architecture can be recognised in several different remote lab systems such as the Labshare Sahara Project, Ciclope[10] and MIT iLabs[11].

1) User Management: Remote laboratory architectures are designed to support multiple experiments and rigs. With multiple experiments and multiple users, there is a need for user and access management. The management of end users allow an organisation to administrate the users, assign their identities, credentials and grant them authorisation to specific resources[12]. For example, the UTS Remote Labs which uses the Sahara framework, currently utilised both the Australian Access Federation (AAF) and an internal university LDAP to authenticate users with their university credentials (even if they are from other Australian universities). Within the application, administrators have the ability to control the authorisation levels and access rights of the individual users.

2) Scheduling: Remote laboratories benefit from scheduling schemes to manage access to resources for concurrent users. The easiest approach is the implementation of a queue that allow users to wait for their turn to access the remote laboratory. This method however is inefficient with larger user populations and would cause strain and unfairness amongst the users. The best suited scheduling schemes are based upon

the consideration of varying factors including the number of concurrent users, the available resources, the average duration of each usage and the availability of the resource.

Sahara has a hybrid scheduling scheme which allows users to make reservations for predefined periods on time on a given date. It also allows users to enter a priority queue for the current or next time allocation if it has not already been reserved by another user[13].

3) Hardware: Remote laboratory architectures rely on certain hardware to control and broker the experiments' inputs and outputs. Microcontrollers such as the Arduino, PIC controller and Raspberry Pi are commonly used in prototyping and building remote lab experiments[14] [15] [16]. These microcontrollers are used to manage the lab equipment and components, whilst also serving as a connection to the Internet. They are also capable of hosting the remote lab interface[16], allowing the remote lab system to be an all-in-one architecture (although this is not a scalable approach). With some remote labs, the microcontrollers are used to program and interface with actual lab equipment such as oscilloscopes and function generators[7] or even FPGA boards[17] [18]. In other cases, the microcontrollers are a part of a dedicated experiment rig, where the sensors and circuits are directly controlled by it as seen in [14].

These devices usually require an intermediate level of programming knowledge to operate which most STEM teachers do not have. The management and setup of the hardware and physical components of a remote laboratory experiment would likely be done by technicians. Beyond the hardware, they would also need specialised software to be developed and hosted, which would require software engineers and developers. The sheer complexity of creating remote laboratory experiment is high and tend to require many different types of expertise.

4) Current Trends and Challenges: A common problem among existing remote laboratories is that they only offer stand-alone solutions, with limited or no capability to co-operate with other platforms. There are similar systems and architectures but most of these solutions are developed as special or ad hoc solutions with varying technologies and standards[9]. The lack of standardisation, portability, scalability and interoperability between different solutions is a current major challenge for remote laboratories. This is likely due to the lack of proper software design, in both the client and server side as well as a lack of communication and collaboration between institutions when it came down to development[19].

However, interoperability between multiple remote laboratory architectures has been attempted for Sahara, iLabs and WebLab-Deusto as seen in [20], in which the goal was to allow users of one institution to use federated remote labs developed for other frameworks. This endeavour has shown great potential and presents further opportunities for resource sharing as well as the possibility for standardisation, reusability and scalability.

Accessibility is also a major concern. Providing easy access to remote laboratories from developing countries (where computer access is limited and bandwidth is constrained) is a major challenge as well as a worthy goal, as remote laboratories are

expected to be facilitators to get access to resources otherwise unavailable[12].

Furthermore, the deployment of a remote laboratory can be complex and require a high level technical knowledge. As a result non-expert users such as STEM teachers would require professional assistance to create an experiment which would result in high cost and development times. Making remote laboratories easily deployable, allowing instructors and students to connect experiments to the Internet is another challenge. This challenge is addressed to both the software and hardware of the remote laboratory architecture as it usually requires both software engineering skills and an understanding for circuits to build setup an experiment.

There have been attempts to make the creation of remote laboratories easier for non-expert users through a variety of architectures and approaches. Unlike the previously mentioned Sahara, iLabs and WebLab-Deusto architectures, the architectures/platforms proposed in [15] and [21] are lightweight solutions that aims to allow users to easily to connect their experiment rigs to the Internet. However, these architectures do not consider the entire process of creating a remote laboratory experiment without technical assistance and extra programming. They also, do not consider the context and environment of which the rigs will be hosted, which overlooks the issue of connectivity to the Internet over a strict network.

From the review of previous works and the literature involving remote laboratories, it is clear to see that most remote laboratory architectures are designed to be one-off solutions that do not allow of change or evolution. The development of remote laboratories tend to be complex and costly, which in turns causes long development timelines. Furthermore, we cannot expect the teachers and other non-technical people to be able to use the existing architectures as they all require technicians, designers or developers to create and maintain the different components from the hardware to the end user interfaces. This shows that there is a definite need for a remote laboratory deployment architecture designed for non-expert users that would simplify the process of creating remote laboratory experiments.

III. DESIGN AND IMPLEMENTATION

By analysing the architectures and platforms discussed in Chapter 2, we have designed a smart, modular and low cost architecture intended for non-expert users to be able to easily setup, deploy and share their own remote laboratory experiments. This chapter discusses in detail, the design and implementation of our proposed architecture.

In regards to the design and implementation, we have approached the issue in a highly Agile and exploratory manner. Throughout the duration of the project we have defined and developed the architecture by researching existing technologies, creating prototypes and improving said prototype incrementally. This implementation of the solution was done with the purpose of piloting it to potential users in the near future so that it can be assessed for feasibility.

A. Requirements

The designed and implemented remote laboratory platform is oriented to the needs of STEM teachers in a secondary

school or university context.

The defined users for this platform are:

- Lab owner: Typically a teacher or instructor, this user sets up and configures the remote laboratory experiment. We are making the assumption that the lab owner has little to no technical abilities in terms of programming and remote laboratories.
- Lab user: Typically a student, this is the end-user of the remote laboratory experiments.

Existing implementations of remote laboratories are complex and require a high level of technical understanding to create and maintain. Through the analysis of existing remote laboratory architectures and in conjunction with leading researchers in the field, we were able to define the requirements for a non-expert friendly remote laboratory deployment architecture. This remote laboratory architecture aims to provide an optimally flexible and dynamic solution, which enables non-expert users to implement remotely accessible experiments with minimal technical expertise and without any coding whilst maintaining a low cost.

To cater to lab owners with limited technical knowledge, an architecture that does not require additional programming or complex circuit building is required. This was achieved with a hardware platform and a software solution. In regards to the hardware, we have created dynamic platform which utilises smart "slave modules" that are programmed to be plug and play and self configuring. These slave modules are plugged into a "rig controller" which acts as the central hub for all slave modules and handles the communication between the rig and the Internet. Additionally, we have also designed a software platform to allow the lab owner to easily configure their hardware and design their remote laboratory experiment interface online via a web browser. The software platform is also used to host the experiment interfaces for lab users to access.

To create a remote laboratory experiment using the proposed architecture, the lab owner would be required to do the following:

- 1) Power up the rig controller device and ensure it is connected to the Internet (via WiFi or Ethernet).
- 2) Go online to <https://remotelab.club> and login using their university credentials through the Australian Access Federation or after creating an account manually.
- 3) Register and configure their rig controller.
 - a) Click "Register New Rig Controller" and find their pending rig controller.
 - b) Sync the rig controller by clicking sync button on the web interface and holding down the sync button on the rig controller for 5 seconds.
 - c) Once synced and confirmed, configure the following:
 - Title
 - Description
 - Type (Publish Only or Interactive)
 - Sharing setting (Public or Private)
 - Password (optional)

- 4) Plug slave modules into the rig controller and connect any additional components to the slave modules if needed.
- 5) Using the User Interface Designer on the web interface, design the experiment interface by dragging and dropping widgets onto the canvas. Widgets can then be configured to be bound to a specific slave modules.
- 6) Once satisfied with their remote lab experiment setup, the lab owner can publish it and allow lab users to access it.

The workflow was derived by identifying and assessing the technical abilities of the expected lab owners to create an optimal user experience where there would be minimal complex steps like programming their own logic or editing configuration files on a Linux shell. The process of creating a remote laboratory was significantly simplified as the traditional steps of programming backend logic and designing user interfaces are encapsulated into basic forms and drag and drop interfaces on a user friendly web application.

B. Technical Design

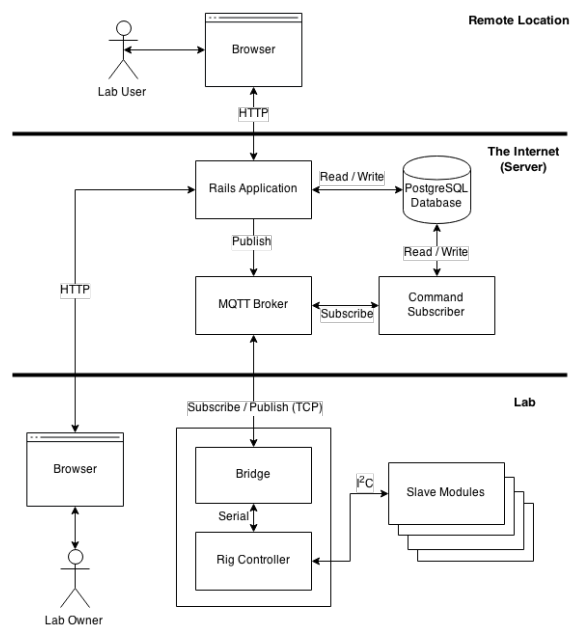


Fig. 1. Technical Overview of Architecture

Our approach adopts an adaptation of the commonly used three-tier architecture which consists of the hardware, a server and some middleware (see Figure 1). To remove the complex step of deploying and maintaining a local server to host the management logic and application of the remote laboratory platform, we have designed our platform to work with a dedicated server on the cloud. Furthermore, the difficulty of the hardware design of an experiment rig is decreased with the proposed "plug and play" platform using defined slave modules.

This section will in detail elaborate on both the hardware and software designs and development of the proposed architecture.

The hardware platform of the proposed architecture consists of a rig controller and a variety of different slave modules.

Note that the implementation of the hardware platform of this architecture was done with the intention that it would be later be implemented on custom printed circuit boards.

C. Rig Controller

The rig controller is the central component of the hardware platform which manages connected slave modules and is the intermediary entity between the hardware and the server. It is based on the Arduino Yn which has an ATmega32u4 AVR microcontroller, an Atheros AR9331 processor which supports OpenWrt Linux and has on board WiFi and Ethernet capabilities. This board was chosen over the other typical boards such as the Arduino Uno or Raspberry Pi because it would remove the need for a dedicated computer to run the communications to the server, but instead have it built into the rig controller. This removes several layers of complexity and reduces the required components which are commonly seen in other architectures.

The rig controller handles the following:

- Manages connected slave modules.
 - Dynamically allocates the slave module addresses (this is discussed in detail in Section III-E).
 - Keeps a record of the slave modules metadata (address, type and status).
- Receive requests from connected slave modules and executes them.
- Receive commands from the server and executes them.
- Send data to the server.

D. Slave Modules

The slave modules are based on the Arduino Uno which has an ATmega328 AVR microcontroller. The idea of slave modules arisen during the analysis of the hardware of existing remote laboratory approaches. Most architectures have either custom designed devices for specific rigs or were made up of a large array of components which would require in-depth knowledge or assistance from experts to build. To avert from this issue, a variety of production ready "plug and play" modules that would be sufficient for most of experiment scenarios was introduced.

During the implementation of the slave modules, we were able to generalise and refactor the underlying logic and functions that make up the base of a slave module into a basic Arduino library and template. This allowed for rapid development of new slave modules which would only require the developer to program the specific functionality revolving around the sensor or component and not have to worry about the communication between devices. Extending the list of available slave modules in the future would be a simple task of copying the base slave class, adding to the list of commands which are callable by the rig controller and editing the configuration variables which determine the type and required pins on the Arduino. This process would be simple for most components that do not require highly complex or convoluted systems.

E. I²C Bus

Communication between the rig controller and the slave modules relies on a master-to-slaves I²C serial bus. By using an I²C serial bus we were able to create the "plug and play" behaviour for the slave modules. The I²C serial bus can handle up to 128 addresses where the rig controller has a fixed address of 1.

The rig controller dynamically allocates addresses for newly connected slave modules (similar to the one proposed in [22]). When a slave module is plugged into the rig controller, on setup, it would request the next available address from the rig controller and registers itself with that address.

The messages that are transmitted between devices as byte streams through the I²C serial bus, we had to use to a special message format consisting of delimited values and ending with a tab character.

`< address >:< command >:< value > \t`

Fig. 2. Message format used during I²C communication

F. Middleware (Bridge)

Running on the OpenWrt Linux environment of the Arduino Yun is the bridge application which consists of a serial service, subscriber service and a publisher. The bridge software is a multi-service application written in Python using the Twisted library which is widely used for communication and protocol management. The application is automatically started when the rig controller is turned on and the Linux environment starts up and runs in the background as a daemon process.

1) *Serial Service*: The serial service reads the byte stream from the serial port with the baud rate of 9600. This component of the application collects the messages from the rig controller which come in the same format mentioned above in Figure 2 and parses it into a Python dictionary (hash table) and executes to appropriate functions. The serial service can call the publisher mechanism to send messages to the server. Furthermore, just as it receives messages from the rig controller through the serial port, the serial service also sends messages back to the rig controller the same way.

2) *Subscriber Service*: The subscriber service of the bridge application, is a TCP client that listens to the MQTT broker of our remote laboratory platform. It subscribes to the "rigs/ < rigHash > /#" topic, where rigHash is the preset rig controller identifier set by the server when the devices are registered and synced. When the service receives a message, it would intelligently parse the topic to determine the required actions to take and use the message value appropriate. In most case, the subscriber server would call the serial service to pass commands to the rig controllers which in turn would pass it to the slaves.

3) *Publisher*: The publisher is a service that is used in the bridge application to communicate back with the server via the MQTT broker. When called, it sends messages with a specified topic which is usually in the "rails/ < rigHash >" topic, where rigHash is the rig controller identifier.

G. Server

One of the major concerns whilst designing and implementing this architecture was the "push to a remote server" approach opposed to the more traditional hosting of a server locally. We pursued the push approach because the context of which the remote laboratory experiment is set up is of great importance as we have to consider the network limitations and firewall restrictions of schools and universities.

In the first stage of development we used API endpoints, which we would POST commands to and regularly poll for new commands. This approach had caused a lot of latency and was an inefficient approach. The API was replaced with a WebSockets server which allows the bridge application to make a TCP connection to it and communicate. This approach was better than the previous, however it also had its limitations as there was a lack of channels and required complex parsing to determine messages and commands. Finally we decided to use a Mosquitto broker to handle communication between the hardware and the software on the server. Mosquitto is an open source MQTT broker that is supported on a variety of operating systems and is easily installed.

MQTT gave us the option to use topics as endpoints, whilst having a similar behaviour as if there was a hard connection to the server with the subscriber services. As previously mentioned in the details of the serial and subscriber services, we used specific topics to handle the communication between the hardware and the server. Commonly used topics consists of the following and their subsets; "rigs/ < rigHash > /#" and "rails/ < rigHash >". Running on the same server as the MQTT broker is a subscriber process which listens to "rails/ < rigHash > /#" topics and executes the requested commands just as the subscriber service on the bridge application.

H. Web Application

Running on the same server (for now) as the Mosquitto broker, is the Ruby on Rails application which is used by the lab owner for hardware configurations and user interface/experience design of their experiment rig and by the lab users to access published experiments. The application uses a PostgreSQL database, served with NginX and is hosted on an Amazon Web Services instance based in Sydney, Australia.

1) *Rig Management*: As mentioned Section ??, one of the steps to register and setup a rig controller requires it to be synced with the user's account on the web application. When the lab owner enters the new rig controller registration page, they will see a list of pending rig controllers that have not been synced yet. Given to the option to ping the rig controller from the web interface (which flashes an LED on the rig controller), the lab owner will be able to find their rig controller on the pending list. Once found, the lab owner can sync it by holding down the sync button on the hardware after initialising the syncing process on the web interface. The rig controller is then recorded in the database and presented on the web application for the lab owner to configure, design and publish their remote laboratory experiment.

2) *User Interface Designer*: Interfacing the hardware with a graphical user interface would usually require a significant

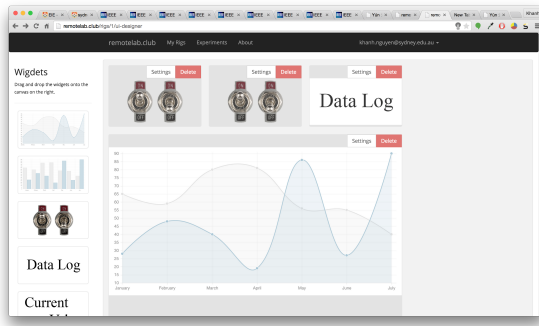


Fig. 3. User Interface Designer

amount of time and resources which in would turn incur a large cost. We have implemented and integrated an easy to use, drag and drop User Interface Designer tool into the web application. This tool allows the lab owner to drag and drop predefined widgets onto a canvas and bind them to slave modules inputs and outputs.

There are two types of widgets:

- Generic widgets are designed to work with most, if not all slave modules. These are usually simple display, graphing or switching widgets which can be bound to slave modules' input or outputs.
- Specialised widgets which were designed to only work with a certain slave module to bring out extra functionality that is not possible with generic widgets.

Once the lab owner is satisfied with the design of their user interface and the configurations of the widgets and slaves, they can save it and publish the remote laboratory experiment.

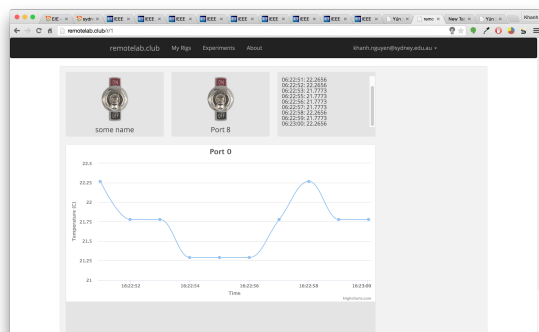


Fig. 4. Experiment rig end-user interface

3) *Experiment Sessions:* When a lab user accesses a published remote laboratory experiment, they will be presented with the user interface that the lab owner had designed. Within the browser they will be able to see the live data from the components and interact with the experiment (if the rig is interactive).

Previously in other architectures and frameworks, the end user interface of a remote laboratory rig is usually implemented using Java applets or with polling AJAX calls with HTML and JavaScript. Both of these approaches have become inefficient

and outdated in light of the recent development of the new web technologies such HTML5 and WebSockets. Our implementation of the experiment session uses HTML5 and Server Sent Events to update the data dynamically without the need for AJAX polling or Java Applets.

When the lab user access an experiment on the web application, the browser immediately subscribes to a channel which received messages from the Rails controllers. When messages are sent to the browser, the JavaScript will automatically update the content on the page. Furthermore, if given a the option, the lab user can also interact with the experiment which triggers AJAX POST requests to the server side which would relay the command to the rig controller.

IV. ANALYSIS

A. Benefits

The discussed architecture allows non-expert users such as teachers and students to easily design and build lightweight remote laboratory experiments at a low cost. The plug and play nature of the architecture along with the software to design and configure it allows lab owners to rapidly build their experiment rigs and easily design an online interface for their remote lab experiment.

The cost of a rig controller would be \$50 and a slave module would cost on an average of \$10 depending on the type of sensor. This means that it is possible to create a minimalistic remote laboratory experiment with a minimum of cost of \$60 using this architecture. This is relatively low compared to the high end remote laboratories developed by universities as those usually require specialised equipment and long development times. By reducing the costs and time to build remote laboratories, this architecture provides an alternate approach to remote laboratory prototyping and development at the cost of quality, extensiveness and robustness. Doing so, this architecture would allow teachers and students to easily explore and innovate with remote laboratories.

The communication logic between the rig controller and the server was designed to be portable and extensible such that it can easily be altered to work with other data storing services and APIs such as Firebase or Twilio.

B. Issues and Problems

The current implementation of this architecture uses the Arduino Yun as the rig controller and multiple Arduino Unos for the slave modules. However, this architecture requires the rig controller and slave modules to be off-the-shelf products for lab owners to easily acquire. As this architecture is targeted at non-expert users with limited technical knowledge, it is not feasible to expect them to be able to build their own rig controller and slave modules.

Furthermore, this architecture can be restrictive as the lab owners are limited to the available slave modules. If a lab owner wants to use their own sensors or hardware, then it would require them to use the base slave module which would require some basic understanding of the Arduino.

The robustness and reliability of the architecture can also be a potential problem due to its restrictive nature and its heavy

dependency on the pre-programmed logic and connection to the server to operate. The architecture also requires an uninterrupted power supply to continually operate, which may be hard to guarantee depending on the individual's circumstances and environment.

C. Comparison to existing architectures

This architecture is comparable to two other existing remote laboratory systems, ISES [21] and the easily deployable low-cost remote lab platform [15] developed by Campos et al. Both of these architectures emphasise a "plug and play" functionality however both have drawbacks in regards to cost and ease of use.

Similarly to Campos' design, our architecture provides a low cost and lightweight solution using inexpensive micro-controllers. However, Campos' architecture requires technical staff to assist teachers in setting up and deploying a remote laboratory experiment. The remote laboratory interfaces are hosted on a micro server which requires port forwarding or similar network configurations. In contrast, our architecture allows teachers to deploy on any network that is connected to the Internet without further configurations.

ISES, on the other hand, presents a high quality plug and play solution with the use of modules that connect via PCI. The consequence of such a high quality product is the high cost as the main PCI board can cost up to \$1500 and individual modules average around \$100. The high cost of platform would not be desirable for non-expert users to use on their own without assistance. Much like other traditional architectures and Campos' platform, ISES also hosts the end user interface or application onboard which would again require further configurations of the network that it is connected.

Furthermore both of these architectures offer software solutions to configure and setup the end user interfaces for the remote laboratory experiments. However unlike the interface designer offered in our architecture, both ISES and Campos' solution require additional programming of the web interfaces. This, again would be undesirable for users who have experience in web development and programming.

V. CONCLUSION

In this paper, we have presented the problems in existing remote laboratory architectures through the review of previous work. We found that the creation of remote laboratories have always required high costs and technical expertise which causes stagnation and inflexibility as existing architectures are difficult to change and evolve. We proposed an architecture that removes these limitations, enabling users of all technical proficiencies to design, build and share their own remote laboratory experiments.

The proposed architecture innovates upon and differentiates itself from any existing solutions as it successfully removes a number of complex processes and requirements seen in the traditional architectures. This was done by simplifying, encapsulating and removing the steps and requirements into basic and user friendly workflows. Furthermore, with the use of technologies such as I²C communication, MQTT, HTML5, and JavaScript this solution provides a lightweight and modular

platform which allows non-technical users to be able to easily connect their experiments to the Internet. The cost and resources required to set up a remote laboratory experiment using this architecture is tremendously lower compared to currently existing high-end alternatives which presents new opportunities for innovation and further explorations into remote laboratory endeavours.

Future lines of work should focus on:

- Increasing the robustness and reliability by adding logic and state checks to the rig controller.
- Removing the restrictiveness caused by limiting the architecture to the slave modules by developing more generic modules which would support existing components and equipment.
- Improving the online platform by adding more functionality to provide lab owners a better experience when configuring and designing their remote laboratory experiments.
- Developing dedicated boards for the rig controller and slave modules and moving away from the prototyping Arduino boards.

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Student-Constructed Concept Maps for Active Learning in a Foundational Undergraduate Engineering Course

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Abstract—As a graphical pedagogical tool for knowledge organization, representation, and elicitation, concept mapping has been widely employed to improve student conceptual knowledge and understanding in a variety of academic disciplines. In the traditional approach to concept mapping, the instructor develops concept maps and then shows them in lectures. This work-in-progress study takes a non-traditional, active learning approach, in which students (rather than the instructor) construct their own concept maps in engineering dynamics, a foundational sophomore-year undergraduate engineering course. This paper provides representative examples of student-constructed concept maps. These maps were collected from a total of 165 engineering undergraduates who took an engineering dynamics course in one of two recent semesters: Semester A (94 students) and Semester B (71 students). Questionnaire surveys including both Likert-type and open-ended questions were administered at the end of each semester. The results show that 37% of the students rated their experience with developing their own concept maps “positive” or “highly positive,” and that 44% of the students “agreed” or “strongly agreed” that developing their own concept maps improved their conceptual understanding. Representative student comments are also provided in this paper.

Keywords—*student-constructed concept maps; active learning; engineering dynamics*

I. INTRODUCTION

Concept maps are a graphical pedagogical tool for knowledge organization, representation, and elicitation. Since Joseph Novak and his colleagues developed the technique of concept mapping [1], concept maps have been widely employed to improve student conceptual knowledge and understanding in a variety of academic disciplines [2-6]. For example, Egelhoff, Podoll, and Tarhini [5] developed a concept map for teaching a Mechanics of Materials course. Ellis, Rudnitsky, and Silverstein [6] developed two concept maps for teaching a Continuum Mechanics I course.

Educational research has been conducted to assess and evaluate the effectiveness of using concept maps to teach and

learn important subjects [7, 8]. For example, Horton, McConney, Gallo, Woods, Senn, and Hamelin [7] conducted a meta-analysis of 19 studies in various science disciplines and found that concept mapping had generally medium-positive effects on students’ academic achievement. Most recently, Nesbit and Adesope [8] conducted a meta-analysis of 55 studies that involved 5,818 students from Grade 4 to postsecondary in science, psychology, statistics, and nursing. They concluded that concept mapping was effective in achieving knowledge retention and transfer [8].

In the traditional approach to concept mapping, it is common for the instructor to develop concept maps and then show them in lectures. Students learn concepts by watching the instructor-constructed concept map and listening to the instructor’s explanations [5, 6, 9]. This traditional way is still passive because students are not fully and actively engaged in the learning process. Moreover, there are many different ways to organize a variety of concepts on a concept map. The concept map developed by the instructor might not be the only map that is technically correct and logically reasonable. In other words, the traditional approach to concept mapping does not provide students an opportunity to assimilate or represent the content in a graphical way.

This work-in-progress study promotes and fosters active learning by providing students opportunities to construct their own concept maps in engineering dynamics, a foundational sophomore-year undergraduate engineering course. The course is required in many undergraduate engineering programs, such as mechanical, aerospace, civil, biological, and biomedical engineering programs. The course covers a broad spectrum of foundational concepts, e.g., displacement, velocity, acceleration, force, moment, mass momentum of inertia, work, energy, impulse, momentum, and vibration [10, 11]. Because of the numerous concepts involved, many students have difficulty seeing connections and relationships among different concepts and fail to see the “big picture” of engineering dynamics [6, 9, 12].

This paper describes how students were offered opportunities to construct their own concept maps in engineering dynamics in two recent semesters: Semester A (94

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students) and Semester B (71 students). Representative examples of student-constructed concept maps are provided. Questionnaire surveys including both Likert-type and open-ended questions were administrated at the end of each semester in order to answer the following research question:

What were students' attitudes toward and experiences with constructing their own concept maps in engineering dynamics?

The scope of this work-in-progress study is limited in using questionnaire surveys to assess students' attitudes and experiences with concept mapping. A detailed assessment of the quality of student-constructed concept maps is beyond the scope of this study and will be addressed in future work.

II. STUDENT-CONSTRUCTED CONCEPT MAPS

A. Offering Students Opportunities to Construct Their Own Concept Maps

The students who recently took an engineering dynamics course in either Semester A or Semester B were offered opportunities to construct their own concept maps. The author of this paper was the instructor of the course in both semesters.

At the beginning of each 16-week semester, the instructor explained to the students what concept maps are, showed the students example concept maps, and taught them how to use a free online software program, IHMC Cmap Tools (<http://cmap.ihmc.us>), to draw a concept map. The students were encouraged to download the free online software to their own computers, so they could use it to draw and modify their concept maps.

At the end of each learning topic (i.e., each textbook chapter), the students were asked to construct their own concept maps and submit their maps to the instructor. Excellent student-constructed concept maps were shared in the class, so all students could learn from each other.

B. Learning Topics Covered in Engineering Dynamics

Each student participant developed a concept map for each of the following eight learning topics in engineering dynamics:

- Kinematics of a Particle
- Kinetics of a Particle: Force and Acceleration
- Kinetics of a Particle: Work and Energy
- Kinetics of a Particle: Impulse and Momentum
- Planar Kinematics of a Rigid Body
- Planar Kinetics of a Rigid Body: Force and Acceleration
- Planar Kinetics of a Rigid Body: Work and Energy
- Planar Kinetics of a Rigid Body: Impulse and Momentum

Each learning topic contains many concepts. For example, the "Kinetics of a Particle: Force and Acceleration" learning topic involves Newton's Second Law, rectangular coordinates, normal and tangential coordinates, and cylindrical coordinates. Throughout the semester, each student participant constructed a total of eight concept maps, covering all the above eight learning topics.

III. RESULTS AND ANALYSIS OF QUESTIONNAIRE SURVEYS

A. Student Participants

A total of 165 students in two semesters participated in the present study. They all signed the Informed Consent letter approved by an Institutional Review Board. Table I shows student demographics in terms of gender. The vast majority (89.7%) of the students were males, while female students accounted for 10.3% only.

Table II shows student demographics in terms of major. The majority of the students were either mechanical and aerospace engineering (MAE, 52.7%) or civil and environmental engineering (CEE, 22.4%) majors. Less than 25% were biological engineering or other majors.

B. Questionnaire Surveys

Questionnaire surveys were administrated at the end of each semester. The surveys include both Likert-type and open-ended questions, for example:

1. Please rate your overall experience with developing your own concept maps: 1) highly negative; 2) negative; 3) neutral; 4) positive; 5) highly positive
2. On average, the time that you spent on developing your own concept maps, including thinking about it and then drawing it with hands or a computer, was 1) < 10 minutes; 2) 10-20 minutes; 3) 20-30 minutes; 4) 30-40 minutes; 5) > 40 minutes for each map
3. Overall, the concept maps helped improve your conceptual understanding of dynamics concepts, laws, and principles as well as their relationships: 1) strongly disagree; 2) disagree; 3) neutral; 4) agree; 5) strongly agree
4. Please describe in detail how the concept maps helped, or did not help, with your conceptual understanding of dynamics concepts, laws, and principles as well as their relationships.

TABLE I. STUDENT DEMOGRAPHICS: GENDER

Semester	Male	Female
Semester A (n = 94)	84 (89.4%)	10 (10.6%)
Semester B (n = 71)	64 (90.1%)	7 (9.9%)
Semesters A and B (n = 165)	148 (89.7%)	17 (10.3%)

TABLE II. STUDENT DEMOGRAPHICS: MAJOR

Semester	MAE	CEE	BE	Other
Semester A (n = 94)	53 (56.4%)	16 (17.0%)	12 (12.8%)	13 (13.8%)
Semester B (n = 71)	34 (47.9%)	21 (29.6%)	11 (15.5%)	5 (7.0%)
Semesters A and B (n = 165)	87 (52.7%)	37 (22.4%)	23 (13.9%)	18 (10.9%)

C. Results and Analysis

As representative examples, Figs. 1 and 2 (see the next page) show two original concept maps constructed by two students on “Kinetics of a Particle: Force and Acceleration” and “Kinetics of a Particle: Work and Energy,” respectively. The two students employed different font sizes on their maps.

In Fig. 1, the student starts from Newton’s Second Law and indicates clearly that it can be applied in three forms using rectangular coordinates, cylindrical coordinates, and normal and tangential coordinates. All three forms can be analyzed through free-body and kinetic diagrams. The student also includes important equations on his concept map.

In Fig. 2, the student places “Work of a Force” in the central position of his concept map. This central concept is linked with three other concepts: power, Conservation of Energy, and the Principle of Work and Energy. The map also clearly shows how the “Work of a Force” concept is associated with other concepts using either equations or linking words.

Tables III-V summarizes student responses to three Likert-type questions employed in the questionnaire surveys. As seen from these tables, among 165 student participants, 37% had “positive” or “highly positive” experiences with developing their own concept maps, 45% spent more than 20 minutes on average in developing each concept map, 44% “agreed” or “strongly agreed” that developing concept maps improved their conceptual understanding. Representative student comments are provided below:

“It help me to put my mind in order. It help me to understand much better because I had to read the chapter before to do the concept map. So when I was reading, I was learning at same time.”

“I was able to spend quality time developing and understanding how each concept connected to other concepts in the chapter and this helped me formulate ideas of practical and academic applications of the content.”

“First of all it made me go back to review the entire chapter after we had finished learning it in class. It also helped me build bridges for which equation can be used in each situation.”

“They helped by piecing together how everything worked together and how it all fit.”

“The concept maps helped me to organize my thoughts about each chapter. It made it so I could see how each all the different concepts, laws, and principles fit together in the big picture.”

IV. LIMITATIONS AND FUTURE WORK

The primary limitation of this work-in-progress study lies in that it has not focused on a detailed assessment of the quality of student-constructed concept maps. Because the study involved 156 students and each student developed eight maps, a total of 1,248 concept maps have been generated from this study. Assessing the quality of each map will take a significant amount of time and effort. Because there are many different ways to organize concepts on a concept map, a detailed rubric will need to be developed to assess the quality of student-cons-

TABLE III. STUDENTS’ OVERALL EXPERIENCE WITH DEVELOPING THEIR OWN CONCEPT MAPS

Semester	Highly Negative	Negative	Neutral	Positive	Highly Positive
Semester A (n = 94)	8%	20%	36%	32%	4%
Semester B (n = 71)	2%	10%	48%	35%	4%
Semesters A and B (n = 165)	5%	16%	41%	33%	4%

TABLE IV. THE AVERAGE TIME STUDENTS SPENT IN DEVELOPING EACH CONCEPT MAP

Semester	< 10 Min.	10-20 Min.	20-30 Min.	30-40 Min.	> 40 Min.
Semester A (n = 94)	32%	34%	20%	12%	2%
Semester B (n = 71)	10%	31%	32%	18%	8%
Semesters A and B (n = 165)	22%	33%	25%	15%	5%

TABLE V. DEVELOPING CONCEPT MAPS IMPROVES STUDENTS’ CONCEPTUAL UNDERSTANDING

Semester	Strongly Disagree	Dis-agree	Neu-tral	Agree	Strongly Agree
Semester A (n = 94)	10%	21%	29%	35%	5%
Semester B (n = 71)	5%	17%	28%	44%	6%
Semesters A and B (n = 165)	8%	19%	28%	39%	5%

tructed concept maps [13, 14]. The development and implementation of this assessment rubric will be a future work.

V. CONCLUDING REMARKS

This paper has described a non-traditional approach to concept mapping, in which students (rather than the instructor) construct their own concept maps in engineering dynamics, a foundational sophomore-year undergraduate engineering course. As students must develop their own concept maps, this non-traditional approach promotes active learning, creativity, and critical thinking. A total of 165 students who took an engineering dynamics course in two recent semesters have participated in this study. The results of questionnaire surveys show that 37% of the students rated their experience with developing their own concept maps “positive” or “highly positive,” and that 44% “agreed” or “strongly agreed” that developing their own concept maps improved their conceptual understanding.

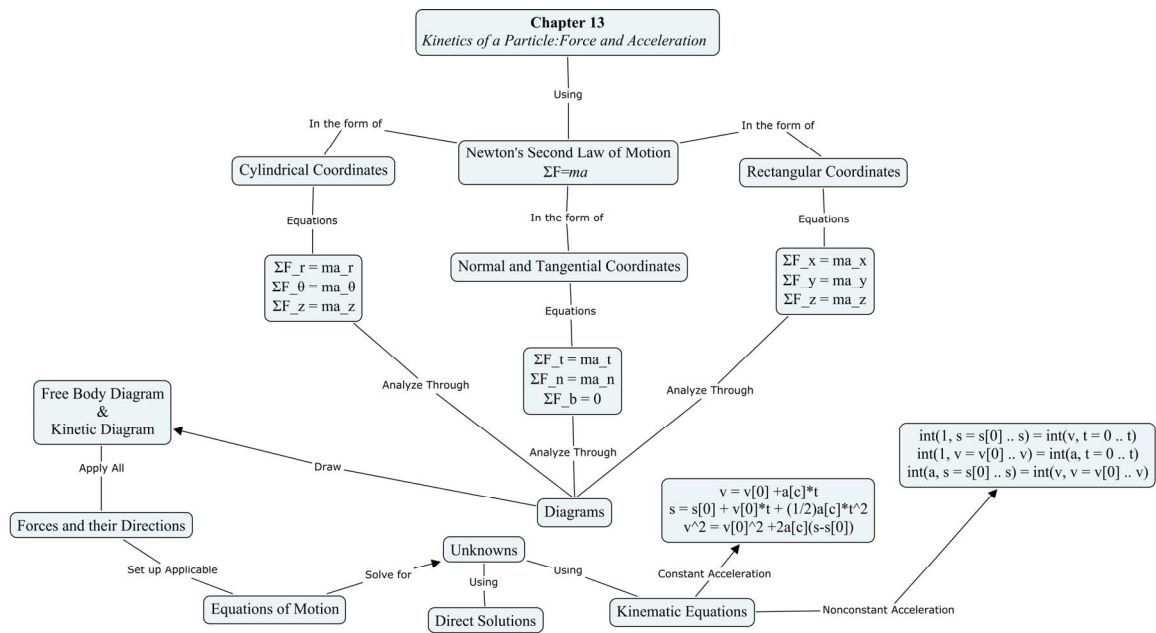


Fig. 1. A student-constructed concept map on the learning topic of “Kinetics of a Particle: Force and Acceleration.”

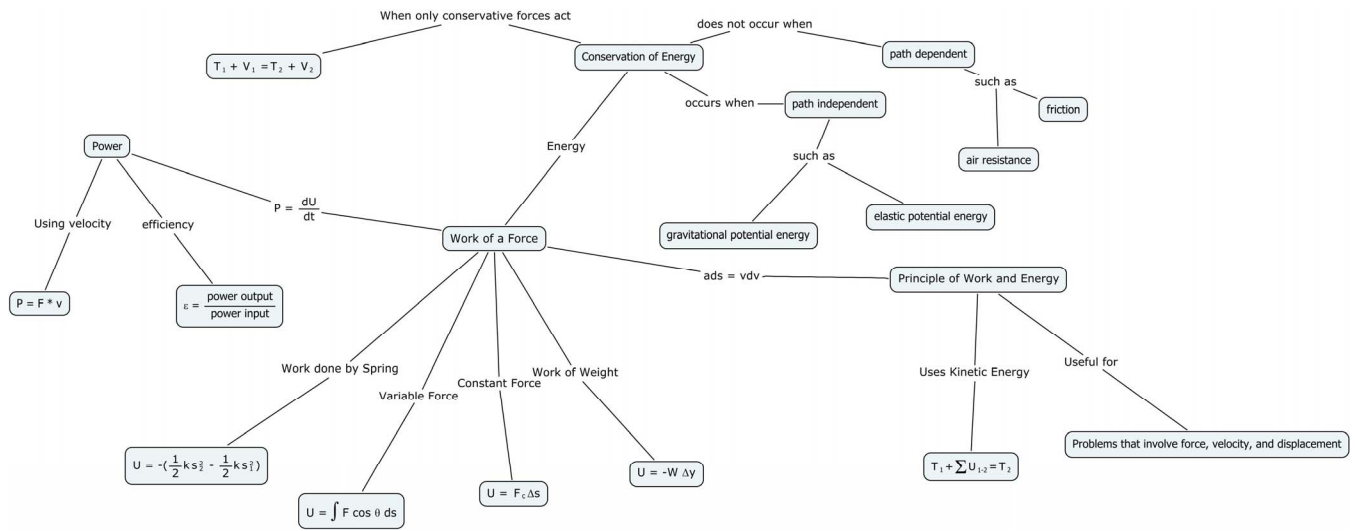


Fig. 2. A student-constructed concept map on the learning topic of “Kinetics of a Particle: Work and Energy.”

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O-Charts: Towards an Effective Toolkit for Teaching Time Complexity

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Abstract—Scientists, business analysts, and others in a growing number of fields are trying to cope with the vast amount of data being generated. The lack of software that can efficiently process large data sets hinders insight into complex relationships. One of the most important concepts in learning how to construct efficient code is time complexity analysis with Big-O notation. Students often find time complexity difficult to learn and too abstract to apply in any meaningful way. Common instructional methods consist of a combination of mathematics and intuitive analysis which are often too cumbersome for practical application or cannot be extended to complex algorithms. Unfortunately, there are few tools available for teaching time complexity that students find concrete, straightforward, and applicable to real problems. In this paper, we present O-Charts, a first step in the development of a practical toolkit for teaching and applying time complexity analysis. O-Charts allow the systematic analysis of deeply nested loops where the use of control variables makes the number of executions difficult to define, calculate, and explain. We report initial results and our plans for future work.

I. INTRODUCTION

As the size of data sets continues to grow, constructing code capable of efficiently processing large amounts of data is increasingly important. A significant part of teaching students how to build efficient code is analyzing algorithm time complexity using Big-O notation. Although extremely important to an increasing number of fields outside of computer science, algorithm efficiency using Big-O notation is rarely taught before a third computer science course. Even during a third course, students often find time analysis difficult to learn and too abstract to apply.

There are few resources available for teaching time analysis in a manner that students find understandable and applicable. Most instructional techniques currently consist of mathematical approaches, intuitive approaches, or a hybrid of mathematics and intuition. The problems associated with current instructional techniques first become evident when asking students to evaluate an algorithm with deeply nested loops where the number and use of control variables obscure a direct analysis. Theoretical approaches for analyzing code with these complex loops require a high level of mathematical preparedness and, even for the mathematically literate, quickly become too cumbersome to develop or communicate in a practical setting. Intuitive approaches and rules-of-thumb are limited to cases where the efficiency can be quickly deduced or where the control variables are used in a straightforward

manner. Hybrid approaches often lack a bridge that cohesively connects the mathematics to intuition.

This work-in-progress introduces O-Charts, our first step in developing a comprehensive and practical toolkit for calculating algorithm time efficiency. O-Charts allow students to methodically analyze code with loops where the efficiency is obscured by the number and use of control variables. O-Charts were successfully employed as a teaching tool in a third semester data structures course to help analyze deeply nested loops with multiple control variables. Students were tracked for their performance on selected test questions and then surveyed at the end of the course. Initial results indicate a step forward in making time analysis more concrete and easier to apply. We plan to use the technique presented here as a starting point in the development of tools tailored for each algorithm type that students find difficult to analyze. This toolkit will make teaching time complexity more targeted and will provide a way of introducing those concepts earlier in the curriculum.

The remainder of the paper is organized as follows. A brief introduction to Big-O is first presented followed by a survey of related work. Next, we present O-Charts. We then describe how O-Charts were used in a third semester data structures course and how we measured student achievement. Finally, future work is presented.

II. BACKGROUND

Quantifying completion times is one of the first steps in analyzing algorithm efficiency. Computer scientists often compare the growth rate of completion times to establish a relative ordering among algorithms [3]. This ordering is based on the number of times that the most time consuming operation (basic operation) is executed and allows algorithm comparisons to be generalized across multiple machines. Of primary importance is an algorithm's upper bound and lower bound. Big-O notation is used for describing the asymptotic upper bound and Big-Omega (Ω) is used for describing the asymptotic lower bound. Big-Theta (Θ) is used to denote an asymptotically tight bound. There are additional classifications depending on the level of desired specificity. We do not consider classifications other than Big-O in this initial attempt since the upper bound is the focus of most algorithm analysis in early computing courses.

Listing 1. Nested loops with a time complexity of $O(n^5)$.

```

1   for(int i = 0; i < n; i++)
2       for(int j = 0; j < i * i; j++)
3           for(int k = 0; k < j; k++)
4               sum = sum + 1;

```

Listing 2. Nested loops with a time complexity of $O(n^7)$.

```

1   for(int i = 0; i < n; i++)
2       for(int j = 0; j < i; j++)
3           for(int k = 0; k < j * i; k++)
4               for(int m = i; m < j * k; m++)
5                   temp = i * j + k * m;

```

A. Summation Notation

The run time of loops is often represented and solved with summation notation. For simple nested loops, students may be able to quickly derive and solve summations. However, as the number of nests and control variables increase or become less direct, quickly deriving and solving summations becomes more difficult. For example, the time complexity for the nested loops in Listing 1 would be found solving

$$\sum_{i=0}^{n-1} \sum_{j=0}^{i^2-1} \sum_{k=0}^{j-1} 2 \quad (1)$$

in terms of n where the constant was derived from the observation that the inner most loop consists of two operations (assignment and addition). For simplicity, we assume each operation takes a single time unit to complete and that all loop setup costs are ignored. A summation similar to that shown in Equation (1) may prove intimidating and difficult for students just being introduced to time analysis. As nests become deeper and variable use less direct, an increasing amount of mathematical maturity is necessary. For example, a time analysis of the nested loops in Listing 2 would require solving

$$\sum_{i=0}^{n-1} \sum_{j=0}^{i-1} \sum_{k=0}^{ji-1} \sum_{m=i}^{jk-1} 4. \quad (2)$$

If students do not have the necessary level of mathematical maturity, solving deeply nested summations requires that an instructor (or employer if in an industry setting) spend time constantly refreshing math skills. Even if the student has a solid background in mathematics, mistakes in applying appropriate rules and identities can significantly alter results. Furthermore, once the final derivation is found a student or employee may have difficulty articulating their findings to other programmers or managers that may not have the same level of mathematical literacy.

B. Rules-of-Thumb and Intuitive Analysis

Mathematics form the foundation of algorithm analysis and are an important part of a computer scientist's education.

However, many data structures instructors spend little time on mathematics and quickly follow any theoretical approaches with simple rules-of-thumb and intuitive analysis. Rules-of-thumb attempt to give simple guidance to quickly analyze frequently occurring code constructs. Rules-of-thumb found in a popular data structures book [3] and used in our data structures course include 1) the running time of a *for* loop is at most the running time of the statements inside the loop multiplied by the number of iterations, 2) nested loops should be analyzed inside-out where the total running time of a statement inside a group of nested loops is the running time of the statement multiplied by the product of all loop sizes, 3) consecutive statements are added, and 4) the time required for an *if/else* statement is never more than the running time of the test plus the most time consuming branch.

Intuitive analysis simplifies the process further. Often, this type of analysis attempts to eliminate all operations that do not contribute to the leading term of the Big-O formulation. For example, an intuitive analysis of an array search may be similar to the following:

In the worst case, the element being searched for may be the last element or not in the array. Therefore, the search may have to include every element in the array and this results in a run time of $O(n)$.

Rules-of-thumb and intuitive methods greatly simplify analysis for instructors, students, and professionals. However, these are difficult to extend to code segments that are more complicated. Using rules-of-thumb for the code in Listing 2 requires calculating the number of iterations of the basic operation which reduces to solving the summation in Equation 2. Intuitive analysis for the same set of loops is, at best, difficult and, at worst, nonexistent. Instructors, students, and professionals using traditional methods must choose between complicated mathematics and oversimplified rules. Neither approach may be appropriate given the background of the analyst or the ones with which the analyst may need to communicate.

III. RELATED WORK

There has been little progress in developing concrete methods to help students understand and apply time complexity. The progress has been so slow that Rouso [2] argues in favor of a new paradigm. Another approach is to better understand why students find Big-O challenging and then change how time complexity is presented according to student needs. Parker and Lewis [1] conducted student interviews and found that students struggle because of both the mathematical function involved in the analysis and the technique employed to solve the analysis. They also found that students feel more comfortable with tangible and concrete analysis methods. O-Charts support this finding by visually bridging the gap between mathematics and intuitive analysis with a concrete, systematic approach.

IV. O-CHARTS

O-Charts are visual tools for methodically analyzing nested loops. To analyze sections of code, O-Charts allow the analyst to substitute inner loop variables with outer loop variables. First, a small chart representing expanded Big-O notation is

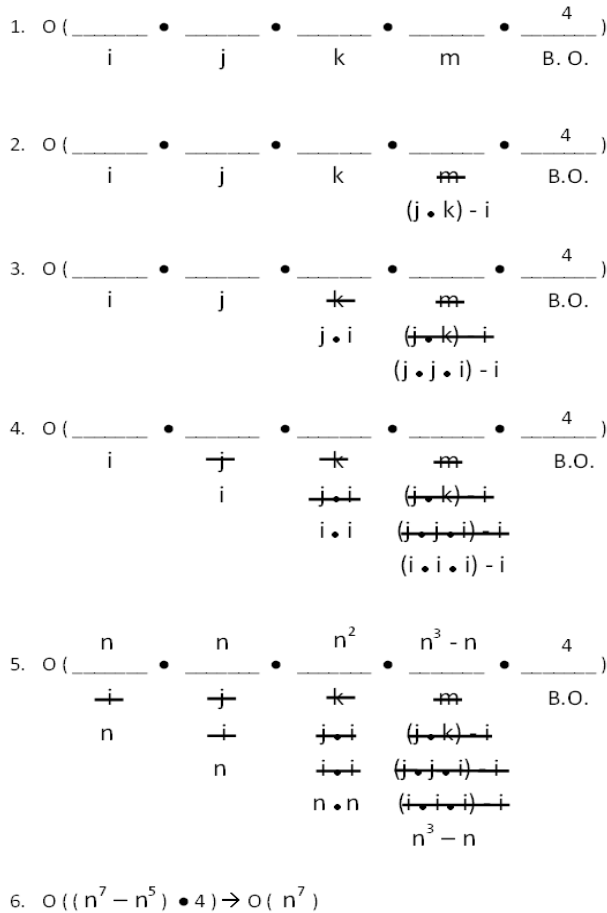


Fig. 1. Steps in determining the time complexity for the nested loops shown in Listing 2 with O-Charts.

drawn with each control variable listed under a single blank. Because the same format will continue throughout analysis, this approach encourages consistency among multiple control variables and eventually to additional code segments. Second, the control variable for each nested loop is systematically replaced with an outer loop variable until all of the variables can be rewritten in terms of the outermost control variable. Third, the terms are combined to find the overall upper bound.

A. Example

We now illustrate how O-Charts can be used to analyze the deeply nested loop in Listing 2. In the example presented here, O-Charts are used to realize the complex multiplicative effects of deeply nested loops without summations. Figure 1 shows the process which is described step-by-step below:

- **Step 1:** Big-O notation is extended to include each control variable and a space for the time of the basic operation. The basic operation has a constant time of 4 (one time unit for each assignment, multiplication, and addition on line 5 in Listing 2) and is listed in the chart.
- **Step 2:** The basic operation is executed m times in the inner most loop. The loop with m is executed $(j \cdot k) - i$

times and this expression replaces all occurrences of m in the chart.

- **Step 3:** The next outermost loop (Listing 2, line 3) iterates k times. The loop with k is executed $j \cdot i$ times and the expression $j \cdot i$ replaces all occurrences of k in the chart.
- **Step 4:** The next outermost loop (Listing 2, line 2) iterates i times. All occurrences of j in the chart are replaced with i .
- **Step 5:** The outermost loop (Listing 2, line 1) iterates n times. The variable n replaces all occurrences of i . All variables in the loops and listed in the chart during Step 1 are now in terms of n . The total number of executions for each variable can be written in the blanks in terms of n .
- **Step 6:** Multiplications are performed and finalized in Big-O notation.

V. EXPERIMENTAL USE AND RESULTS

O-Charts were used in one section of a third semester data structures course at Western Carolina University. Students entering the course had either limited or no experience in time analysis. Big-O was first presented with summation notation, second with O-Charts, and third with intuitive analysis. O-Charts were presented between the two techniques because they are less complicated than summation notation but more detailed than intuitive analysis.

Student use of O-Charts was evaluated by both quantitative and qualitative methods. Quantitative evidence was gathered by evaluating performance on selected test questions that asked students to use O-Charts to derive the time complexity. 85 percent of students correctly analyzed the loops in Listing 1 as having an upper bound of $O(n^5)$. 53 percent of students correctly analyzed the loops in Listing 2 as having an upper bound of $O(n^7)$.

Qualitative evidence was gathered by anonymously surveying the students. Thirteen students completed the survey that included the following questions:

Question 1: *If someone asked you to find the worst case time complexity for a section of code, would you rather use summation notation or the chart method? Why?*

Question 2: *If someone asked you to explain the worst case time complexity for a section of code to someone else, which method (summation notation or the chart method) do you think would help you explain it more effectively? Why?*

One survey was discarded because the responses were unclear but the remaining results were overwhelmingly in favor of O-Charts. All students preferred O-Charts to analyze code segments (Question 1). According to the written responses from the survey, the charts were

- *Easier to visualize*
- *Simpler and less math intensive*
- *More straightforward and obvious to solve*

Nine of the twelve students would prefer to use O-Charts to explain the analysis to others instead of summation notation (Question 2). The students responded that the chart method

- *Breaks down each loop separately*
- *Isn't as confusing*
- *Easier to understand how each for loop relates to the others*

Although most of the students preferred using O-Charts to explain their analysis to others, three thought summation notation was the preferred method. Students that preferred summation notation believed that the mathematical approaches are more detailed, relate directly to the code, and may appeal to a more mathematically literate audience.

We also asked students to rate how easy each of the two methods were to use from 1 (easy) to 5 (difficult). The O-Charts averaged 1.9 and summations averaged 3.9. The distribution for each type of analysis on the easy to difficult scale is shown in Figure 2.

VI. DISCUSSION

Results indicate that O-Charts worked well for the specific types of loops described here and shown in Listings 1 and 2. Student satisfaction was higher for O-Charts than for summation notation. This is an important finding considering that the simplicity of O-Charts allowed the instructor to efficiently present loops that were more deeply nested than the loops presented with summation notation. We recommend using O-Charts between the mathematical and intuitive approach since this order introduces students to both the theoretical and intuitive approaches with decreasing granularity. Not only does this order provide a cohesive bridge between the traditional methods, it also fits the approach of following mathematics with intuition already used by many instructors.

In the code examples here (Listing 1 and 2), only a single set of nested loop is considered. O-Charts can be extended to larger sections of code that include multiple nested loop segments. As students progress in the analysis, they simply construct a chart for each consecutive statement and then sum the individual chart results.

Although effective, O-Charts represent an initial attempt and should be further refined. Improvements include capturing more code constructs, such as searching and sorting algorithms, that students find difficult to analyze. Additionally, O-Charts should be flexible enough to express more algorithm classes (Ω , Θ , etc.).

VII. CONCLUSION AND FUTURE WORK

In this work-in-progress, we have presented our first steps in building an effective toolkit for teaching and applying time complexity. Students performed well when analyzing deeply nested loops. They also reported feeling more comfortable using and applying O-Charts than mathematical techniques. For instructors, O-Charts fill a gap when transitioning from mathematical techniques to intuitive analysis.

There are many avenues for future work. First, we only tracked student performance on O-Charts. In the next phase of

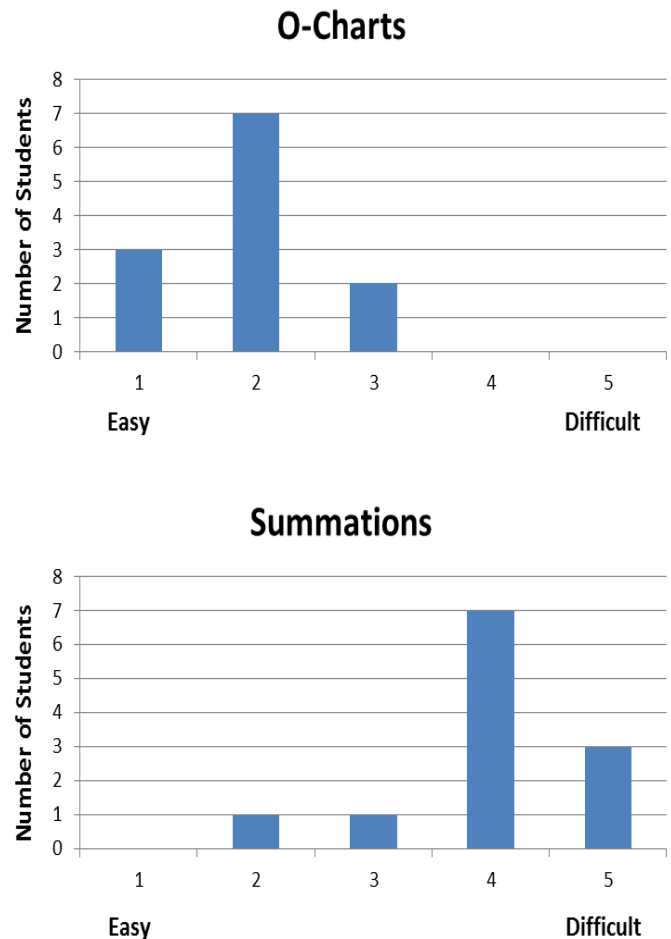


Fig. 2. Students rated O-Charts (top) and summation notation (bottom) from easy to difficult. Each column represents the number of students for a given rating. The results reveal that the students found O-Charts much easier to use than summation notation.

research, we would like to more directly compare summation notation, O-Charts, and intuitive analysis techniques on the same segment of code. Second, we would like to experiment with a more thorough introduction to time analysis earlier in the curriculum. The quick and systematic approach presented here make O-Charts a viable possibility for the early introduction of time complexity. Third, more algorithm classes should be included. Finally, more code constructs which present problems for students, including advanced searching and sorting techniques, need to be identified so that O-Charts can be altered appropriately or additional tools developed.

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Analyzing Educational Comments for Topics and Sentiments: A Text Analytics Approach

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Abstract— Universities collect qualitative and quantitative feedback from students upon course completion in order to improve course quality and students' learning experience. Combining program-wide and module-specific questions, universities collect feedback from students on three main aspects of a course namely, teaching style, content, and learning experience. The feedback is collected through both qualitative comments and quantitative scores. Current methods for analyzing the student course evaluations are manual and majorly focus on quantitative feedback and fall short of an in-depth exploration of qualitative feedback. In this paper, we develop student feedback mining system (SFMS) which applies text analytics and opinion mining approach to provide instructors a quantified and exhaustive analysis of the qualitative feedback from students and avail insights on their teaching practices and this in turn will lead to improved student learning.

Keywords—Student feedback, education data mining, topics, sentiments, text analytics, clustering.

I. INTRODUCTION

Universities employ various formal and informal methods to collect and analyse feedback from students in order to enhance the quality of teaching and learning. Many institutions have implemented evaluation surveys which combine "program-wide" questions and "module-specific" questions that enable comparisons to be made across the institution whilst allowing flexibility for individual modules [4]. These surveys provide valuable feedback that helps course designers towards improving teaching style, course content and assessment design, and overall student learning [2][3]. The feedback must be analysed and interpreted with great care so that action, and ultimately improvement, can result from feedback process [1].

Students provide feedback in two distinct forms namely quantitative (numerical) ratings for questions and qualitative comments related to teaching, content and learning [5]. The teaching component refers to instructors' interaction, delivery style, ability to motivate students, out of class support, etc. The content refers to course details such as concepts, lecture notes, labs, exams, projects, etc. The learning refers to students learning experience such as understanding concepts, developing skills, applying skills acquired, etc. Analysing and evaluating this qualitative data to help us make better sense of student feedback on instruction and curriculum.

Current methods for analysing student course evaluations are manual and majorly focus on the quantitative feedback [17] [18]. More often, an analysis of student feedback falls short of an in-depth exploration of a qualitative feedback [32], thereby limiting instructors to the numerical scores and a human understanding of a sample of the feedback, which abstracts collective sentiments for individual components of courses. The question is to how to help the faculty to better digest such large amounts of comments and discover the gaps in the course delivery.

Going forward, a more useful approach will be to map the students' qualitative feedback in the form of topics and sentiments towards the three major components namely teaching, content and learning. Figure 1 shows the problem setup. The input data is a set of students' comments given for an information systems curriculum undergraduate course, IS304, process modelling and solution blueprinting.

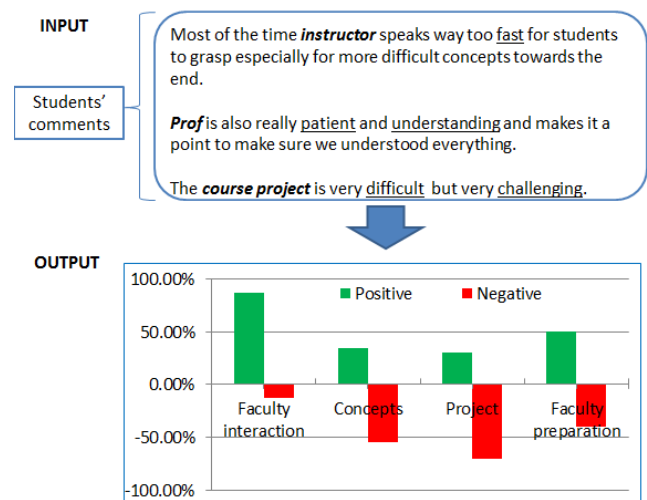


Fig. 1. Sample comments from students for an information systems curriculum undergraduate course. Bolded words are the topics and underlined words are the sentiment words.

With such data, an instructor can only get an overall impression of the course and not the deeper insights. It is infeasible to go over all the comments for deeper analysis. In contrast, an output such as topic based summary on sentiments as shown in Figure 1 provides a detailed analysis. A **topic** refers to an aspect of the course such as concepts, delivery style, understanding, lab, faculty interaction, skills, learning,

etc., and **sentiment** refers to positive or negative experience with the corresponding topic. Figure 1 shows the topics such as “concepts” and “project”, and sentiment words such as “patient”, “understanding”, “challenging”, etc. The overall sentiment for *professor* is positive, while the sentiment on *concepts* is negative. Extracting individual topics and sentiments automatically provides instructors and curriculum managers a data-driven approach for improving teaching and learning. Decisions can be made while constructing future cycles of course delivery to maintain or improve components as per feedback and measure the impacts.

In this paper, we provide automated techniques to diagnose textual feedback. The main challenge with this task is the textual nature of comments which are expressed in natural language. Furthermore, the feedback topics and sentiments are embedded within the text. Opinion mining, topic extraction and NLP techniques [8] [15] [16] from the text analytics and linguistics research are widely popular for mining users’ comments in social media. Sentiment mining techniques are widely used for product review mining in consumer business world [9] [12]. We leverage these techniques for building the student feedback mining system (SFMS). SFMS applies data mining, text mining and opinion mining techniques on qualitative comments to extract topics and sentiments on courses aiding in generating quantitative visuals to support a deeper analysis.

We evaluated SFMS using student feedback provided by the students for undergraduate core courses taught at the School of Information Systems, Singapore Management University collected for two semesters on seven courses. Information Systems is classified under science and technology education (all engineering courses as classified under this) by Ministry of Education, Singapore. The evaluation is conducted in two phases; quality of the topic extraction and quality of the sentiment extraction. Our experiments show that SFMS system provided meaningful clusters of comments and aspect words for topic extraction task and precision of 80.1% for sentiment extraction task.

The paper will be structured as follows. Section II will review the key background of text analytics techniques and opinion mining problem. Section III will be devoted to literature review and will primarily focus on describing the current research done in the field of student feedback analysis. Section IV describes our system in detail for topic and sentiment extraction from students’ comments. Section V describes our dataset and pre-processing of data. In section VI, we focus on experiments, results, discussions and pointing some interesting future directions of our work, and we conclude in section VII.

II. BACKGROUND

Text mining and natural language processing techniques are useful for opinion mining research. Therefore, we first provide a brief description of few text analytics techniques that are key components to our system, followed by the background of opinion mining research.

A. Text Analytics Techniques

Text analytics or text mining is a knowledge discovery technique that provides computational intelligence [12] [19] through devising of patterns and trends. The techniques comprise of multidisciplinary fields, such as information retrieval, extraction, text analysis, natural language processing, and data mining. Text mining techniques enable to identify similarities between text attributes [12]. Some of the natural language issues that should be considered during text mining are tokenization, stop word lists, etc.

Stop word removal: Most frequently used words in English are useless in Text mining. For example “has”, “if”, “and”, “on” etc. Such words are called stop words. Stop words are language specific functional words which carry no information and therefore removed from the documents during data pre-processing stage. Parts of Speech such as pronouns, prepositions, conjunctions are defined in stop word list¹.

Tokenization: Tokenization deals with the splitting of text into units during data pre-processing. Text can be tokenized into paragraphs, sentences, phrases and single words. The delimiters used in this process vary with data sets.

Stemming: This method is used to find out the root/stem of a word. Words are stemmed using the Porter Stemming algorithm [31], which returns the root form of a word. For instance, the word “progression” is stemmed as “progress” and “progress*” is formed as part of the query. However, in our preliminary experiments we observed that, stemming impairs our results. Therefore, we do not use stemming.

Document Representation: In order to score the similarity between two documents, we need to first adopt a vector space representation of a document where each document is evaluated as a term-frequency (TF) vector [18] and inverse document frequency (IDF) [18]. TF-IDF is a statistical measure or weight often used in information retrieval and text mining to evaluate how important a word or term is to a document in a collection or corpus. Term frequency is the number of occurrence of a term in a document. The information that is captured by term frequency tells how salient a word is within a given document. Document frequency on the other hand can be interpreted as an indicator of informativeness. Inverse document frequency is used to scale down the term frequency of terms with high total number of occurrences in the collection. Both these measures aids in generating the aspects or topics for a comment in our case. One way to combine a word’s term frequency and inverse document frequency into single weight is a TF-IDF. Finally, each document in the dataset is represented as a document-term matrix.

Document similarity score: The similarity score between two documents determines the co-occurrence of a primary topic between two documents to cluster them together. We compute this score by computing the cosine angle between them [18] which are modeled as vectors in a vector space.

¹ www.ranks.nl/resources/stopwords.html

Agglomerative Clustering: Clustering algorithms are exploratory data analysis tools that have proved to be essential for gaining valuable insights on various aspects and relationships of the underlying textual data [16]. Agglomerative algorithms find the clusters by initially assigning each object to its own cluster and then repeatedly merging pairs of clusters until either the desired number of clusters has been obtained or all the objects have been merged into a single cluster leading to a complete agglomerative tree. The key step in these algorithms is the method, also referred to as clustering function, used to identify pairs of clusters to be merged iteratively.

B. Opinion Mining

Opinions are central to almost all human activities and are key influencers of our decision making process. Opinion mining is a well-studied research topic for the past ten years mainly focusing on opinion extraction, sentiment classification, opinion summarization and applications in real world. Opinion mining found its roots in many real-life applications and several application-oriented research studies have been published.

Figure 2 shows the architecture of opinion mining. Opinion mining architecture takes users' comments as inputs to generate sentiment analysis visualizations as outputs that can aid the decision makers in decision making process. The text processing component handles data cleansing and processing issues. In next subsections, we briefly explain the main components of the architecture namely, topic extraction, sentiment classification and opinion summarization.

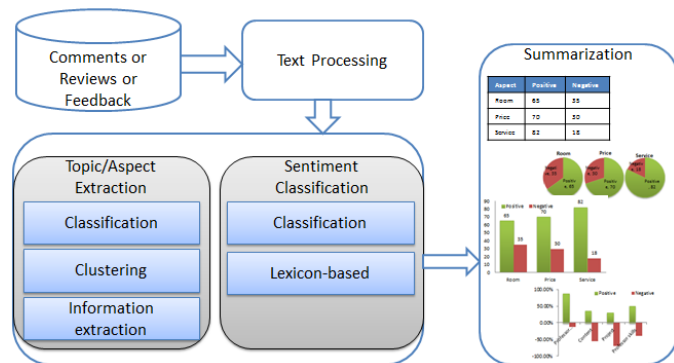


Fig. 2. Opinion mining architecture.

C. Topic Extraction

Opinion extraction aims at automatically finding attitudes or opinions about specific targets, such as named entities, consumer products or public events [8] [15]. An opinion without its target being identified is of limited use [9]. For many applications opinion extraction is insufficient, and a fine-grained opinion mining and analysis such as topic or aspect extraction is highly effective [9] [10]. "The iPhone's call quality is good, but its battery life is short" evaluates two aspects, call quality and battery life. Hu and Liu used a data mining algorithm that finds explicit aspect expressions that are nouns and noun phrases from a large number of reviews in a given domain [9]. Jiang et al. proposed how a dependency

parser was used to generate a set of aspect dependent features for classification [15]. Many algorithms based on supervised learning have been proposed in the past for information extraction [14]. Clustering based feature extraction techniques are implemented by some research works [6] [7]. Beil et al. designed clustering technique on the basis of frequent pattern mining [7]. Lu et al. proposed clustering based technique for discovering aspects from users' comments [6]. Inspired by these works, we use agglomerative clustering to group comments into clusters based on their cosine similarity.

D. Sentiment Classification

Sentiment classification aims at classifying the data into positive or negative polarities [12] using supervised methods or unsupervised methods. Similar to opinion extraction, fine grained sentiment analysis is desired as it is highly effective to understand the pulse of the consumers at feature level. The task of sentiment target detection [9] aims at extracting the sentiment targets in the reviews using multiple heuristic techniques. Pang et al. examined several supervised machine learning methods like SVM and Bayes classification for sentiment classification of movie reviews and showed that classifiers performed poorly on sentences as sentences contains less information [12].

Lexicon methods are based on sentiment words and phrases which are instrumental to sentiment analysis for obvious reasons [8]. A list of such words and phrases is called a sentiment lexicon (or opinion lexicon). Over the years, researchers have designed numerous algorithms to compile such lexicons; SentiWordNet [11] and Sentiment lexicon [9]. Our system generates sentiment for each topic using classification approach.

E. Opinion Summarization

Summarization is a study that attempts to generate a concise and digestible summary of a large number of opinions [8]. Current research aims at two types of summarization: aspect-based summarization and non-aspect-based summarization. Aspect-based summarization divides input texts into aspects, which are also called features, and generates summaries of each aspect [9] [13]. A common form of summary is based on aspects and is called aspect-based opinion summary (or feature-based opinion summary) [8] [9].

III. RELATED WORK

Traditionally, universities collected written feedback from students regarding the course taught and the professor's engagement in order to assist the development of the course through future cycles. Pedagogical theory of student feedback describes the need for interpreting students' perceptions and sentiments for overall teaching evaluation and improvements [33]. Donovan et al. [17] found that online student feedback comments were longer and that they were more formative in nature than the traditional written feedback. Moreover, online feedback received longer and half as many (54% or more) comments as traditional written comments. This highlights the importance of collecting online comments. However, manually reading and analyzing these online comments takes a lot of time and hence the need for an automated feedback system

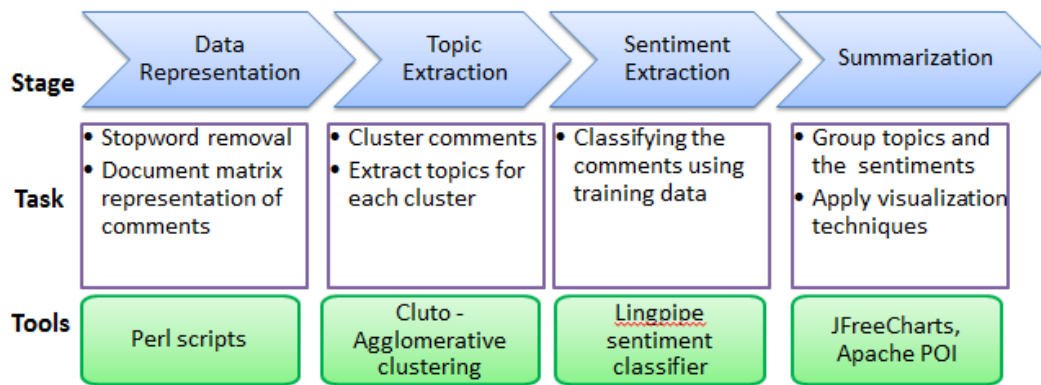


Fig. 3. SFMS system architecture

which automates feedback collection and analysis, allowing a visual analysis of opinions or sentiments on different aspects of the course.

In existing research on educational data mining, the more prominent forms of analysis are with Apriori algorithms, decision trees and clustering algorithms [18] with most research being done on association pattern mining to find links between opinions on courses and professors in order to better cater to students, enhance their grades, prevent drop-out or transfers and improve the overall degree experience. Altrabsheh et al. devised a system to analyze sentiments in real time to provide real-time intervention in the classroom. Their experiments yielded the conclusion that Support Vector Machines and Complement Naïve Bayes produced the most accurate results while learning sentiment [19]. Hajizadeh et al. experimented on student feedback to analyze whether or not a student would retake the course [20] indicating sentiment opinions about the course. Rashid et al. used generalized sequential pattern mining and association rule mining with 87% accuracy to analyze opinion words from student feedback while stopping short of sentiment classification upon identification of the opinion words [21]. Gamon et al. took another approach for analyzing sentiment in free flowing text – as is with student feedback as well – by building a system, Pulse, that brought together algorithms that clustered topics and classified sentiments with intuitive visualization to allow a deeper analysis of customer feedback and sentiment on special topics [22].

Qualitative research in education suggests that student feedback is not only important for course improvement; it also allows universities to align their courses to international accreditation standards in the avenue of quality control and assurance of universities [23]. The actual use of the analyzed data is also a subject for research where researchers have tried to tie feedback to changes in teaching, grading and self-evaluation for professors. Yao et al. found that professors do indeed care about student feedback and used discretion in using formative comments in modifying their teaching. Despite variations in the ultimate use of the feedback collected, they found that sentiments towards student feedback ranged from neutral to positive, indicating the usefulness of collecting feedback [24].

Given course codes and students' comments as inputs, the goal of our project is to develop a system that can extract and

visualize the topics and sentiments on courses. In the next section, we explain the details of SFMS system.

IV. STUDENT FEEDBACK MINING SYSTEM (SFMS)

In this section, we describe the architecture of SFMS (depicted in Figure 3), which basically follows the opinion mining architecture shown in Figure 2. The first layer in the architecture shows the main stages of the system. Second layer depicts the key tasks in each stage. The third layer depicts the tools or techniques used to accomplish the tasks in each stage.

The system consists of four main stages as shown in Figure 3. In first stage, a dense matrix of comments is generated after preprocessing the data. In second stage, the comments are clustered based on their primary common topic. In third stage, sentiment of each comment is extracted, and finally in the fourth stage, topics and sentiments are aggregated for comprehensive reporting. SFMS system is developed in Java platform.

The system initiates with the course codes and corresponding comments as inputs and executes all the stages to generate visual analysis reports. For example, “The course project is very difficult but very challenging” is a comment for a course code, IS203. We explain each stage in detail in the subsequent sections.

A. Data Representation

In data representation stage, first, all terms are extracted from input comments using tokenization by space. Second, stop words are removed from each comment using the stopwords list. Document representation is shown in Figure 4.

	Feature	Value	Feature	Value	Feature	Value
1	pace	1.000000	time	1.000000	uploaded	1.000000
2	sometimes	2.000000	require	1.000000	meet	1.000000
3	students	1.000000	sometimes	1.000000	factor	1.000000
4	meet	1.000000	teams	1.000000	factor	1.000000
5	ridiculous	1.000000	is480	1.000000	grades	1.000000
6	students	2.000000	especially	1.000000	understand	1.000000

Fig. 4. Document representation matrix (document – term – value). Each row represents comment. Feature represents word or term and value represents frequency of a term in the document. Due to space constraints only three features for sample comments are depicted.

In order to calculate the similarity between two comments, we need to transform the free-flowing text in the comment into a numerical matrix as shown in Figure 4. Each row denotes a comment, and each cell in that row is occupied by a single word (or feature) from that comment together with its term frequency (log or square root).

Such data representation would assist in judging the importance of each word in a comment and therefore measuring the similarity between comments. To generate the document term matrix, we use perl scripts. Our interface takes the comments and stopword list as inputs and generates document matrix.

B. Topic Extraction

A topic is the subject or target of a student's comment. For example, given the comment, "The course project is very difficult but very challenging", "project" is the topic of the comment. In topic extraction phase, the objective is to breakdown all the comments by topics such as teaching, content, learning etc. To achieve this, the first task is to cluster the comments using clustering algorithms and specific clustering functions.

Various clustering criterion measures such as I_1 , E_2 , H_2 etc., are available for measuring the clustering similarity [29]. These schemes differ on how the similarity between the individual objects in various clusters is combined to determine the similarity between the clusters themselves. Table I provides the notation for the formulae and Table II provides the formulae for selected clustering functions.

TABLE I. NOTATION

S : collection of documents
$S_1, S_2, \dots S_k$: set of document of k -th cluster
k : number of clusters
$n_1, n_2, \dots n_k$: number of docs of corresponding clusters
C_r : centroid vector of r -th cluster
C : the centroid vector of the entire collection
d_i, d_j : i -th and j -th documents
D : the composite vector of the entire docs

TABLE II. MATHEMATICAL FORMULAE FOR CLUSTERING CRITERION [29]

Criterion	Formula
I_1	$Maximize(I_1) = \sum_{r=1}^k n_r \left(\frac{1}{n_r^2} \sum_{d_i, d_j \in S_r} \cos(d_i, d_j) \right)$
I_2	$Maximize(I_2) = \sum_{r=1}^k \sum_{d \in S_r} \cos(d_i, C_r)$
E_1	$Minimize(E_1) = \sum_{r=1}^k n_r \cos(C_r, C)$
H_1	$Maximize(H_1) = \frac{I_1}{E_1}$
H_2	$Maximize(H_2) = \frac{I_2}{E_1}$

I_1 : This function tries to maximize the intra cluster similarity between the elements of a cluster.

I_2 : This function also tries to maximize the intra cluster similarity between the elements of a cluster. The only difference between I_1 and I_2 is that while calculating I_2 we must take the square root of the function.

E_1 : This function divides the intra-cluster similarity with inter cluster similarity.

H_1 : This is a hybrid function to maximize I_1/E_1 .

H_2 : This is a hybrid function trying to maximize I_2/E_1 .

To cluster the comments, we use agglomerative clustering algorithm, and the tool we use is Cluto clustering library [25]. Similar comments will be grouped together by the clustering algorithm. The top words in the cluster represent the topic of the cluster. The examples are demonstrated in our experiments section.

Once clusters are generated, the second task is to extract topics for the clusters. In this context, the topics are the high frequency words that appear in each cluster. For example, the words like *project*, *time*, *practice* etc., are some of the high frequency words that represent the cluster with comments related to topic, *project*. However, the label for the cluster should be manually provided to generate a meaningful representation for a cluster. We developed an interface that accepts users' inputs for the cluster labels and the system uses them for subsequent phases.

Mostly student comments refer to a single topic, but there are few instances that they may span across many topics in a single comment. A comment with multiple topics is not a focus of our work and we leave it to future work.

C. Sentiment Extraction

Discovering the sentiment of each comment provides the user with an analysis of collective sentiments against each topic or each cluster in the entire collection. Sentiment refers to the positivity or negativity of a given comment. For example, given the comment, "The course project is very difficult but very challenging", the sentiment is "negative".

In this phase, the objective is to find the overall positive or negative sentiment for a given comment. We propose a classification based approach for this task and therefore created a training set for the training the classifier. For this purpose, we use LingPipe Language Identification Classifier [26] which adopts the classification approach to sentiment analysis using a sentence-level logical regression classifier. It deconstructs each comment sentence into n-grams, or number of words evaluated at a time while processing the sentiment of the comment. We have chosen to use bi-grams for sentiment extraction task. We use bi-grams as they aid in processing negating phrases such as "not good".

Using bi-grams, LingPipe evaluates two words at a time before assigning an overall sentiment to the comment. This allows evaluation of double negatives which allow a better evaluation of sentiment. The classifier learns the natural distribution of characters in the language model of a training

data set and then assigns a sentiment probability to each evaluated bi-gram according to a probability distribution. Eventually leading to an aggregated final sentiment for each comment evaluated. Agarwal et al. [30] evaluated the use of three categories of sentiment for basic polarity in sentiment – negative, positive and neutral, but found that the results were better with strict polarity between positive and negative only. In our preliminary studies, we observed that the students’ comments are mostly negative or positive. We leave neutral component for future exploration.

D. Summarization

Summarization is the final stage where the goal is to provide user friendly summaries of the quantitative results obtained from the previous phases. Once the comments have been clustered into topics and the sentiment for each cluster is known, we categorize the comments by course. Therefore, each course has its own set of k clusters with their individual comments annotated with a sentiment. Essentially, the courses serve as high level category or a curriculum level summarization. In contrast, individual comments serve as course level summarization. Visualization charts use the topics, sentiments and course codes as inputs. The charts are generated using JFreeCharts [27] and inserted into Microsoft Excel files that are created and manipulated using Apache POI libraries [28] for enabling users with easy analysis. We adopt the charts similar to feature-based sentiment summaries by Hu et al. [13].

V. DATASET

We use dataset of feedback comments given by students attending courses offered by the School of Information Systems at Singapore Management University for the academic year 2013-14. These comments are collected at two feedback cycles, midterm and end-term, and span across two semesters. In total, seven courses are evaluated, yielding 5,341 comments for evaluation.

In our data analysis, we noticed that some students provide “NA” or “Nil” comments. In order to avoid noise in the results, we removed comments with less than 10 characters. This allows us to focus on those comments which would yield a constructive view on topics being discussed and their respective sentiments. Finally, we have 3,144 comments for our experiments.

VI. EXPERIMENTS

We first explain experiment setup followed by the results.

A. Experiment Setup

We developed SFMS as a desktop application with simple graphical interface. Recall that our first stage of SFMS system is to generate document representation in matrix format. To generate the document term matrix, we use *doc2mat* perl scripts provided in the Cluto library [25] and Figure 5 shows the GUI for data representation stage. The UI takes the comments and stop word list as inputs and generates document matrix in a given location. We observed that words such as “students”, “course” etc. that occur very frequently in the

dataset generate noise and impact the quality of customers. Therefore, these words are added to the current stopword list.

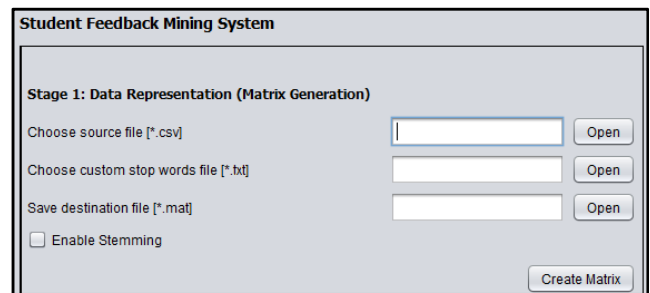


Fig. 5. SFMS System UI: Data Representation Stage.

Cluto API is an easy-to-use platform that combines a variety of different clustering algorithms. We use vcluster (agglomerative) in the toolkit to generate clusters. Cluto provides three row models; log, MAXTF and square root. All our experiments are based on agglomerative clustering with cosine similarity and log model. We set number of clusters to 10 after some preliminary experiments. For sentiment classification, we use Lingpipe [26] which provides a sentence based logistic regression classifier for sentiment classification.

B. Topic Extracion Results

We first present quantitative results on clusters followed by qualitative analysis of topics generated. Recall that Cluto provides multiple clustering functions to determine clusters as described in Section IV. Figure 6 depicts the GUI for cluster generation.

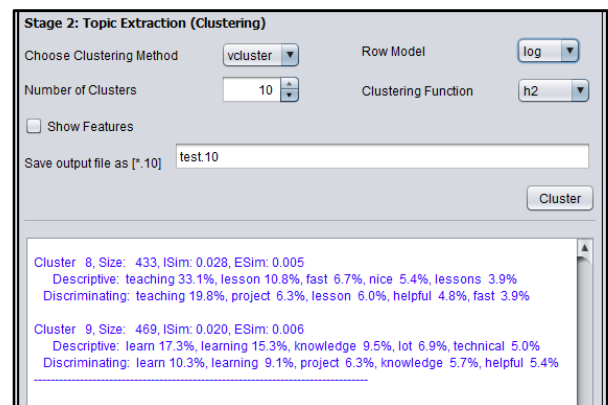


Fig. 6. SFMS System UI: Topic Extraction Stage (Clustering task).

The UI allows users to choose cluster methods, term frequency measures, count of clusters, and clustering functions to generate clusters. Various clustering criterion measures such as I_1 , E_2 , H_2 etc., are available for measuring the clustering similarity [29] as described in Section IV. SFMS calls Cluto API with the user inputs and performs clustering. For our preliminary experiments, we tested with multiple combinations. However, we present only the results from the selected combinations that provide better performance. We use *Purity* (the higher the better) and *Entropy* (the lower the better) to evaluate the performance of clustering algorithm in topic extraction phase [8]. From our results, we observed that the clustering function, H_2 provides Purity of 93.4%, which is

slightly higher than other clustering functions and Entropy of 0.214. Therefore, we use H_2 for subsequent experiments. We now present the qualitative analysis of topics generated by clustering task. Using H_2 , the comments are clustered and the top features of each cluster are as shown in Table IV.

TABLE III. TEN CLUSTERS WITH TOP WORDS AND HUMAN ALIAS (H_2)

Cluster #	Top frequency words	Alias
0	approachable, friendly, enthusiastic, consultation, help	Faculty interaction
1	helpful, feedback, concepts, understanding, encouraging, help	Faculty feedback
2	patient, knowledgeable, passionate, responsible, fun	Faculty preparation
3	project, heavy, time, requirements, lot	Project
4	time, assignment, sql, labs, php	Assignments
5	challenging, lab, test, project, exercises	Labs
6	excel, future, skills, real, applicable	Skills
7	understand, concepts, help, questions, explain	Concepts understanding
8	teaching, lesson, fast, nice, lessons	Classroom delivery
9	learn, learning, knowledge, lot, technical	Learning experience

Each cluster has distinguishing or determining features or words which determine the topic of the cluster. We notice that all clusters are very coherent and meaningful except clusters 4 and 5 which both refer to labs. This is one of the drawbacks of clusters as it is unsupervised. To improve the quality, one approach is to exploit the questions together with the comments and we leave it to future work on improving the quality of the clusters. SFMS system provides an UI to users to provide *Alias* or *labels* for each cluster as shown in Figure 7. Once aliases are provided, the comments are also categorized by course codes. This categorization aids in generating user friendly visual reports.

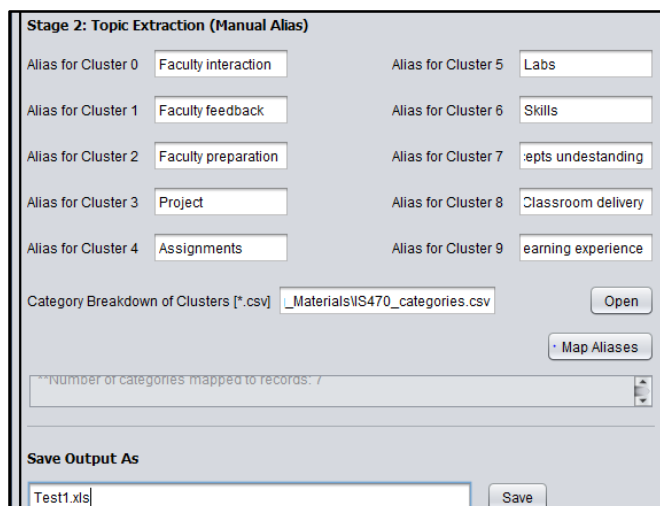


Fig. 7. SFMS System UI: Topic Extraction Stage (Human labeling task).

C. Sentiment Extraction Results

In the sentiment extraction phase, we use human labeling for training the data and evaluating SFMS. Lingpipe uses logistic regression and we evaluated the effect of domain knowledge on the training of sentiment classifier. Figure 8

shows UI for sentiment classification. The UI allows users to provide training data to SFMS to train the classifier.



Fig. 8. SFMS System UI: Sentiment Extraction Stage.

We used log regression model trained on Internet Movie Database (IMDB) domain and education domain. Sample comments and the corresponding sentiment classification results are depicted in Table II. We observe that training the classifier on education domain gives best results instead of the standard (IMDB) dataset provided by Pang et al [6].

TABLE IV. SAMPLE COMMENTS AND COMPARISON OF BOTH DOMAINS FOR SENTIMENT CLASSIFICATION TASK

Function	IMDB	Education
very knowledgeable, patient and easygoing	-ive	+ive
sometime he went through the concepts a bit too fast for us to grasp.	+ive	-ive
always concern for student and willing to help weaker student	-ive	+ive
Asks challenging questions to get us to think deeper.	+ive	-ive

Table II shows some example comments and the corresponding sentiment labels generated by SFMS when trained on IMDB and education domain. In our analysis, we observed that low precision for IMDB domain is due to false positives. In contrast, the classification approach labeled it as positive. Overall, the sentiment extraction phase with education domain training has a precision of 80.1%, which is significantly higher than IMDB trained classifier.

D. Feedback Summarization Results

Topics and sentiments generated by previous phases are used for reporting using JFreeCharts [27].

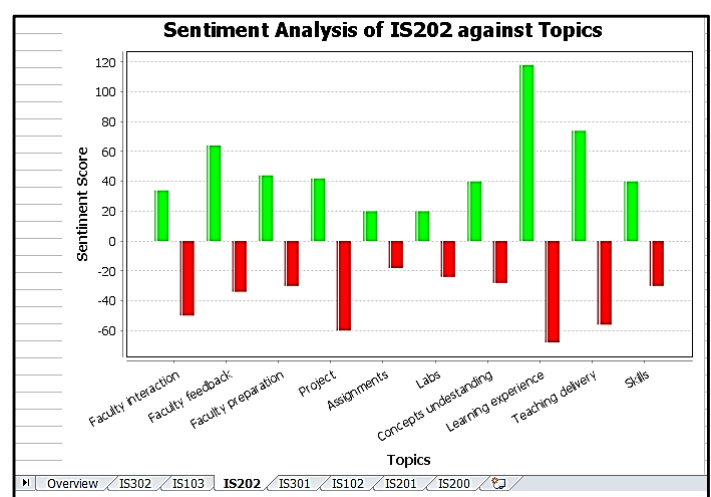


Fig. 9. Integrated visualization of topics and sentiments for seven courses in Information systems curriculum. Excel sheet generated by SFMS.

Figure 9 shows the integrated reporting view of student feedback which can be useful for curriculum designers and management. To categorize the results, course codes are used for generating reports. It has the clusters information as well as reports for every course in our dataset. Figure 10 provides deeper analysis for the course instructors on various aspects of the course.

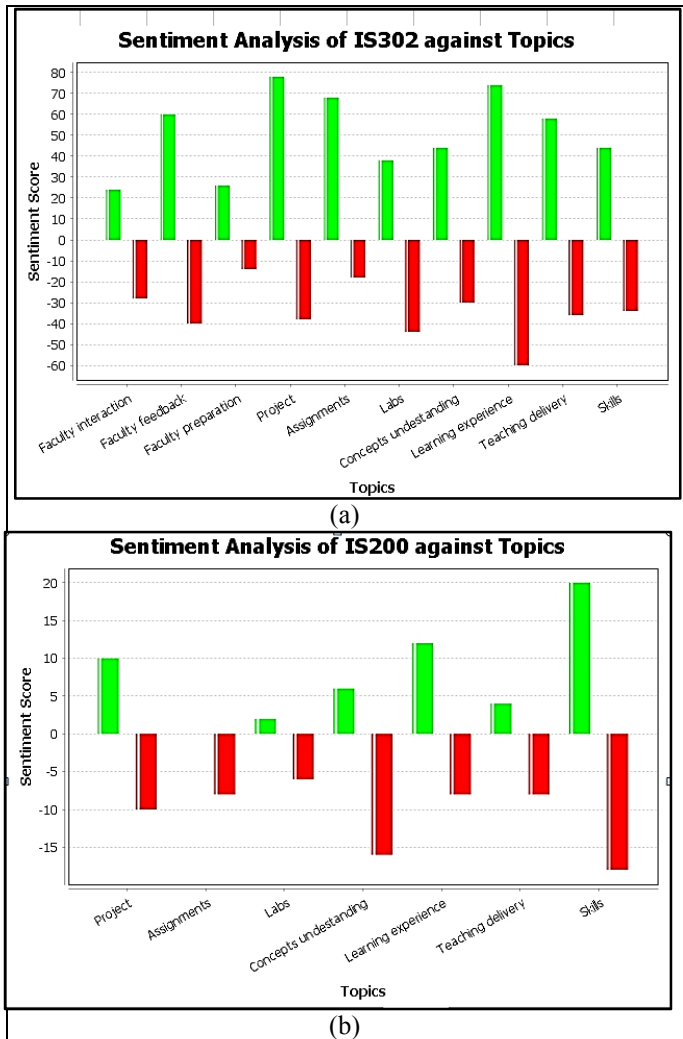


Fig. 10. Visualization of topics and sentiments for Information systems course codes. (a). Course code, IS302 - Information security & trust.(b). Course code, IS200 - Software Foundations.

We observe that the students provides comments on aspects such as project, labs, skills, etc. of IS200 (IS software foundations) course, which is programmatic in nature. However, the faculty feedback and interaction is not of their concern. In contrast, for IS302 (Information security & trust) course which is less programmatic in nature, but with an open research project, the students are concerned with the faculty feedback and interaction. We observe the negative sentiments are also quite high. Therefore, there is a need for the faculty to plan for some changes in the project or consultation sessions. For example, faulty may provide additional consultation hours or online discussion forums. For IS200, faculty may provide some extra tutorials to improve student learning experience.

E. Discussions and Future Work

One major limitation of Cluto is that, each comment can only belong to one cluster. This means that even though a single comment can span multiple topics, it will be clustered under the primary topic – or the topic with most of its discriminating significant words similar to those in the comment, as judged by the clustering function. Topic models such as LDA can be explored to overcome this limitation which we leave it to future work. Similarly, exploring sentence based topic-sentiment is an interesting future work. Currently, SFMS can only take in a single-level categorization for distribution of clusters. Other categories such as term, year, school, faculty, etc., can provide detailed analysis. Future iterations of the development of this system could create dynamic hierarchies of categories that will allow users and analysts to drill down dynamically into topics and sentiments by each level for deeper analysis. Secondly, SFMS offers a sentiment score for each topic being discussed by students but does not go deeper to signify what the actual comments spoke about. Faculty might want to retrieve the comments interactively for further analysis. Lastly, students often leave suggestions for professors regarding delivery, content, interactions and so on. Since these relate strongly to each of the topics being analyzed, each topic and its respective sentiment can also have a highlighted set of suggestive comments to take the system one step forward from descriptive analytics to actionable insights.

VII. CONCLUSION

In this paper, aspect or topic based sentiment mining techniques are evaluated in order to build a desktop-based solution to analyze topics and their sentiments from student generated feedback in universities. We found that agglomerative clustering with cosine similarity using a hybrid approach generates coherent clusters for topic extraction task. Further, using a logistical regression algorithm, which is trained on education domain, extracts sentiments on comments with higher accuracy compared to the classifier trained on movies domain. Free flowing textual data like student feedback in an education context can be therefore analyzed automatically in order to gather a deeper understanding and facilitate the stakeholders in course improvement cycles.

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Preparing ECE Students for Research Career in Nanotechnology via Track Program

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Abstract— This paper details the research participation of undergraduate students from the freshman to the senior year. Four courses were designated to prepare students for a nanotechnology research career. New modes of instructions leading to research participation followed in this curriculum have been reported. This covers integration of knowledge, just in time approach, and project portfolio based curriculum. Courses developed in this track emphasize research and applications in health sciences and renewable energy areas. The structure of the track program was presented before with emphasis on the senior level courses of the track. The work in this paper, however, emphasizes research participation in nanotechnology of the junior students within the electrical engineering, computer engineering, and mechanical engineering disciplines. The multidisciplinary components in nanotechnology research topics were attractive to students to work in team. The topics covered in this course included nanotechnology applications in diabetes, cancer research, and neurosciences. Lecture materials were all from up-to-date research papers, and can be altered with the course updates. Students registered for this course were required to emphasize two research topics seven week each, and prepare research posters in a research day where industrial representatives are invited to participate in the discussions with students. Students who completed this course were interested to continue with nanotechnology individual research and get enrolled in upper level courses.

The course starts with introducing students to the nanotechnology applications in various fields, including environment, society, consumer electronics, computers, health sciences, optics, electromagnetics, energy, and medical imaging. The course then introduces students to research issues emphasizing health sciences and renewable energy. Students will be required to expand their research to cover in depth one or two research issues that fall within their interests. In the research projects, students work in team, two students/team, and assignment is given to each to share the contribution of the project.

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The course was assessed with student satisfaction, and the objectives and the outcomes of the course were met.

Index Terms—undergraduate track, research career in nanotechnology, undergraduate research projects, multidisciplinary, innovation.

I. INTRODUCTION

Engineering major is considered in many disciplines as applied sciences where math and sciences knowledge are applied into real engineering products. Near 25% of engineering curriculum is covered from Math and Sciences course. Big emphases on the engineering programs are invested in mathematical and computer models, a very important element in engineering research. This emphasis assists undergraduate students with integrating knowledge from math and sciences into engineering system modeling. These systems may range from the device level to the system level. Classroom engineering instructions provide engineering students with research tools, including hands on practical models, mathematics models, and computer models. Software engineering is an integral component in the EE, CmpE, and ME curricula. These tools equip engineering students with research foundation. Undergraduates at Indiana University Purdue University Indianapolis (IUPUI) team up with graduate mentors, to explore research hypothesis in various areas.

At IUPUI, undergraduate students are engaged in research at early stages in the curriculum via individual research courses, multidisciplinary research courses, and industrial based research/design courses. Undergraduate research has become a part of the educational culture. They are given plenty of opportunities to apply math and sciences into engineering curricula.

Undergraduate research opportunities at IUPUI lie on the faculty research expertise. One of the research areas emphasized in the past 5 years was nanotechnology, where engineering and sciences faculty members integrating their efforts towards new engineering/science applications. Research topics range from bioengineering/biosensors, solid state nanotechnology and molecular devices, and nanomaterials. There are two areas of concentration

emphasized by the Integrated Nanosystems Development Institute (INDI) group with the IUPUI campus. These are the health sciences, and the renewable energy. Our dedicated faculty and research resources on campus have led to the success of this emphasis. The collaboration of the IU Medical School has added to the future potential of this institute.

In 2010, the team of engineering from ECE and ME together with INDI received an NSF NUE grant leading to the development of a track program within ECE and ME programs, taking the students for nanotechnology road from the sophomore year to the senior year. Educational outcomes from this track program have been presented elsewhere [1-5]. Unlike the other STEM programs that combine math and sciences into K-12 education [6-8], this development features a multidisciplinary area where a nanotechnology theme is the focus that let participation from ME, ECE, BME, Chemistry, and Physics all into the same program.

II. ABOUT THE NANOTECHNOLOGY TRACK

The team of faculty from engineering and sciences has provided innovative educational opportunities in nanotechnology. With the collaboration with INDI, important features of this program have been integrated into the curricula. This included lab-based curricula; strong linkages to existing undergraduate research programs; technical and research courses; and integrated Themed Learning Communities (TLCs) in nanotechnology. Students pursuing the nanotechnology track will have lectures and laboratory research experiences to prepare them to enter the global workforce and to become leaders of research and development in industry, business, and academia in the emerging era of nanotechnology. The nanotechnology track was designed in a way that will not exceed the plan of study (P.O.S) credit hours meeting the minimum credit hours needed for the ECE or ME degrees. Students may choose four within the allowable elective list “tech electives, EE electives, ME electives, CmpE electives, math/science electives, and free electives [9] of their programs.

Students are prepared for the nanotechnology track via freshman engineering courses where TLC “Theme Learning Community” where cohort of 15 students are taking freshman courses emphasizing the future applications of nanotechnology. Some projects in the problem solving freshman course are pursued where some mathematical background are emphasized. The students pursuing this track must have gone through the TLC experience at the freshman year.

The following gives a brief description of each course under the nanotechnology track program.

A. *Introduction to Nanotechnology and Applications 3 credits*

The course aims to help students understand the scale of nanotechnology, identify materials used in nanotechnology, evaluate forces acting in nanomaterials, describe electronic and mechanical behaviors on the nanometer scale, and

describe applications in industries and life sciences. Nano-versus micro-technology in the evaluation of potential risks and benefits will be covered with emphasis on their societal impact.

B. *Nanosystems Materials and Measurements (Lab-based Course) 3 Credits*

The course introduces students to statistical process control, optical microscopy (light propagation, Snell’s law, mirrors, prisms, lenses and beam-splitters, etc), scanning electron microscopy, atomic force microscopy, scanning tunneling microscopy (STM), near-field microscopy, transmission electron microscopy, surface roughness and step profilers, roughness step testing (RST), and reflectometry, and ellipsometry. Nanosystem measurement laboratory is associated with the course.

C. *Nanosystems Principles 3 Credits*

This course introduces students to the principles and applications of nanosystems, including: nanoscale materials, processes, and devices. It also provides students with a basic understanding of the tools and approaches that are used for the measurement and characterization of nanosystems and for their modeling and simulation. Moreover, the course covers the applications of nanosystems in a wide range of industries: information technology, energy, medicine, and consumer goods.

D. *Nanosystems Processes and Devices (Lab-based Course) 3 Credits*

This course introduces students to processes and devices associated with integrated nanosystems. “Integrated Nanosystems” refers to systems which consist of integrated micro-, meso-, and/or macro-scale parts and their core components in nanoscale materials, processes, and devices. The course focuses on the theory and operation of select electronics, electromechanical, and biomedical devices which are used for information technology, sensing, medical, and other applications. The lectures will be complemented by hands-on laboratory experience.

E. *Research*

Students are encouraged to pursue research during their undergraduate studies. During the sophomore year, the students are divided into teams to work with faculty mentors, who assign a literature search on a given nanotechnology research topic. During the junior year the students will pursue a research project with their faculty mentor on an assigned research topic. The first course in this track prepares students for a research career in nanotechnology.

III. THE SOPHOMORE COURSE

ECE495/ME397: Intro to Nanotechnology and Applications (3 credit hours)

Required Course for nanotechnology track:

A. Bulletin Description

The course introduces students to the scale of nanotechnology, materials used in nanotechnology, forces acting in nanomaterials, electronic and mechanical behaviors on the nanometer scale, and applications in industries and life sciences. Nano-versus micro-technology in the evaluation of potential risks and benefits will be covered with emphasis on their impact on society.

B. Prerequisite or co-requisite

ECE 204 (for ME major); ECE270 and ECE201 (for ECE major)

C. Prerequisites by topic

TABLE I
COURSE OUTLINE

Lecture #	Conversion from Gaussian and CGS EMU to SI ^a
1-3	Introduction to nanotechnology: Perspectives and businesses, and infrastructure
4	Nanotechnology products
5	Nanotechnology standards
6	Environmental, Health and Safety Aspects of Nanotechnology
7-8	Nanotechnology manufacturing: (tools, molecular assembly, quantum metrology)
9-12	Nano electronics (band structure, conductors, semiconductors, device strategies, CNT, Nano devices and single electron tunneling, and molecular wires). Design approach for device characteristics
13-16	Nano-optics (interaction of light with matter & Nano-perspective, surface Plasmon, Quantum dots, Nano photonics, fabrication and applications). High efficient quantum dot solar cells, design approach.
17-21	Nano magnetism (introduction, Nano magnetic materials, physical properties, magnetic Nano-structures, and Nano magnetism applications)
22-26	Medical nanotechnology: medical breakthroughs, nanoparticles and Nano capsulation, and stimulating Tissues and functions
27	Term Paper discussions
28	Students' presentation

Semiconductor devices (pn-junction diodes, BJTs, MOSFETs), digital logic (Boolean functions, logic building blocks, and finite state machines).

D. Textbook

Gabor L Hornyak, John J Moore, Harry F. Tobbals, and Joydeeo Dutta, "**Fundamentals of Nanotechnology**" CRC 2009. ISBN # 978-1-4200-4803-290000

E. Goals

Introduce students to the nanotechnology area in various applications, and providing them with research hypothesis as applied to nanotechnology materials and devices. The course was structured to provide a number of research areas that are suited for the engineering discipline.

F. Outcomes

After the successful completion of this course, a student should be able to:

- 1) Describe the status of nanotechnology infrastructure and products in the USA in instrumentation, devices, materials, and applications. [a,b,c,d] .

TABLE 2
ABET CATEGORY

Engineering domain	Credits	Percentage
Science	2	67
Design	1	33

- 2) Compare Nanotechnology to microtechnology issues. [c,e,k].
- 3) Demonstrate knowledge of Nanotechnology standards, tools, and nanomanufacturing (a, c).
- 4) Explain the features of nanoscale electronics [b, c]. Communicate team project or team research term paper work through oral presentation, and technical report (b, c)

IV. EVALUATION METHODS

Midterm exams and a comprehensive final exam. Homework assignments and term paper presentation.

V. SAMPLE RESEARCH PROJECTS

A. Non-Invasive Diabetes Monitoring Devices

Monitoring glucose levels using nanotechnology devices "smart Tattoo" that can detect glucose molecules in the absence of enzymes. This emits a florescent color that correlated to the level of glucose. The sensor is based on a plant-sugar-binding protein.

Students studied the current technologies of monitoring glucose levels, and the promising solutions to the invasive issue by allowing new types of nan-invasive blood glucose sensing devices that can utilize other bodily fluids in addition to blood. The research project covers the electrochemical reaction using diffusible or immobilized mediator to transfer the electrons from the glucose oxidase to the electrode. With the use of nanotechnology, however, the electrode is able to perform direct electron transfer utilizing organic conducting materials. This allows for implantable, continuous monitoring devices.

B. Nanotechnology in Bone Regeneration

This research explores how nanotechnology has begun to impact this future field. There have been many unanswered

questions there nanotechnology can potential contribute to such important medical fields. Current technology have limited available quantities, inability to possess the same properties as bone, provoking immune system response, infection transmission, and cost. The research also focuses on how advancements in nanotechnology can be applied towards various tissue-engineering strategies. Students study more in regenerative medicine with the development of nanostructures and biomaterials with potential clinical implications. The studies included scaffolds that are biocompatible, extracellular matrix (ECM) in cartilage cells to produce bone, synthetic bio-scaffolds.

C. Nontechnology Applications for Cancer Detection and Treatment

Research covers new technology for screening for cancer detection from benefiting of biomarkers in tissue and fluids. Quantum dots are a way that enables the simultaneous detection of multiple markers. They are nanoparticles that emit light of different colors depending on their size. The photoluminescence signals from antibody-coated quantum dots can be used to screen different types of cancer. The different colored dots can be attached to antibodies for cancer biomarkers to allow oncologists to discriminate cancerous and healthy cells by the spectrum of light they sea. Carbon nanotubes are a type of nanodevices for biomarker detection. Therefore, biomarker screening can help in cancer detection. Cancerous cells may also absorb the nanocarriers to bring drugs into the cells. The research deals with the methodology of treatment and diagnosis.

D. Molecular Nano-Communications

This research studies the nanoparticles and nanowires based sensors since they are utilized in FET devices. The nanowire FET may be converted into nanowire nanosensors for pH sensing.

E. Nanotechnology Based SOC

System on Chip is an area where integrated sensor system can be implemented on board for different sensing functions. Some of the designed systems are applied to health care, while others for renewable energy.

VI. RESULTS AND DISCUSSION

A. Motivation

The course motivates undergraduate students who are pursuing a career in nanotechnology or sometimes a research career. Since the course is a sophomore course, introducing students to research hypothesis, and teach them how to search to find research activities that have been introduced into this research issues, means of approaching solutions, and limitations of various approaches, the courses gained popularities within the ECE and ME departments. The team work and the multidisciplinary aspects of the projects have enhanced students' motivations into the research.

B. Research Outcomes

At the end of the semester, four poster papers were presented in a poster research day on campus, where industry representatives and faculty members from School of Sciences, Engineering, and others have attended and had exchanged research ideas with the students.

C. Research Integration

Student contribution was limited to the mathematical models, software development, and simulations. Students had lab tours to the microscopy center on campus and had discussions with the research scientists running these equipment.

D. Feedback

The students' feedback on the course contents in the different areas and the research components of the course. All students have reposted very high satisfactory results in all questions regarding the course materials, research topics, course preparation on future research, and their expectation with the course multidisciplinary aspects, the team work, and poster presentations.

VII. CONCLUSION

The new research course developed at the sophomore year has enhanced the students' interests in pursuing a future career in nanotechnology. Majority of students are progressing more of nanotechnology courses in their junior and senior years. The new course provides integration of knowledge from math and sciences, and various components from ME, ECE, and BME. The knowledge learned in this course may also assist students with other areas such as DSP, Medical devices, communications, and instrumentations. In addition, the research apparatus involved in this research will assist students in integrated circuit design for both digital and analog applications.

ACKNOWLEDGMENT

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Curriculum Driven Classroom Design

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Abstract— Classrooms and learning environments are almost as diverse as the curriculum that is taught in them. However, one thing that almost all classrooms have in common is that they are designed before the curriculum is developed. This leads to the design of common, generalized learning environments. These generalizations can lead to inconveniences in the classrooms, which cause deficiencies in learning. This problem is particularly true in engineering, where curriculum can be lecture based, design based, or project based. The goal with this project is to design a classroom and lab to fit the needs of specific undergraduate engineering curriculum. Allowing the classroom design to be driven by the curriculum that will eventually be taught there will result in a more efficient and effective learning environment. Current freshman engineering students in the existing labs were surveyed, and next year's freshman engineering students in the new lab will be surveyed to collect data about their experiences in the current learning environment. When the classroom construction is complete, a comparative analysis of the classroom dynamics both of the old and new classrooms will take place in order to determine the success of the work.

Keywords—*curriculum based design; engineering design; classroom; engineering lab (key words)*

I. INTRODUCTION AND BACKGROUND

Drexel University's College of Engineering consists of five departments, and approximately 3,800 undergraduate students. As part of the freshman year curriculum, all engineering students take a series of Freshman Engineering Design courses (ENGR 101, 102, and 103). This sequence of courses follows a structured to free-design model. ENGR 101 consists of a single engineering project, where students have set parameters and guidelines to follow. In ENGR 102, students have two different projects to choose from. In these projects, there are still parameters and guidelines, however, there is more freedom and creative design incorporated. For the last course of the sequence, ENGR 103, students complete their freshman design project. Students are presented with a free-design project where they can choose from a list of existing projects, or work to create their own design project.

Many undergraduate college engineering programs have a freshman design project as part of their first year engineering curriculum. These design projects are pivotal in providing a complete learning experience for freshmen in their first year of engineering, as they provide a first-hand view of the engineering design process [1 - 4]. In order to for students to

complete their projects, they go through an extensive design and construction process. This process is often completed in basic, standard engineering labs, which do not always provide a suitable or efficient working environment for these students [5]. Without a work space that is conducive to intensive design projects, students are not always able to complete their projects efficiently or to the highest quality. One way this problem can be solved is by designing these engineering labs and classrooms to accommodate curriculum requirements.

There have been a few instances in which universities have addressed this problem by designing learning environments focused on housing specific curricula. The University of Colorado at Boulder's Integrated Teaching & Learning Laboratory (ITLL) supports a first-year engineering design course with its curriculum-driven designed lab. This lab has received the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education in 2008 [6, 7]. The Olin College of Engineering in Needham, MA conducted an interesting experiment to kick-start their program. Olin's main academic facility, The Academic Center, was constructed only after a year of curriculum development and testing. This allowed for the curriculum to influence the design of the facility, resulting in a much more dynamic environment [8, 9]. Drexel University's College of Engineering is currently able to perform similar experiment in which a new freshman engineering lab will be based on the curriculum that will be taught there.

The process for the current project consists of three phases: implementing a curriculum with no lab space, to then having a pre-existing lab space, to finally having a custom designed lab space where the curriculum will be taught. During the winter and spring terms of 2014, Drexel University's College of Engineering piloted a section of new curriculum involving the design and construction of Rube Goldberg machines. This section of students, who were enrolled in the second and third courses of Drexel's Freshman Engineering Design sequence (ENGR 102 & 103), was broken up into 14 groups of approximately 3 people each. Each group was tasked with designing and building a Rube Goldberg machine with between 25 and 30 events. An "event" in a machine is defined as an interaction between two unique objects in which energy is transferred from one object to the other. Fig. 1 shows an image of the machine designed and constructed by one of the groups. These individual Rube Goldberg modules were then linked together to form one long chain of energy transfers totaling approximately 315 events. This new curriculum was

implemented with no change in the classroom or lab space, which caused several problems. The original space was not outfitted to support such a large-scale design project. With little space in the lab to construct the machines, and a far distance from the lab to the machine shop, a new space had to be utilized for the project. A large, empty office space was found to be used as the machine construction zone, which was located adjacent to the machine shop. Further adjustments had to be made throughout the process to better suit the students' needs for the design project.



Fig. 1. Example twenty-nine event Rube Goldberg Machine from Spring term 2014 pilot section. Machine begins at top right, near wind-chimes, and ends at left near rubber duck. Events travel along multiple levels, traveling both upwards and downwards. Machine is approximately 1m wide by 1m deep, and 1.5m tall.

A revised version of this same project was rolled out as a new ENGR 101 project for all entering freshman engineers beginning the fall term of 2014. Approximately 900 freshmen engineers participated in this new curriculum as the first course of their Freshman Design sequence. Groups of three students each were tasked with constructing a six-event Rube Goldberg machine that fits on a two-foot by three-foot platform. These individual machines were then linked together in chains of either eight or sixteen to form a section-wide machine.

As the curriculum was developed, a student's perspective provided input on factors that could help enhance the students' learning experiences. At the same time, a new freshman engineering lab space was being designed for opening in the fall term of 2015. Drexel University's 3101 Market St. building is undergoing a renovation, which will house this new freshman engineering lab, along with other new research facilities. This new lab will be the home for the Rube Goldberg curriculum, creating a unique opportunity to design and develop the curriculum and the lab concurrently. Working on both projects at the same time exposed the connections between the two, and the benefits of designing each with the other in mind. By making decisions about the classroom layout and design with the specifics of the curriculum in mind, the resulting classroom should lend itself to a more efficient and exciting learning environment.

II. METHODS

In order to begin the design of the lab space based on the curriculum, a baseline layout was first used to get an idea for the room requirements. Fig. 2 shows the baseline layout that was originally planned by the architects working on the renovation. This shows the large lab space divided into two areas by a hanging room divider. On each side of the divider sit 10 work benches with 20 stools (shown at the top of the figure), 6 lab desks with 36 chairs (shown in the middle of each room), 2 project tables (large squares toward the bottom of the figure), and one instructor desk (shown between the two project tables). The room divider provides the opportunity to separate the space, allowing the room to be more suitable for smaller class sizes when needed. The un-shown room to the right of the figure is the university's Machine Shop, creating an ideal situation for collaboration between the two rooms.

However, the layout of this room shows some design aspects that could make working on an intensive design project such as the Rube Goldberg module difficult. Some of these inefficiencies include the separation of the work benches from the Machine Shop and project tables, static furniture, and the lack of room for placing the Rube Goldberg machines.

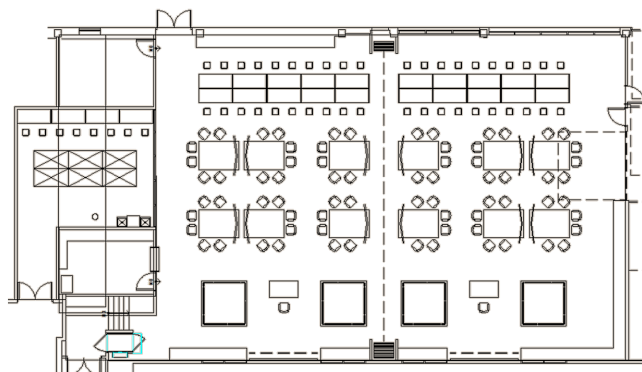


Fig. 2. Baseline layout of new freshman engineering lab [10]. Notice the workbenches and stools located at the top of the figure. Below them, student lab desks are shown six students to a table, which encourages collaboration. Toward the bottom of the figure notice the two square project tables, along with instructor stations.

In addition to foreseeing problems that may occur with the layout for the new Rube Goldberg curriculum, problems from the pilot project that took place in the 2013-2014 school year were also considered. The major problem that was encountered by students working on this project during the Spring term of 2014 was the lack of designated space to construct their machines in the engineering lab. Furthermore, once a space was found for a construction zone, the groups built their projects exclusively by themselves, with not much interaction between groups. It is important for there to be a specific area of the new lab reserved for the building of the machines. Additionally, this work space should be open and inclusive of all groups working on the project. This will spark collaboration among the groups, leading to a more cohesive and successful machine.

After previous experience and the dynamics of students in the classroom were reflected on, adjustments to the layout of the room were considered in order to improve efficiency. AutoCAD was used to rearrange the furniture into new

possible formations. One example of these changes is shown in Fig. 3, below. 3D models of the new lab space were also created, using Google SketchUp to get a better idea of what the room would look like once construction is complete. A perspective view within the model is shown in Fig. 5 below.

As construction on the new lab space began, analysis of students was underway. The first class of freshman engineering students was enrolled in the new Rube Goldberg curriculum in the Fall term of 2014. This class was held in existing engineering labs on campus. Sociometric badges were utilized to record student dynamics within the lab. The students were also surveyed at the end of the term to gather qualitative responses as to how they felt the lab space suited their needs during the project. Data of this nature will continue to be collected during the Spring term of 2015, the Fall term of 2015, and the Spring term of 2016. A comparison of this data will result in a determination of the current success of the project, and lead to further improvements and adjustments of the layout.

III. RESULTS AND DISCUSSION

One new possible classroom layout was designed with the current considerations and analysis in mind. The resulting layout takes into consideration all of the problems encountered in the Methods section. Fig. 3 depicts this new layout after making all of the changes. One of the changes that was made is the location of the furniture within the room. The workbenches, now shown at the top and bottom on the right of the figure, were moved to be in closer proximity to the Machine Shop. This would reduce traffic between the workbenches and the Machine Shop, creating a more efficient environment. Between the two sets of workbenches are the project tables. These project tables were reworked to be useful for both the existing curriculum, and the new curriculum, reducing the amount of space and new furniture needed. This is detailed further in Fig. 4.

The remaining lab tables were positioned on the opposite side of the lab. Positioning the lab tables further away from the Machine Shop will also reduce the noise from the machines in the main room. Placing the furniture in this layout creates two distinct areas in the lab: a work space, and an instructional space. This type of formation fits well with the needs of design projects, such as the ones that will be taught in this lab.

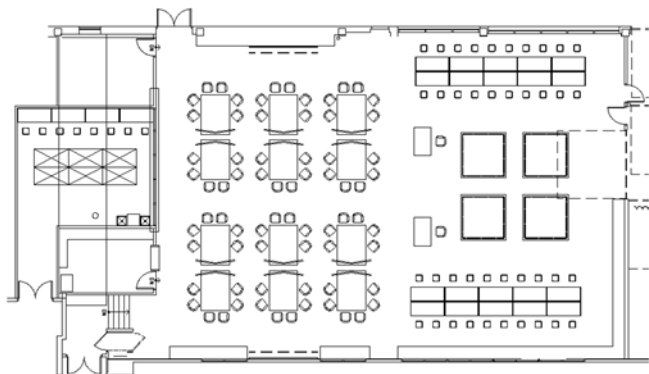


Fig. 3. Layout of new freshman engineering lab with modifications [10]. Student lab desks are now situated on the left side of the figure, creating an

instructional zone. On the right of the figure lie the student workbenches and project tables, creating a work and construction zone. The instructor stations are positioned between the two zones to provide a view of both sides of the lab space.

Once the new lab space was reorganized based on efficiency for design projects, the specifics of the Rube Goldberg machine module were considered to further accommodate the room. One of the problems encountered in the baseline layout was that there was no place for students to connect their machines to form one long chain of events. To accommodate this, the existing Winter term furniture (project tables) was redesigned to include spaces for the machines to be linked together. These square, 8' x 8' project tables are needed for the Winter term curriculum, and therefore need a designated space in the lab. Making modifications to these tables allows them to remain in the lab year-round, and eliminates the need to purchase new furniture for the Fall term curriculum.

As seen in Fig. 4 below, two project tables will be used together to create a platform for sixteen individual group machines. The specific layout of the machines had to be designed purposely for several reasons. The first and main restriction on the design of the layout was that students need to be able to have easy access to their machines in order to re-set them or make adjustments. By lining the machines along the outside of the platform, students will easily be able to adjust and re-set their machines when necessary. Another restriction was that the layout of the two tables needed to be the same, or a mirror image of each other. This allows for single-section classes to run their combined machine with eight groups, and for double-section classes to run their combined machine with sixteen groups. Working on the specifics of the classroom and furniture will better integrate the curriculum with the space it is taught in.

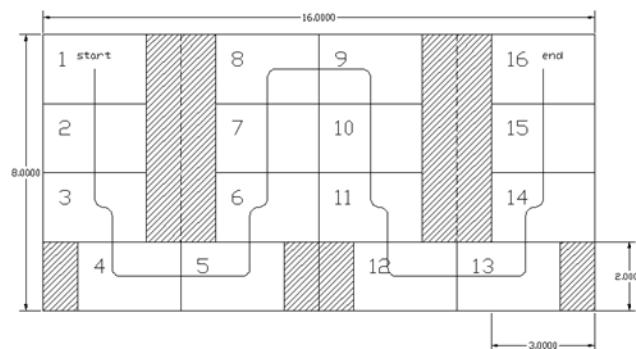


Fig. 4. Project table layout for new module incorporating existing furniture. Notice the "U"-shape design, allowing access to all machines within the chain. The mirror image layout (1 through 8 is mirror image of 9 through 16) allows for single- or double-section machines to be assembled.

However, there are drawbacks to this newly reworked design. Rearranging the furniture in this layout eliminates the possibility of dividing the space into two separate, complete classrooms. This would be an inconvenience for when having smaller class sizes is preferred. It is, on the other hand, a more convenient layout for large design projects, such as ones that are done in the third class of the Freshman Engineering Design sequence (ENGR 103).

After reviewing these considerations, it was decided that the most important feature of the room be the capacity to take on different forms. This led to the reworking of the electrical and furniture plans to allow the furniture in the room to be dynamic, movable, and yet still connected almost anywhere in the room. This plan allows for different layout testing, and adjustment based on the type of project that is taking place in the room during a certain term.

Flexibility both within the room and among the rooms themselves is the key factor to take away. The adjacent storage area and parts room with a distribution window allow for project materials to flow into and out of storage and the lab space with ease. These rooms make transitions within and between projects much more convenient. Furniture flexibility was achieved by utilizing non-stationary furniture, and outfitting the space with capabilities to connect the furniture to power and data in many different configurations. The room divider and garage-style doors connecting the lab to adjacent resources allow the space to become totally open or closed off as necessary.

IV. CONCLUSION

The new layout, which was based on the curriculum being taught in the classroom, was finalized and presented to the architects and faculty. Upon review, it was decided that the infrastructure and utilities would be installed so as to incorporate the multiple layouts such that the room can be rearranged between terms to accommodate the multiple modes of educational delivery. This reconfigurable layout was designed with an extensive engineering design project in mind, and therefore should be a great fit for the Spring term design project in ENGR 103. A screenshot of the 3D model drawn in Google SketchUp is shown in Figure 5. Once the classroom is constructed and furnished, planned future work, detailed below, will help to determine the success of the project.

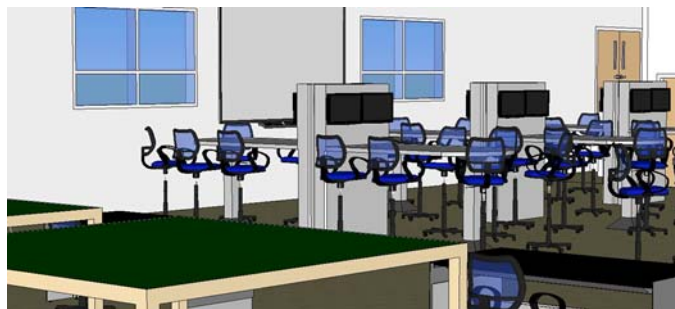


Fig. 5. Perspective view in 3D model of lab. Lab desks with computer screens for each group are shown. White board exists both on shown side and opposite side, allowing all students to view board. Instructor station (shown at bottom right of figure) has view of both instructional zone and construction zone.

In order to determine whether or not this model for designing classrooms and lab spaces is beneficial, data must be collected. For Academic Year 15-16, the original layout will be

deployed for the Fall and Winter terms, and the new layout for the Spring term provides an opportunity to study the reconfigurable nature of the room. The dynamics of the students in the classroom can be observed both during the Fall/Winter and the Spring in the new lab space. Things to look for when observing the students will include: which places they walk to most often, the distance from their start and end points, how each part of the classroom is being used, where the most collaboration takes place, and how often the two sides of the classroom are divided. Comparing the way students move differently in each layout will provide quantitative data as to whether or not this model was a success.

Additionally, surveying students and faculty who teach and work in the room will provide qualitative feedback. The survey should include questions regarding the benefits and deficiencies of each classroom layout (particularly regarding the use of the space for different project types). Feedback and suggestions can be used to further determine how to most efficiently arrange the space.

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Rubrics for Assessment Item Difficulty in Engineering Courses

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Abstract—A course in Engineering programs is designed and conducted to facilitate students to acquire a set of competencies to meet a subset of Program Outcomes(Graduate Attributes) identified by the accreditation agency. Formative and summative assessments, if in alignment with the competencies, enable the instructor to guide the students to learn well, and to measure the level of attainment of competencies. The difficulty levels of the assessment items are a measure of mastery of the competencies. Well defined difficulty rubrics provide guidelines to the instructor to prepare assessment items with stated difficulty levels. Several difficulty rubrics which are learner dependent or independent, subject specific or non-specific and score-based or score-independent to characterize the difficulty level are reported in the literature.

This paper presents a set of learner-independent and score-independent difficulty rubrics. The parameters that characterize these rubrics are arranged in a hierarchy. The nodal parameters are content, task and structure (stimulus) of assessment items. The leaf and atomic parameters are identified in the framework of Anderson-Bloom taxonomy. The parameters for a given assessment item are identified and difficulty is determined by applying weight based and fuzzy logic rule based methods. The efficacy of the proposed item difficulty rubrics is validated by designing different difficulty level items for the course Basics of Digital Systems, and validating the difficulty of the designed items by the subject matter experts.

Index Terms—Assessment, Difficulty, Fuzzy logic, Learner independent

I. INTRODUCTION

Engineering programs are designed and conducted to facilitate students to acquire a set of Program Outcomes identified by the accrediting agency of the country. Each course of an engineering program must formulate competencies that foster attainment of subset of these Program Outcomes. Competencies represent what the students should be able to do at the end of a course as per the instructor. Each competency statement is mapped to one of the cognitive levels and one or more categories of knowledge of Anderson-Bloom's taxonomy[1]. The assessment items associated with a competency are termed to be aligned if they belong to the same or lower cognitive level as that of the competency. Mastery of a competency gained by the student can be evaluated by offering them items of varying difficulty levels.

Here we propose item difficulty rubrics which will help instructor to arrange the available items in three difficulty level categories: easy, medium and hard. The intent is to capture in a gross way how instructors think about difficulty. These rubrics will also enable instructor to design items of three

difficulty levels at each cognitive level. The difficulty levels are not comparable across subjects and cognitive levels. Proposed fuzzy evaluation and weight based model estimates difficulty using an identified set of hierarchically arranged parameters. The designed rubrics are:

- 1) Independent of scores
- 2) Learner independent
- 3) Subject non-specific

While assessment items can be different for oral exams, lab viva, project demonstration and classroom assessment, we restrict our rubrics to items used in fixed duration classroom formative/summative assessments. Following section presents the existing difficulty frameworks and parameters used by each of them, and also a discussion on the characteristics chosen for the proposed difficulty rubrics.

II. LITERATURE REVIEW OF EXISTING DIFFICULTY RUBRICS

Difficulty rubrics have been explored in a variety of scenarios based on the roles of usage, learners, scoring and subjects. Table 1 presents an overview of the existing literature. The usage refers to classroom assessment (CA), intelligent tutoring system (ITS) and computer adaptive testing (CAT). Rubrics have been defined with respect to learners as either learner dependent (LD) or learner independent (LID), score based (SB) or subject matter expert based (SME), and subject specific (SS) or subject non-specific(SNS). It is very clear that majorly used approaches are either learner dependent and/or use students evaluation scores.

There can be various reasons, other than inherent difficulty of an item, because of which a student finds an item difficult. These include the effort involved in processing, student's mental model, motivation, interest, prerequisite knowledge, intelligent quotient and meta-cognitive knowledge. An assessment item, therefore, will be perceived differently by different students with regard to the difficulty level. Quantifying the LD parameters accurately within a span of a semester is a challenge. Also, the measures of the LD parameters for one batch of students may not be applicable to another batch of students[15]. *We consider here learner independent parameters by focusing on inherent difficulty of assessments items while designing the rubric by assuming that all the students have required prerequisite knowledge.*

Each of the approaches listed in Table 1 gives qualitative and quantitative measures for item difficulty, apriori or post assess-

Approaches	Usage	LD	LID		Score Based	SME Based
			SS	SNS		
Concept/Ontology/Knowledge map[6][7][8][9]	ITS, CAT		✓	✓		✓
Rasch models(IRT,LLTM) [10][11][12]	CAT, CA	✓			✓	
Psychological models [13][14][15]	ITS, CA	✓	✓	✓		✓
Rule based AI techniques [16][17][18]	CAT, CA	✓		✓	✓	

TABLE I
VARIOUS APPROACHES USED FOR ESTIMATING ITEM DIFFICULTY

ment administration. For apriori estimate, difficulty is found out using LD and/or LID parameters. For post assessment difficulty estimation approaches, difficulty of an item is found out by offering it to students and by calculating the proportion of students in class who got the item correct[4]. True score for a student may be different from the evaluation score due to the presence of random and systematic errors in the evaluation (scoring) processes involved[5]. Therefore, difficulty estimate based exclusively on evaluation scores fails to give the actual estimate for item difficulty. *The proposed rubrics aim at estimating difficulty apriori to assessment administration and evaluation.*

Engineering subjects can be descriptive, abstract and or computational. Therefore, every subject has some characteristics that make it different from other subjects. Also, the concerned instructor of a subject may restrict the competencies to lower cognitive levels while some other instructor may want to address higher cognitive levels. Also, items of the same difficulty level for two different subjects may not be comparable. The amount of detailing is more for subject specific approach. On the other hand, generalization of these models across subjects leads to abstraction. There is a clear trade off between generalization and the amount of detailing for these models. *The proposed rubrics are based on subject non-specific parameters, and are applicable to a wide range of engineering courses.*

III. DIFFICULTY AND COGNITIVE LEVELS

Because of the hierarchical nature of cognitive levels, there is a notion among instructors and researchers that items measuring abilities of students for higher cognitive processes are more difficult than items measuring lower cognitive processes. In the literature, there are some experimental evidences to disapprove this hypothesis by proving that difficulty and cognitive processes hierarchies are not necessarily same[19][20][21] based on estimating difficulty level using scores. The validity of this type of differentiation is always in question because of the influence of various random and systematic errors over scores[5]. We have tried to resolve the fuzziness between the terms difficulty hierarchy and cognitive process hierarchy by conducting an experiment for the following hypothesis.

Hypothesis 1: *Assessment items at higher cognitive level are not necessarily of higher difficulty levels than assessment items at lower cognitive levels.*

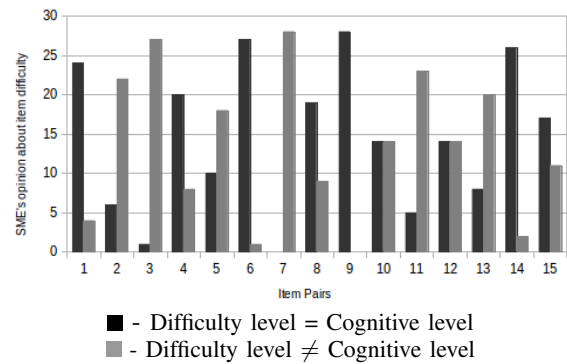


Fig. 1. Relation between Difficulty and Hierarchy of Cognitive Process

Basics of Digital Systems course was chosen for validating the above hypothesis statement. A large number of assessment instruments for this course were collected from various universities. A subset of assessment items from these assessment instruments was selected for conducting the survey. Each item was tagged with their respective cognitive level as per Anderson-Bloom's taxonomy[1] by pedagogy experts. Twenty eight SME's having two to five years of experience in teaching the same course were selected randomly for taking part in the survey. Each question in the survey had an item pair with items from different cognitive levels.

SME's were asked to make a binary comparison of difficulty level(DL) among each pair of items and mark the items with tags DL_{LOW} and DL_{HIGH} . There were mixed opinions among experts as shown in Figure 1. For some item pairs, few SME's marked item at lower cognitive level as DL_{HIGH} and for some item pairs, item at higher cognitive level was marked as DL_{LOW} . Also for a few item pairs, higher cognitive level item was marked as DL_{HIGH} and lower cognitive item was marked as DL_{LOW} . From the survey, it is clear that cognitive level and difficulty level is not necessarily related which proves our hypothesis that assessment items at higher cognitive level are not necessarily of higher difficulty levels than assessment items at lower cognitive levels. Proposed difficulty rubrics facilitates designing different difficulty level items for each cognitive level.

IV. PROPOSED DIFFICULTY RUBRICS

An analysis of Osterlinds[2] definition of a test item suggests, intrinsic difficulty resides in the content assessed, stimulus and task to be performed. *Content difficulty* is related to various elements of knowledge such as facts, concepts and procedures. *Stimulus difficulty* is related to the manner in which the item is presented to the students which includes words, phrases and information which is packed along with the item. *Task difficulty* refers to the difficulty that the students face when they generate their responses. The content to be assessed is related to the knowledge dimension while task to be performed is related to the cognitive level dimension of Anderson-Bloom taxonomy[1] table which is used as a tool to guide the development of item difficulty rubrics. We have

used content, task and structure as nodal parameters for our rubrics. Equation (1) gives difficulty(D) for assessment item.

$$D_{\text{item}} = D_{\text{task}} + D_{\text{content}} + D_{\text{stimulus}} \quad (1)$$

The cognitive dimension of taxonomy table consists of the cognitive processes and categories of knowledge. The cognitive processes are the updated versions of Blooms categories and they include, hierarchically, Create, Evaluate, Analyze, Apply, Understand, and Remember. The categories of knowledge include Factual, Conceptual, Procedural and Meta-cognitive. Taxonomy Table was created with six cognitive levels as columns and four categories of knowledge as rows. From a survey of existing assessment instrument for fixed duration classroom assessments, it was observed that assessment items from analyze, evaluate and create cognitive levels were not included for such assessments. Also, it is difficult to assess meta-cognitive knowledge for such assessments[3]. Based on our observation about the cognitive level and knowledge category for assessment items, we have designed our difficulty rubric for three cognitive levels(Remember, Understand, Apply) and three knowledge categories(Factual, Conceptual, Procedural). Each knowledge element can be assessed for one or more cognitive levels. Therefore, the resultant difficulty rubrics is defined for {remember-factual, remember-conceptual, remember-procedural, understand-conceptual, understand-procedural, apply-procedural} cells. Following is a discussion on three nodal parameters of difficulty considered for our rubric.

A. Task Difficulty

Task difficulty for an item comprises of any one of the cognitive levels: remember, understand and apply.

$$D_{\text{task}} = \{D_R, D_U, D_A\} \quad (2)$$

- 1) **Remember:** When the objective of assessment item is to assess retention of the instruction material in much the same form as it was taught/ delivered, the relevant cognitive level is remember. The associated sub cognitive processes are recognizing(TC_{R_1}) and recalling(TC_{R_2})[1]. Recognize cognitive process have more number of cues as compared to recall cognitive process as assessment items associated with recognize cognitive process are selective type. The cue for such items is in the form of list of answers. Memory is organized as chunks which can be considered as basic interconnected units. Connection between two chunks is called as association. When something in our current environment is strongly associated with a chunk in our memory, it spreads activation to that chunk. Because of available cues for recognize items, activation is spread fast to memory chunks in case of recognize cognitive process as compared to recall[23]. Therefore, recognize assessment items are easier as compared to recall assessment items. The difficulty of remember task increases if more amount of data need to be remembered. Number of unknowns(R_1) in an assessment item influences the

difficulty of remember cognitive process. Unknown can be either fact or concept or procedure. The difficulty of remember task is given by D_R .

$$D_R = D_{R_1} + D_{TC_R} \quad (3)$$

$$D_{TC_{R_1}} < D_{TC_{R_2}} \quad (4)$$

- 2) **Understand:** Student should be able to construct meaning from the instructions delivered by the instructor. When the objective of assessment item is to assess transfer of the instruction material, the relevant cognitive level is understand. This cognitive category is closely linked with Conceptual Knowledge. The associated sub cognitive processes are interpreting, exemplifying, classifying, summarizing, inferring, comparing and explaining[1]. Exemplify and classify processes occurs when student links example with a concept or vice versa. Infer involves linking a pattern with appropriate concept. For our rubric, we have assumed that summarize and explain forms the lowest difficulty level. Exemplify, classify and infer cognitive process are considered to be hardest as student need to understand two concepts/procedures for generating their response. The sub cognitive processes for understand cognitive level can be arranged in three groups in increasing difficulty level as TC_{U_1} {summarize, explain}, TC_{U_2} {compare, interpret}, TC_{U_3} {exemplify, classify, infer}.

The difficulty parameter for assessment items belonging to understand cognitive category is number of unknowns(U_1), number of concepts(U_2) and number of conditions(U_3). Students are expected to use some specific resource while giving response for assessment items which is termed as conditions.

$$D_U = D_{U_1} + D_{U_2} + D_{U_3} + D_{TC_U} \quad (5)$$

$$D_{TC_{U_1}} < D_{TC_{U_2}} < D_{TC_{U_3}} \quad (6)$$

- 3) **Apply:** Apply cognitive process involves procedures to perform exercises or solve problems and is closely linked with Procedural Knowledge. The Apply category consists of two cognitive processes: executing(TC_{A_1}) and implementing(TC_{A_2})[1]. In executing processes, there are sequence of steps which are followed in fixed order. Students are more familiar with such tasks. On the other hand, students encounter unfamiliar task for implement processes and they need to select the procedures and their sequence[1].Therefore, implement process is considered to be more difficult as compared to execute process.

The difficulty parameter for assessment items belonging to apply cognitive category is number of unknowns(A_1), number of concepts(A_2), number of procedures(A_3), number of inputs(A_4) and number of conditions(A_5).

$$D_A = D_{A_1} + D_{A_2} + D_{A_3} + D_{A_4} + D_{A_5} + D_{TC_A} \quad (7)$$

$$D_{TC_{A_1}} < D_{TC_{A_2}} \quad (8)$$

B. Content Difficulty

Content difficulty for an item comprises of any one or more knowledge elements: factual, conceptual and procedural.

$$D_{\text{content}} = \{D_F, D_C, D_P, D_F+D_C, D_F+D_P, D_C+D_P, D_F+D_C+D_P\} \quad (9)$$

- 1) **Factual:** It contains the basic elements a student should know to be acquainted with the discipline or to solve any problems in it. The two sub-types of this type of knowledge are knowledge of terminology(KC_{F_1}) and knowledge of specific details and elements(KC_{F_2})[1]. KC_{F_1} is considered to be easier as compared to KC_{F_2} as terminology deals with the vocabulary used for a course while specific details require to produce some specific information about the vocabulary used for a course. For example: the item “what is excitation table?” is easier as compared to “what is the excitation table for D flip flop?”.

$$D_F = D_{KC_F} \quad (10)$$

$$D_{KC_{F_1}} < D_{KC_{F_2}} \quad (11)$$

- 2) **Conceptual:** A concept is an abstract or generic idea generalized from particular instances. A conceptual knowledge element often requires knowledge of many concepts. The three sub-types of this type of knowledge are knowledge of categories and classification(KC_{C_1}), knowledge of principles and generalization(KC_{C_2}) and knowledge of theories, models and structures(KC_{C_3})[1]. KC_{C_2} is composed of KC_{C_1} and KC_{C_3} is composed of KC_{C_2} . Therefore, KC_{C_3} is considered to be more difficult than KC_{C_2} and KC_{C_2} is considered to be more difficult than KC_{C_1} . Some examples of KC_{C_1} are combinational, sequential functions, moore, mealy functions and synchronous, asynchronous functions. Items for KC_{C_2} relate to usage of clock signal for avoiding race around condition and increase in execution speed for asynchronous functions. Items based on digital representation of information represents KC_{C_3} .

$$D_C = D_{KC_C} \quad (12)$$

$$D_{KC_{C_1}} < D_{KC_{C_2}} < D_{KC_{C_3}} \quad (13)$$

- 3) **Procedural:** Procedure is a series of steps/ actions done to accomplish a goal. Knowledge of procedures is referred to as procedural knowledge. Procedures can be predetermined sequence of actions that will lead to correct answer when executed correctly or it can be possible actions which must be sequenced appropriately to solve a problem. The three sub-types of this type of knowledge are knowledge of subject specific skills and algorithms(KC_{P_1}), knowledge of subject specific techniques and methods(KC_{P_2}) and knowledge of criteria for determining when to use appropriate procedures(KC_{P_3})[1]. Fixed order of decisions are taken and the the end result of the procedure is fixed for KC_{P_1} . Order of decisions and end result for the procedure is

not fixed for KC_{P_2} . KC_{P_3} helps in taking decisions for KC_{P_2} based on certain criteria. Therefore, KC_{P_3} is considered to be more difficult than KC_{P_2} and KC_{P_2} is considered to be more difficult than KC_{P_1} .

$$D_P = D_{KC_P} \quad (14)$$

$$D_{KC_{P_1}} < D_{KC_{P_2}} < D_{KC_{P_3}} \quad (15)$$

- 4) **Relationship between Difficulty of Knowledge Elements:** Factual knowledge is required to understand any concept or solve any procedure and they can be considered in isolation which have some value in and of themselves. It is considered to be less difficult as compared to conceptual and procedural knowledge element[1]. Conceptual and procedural knowledge categories cannot be considered independently. There is significant amount of research which discusses that these two types of knowledge are related[22]. There is a causal and bidirectional links between conceptual and procedural knowledge. Conceptual tasks are relatively unfamiliar to students, they need to derive answer from their conceptual knowledge rather than implement a procedure for solving the task. Therefore, conceptual knowledge element is often considered to be more difficult as compared to procedural knowledge element[1].

$$D_C > D_F, D_P > D_F, D_C > D_P \quad (16)$$

C. Stimulus Difficulty

This type of difficulty refers to the difficulty faced by the student to understand and analyze the item statement. Same item can be presented to students in many different ways by changing the type of vocabulary used. The amount of effort in analyzing the item statement increase as the number of deductions(S_1) increases. The difficulty for an item decreases if students are guided with some number of hints(S_2). While attempting the item, often student need to identify certain number of implicit assumptions(S_3) to reach the final solution. More is the number of such implicit assumptions, more is the difficulty.

$$D_{\text{stimulus}} = D_{S_1} + D_{S_2} + D_{S_3} \quad (17)$$

Table II shows difficulty rubrics which indicates difficulty parameters for each cognitive level.

V. ESTIMATION OF DIFFICULTY

In this paper, we have tried to estimate difficulty using proposed difficulty rubrics by following two methods. We have then compared the performance for each of these methods with SME's perspective of item difficulty gathered through a survey.

A. Weight Based Method

The weights(W) given to each of the nodal parameters(content, task, structure) is subject specific. Weights for nodal parameter are decided by SME's by considering the nature of the subject. For example, courses which include various types of computation, maximum weight is given to task

D _{item}	D _{task}	D _{content}	D _{stimulus}
Remember (R_D)	{D _{R₁} , D _{TC_{R₂}} }	{D _{KC_{F₁}} , D _{KC_{F₂}} , D _{KC_{C₁}} , D _{KC_{C₂}} , D _{KC_{C₃}} , D _{KC_{P₁}} , D _{KC_{P₂}} }	{D _{S₁} , D _{S₂} , D _{S₃} }
Understand (U_D)	{D _{U₁} , D _{U₂} , D _{U₃} , D _{TC_{U₁}} , D _{TC_{U₂}} , D _{TC_{U₃}} }	{D _{KC_{C₁}} , D _{KC_{C₂}} , D _{KC_{C₃}} , D _{KC_{P₁}} , D _{KC_{P₂}} }	{D _{S₁} , D _{S₂} , D _{S₃} }
Apply (A_D)	{D _{A₁} , D _{A₂} , D _{A₃} , D _{A₄} , D _{A₅} , D _{TC_{A₁}} , D _{TC_{A₂}} }	{D _{KC_{C₁}} , D _{KC_{C₂}} , D _{KC_{C₃}} , D _{KC_{P₁}} , D _{KC_{P₂}} }	{D _{S₁} , D _{S₂} , D _{S₃} }

TABLE II
DIFFICULTY RUBRICS

difficulty. On the other hand, courses which give more emphasis to organizing and attributing the subject matter, structure difficulty carries maximum weight. Figure 2, 3 and 4 shows the difficulty parameters for remember, understand and apply cognitive levels arranged hierarchically. We have drawn these weight graphs for Basics of Digital Systems course which is focused primarily on design of digital functions. Therefore, we have allotted maximum weight to task parameter.

The weights given to the intermediate level parameters and atomic parameters is subject non-specific. It is based on our discussion in section IV and equations (1) to (17) which mostly consider pedagogical theories to compare difficulty related to each parameter. Each assessment item has content, task and stimulus difficulty. Content can be either factual, conceptual and procedural. Task is a combination of difficulty due to any one item category and the cognitive process difficulty parameters. Stimulus is again combination of stimulus difficulty parameters. Each item has certain number of cognitive process parameters and stimulus parameters in it. Difficulty increases as the number of each of these parameters increases except for the parameter number of hints. Difficulty decreases as number of hints increases. The bold lines in the weight graphs indicate that the weights of leaf parameters need to be combined. The dotted lines indicate the exclusivity of the leaf parameters, that is any one leaf parameter weight which is applicable for the assessment item need to be selected.

Initially, specific knowledge category(KC) and item category(TC) for an item are identified. $R_1, U_1, U_2, U_3, A_1, A_2, A_3, A_4, A_5, S_1, S_2$ and S_3 are related to numbers, each of which has a maximum value. Let $Num_{R_1}, Num_{U_1}, \dots$ be number of parameter present in an assessment item. Let $Max_{R_1}, Max_{U_1}, \dots$ be the maximum number of parameters that can be present in an assessment item. The difficulty is found out using the following equations:

$$N_p = Num_p / Max_p \text{ where } P = R_1, U_1, U_2, \dots, S_3 \quad (18)$$

$$D = W_{KC} + W_{TC} + \sum (N_p * W_p) \text{ where } P = R_1, U_1, U_2, \dots, S_3 \quad (19)$$

where W_{KC} , W_{TC} , W_p denotes weight for knowledge category, task category, cognitive process and stimulus difficulty parameters respectively.

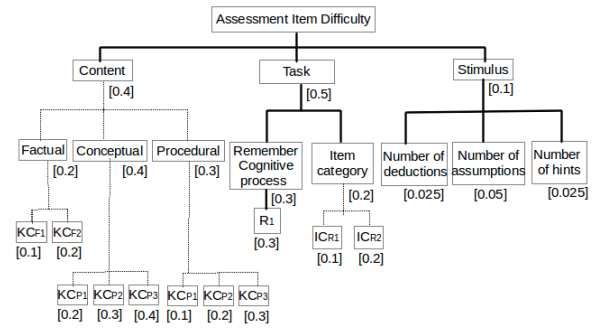


Fig. 2. Weight Vectors for Remember Cognitive Process

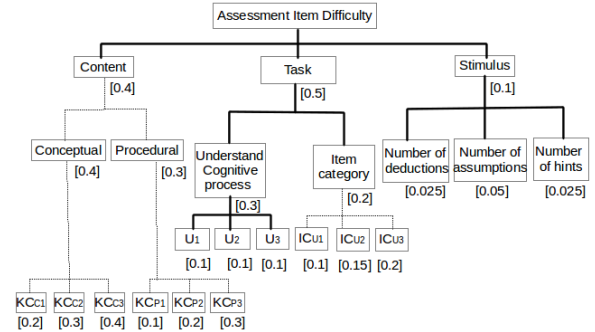


Fig. 3. Weight Vectors for Understand Cognitive Process

Table III shows some examples from {apply-procedural} cell and Table IV shows their difficulty estimation using this method. Difficulty level is easy(1) if the estimated difficulty value is less than 35, it is medium(2) if it is less than 65 and hard(3) if it is more than 65.

Decision making frameworks based entirely on weight is often influenced by SME's view and opinion about the subject matter. Also, it is a challenge to extract the highest count which can be present in items corresponding to each parameter for normalising them. For such vague and imprecise scenarios, fuzzy logic often proves to be a better approach.

B. Fuzzy Logic Rule Based Method

The way instructors think about difficulty is inherently fuzzy. Each instructor may decide different combinations and

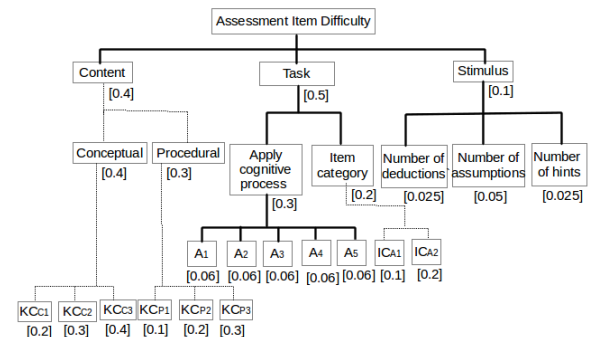


Fig. 4. Weight Vectors for Apply Cognitive Process

AI1	Construct a logic circuit using NAND gates only for the expression $x = A \cdot (B + C)$.
AI2	Design a counter that might be used to simulate the roll of a die in a dice game. Use D flip-flops and a 3-input NAND gate. Draw the corresponding timing diagram.
AI3	Design a simplified traffic-light controller that switches traffic lights on a crossing where a north-south (NS) street intersects an east-west (EW) street. The input to the controller is the WALK button pushed by pedestrians who want to cross the street. The outputs are two signals NS and EW that control the traffic lights in the NS and EW directions. When NS or EW are 0, the red light is on, and when they are 1, the green light is on. When there are no pedestrians, NS=0, EW=1 for a minute, follow by NS=1 and EW=0 for 1 minutes, and so on, when WALK button is pushed, NS and EW both become 0 for a minute when the present minute expires. After that the NS and EW signals continue alerting. For this traffic-light controller: a) Develop a state diagram. (Hint: can be done using 3 states) b) Draw the state transition table. c) Encode the states using minimum number of bits. d) Derive the logic schematic for a sequential circuit which implements the state transition table.

TABLE III
SAMPLE ASSESSMENT ITEMS

AI	KCP	IC _A	A ₁	A ₂	A ₃	A ₄	A ₅	S ₁	S ₂	S ₃	D
W	0.3	0.3	0.06	0.06	0.06	0.06	0.06	0.025	0.05	0.025	
AI1	KCP ₂	IC _{A1}	1	2	1	3	0	0	0	0	
Np	-	-	0.25	0.2	0.1	0.75	0	0	0	0	
D	0.2	0.1	0.015	0.012	0.006	0.045	0	0	0	0	0.37
AI2	KCP ₂	IC _{A1}	4	10	7	3	1	1	0	0	
Np	-	-	1	1	0.7	0.75	0.33	0.33	0	0	
D	0.2	0.1	0.06	0.06	0.042	0.045	0.02	0.0083	0	0	0.54
AI3	KCP ₃	IC _{A2}	4	9	7	3	0	2	0	1	
Np	-	-	1	0.9	0.7	0.75	0	0.66	0	0.33	
D	0.3	0.2	0.06	0.054	0.042	0.045	0	0.01	0	0.017	0.75

TABLE IV
DIFFICULTY ESTIMATION USING WEIGHT BASED METHOD

values of parameters for easy, medium and hard items. We have used fuzzy logic technique[24] for estimating difficulty by considering proposed difficulty rubrics as shown in Table II. The difficulty parameters for each cognitive process are:

$$R_D = \{KC_F, KC_C, KCP, R_1, TC_R, S_1, S_2, S_3\} \quad (20)$$

$$U_D = \{KC_C, KCP, U_1, U_2, U_3, TC_U, S_1, S_2, S_3\} \quad (21)$$

$$A_D = \{KC_C, KCP, A_1, A_2, A_3, A_4, A_5, TC_R, S_1, S_2, S_3\} \quad (22)$$

- Fuzzy sets:** The domain of the parameters $R_1, U_1, U_2, U_3, A_1, A_2, A_3, A_4, A_5, S_1, S_2$ and S_3 range over set of values. Since the range of values is not clearly defined for easy, medium and hard items, these sets need to be defined as fuzzy sets as shown in Table V. The parameters $KC_F, KC_C, KCP, TC_R, TC_U$ and TC_A have pre fuzzified values which are ordered hierarchically and are given values as shown in Table VI. As discussed in rubrics, sub-knowledge categories and sub-cognitive processes exist for these parameters which are arranged in increasing difficulty level. These sub-parameters are inherently fuzzy. Usually the inputs to fuzzy inference system is given as crisp value. But for certain inputs, such as KC_F, KC_C and KCP , the given values are already fuzzy. Fuzzification process is not required for such input values. Therefore, we have termed them as pre fuzzified sets.
- Membership function:** These are formed by assigning proper range to respective linguistic variables for fuzzy sets: low, medium, high. We have chosen combination of triangular and trapezoidal membership function(μ) for $R_1, U_1, U_2, U_3, A_1, A_2, A_3, A_4, A_5, S_1, S_2$ and S_3 . The membership function for U_2 is built by choosing trapezoidal membership function for each linguistic variable

Fuzzy variables	Low(1)	Medium(2)	High(3)
Number of unknowns(R_1, U_1, A_1)	{1,2}	{1,2,3}	{2,3,4}
Number of concepts(U_2, A_2)	{1...5}	{3...8}	{6...12}
Number of procedures(A_3)	{1...5}	{3...8}	{6...12}
Number of inputs(A_4)	{1,2}	{2,3,4}	{3,4,5}
Number of conditions(U_3, A_5)	{1,2}	{2,3,4}	{3,4,5}
Number of assumptions(S_1)	{1,2}	{2,3,4}	{3,4,5}
Number of deductions(S_2)	{1,2}	{2,3,4}	{3,4,5}
Number of hints(S_3)	{1,2}	{2,3,4}	{3,4,5}

TABLE V
DIFFICULTY EVALUATION CRITERION INTERVAL FOR FUZZY SETS

Fuzzy variables	Values	Fuzzy variables	Values
{ KC_F, KC_C }	{1,2}	{ TC_R, TC_R }	{1,2}
{ KC_C, KC_C, KC_C }	{1,2,3}	{ TC_U, TC_U, TC_U }	{1,2,3}
{ KCP, KCP, KCP }	{1,2,3}	{ TC_A, TC_A }	{1,2}

TABLE VI
PREFUZZIFIED SETS

as shown in Figure 5. In a similar way, membership function for other parameters are also built as shown in Table VII. For variables having prefuzzified sets, prefuzzified membership functions are chosen. For pre fuzzified membership function, each term has value 1, 2 or 3 depending upon the pre fuzzified set.

- Fuzzy Rules:** Fuzzy rules are written for combination of values of fuzzy sets. The accuracy of the output estimation increases with the number of rules. For our application of estimating difficulty, rule base needs to be written for all the combinations of R_D, U_D and A_D . Each difficulty parameter for R_D, U_D and A_D can have value {1, 2} or {1, 2, 3} based on their fuzzy and prefuzzified sets. The total number of combination of values for R_D is 2916, U_D is 19683 and A_D is 118098. It is practically in-feasible to design rule base for these many combinations manually. Therefore, we have automatically generated the rule base. The algorithm for the automatic generation of rule base is based upon the intuition that there is a positive correlation between difficulty and the distance of any combination of values to the origin of multidimensional space of difficulty parameters. More is the closeness to the origin, more is the easiness for items. A reasonable approach can be to find sum of fuzzy values of vectors R_D, U_D and A_D for finding

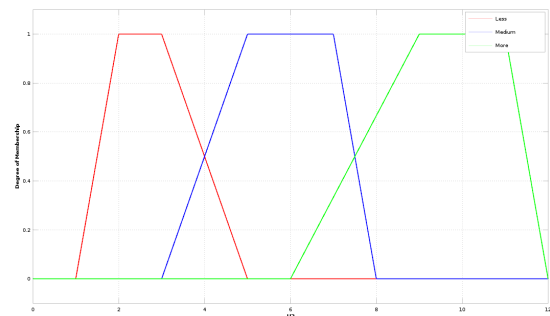


Fig. 5. Membership function for U_2

Parameters	$\mu(\text{variable}_1)$	$\mu(\text{variable}_2)$	$\mu(\text{variable}_3)$
R_1, U_1, A_1	{0,1,2}	{1,2,3}	{2,3,4}
U_2, A_2	{1,2,3,5}	{3,5,7,8}	{6,9,11,12}
A_3	{1,2,3,5}	{3,5,7,8}	{6,9,11,12}
A_4	{0,1,2}	{1,2,3,4}	{3,4,5}
U_3, A_5	{0,1,2}	{1,2,3}	{2,3,5}
S_1	{0,1,2}	{2,3,4}	{3,4,5}
S_2	{0,1,2}	{2,3,4}	{3,4,5}
S_3	{0,1,2}	{2,3,4}	{3,4,5}
KC_F	0	1	2
KC_C	1	2	3
KC_P	1	2	3
TC_R	0	1	2
TC_U	1	2	3
TC_A	0	1	2

TABLE VII
MEMBERSHIP FUNCTIONS FOR INPUT PARAMETERS

KC_F	KC_C	KC_P	R_1	TC_R	S_1	S_2	S_3	Sum	R_D
1	1	1	1	1	1	1	1	8	Easy
1	2	1	1	1	1	2	1	10	Easy
2	2	2	1	1	3	1	2	14	Medium
2	3	3	1	2	3	1	2	17	Medium
1	3	3	1	2	3	3	3	19	Hard
2	3	3	1	2	3	3	3	20	Hard

TABLE VIII
SAMPLE RULE BASE FOR D_R

the distance from the origin of multidimensional space. The sum of vectors R_D , U_D and A_D is found out with minimum and maximum fuzzy value for each parameter. These sums are denoted as Sum_{min} and Sum_{max} . The difference(D_f) between Sum_{max} and Sum_{min} is used to form three equal categories, one each for every difficulty level. Equation (23) denotes rule base for deciding easy, medium and hard difficulty levels.

$$D = \begin{cases} Easy, & \text{if } Sum < Sum_{min} + D_f/3. \\ Medium, & \text{if } Sum < Sum_{min} + (2 * D_f/3). \\ Hard, & \text{if } Sum \leq Sum_{max}. \end{cases} \quad (23)$$

where Sum is the result of addition of fuzzy values for each parameter. An example rule base generation for R_D for some combinations is as shown in Table VIII.

$$Sum_{max} = 2 + 3 + 3 + 3 + 2 + 3 + 3 + 3 = 22 \quad (24)$$

$$Sum_{min} = 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 = 8 \quad (25)$$

$$R_D = \begin{cases} Easy, & \text{if } Sum < 13. \\ Medium, & \text{if } Sum < 18. \\ Hard, & \text{if } Sum \leq 22. \end{cases} \quad (26)$$

- 4) **Fuzzy output and Defuzzification:** The output variable is *assessment item difficulty*, which has again three linguistic variables: easy, medium and hard for D_R , D_U and D_A . The degree of membership functions is given by following equations:

$$\mu_F(R_D) = \max[\min[\mu_{K_F}, \mu_{K_C}, \mu_{K_P}, \mu_{R_1}, \mu_{TC_R} \mu_{S_1} \mu_{S_2} \mu_{S_3}]] \quad (27)$$

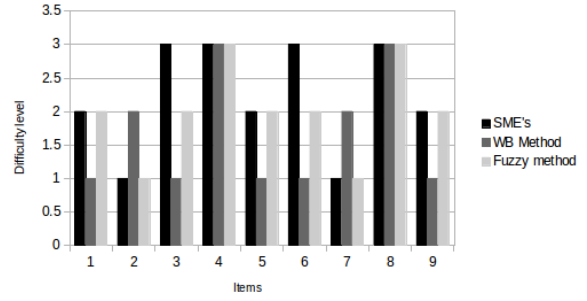


Fig. 6. Comparison of SME's opinion with Weight Based and Fuzzy Rule Based Method

$$\mu_F(U_D) = \max[\min[\mu_{K_C}, \mu_{K_P}, \mu_{U_1} \dots \mu_{U_3}, \mu_{TC_U} \mu_{S_1} \dots \mu_{S_3}]] \quad (28)$$

$$\mu_F(A_D) = \max[\min[\mu_{K_C}, \mu_{K_P}, \mu_{A_1} \dots \mu_{A_3}, \mu_{TC_A} \mu_{S_1} \dots \mu_{S_3}]] \quad (29)$$

These equations determine an output membership function value for each active rule. After completing the fuzzy decision process, the obtained fuzzy output is converted to a crisp value by applying centroid technique. Difficulty level is easy(1) if the estimated difficulty value is less than 35, it is medium(2) if it is less than 65 and hard(3) if it is more than 65.

VI. PILOT STUDY AND RESULTS

We have conducted a pilot field study with assessment items for Basics of Digital Systems course. Twenty three SME's having two to five years of experience in teaching the same course were selected randomly for taking part in the survey. The assessment items chosen for the survey were selected from question papers from various universities for the same course. We have conducted an experiment for the following hypothesis with 9 items, 3 each from remember, understand and apply cognitive level.

Hypothesis 2: *Fuzzy rule based difficulty estimation using proposed difficulty rubrics correlates better with subject matter expert's perspective of difficulty as compared to weight based difficulty estimation.*

The chosen items were given to SME's to mark them as easy(1), medium(2) and hard(3). The cognitive level information was not revealed to experts. We have estimated the value of difficulty for these 9 items using weight based and fuzzy rule based method. We have then compared the performance of both these methods with SME's opinion as shown in Figure 6. It was observed that fuzzy logic difficulty estimation correlates better with SME's opinion as compared to weight based method which proves our hypothesis. The accuracy of difficulty estimation using weight based method can be improved by modifying weights allotted to difficulty parameters corresponding to task, content and stimulus difficulty.

VII. CONCLUSION AND FUTURE WORK

Rubrics to identify the difficulty level (difficulty rubrics) of an assessment item can greatly facilitate the instructors of engineering courses to aim at and achieve the right level of mastery of learning. Difficulty rubrics that are learner independent, subject non-specific and score-independent will make them easier to use. The estimation of difficulty level of an assessment item is based on three of its aspects: task, content and stimulus. Task difficulty is based on the sub-processes of Blooms six cognitive levels. It should be noted that difficulty level of items at higher cognitive levels are not necessarily higher. However, it is possible to arrange subsets of the sub-processes associated with a cognitive level at different difficulty levels. Therefore, it becomes necessary to address each cognitive level with respect to difficulty level. Difficulty rubrics in this paper are restricted the most dominant cognitive processes, namely, remember, understand and apply.

The number of parameters to be considered to determine the difficulty becomes impressively large. Weight based and fuzzy logic based methods are proposed to make the process of determining the difficulty of an assessment item tractable. The difficulty levels of a given set of items related to the first level course on Digital Systems as determined by these two methods differed from each other, with fuzzy based method giving results closer to the opinions of subject matter experts.

Deeper understanding of engineering concepts is a pre-requisite for applying engineering knowledge and skills in practical and professional situations. Formative and summative assessment designed using wide range of difficulty level assessment items, will facilitate instructors to assess students abilities pertaining to course competencies completely.

Though these rubrics prove to be effective, the precision can be further increased by conducting survey with sufficiently good number of experts and using the survey results as a feedback to the fuzzy model for changes with respect to the membership function and rule base. Also, a training data set with large values may prove to be helpful for the fuzzy model to become more accurate and precise. We also aim to extend this contribution by designing rubrics for analyze, evaluate, create cognitive levels and engineering specific categories of knowledge as proposed by Vincenti[25] namely Fundamental Design Concepts, Criteria and Specifications, Practical Constraints and Design Instrumentalities.

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Inspiring Undergraduate Students in Engineering Learning, Comprehending and Practicing by the Use of Analog Discovery Kits

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Abstract—‘Flipping the Classroom’ is a well-known effective educational approach which can produce significant learning gains. Students are doing the preliminary cognitive work to gain knowledge and comprehension outside of class, then focusing on the advanced cognitive work on application, analysis, synthesis, and evaluation in class. However, practically its application is quite challenging due to the limited accessible resources on both timing and spatial, especially in teaching engineering courses. In dealing these issues, in this paper we present our initiative works on improving the learning process of undergraduate students by applying this approach, by the use of the key laboratory equipment ‘Analog Discovery’. We applied the AD kit in three levels in teaching various electrical engineering courses: lecture, laboratory and senior design. Moreover, a series of engineering workshops are also developed targeting on various topics, with the direct support with AD kits. The results have shown a significant improvement on students’ learning. The application of AD kit in engineering education can greatly help students’ comprehension on knowledge, facilitate their engineering practice, and inspire their interests and motivation on learning.

Keywords—Analog Discovery Kit, Flipping the Classroom

I. INTRODUCTION

To improve the learning effectiveness in engineering education, diversified theories have been proposed and practiced by educators, among which ‘Flipping the Classroom’ and ‘Experiential Learning’ are two of the most well-known methods.

The ‘Flipping the Classroom’ enables an instructor to provide traditional, low cognitive level, lecture materials in an alternative format outside the classroom, freeing up class time normally used to ‘convey’ information to students [1]. Instruction that used to occur in class was then accessed in advance of class (generally at home), so that students were well prepared and could derive the most benefit from time spent in the face-to-face learning environment. In this scenario, class becomes the place to work through problems, advance concepts, and engage in collaborative learning. Most importantly, all aspects of instruction can be rethought to best maximize the scarcest learning resource – time [2, 3].

On the other hand, Experiential Learning Theory (ELT) provides a holistic model which emphasizes the central role that experience plays in the learning process. The most widely

used learning theory is Kolb’s experiential learning cycle [4-6] as shown in Fig. 1. According to the Kolb’s cycle, the four experiential learning stages are Concrete experience, Reflective observation, Abstract conceptualization and Active experimentation.



Fig. 1. Kolb’s cycle of experiential learning [7].

Practically, one of the major issues in applying these advanced teaching methods in engineering education is the gap between the limited facilities and students’ accessibility of required resources. Especially in teaching electrical engineering courses, the number of expensive equipment and working stations rarely meets the requirements of students, and it is always a trouble for all students to agree on a schedule to work together after class.

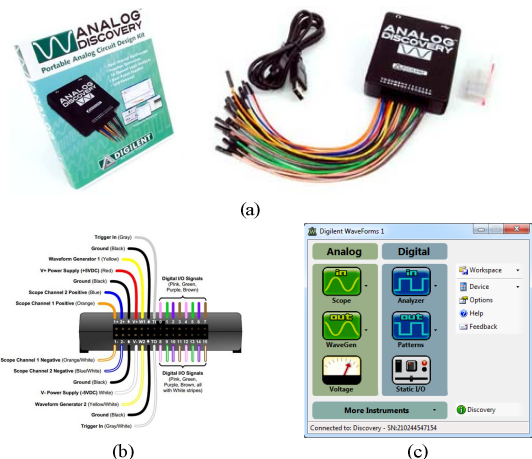


Fig. 2. a) Analog Discovery kit, b) pin-out, and c) interface of ‘Waveform’.

In dealing with these issues, we tried to integrate the Analog Discovery (AD) kit into our teaching practice to undergraduate engineering students. The AD kit is a small (3.2"×2.6"×0.8"), portable and low-cost (\$99 for US student)

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multifunction instrument that can measure, record and generate analog and digital signals. A PC based free software 'Waveforms' is provided to control all I/O of the AD, by which the kit can be configured to work as all major laboratory instruments including multimeter, function generator, DC power supply and oscilloscope. Fig. 2 shows the AD kit, its pin-out, and the software interface [8]. In short, the AD kit can drive, measure, and visualize, for both analog and digital signals.

The AD kit has been applied in three different levels in teaching various electrical engineering courses: lecture, laboratory and senior design. Moreover, a series of engineering workshops are also developed targeting on various topics, with the direct support with AD kits.

From the beginning, most engineering students in the department are recommended by instructors to play with the AD kit in different courses. A pre-survey is required when they pick up the kit. Then by the end of the semester, students are requested to return the AD kits, or submit the application to keep the AD kit for another semester. Meanwhile they are also requested to complete a post-survey. These data are collected and analyzed for the assessment of AD kit's effectiveness.

Up to date, according to the feedback collected from involved students, the AD kit brought them an unprecedented learning experience on various engineering courses. First of all, the AD kit enables students' engineering practice on anytime and anywhere, but no longer limited in the laboratories. This unique feature has significantly changed many aspects of engineering education. The effectiveness assessment has shown great improvement on teaching outcomes.

The paper is organized as following: Sect. II introduces the methodological approaches applied; Sect. III illustrates typical case studies, Sect. IV presents the effectiveness assessment of proposed educational methods, and Sect. V concludes the whole work.

II. METHODOLOGICAL APPROACHES PROPOSED

The educational practice of integrating the AD kit into engineering curriculum teaching is in three levels: lecture, lab, and senior design, plus a series of workshops.

Level I – Lecture

The Kolb's experiential learning model was applied in teaching engineering courses by using the AD kit. Many engineering courses in the curriculum are suitable for this application, ranges from Basic Circuit Theory, Digital Logic Design, Electronics, to Instrumentation, etc. This different approach from the traditional didactic or demonstrative way now makes the teaching more interactive and the learning is more substantial.

For instance, in teaching the Boolean algebra in Digital Logic Design, originally the instructor will introduce concepts in class first, from 'AND', 'OR' and 'NOT' operations, to symbol of gate, and truth table, etc. Later in the lab (maybe a few days after) these concepts need to be reviewed again, then add up with new contents such as the logic '1' ($\sim +5V$) and '0' (GND), and 74-series ICs using guidelines. Such an exposure to a high

volume of new knowledge is quite challenging to beginners, whereas the separation of theory (lecture) and practice (lab) makes things even worse. Instructor may want to move his class to a laboratory, to give students an instant experience. However not all schools have enough lab stations and equipment to support. The effectiveness of lecturing in laboratory is also questionable.

By using the AD kit now, students' learning and practicing can be seamlessly integrated during regular class hours. In the new 'Experiential Learning' style, every student needs to have the laptop and AD kit properly setup before the class. During the class hours, they are provided with a small breadboard and various IC chips. Right after the instructor's introduction of each logic operation, students will practice and verify the function of a corresponding gate on the breadboard. Undoubtedly such experience is more direct, substantial and inspiring. In this scenario, the instructor can expect the ignition of a warm discussion, whereas students are excited and eager to learn more technical details and advanced contents. In this way their study process as well as the width and depth of their comprehension can be greatly expedited through experimental learning.

A similar example can be found in introducing the propagation delay of logic gates in teaching the same course. In the past this concept was confusing to many students, especially those who have not passed the Electronic course yet. By the use of the AD kit and other basic components, everyone can build a ring oscillator in a few minutes in class, to observe/measure the propagation delay of a single gate on the laptop display. Fig. 3(a) and Fig. 3(b) show the circuit setup and result of a three-inverter ring oscillator.

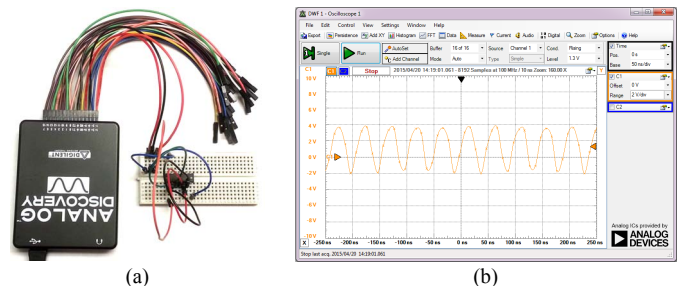


Fig. 3. a) Circuit setup of ring oscillator, and b) output of the ring oscillator.

Moreover, the AD kit offers additional functions that can help students to easily exercise on advanced materials. For instance, now students are using the kit to generate Bode plots in doing homework of Power Electronics and Control System.

A. Level II – Laboratory

The AD kit was applied in practicing the interactive engagement pedagogy 'Flipping the Classroom' in various engineering labs, including Basic Circuit lab, Electronics lab, Digital Logic lab, etc. All experiments were redeveloped with new labs added to support the utilization of AD kit.

One fundamental requirement for applying the 'Flipping the Classroom' in lab teaching is to enable students to finish experiments in advance. Essentially, the AD kit is a complete portable laboratory with all essential equipment for

implementing most basic experiments, which provides the capability to students. In the new teaching style, students were given lab manuals in advance and they requested to finish on their own time with the AD kit before the class.

The regular lab hours were much more enriched with diversified sessions. The students were then asked to first perform a demonstration of their individually. They were then to demonstrate the completeness of their lab work as a team. They needed to setup the circuit, operate and show all measurements or functions. Meanwhile, instructors (and other students) may ask questions to evaluate the performance of each team member. The second session was for questions, answers, and discussions, which provides the students with the opportunity to raise all questions and issues they experienced. After all questions have been addressed, the third session was used to test the students' understanding of the experiment. The third session is different from the first session as it was used to evaluate students' practical skills on implementation. The quiz focused more on testing their comprehension of theories. The fourth session was used to discuss advanced topics. It is also the opportunity for the instructor to expand students' comprehension of related teaching materials in scope and depth. The last session was used to assign of next lab, together with the brief review of major related concepts and tips students should be aware of. This process was repeated until the final project/exam.

With the support from the AD kit, quite a few extra benefits can be derived from the 'Flipping the Classroom' teaching, which are impossible on the past:

- All students are guaranteed of completely 7/24 access to laboratory resources. Instructors are no longer concerning about the participation of every student in the large group due to limited number of lab stations.
- The new teaching style enables students to spend more time on learning, practicing, critical thinking and identifying special questions than merely go through the basic experimental materials quickly in regular lab hours.
- The training to students on team working can be greatly enforced in the new style as well. All team members now have a more flexible schedule to meet, discuss and work together, in classroom, library, or even in Starbucks. Moreover, when time is not a big concern, students are more inclined to learn from each other, share experiences and try to contribute more to the project. To the contrary, these needs are suppressed or skipped in the past when the completion of lab in regular hours is the first priority.
- The instructors are also enabled with more flexibility on lab design while in the past during the lab hours the instructors are always too occupied on dealing with student questions to work on alternative ways of strengthening the teaching performance. In the new style the instructor can concentrate much more than before on improving the learning effectiveness, adding attractive materials, design challenging experiments, etc.

B. Level III – Senior Design

The integration of AD kit in engineering education was

expanded to include the teaching of Senior Design projects. With the kit, students' engineering project practice is no longer limited in the lab but can be anywhere. Fig. 4 illustrate an senior design project example, exoskeleton 'B.T. Suit'. By the use of the kit, student can run on-site test of its functions on extreme conditions anywhere, which will be very inconvenient on the past.



Fig. 4. a) The project suit, and b) demonstration of firethrower [8].

Moreover, the AD kit brings not only the convenience of testing and measurement, but expanded the way students perceive, explore and comprehend the engineering world. For the time being, they are more used to play and learn new stuff with the kit, as the extension of their fingers and eyes. Fig. 5 illustrate a senior design project, wearable device 'Communicare'. Students replaced the heart rate sensor with the AD kit to mimic pulses in different rates in testing the cardiac analytic algorithm they developed.

By the use of the AD kit, students are excited to learn and practice various sensors and integrate into the system. For instance, they tested the features such as the heart rate sensor with the kit, developed the algorithm on microprocessor to analyze the heart rate behavior, and then tested the algorithm by mimicking the signal by using the AD kit.

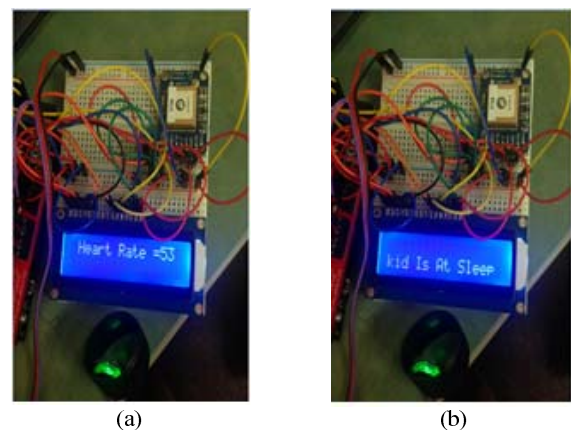


Fig. 5. Senior design project: wearable device 'Communicare'.

C. Additional Workshops

In addition the AD kit's application on the curriculum teaching, targeted to students' special needs a series of workshops on special topics that are offered from time to time. One example is the recent workshop on 'Microprocessor Arduino and Pulse Width Modulation for Motor and Servo Control'. The workshop was offered to engineering students especially those juniors who are interested in participating in an ongoing project of developing unmanned ground/surface/aerial vehicles. Fig. 6 shows example slides presented during the workshop to introduce the PWM implementation. In general, with the use of AD kit, the effectiveness of a workshop can be always improved. Every participant can practice more interactively with the instructor with directed experience and their questions will be addressed and solved immediately.

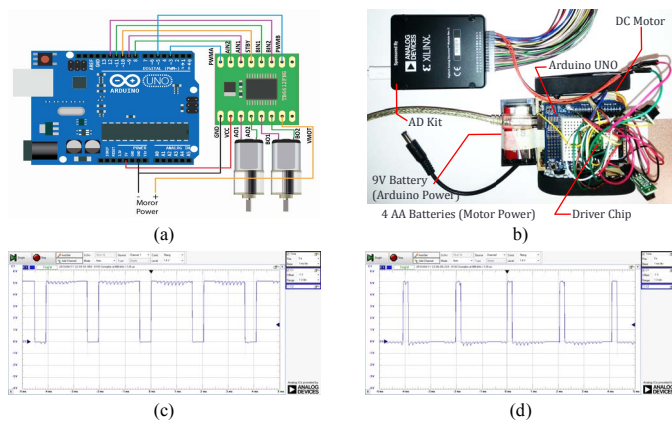


Fig. 6. a) Circuit setup, b) circuit diagram; c) PWM output on 78% duty, and d) PWM output on 10% duty.

III. ASSESSMENT

Diversified methods have been applied to access the effectiveness of this experiment, including pre/post-survey and statistics analysis of students' grades. Officially our application of the AD kit started only one semester ago. The status of this experiment is still in the collection of the first batch of data. However the students' feedback so far has already shown a significant improvement on their learning process. Fig. 7, Fig. 8 and Fig. 9 show students' recognition on the effectiveness of integrating the AD kit into the teaching process, the helpfulness of AD kit on their course learning, and the enhancement of AD kit on their professional, respectively.

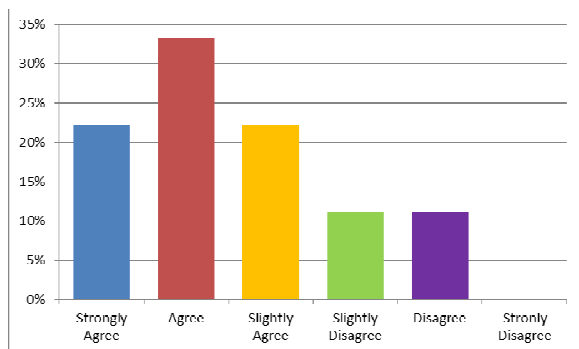


Fig. 7. Effectiveness of the intergration of AD kit on teaching.

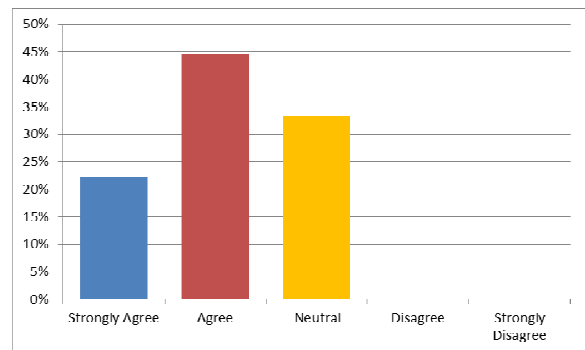


Fig. 8. The helpfulness on course learning by the use of AD kit.

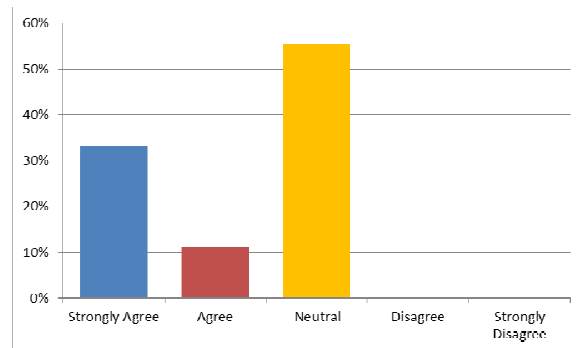


Fig. 9. The enhancement on professional abilities by the use of AD kit.

IV. CONCLUSION

In this paper the authors have introduced our experience on integrating a portable laboratory device, AD kit into our education practice. In conclusion, by the use of the kit, we successfully applied the 'Flipping the Classroom' method in engineering courses teaching, and the 'Experiential Learning' in engineering lab teaching. Assessment results have shown that such integration can greatly improve students' learning, enhancement their professional abilities development, and inspire and motivate their interests to explore a much wider engineering world.

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Teaching Project Management using a Real-World Group Project

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Abstract—It is well established that an effective pedagogy for project management requires students to get real-world experience. The challenge in providing this when teaching undergraduate engineers is the dichotomy between achieving realism and maintaining sufficient simplicity to make the course tractable. A real-world group technology project at Victoria University of Wellington (VUW) in New Zealand establishes essential non-technical attributes required by the engineering profession while covering key elements of the project management body of knowledge (PMBOK). This paper first shows how the project covers the knowledge required in project management and then presents the results of two years of data collected from students' reflection on their own learning. We have established a pleasing congruence across the years against the specific learning topics of team working skills, communication skills and personal working skills with an improvement in project management skills. A key finding emerging from our analysis is the importance of reinforcement learning and reflective learning. We show a key link between these two learning mechanisms and the project pedagogy. Further analysis shows the link between the project pedagogy and four skill areas acquired. Finally, our research has identified specific areas for us to focus on for subsequent years.

Keywords—project management, real-world project, graduate attributes

I. INTRODUCTION

It is not sufficient to equip engineering undergraduate students with just a technical education. The professional requirements for accreditation of engineering education in New Zealand [1] define more non-technical attributes for graduates than technical attributes. One of the ways Victoria University of Wellington (VUW) addresses non-technical attributes is through a practical application of project management to an environmental technology programme using group work.

Addressing non-technical attributes through project management starts with defining a practical scope and making it relevant to students focused on demonstrating technical prowess. There are several obstacles: project management is met with scepticism from non-practitioners, there is only a vague consensus over what it should be and there is no single model [2]. This is despite, or maybe because, established approaches such as PMBOK [3] and PRINCE2 [4] (the acronym for Projects IN Controlled Environments, which is a de facto process-based method for effective project management), and modern methods such as SCRUM [5] have

been applied to impose conformity and control on their practitioners in the name of professionalism [2][6]. Far from there being consensus, project management models are diverse, with as many as 1,000 in publication [7].

In New Zealand scepticism about formalising approaches resonates with the local culture of using a basic approach and “she’ll be right”. But “she isn’t right” and out-of-control projects continue to reap disaster with as many as one in six organisational change technology projects having 200% cost overruns [8]. Just recently two NZ government IT projects blew out from \$33m to \$163m [9] and from \$71m to “in the range of” \$155m [10] respectively.

Another key challenge is learning and teaching: how to ensure real learning that makes a difference to students’ engineering attributes. It is well established that it is not sufficient merely to ‘teach’ project management [11]; group work [12] and realistic project contexts [13] are essential to learning. Using a group project to achieve non-technical outcomes has to be simple enough to fit within the undergraduate teaching programme yet realistic enough to ensure students acquire skills for employment.

To solve these challenges, at VUW we follow up in-class teaching with a practical project that gives students responsibility for real-world outcomes to develop their learning of non-technical skills. We have found this to be a good pedagogy for grounding the project management teaching, establishing its relevance to the students and enabling them to learn essential non-technical engineering attributes. However, this is not the only approach available, as we discuss next.

II. PEDAGOGICAL ALTERNATIVES

There are a number of pedagogies available for project management. Professional project management development and certification through Project Management Institute (PMI) and PRINCE2 are predominantly based on training courses. These are available from around 2,000 providers worldwide [14][15]. While direct teaching is an important component of learning, it should be supplemented with other teaching methods, such as modelling, simulations, case studies and group projects. How does the use of a real-world group project compare to these?

Using real-world projects to teach construction project management is simply not practical: realism requires a scale that is too large and it takes too long for students to understand

and apply the method [13]. To overcome this, Stanford University uses software modelling tools to enable students to create construction plans that have sufficient detail and completeness to learn important project management concepts first-hand [13]. Important lessons learned include: time-based quantities, intuition for workflow, project monitoring (by plan features) and project fundamentals (also by plan features). Even so, direct experience stops at planning, so lessons to be learned in project execution are at best left to inference from the plan.

Simulations extend the software model into the project execution phase and become tractable as a learning tool in software engineering project management. The University of Stuttgart has developed a software engineering simulation tool used by nine Universities in Austria, Germany and Slovakia to supplement classroom teaching of project management [16]. This enables students to create software development projects and to execute them by simulation, gaining feedback and having the opportunity to change decisions to improve results. A system dynamics tool used at the University of Reading used simulation in an experiment to confirm that students gained better understanding of typical behaviour patterns of software engineering projects and raised their interest in project management [17].

The key limitation of simulations is that they lack real people, having neither a real client with real outcomes nor a real development team. Simulations can have other limitations, e.g. in supporting agile lifecycles or only modelling basic principles. This illustrates that significant investment is needed to get realism from software tools be it models or simulations.

A third alternative used in universities is case studies, through documentation, class discussions and/or by inviting in guest speakers with first-hand knowledge [12][18][19]. These go beyond simple classroom exercises and anecdotes from the lecturer's experience, to use real-world scenarios that students analyse to undertake assignments that they can evaluate from actual outcomes. While this presents more realism, key limitations are that students are learning second-hand and have little opportunity to ground their learning with direct experience. This limits case studies as a means to acquire practical skills [11].

A group project addresses some of the limitations of using modelling, simulation and case studies by enabling students to get first-hand experience of managing a project. This can be combined into an integrated approach, where more mature students manage group projects that teach technical skills [20]. However, it is not a given that group projects address the scope of learning required or provide real-world experience.

III. LEARNING REQUIREMENTS FOR A REAL-WORLD PROJECT

To understand how a real-world project can enable undergraduates to acquire the non-technical attributes specified by the engineering profession, we must first ask what attributes are required, how should they be learned and what scope of project management should be covered?

The seven non-technical graduate attributes defined by the Institution of Professional Engineers New Zealand (IPENZ) [1]

are based on international accord and are itemized in the following list. The VUW project has elements of all of these, which are all part of applying technical skills in professional practice:

1. Assess health, safety, legal and cultural issues of the engineer and society
2. Evaluate the impact of engineering on sustainability and the environment
3. Apply ethical principles to engineering practice
4. Function effectively as an individual and in a team
5. Communicate effectively on complex engineering activities
6. Apply management principles and economic decision making to manage projects
7. Prepare to engage in life-long learning.

The scope of project management as defined by PMBOK [3] includes knowledge areas itemized in the following list. The VUW project has elements of all these areas:

1. Organizational influences: the project environment
2. Project life cycle and processes
3. Management of project:
 - a. Integration
 - b. Scope
 - c. Time
 - d. Cost
 - e. Quality
 - f. Human resources
 - g. Communications
 - h. Risks
 - i. Procurement
 - j. Stakeholders.

Previous research by Ojiako *et al.* [21] identified the project management pedagogy 'dimensions' important to engineering students. These were in-class learning, out-of-class learning (provided through another course at VUW) and acquisition of generic skills (supporting the IPENZ requirements for these).

In another paper [22], the authors identify the key generic or transferable skills as the following:

1. Development of inter-personal skills
2. Experience of self-management
3. Development of critical thinking
4. Development of communication skills with others.

In the next section we show how our real-world project at VUW brings all these threads together to give engineering students a first-hand learning experience in these areas.

IV. THE VUW RIVERWATCH PROGRAMME

Engineering at VUW comprises three majors: electronic and computer system engineering, network engineering and

software engineering. In their third year, undergraduate students take two courses in project management, the first being a taught theory course using lectures, in-class discussions and group work, and the second being practical application of the theory through participation in the RiverWatch programme.

RiverWatch is a multi-year, multi-project programme to develop a technology platform for a voluntary organization called WaiNZ [23] that enables the New Zealand public to become “kaitaki” (Maori term for guardians) of their rivers and streams. Students have developed a website, smartphone applications, unmanned aerial vehicles (UAVs) and water quality data sensors for this purpose. Each year students form teams of five to broaden the base and push the boundaries of the platform with new development projects. The 2014 cohort’s key highlights included developing new iOS, Android and Windows phone apps, prototype water quality measurement devices, a UAV relay network to extend monitoring range and website enhancements. The programme has run for three years.

Students learn professional skills directly through their project work via the following mechanisms:

1. Creating self-organizing project teams [24]
2. Selecting and elaborating client requirements
3. Preparing project initiation documents, covering: requirements, business case, work breakdown structure (WBS) & Gantt chart, risk management, quality plan and communications plan
4. Communicating with the client weekly

5. Maintaining working documents, including team meeting minutes, updated Gantt chart and risk register
6. Presenting team achievement to the client
7. Demonstrating the team product to the client.

As a result of feedback appraisal from 2013, the two project management courses were adjusted to improve learning:

- The RiverWatch programme was introduced during the theory course to improve familiarity with it and the students produced an outline initiation document for the programme as part of that course
- The time available for students to do project initiation at the start of their RiverWatch project was extended by one week in the practical course to reduce risk
- Practical approaches to undertaking risk management were taught in the theory course and applied to the RiverWatch programme
- Communication with project stakeholders was introduced for the first time in the theory course to extend the students’ learning of communication skills
- Writing an individual reflective report.

The RiverWatch project addresses the IPENZ graduate attributes through the direct student experiences shown in Table 1 and addresses the PMBOK knowledge areas as shown in Table 2. The generic or transferable skills identified in the previous section are addressed as shown in Table 3.

The next section presents how we evaluated these learning experiences.

TABLE I. HOW RIVERWATCH ADDRESSES IPENZ GRADUATE ATTRIBUTES

IPENZ Graduate Attribute (3. and 7. Excluded)	RiverWatch Learning Experience
1. Assess health, safety, legal and cultural issues of the engineer and society	1. Comply with VUW laboratory and offsite health and safety requirements during their project 2. Identify project risks as a team and manage them through team meetings 3. Achieve community cultural outcomes with technology products to meet WaiNZ goals
2. Evaluate the impact of engineering on sustainability and the environment	4. Apply technology to enable WaiNZ and the public to improve the sustainability of beef and dairy farming and to protect the river environment in NZ 5. Define the environmental context in the product demonstration and answer client questions
3. Apply ethical principles to engineering practice	4. Apply ethics to client commitments, working together as a team and University requirements
4. Function effectively as an individual and in a team	6. Deliver an individual contribution to a group project with individual accountability to the team and to achieve personal assessment marks 7. Learn about team dynamics, leadership and motivation through teamwork and inter-project collaboration, by making real-world project decisions that result in a usable end product
5. Communicate effectively on complex engineering activities	8. Learn to write specifications and plans the project team can use effectively 9. Take turns to provide a verbal achievement report to the client weekly and get a real-world response back 10. Communicate effectively with the business owner (course lecturer) by producing project and technical documentation in writing and get feedback through assessment 11. Present achievement to the client and business owner in a formal team presentation and answer real-world questions 12. Demonstrate tangible end products to the client and answer real-world questions 13. Submit apps to the app stores for publication 14. Write a reflective end of project report to capture learning from the project experience and receive assessment and feedback
6. Apply management principles and economic decision making to manage projects	15. Work to a project brief the team has created and had reviewed 16. Choose an appropriate project lifecycle and plans and execute them, monitoring actual achievement against real deadlines 17. Produce an outline business case including project costs
7. Prepare to engage in life-long learning.	18. Capture key learning in project closure and produce a personal plan to for its future application and development.

TABLE II. HOW RIVERWATCH ADDRESSES PMBOK KNOWLEDGE AREAS

PMBOK Knowledge Area	RiverWatch Learning Experience
1. Organizational influences: the project environment	1. Work within a programme structured of multi-year stages and sub-projects with dependencies 2. Resolve the relationship between project, programme and organisational goals
2. Project life cycle and processes	3. Understand the organisation of the RiveWatch programme and its communication 4. Apply agile lifecycles in a real-world multi-subproject environment to manage risk
3. Development of critical thinking	
a. Development of critical thinking Integration	5. Integrate mechanisms to manage the project effectively within the RiverWatch programme 6. Apply planning and change control to achieve a real-world product within constraints
b. Scope	7. Collect client requirements accurately and unambiguously 8. Work with the client and proactively elaborate requirements 9. Use a WBS to ensure nothing is omitted or duplicated
c. Time	10. Use a Gantt chart to allocate activities and manage their dependencies and timing 11. Manage real-world resource constraints in the project plan
d. Cost	12. Create a simple business case and project budget
e. Quality	13. Apply quality planning and control to achieve product acceptance and client satisfaction
f. Human resources	14. Assign work, motivate the team, monitor performance, make decisions and manage time
g. Communications	15. Apply taught theory to real client communication, team meetings and presentations
h. Risks	16. Identify, analyse and manage real-world project risks and handle their impact
i. Procurement	17. Budget for, specify and procure engineering components
j. Stakeholders.	18. Manage the expectations of a client, other teams and technical stakeholders.

TABLE III. HOW RIVERWATCH ADDRESSES KEY TRANSFERABLE SKILLS

Transferable skill	RiverWatch Learning Experience
1. Development of inter-personal skills	1. Work with others in a group project and with other teams in a multi-disciplinary environment
2. Experience of self-management	2. Manage own work and motivation to meet the project plan and team commitments
3. Development of critical thinking	3. Research and analyse project requirements and solutions, reflect learning in logbook, write report
4. Development of communications skills with others.	4. Work in a group environment to make decisions, control project interdependencies, present achievement to a client and produce technical and user documentation.

V. EVALUATIONS OF STUDENT LEARNING

At the end of the project management course each student produces an individual reflective report that describes their own evaluation of the project and what they learned from it. There were 40 students in 2013 and 56 students in 2014. This section explains how an analysis of the student reflections on their learning using grounded theory [24] provides an assessment of the pedagogy of the course.

Student learning from their reports was initially coded into specific learning points identified by the students from their project experience, i.e. what they did. Using concurrent data generation and analysis these were then coded into project management skill categories, which was complete when student learning fitted all the categories identified, yielding 618 reflections. This eliminated the trite repetition of textbook theory by verifying each learning point from direct evidence cited in the report, for example, "I found that referencing the plan was useful for drawing attention to forgotten tasks. It was easy for us to focus on the technical implementation, while neglecting components such as presentations and documentation."

Two types of learning emerged from this coding: reinforcement learning and reflective learning. Reinforcement learning is where students applied their learning and gained a positive outcome that reinforced it. Reflective learning is where students failed to gain a positive outcome from a key learning point but through reflection learned from their mistake. For example, some student projects followed their project plans while others did not, with students that did not learning on reflection that more investigation was required to obtain a successful plan. Reflective learning does not indicate poor pedagogy, as learning from making mistakes is a powerful way of learning [26]. However, it indicates where further research into the taught element is required.

The learning was then further coded to understand the type of project experience that drove it in order to see whether the assertions of using a real project made in previous research can be supported from RiverWatch. To do this, each learning point and the evidence for it were examined to determine the generic mechanisms driving the learning point. The results of our analysis and its consistency over two years are presented in the next section. The two graphs of results on the next page are explained the text on the following page.

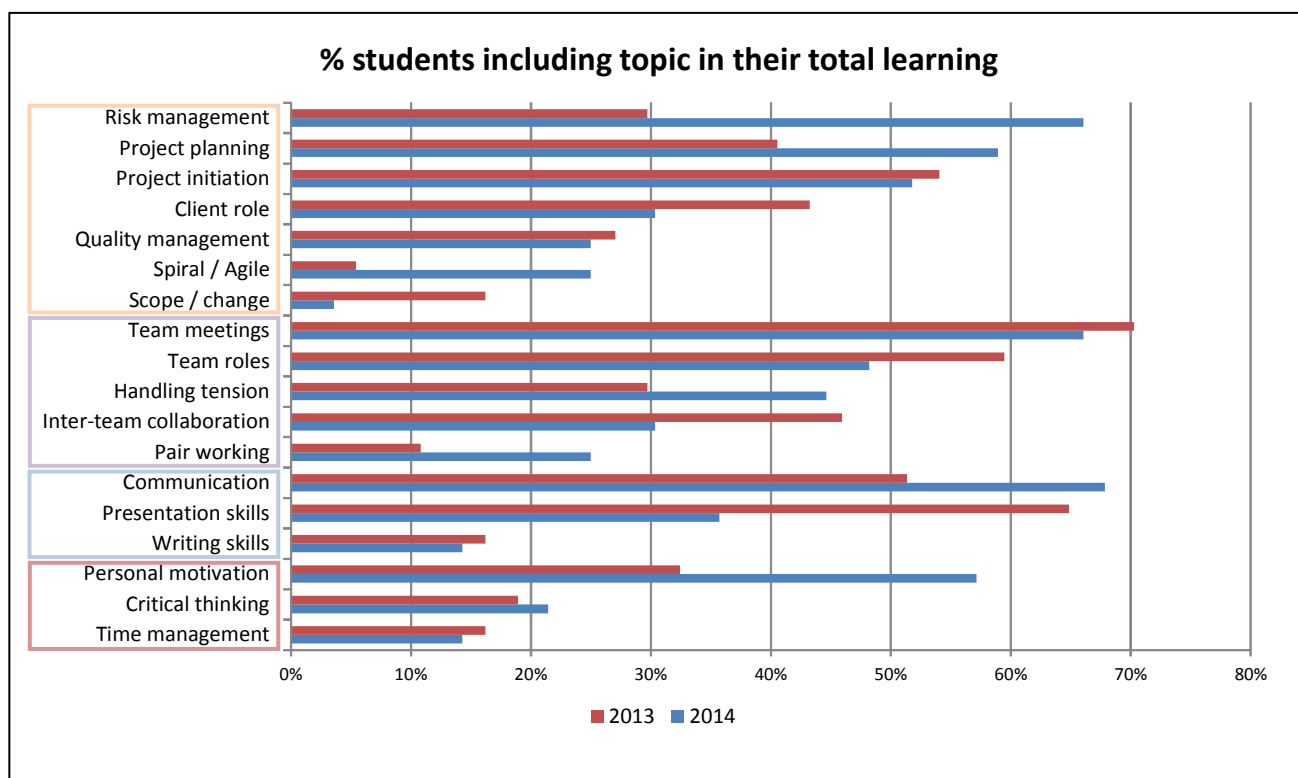


Fig. 1. Total learning points grouped by the skills shown in TABLE IV.

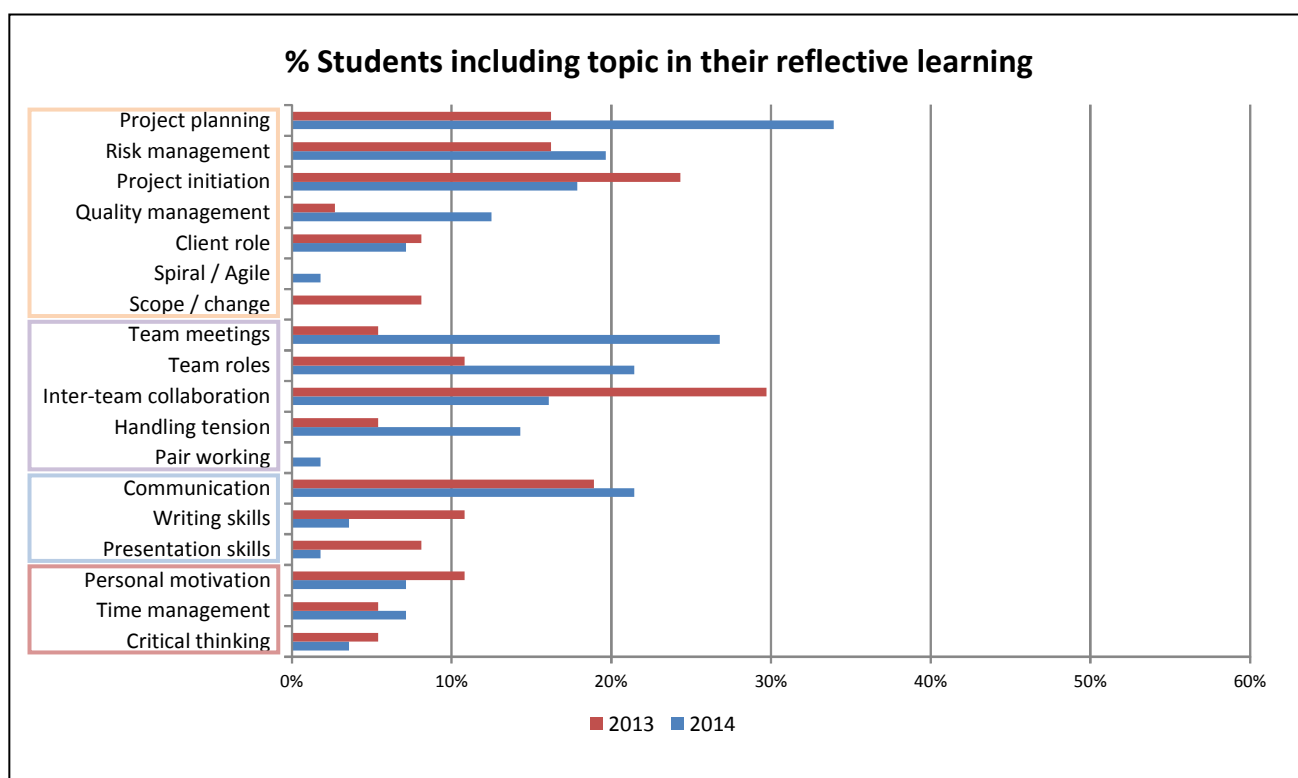


Fig. 2. Reflective learning points grouped by the skills shown in TABLE IV.

VI. EVALUATION RESULTS

The student learning points from the above evaluation are presented as total learning and reflective learning. The total learning is grouped into four skill areas. Following this, the experiential source of this learning is presented.

A. Total learning points

Fig. 1 summarizes all the learning topics identified from the analysis by the percentage of total students reflecting on them in their final reports in 2013 and 2014. These are grouped into the four skills areas and then ordered from the largest number of topics to the smallest in 2014.

The average number of topics reported by each student in each skills area is shown in Table IV.

TABLE IV. TOTAL LEARNING POINTS IN FOUR SKILLS AREAS

Skill area	2013	2014
Project management skills	2.2	2.6
Team working skills	2.2	2.2
Communication skills	1.3	1.2
Personal working skills	0.7	0.9

The summary of student learning by skill area in Table IV shows the consistency across the two years. It shows that learning transferable skills through the group projects is on par with learning project management skills. Personal motivation dominates the personal working skills.

B. Reflective learning

Fig. 2 summarizes the learning topics identified by the percentage of students reflecting on what they learned from their mistakes. (Reinforcement learning makes up the difference between Figs. 1 and 2).

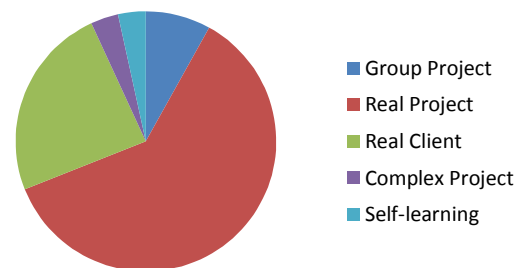
The total number of reflective learning topics went up from 1.9 in 2013 to 2.2 in 2014, with most topics at one per five students or below.

C. Sources of learning

The experiential sources of the students' learning are shown across the two years for each of the four skill areas in Figs. 3 to 6. This was determined by examining the experiential context of the learning previously analyzed. This addresses the question of how much learning comes from the real-world group project with a real client with programme complexity verses self-learning.

As might be expected, personal working skills have a significant self-learning component. The other key skill areas, especially the transferable skills of communication and team working are predominantly learned from the real group project. Communication and project management skills had a significant real client component. The real-world group project learning has increased in 2014 in all cases except team working, where it is insignificant.

2013 Project Management Sources



2014 Project Management Sources

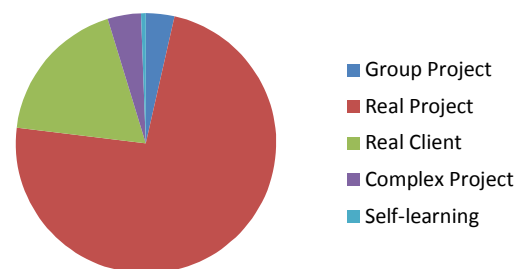
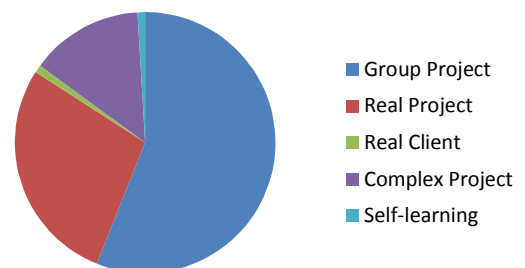


Fig. 3. Project management skills learning sources 2013 & 2014

2013 Team Working Sources



2014 Team Working Sources

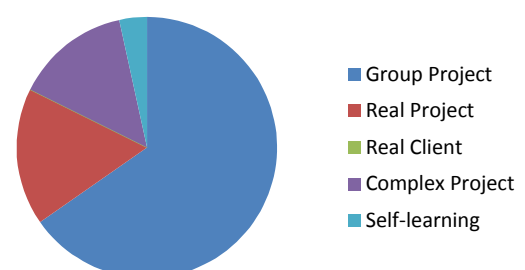


Fig. 4. Team working skills learning sources 2013 & 2014

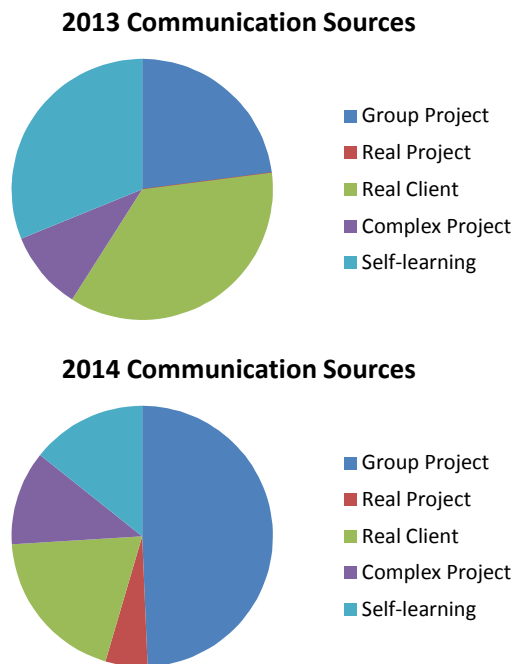


Fig. 5. Communication skills learning sources 2013 & 2014

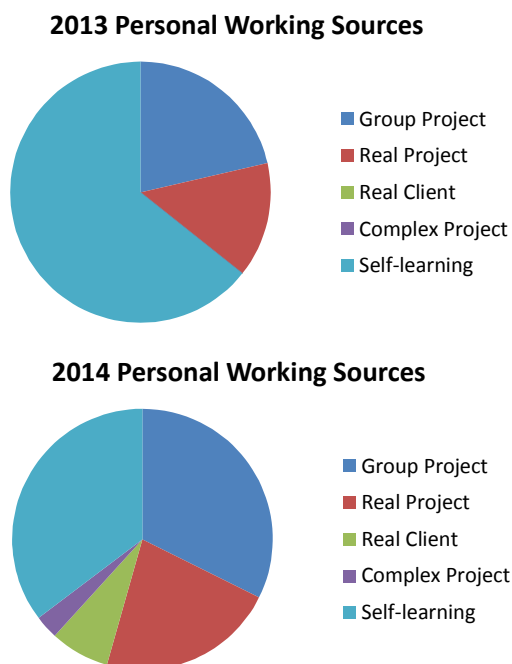


Fig. 6. Personal working skills learning sources 2013 & 2014

VII. SIGNIFICANCE OF RESULTS

The evaluation results support the effectiveness of improvements made in 2014 described in section IV. High levels of reflective learning on project initiation and inter-team collaboration in 2013 were significantly reduced in 2014. Reinforcement learning of communication increased in 2014, reflecting its wider application beyond just presentations. Reinforcement learning of risk management doubled and there were fewer changes to project scope resulting in reduced reflective learning from this.

The evaluation of reflective learning also reveals two unexpected regressions in 2014. The first is in team working, where a timetable conflict was introduced by a change to another course that increased reflective learning due to fewer meetings being scheduled.

The second is the increase in reflective learning in project planning. This is dominated in both years by learning the truism that original plans and estimates often don't survive in a real project. Further research is required to identify the cause of this, but it may be due to more detailed planning being practiced in 2014.

A summary of the explanations of the differences in total learning is shown in Table V.

The sources of learning identified show that all four key skill areas acquired through the RiverWatch project derive predominantly from the students' direct experience of group working on a real project with resource constraints, deadlines, hard measures of success, a real client and complex characteristics, such as, stakeholders, inter-dependencies and multiple stages. The amount of self-learning reduced from 16% in 2013 to 10% in 2014. Further research is required to identify the cause of this, and will be part of our future work.

TABLE V. EXPLANATION OF CHANGES IN TOTAL LEARNING

Learning topics	Change between 2013 and 2014
Risk management Project planning Spiral/Agile	These project management topics were all taught more practically in 2014 resulting in an increase in learning
Team roles Inter-team collaboration Pair working	The first topic scored lower in 2014 due to calendar conflicts, while inter-team collaboration saw a reduction in reflective learning and pair working increased
Communication Presentation skills	Communication was taught more broadly in 2014, reducing the focus on presentation skills
Personal motivation	Increased to become a significant learning point issue in 2014, possibly reflecting less mature and overseas students than in the 2013 class
Client role Scope/Change	The class lecturer and tutors played a stronger role in 2014, possibly diluting client focus, but reducing scope change due to problems.

VIII. SUMMARY AND CONCLUSIONS

This paper has shown how teaching project management through a real-world project has addressed the needs of the engineering profession and covered the scope of the project management body of knowledge. The analysis of the students' personal reflection shows the key learning points achieved through the course and indicates where further adjustments will be beneficial.

This analysis corroborates previous research in showing that the generic transferable skills are rated by students as important learning [19][20]. Communication (including presentation skills) is the highest learning topic reflected by both quantity and importance, with team working also significant in the total number of generic transferable skill reflections.

Project management skills are also rated highly, with project planning, project initiation and risk management being the top six important learnings reflected by students.

The research also shows that learning can be improved by focusing on the reflective learning points to enable greater reinforcement learning. Key points to take forward from this are to ensure the reflective learning does not represent over-challenge and to review key topics such as project planning and team working to ensure student motivation is maintained. The precise pedagogy that increased learning from the real-world project in 2014 also needs further research.

We conclude that the use of a real-world project has been a success in addressing the IPENZ non-technical attributes, as reflected in student learning. The students' reflections provide direct evidence of learning from the real-world project, with group working and a real project being the biggest drivers.

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Using 3-D Open Source Software to Facilitate Students' Spatial Visualization Skills

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Abstract—This study investigated the effect of Google SketchUp on students' learning achievements in spatial visualization. A quasi-experimental with pre-test and post-test design was used to conduct the research. Eighty-four fifth graders from a public elementary school in Taiwan voluntarily participated in the study. Students from different classes were divided into three instructional modules: Google SketchUp (with full features), Google SketchUp (with limited features), and traditional instruction (hand-held objects). Students in each of the three experimental groups were instructed to manipulate various 3D objects that were created by a class teacher. A criterion test was developed to measure students' understanding about basic concepts of spatial visualization. The educational experiment was completed within three weeks. The results showed that Google SketchUp (with full features) was an effective learning tool to support students in developing spatial visualization skills ($F=8.20$, $p < 0.01$).

Keywords— *spatial visualization; open source software; k-12 engineering education*

I. INTRODUCTION

Spatial visualization skills refer to the ability to mentally process and manipulate two-dimensional (2D) or three-dimensional (3D) visual objects [1]. Due to the significance in engineering professions, engineering educators contended that spatial visualization skills were emphasized in all engineering disciplines and not limited to graphic design-related disciplines [2-3]. These skills are particularly important for architectural, manufacturing, and electronic engineers.

With advances of information technology in engineering education, traditional hand-held visual aids in supporting spatial visualization skills have been replaced by 3D multimedia tools. They may provide additional learning opportunities for learners and attract their attention. For example, Christou et al. [4] found that features of 3D multimedia tools motivated students to manipulate virtual visual objects on the computer screen and resulted in better learning outcomes. Similarly, Wu and Shah [5] considered that animations embedded in 3D multimedia tools clearly demonstrated spatial concepts and effectively lowered learners' cognitive learning loads.

Google SketchUp developed by Google Company is a 3D multimedia tool that allows students to design and develop 3D

visual objects. Being open source software, Google SketchUp has been widely used for creating 3D building models in architectural engineering, interior design, and civil engineering [6]. Kurtulus and Uygan [7] and Erkoc and Gecu [8] were pioneers who explored the use of Google SketchUp in mathematics classes. However, even though they employed an experimental method to examine the effect of Google SketchUp on students' geometric learning performances, a major problem was that student participants in these studies were asked to draw 3D models rather than manipulating visual objects. Training students to create visual models in limited time may pose a severe threat to the external validity of experimental design [9].

Therefore, the current study aimed to investigate how elementary school students employed Google SketchUp to support their mathematics learning regarding spatial visualization. An educational experiment was conducted in three fifth-grade classes where 84 student participants manipulated various types of 3D geometric models (computer-based vs. hand-held objects) created by one class instructor. One major research question was as follows: Did significant differences exist on learning achievements in spatial visualization for students manipulating different types of 3D geometric models?

II. RESEARCH METHOD

A. Research Design

A quasi-experimental with pre-test and post-test design was adopted in the study to explore the effect of Google SketchUp on students' learning performances. The independent variable was the type of 3D geometric models manipulated by students. The dependent variable was students' learning achievements in spatial visualization.

Three different treatments were used to investigate Google SketchUp's learning effectiveness. Students in Treatment 1 employed Google SketchUp with full features to manipulate virtual 3D objects. In Treatment 2, one major feature (object transformation) in Google SketchUp was disabled. Students only used limited features in Google SketchUp to manipulate virtual 3D objects. Treatment 3, used as a control group, provided each student with a package of cardboard-made geometric objects to practice spatial visualization skills. One

week before and after the implementation of the study, students received a pre-test and a post-test on spatial visualization.

B. Research Instruments

One mathematics-learning unit regarding geometric objects was selected as the main instructional content. Virtual 3D objects were created in Google SketchUp. These geometric models served as computer-based visual aids that supported students in comprehending important concepts of spatial visualization. A criterion test was developed to measure students' understanding about basic concepts of spatial visualization. The test contained 18 multiple-choice questions. The test items were directly related to these three major constructs: spatial comparison (similar to spatial rotation), spatial measurement, and spatial transformation. For example, one of the test items asked students to compare the surface areas of two given geometric objects. Higher scores in the measurement represented students' higher learning achievements. The score range of the test was between 1 and 18. The Kuder-Richardson 21 (KR-21) coefficient of reliability was calculated as 0.9.

C. Participants

Eighty-four fifth graders from a public elementary school in Taiwan voluntarily participated in the study (Treatment 1: 28; Treatment 2: 29; Treatment 3: 27). Overall, students in Google SketchUp groups had medium-level computer literacy since they received computer knowledge at computer courses.

D. Procedures

The educational experiment lasted for three weeks; in each week, students received various instructional treatments within one hour. In Treatment 1 and 2, the course instructor taught mathematics through oral presentation, demonstrated 3D objects in Google SketchUp, and allowed students to manipulate 3D objects by using five features in Google SketchUp. In Treatment 3, in addition to class lecture, the course instructor also demonstrated hand-held objects and asked students to practice with cardboard-made visual aids.

E. Data Analysis

One-way analysis of variance (ANOVA) was used for data analysis. When the significance value was realized, a post-comparison method was used to compare mean differences among experimental groups. The significance level was set to 0.01 in the study.

III. RESULTS AND DISCUSSIONS

A. Mean Difference Among Groups

Table I summarizes the results of descriptive statistics regarding the pre-test and post-test. Table II reports the ANOVA results for each of the three experimental groups.

TABLE I - SUMMARIES OF PRE-TEST AND POST-TEST RESULTS

Experiment Group	N	Pre-Test		Post-Test	
		Mean	S.D.	Mean	S.D.
Treatment 1	28	6.68	3.50	11.71	4.59

Treatment 2	29	5.48	4.29	7.31	4.45
Treatment 3	27	6.52	4.01	8.96	5.50

TABLE II - ANOVA RESULTS FOR GROUPS

Source	SS	DF	MS	F
Between	259.56	2	129.78	8.20**
Within	1265.71	80	15.82	
Total	1525.27	82		

** $p < 0.01$

Table I shows that students in the three experimental groups all improved their spatial visualization skills after receiving various instructional methods. Compared to the pre-test, students in the Treatment 1 earned more points (mean differences: 5.03) in the post-test. Table II indicates that there was a significant difference among the three experimental groups ($F=8.20$, $p<0.01$). Thus, a post-comparison test was performed to compare mean differences in the post-test. Table III lists the comparison results.

TABLE III - POST-COMPARISON RESULTS

Group	Modified Mean	Post-Comparison
Treatment 1	11.70	T1>T2**, T1>T3**
Treatment 2	7.54	T1>T2**
Treatment 3	8.74	T1>T3**

** $p < 0.01$

The results in Table III showed that a significant difference existed between Treatment 1 and 2 ($p<0.01$) and between Treatment 1 and 3 ($p<0.01$). However, no significant difference was found between Treatment 2 and 3. Therefore, students in Treatment 1 group performed significantly better than the other two groups.

B. Discussions

After the implementation of a three-week experiment, students' spatial visualization skills in three experimental groups were increased through various instructional models. From a starting point (pre-test), students in the Google SketchUp (with full features) group achieved a better learning improvement in the post-test. In contrast, students' post-test performances in Google SketchUp (with limited features) and traditional instruction groups grew by a small margin.

Regarding group comparison, there was a significant difference between Google SketchUp (with full features) and Google SketchUp (with limited features) and between Google SketchUp (with full features) and traditional instruction (hand-held objects). This finding showed that Google SketchUp (with full features) is an effective instructional solution in developing elementary students' spatial visualization skills. While engaging in Google SketchUp (with full features) group, students might use five main features to manipulate virtual 3D objects to obtain full understandings of basic concepts in spatial visualization. The result supported previous research, which reported that 3D multimedia tools could support students in learning mathematics concepts [4].

Even though students with limited features strengthened their knowledge base in the post-test, no significant learning benefits were identified. Their learning performances were lower than those that received traditional instruction (hand-held

objects). In Treatment 2, Google SketchUp lacked one major feature (object transformation) for students to manipulate 3D virtual objects. Limited learning gains resulted from the effect of the computed-based visualization tool being blocked. This phenomenon can be attributed to the role of object transformation being disabled in the Treatment.

Traditional instruction (hand-held objects) served as a comparison group to reflect the function of treatment groups. However, the findings showed that students under traditional instruction still performed well. Although there was no significant difference between Treatment 2 and Treatment 3, students' learning performances in traditional instruction surpassed those in Google SketchUp (with limited features) group. In other words, a learning value indeed exists for physical contact with cardboard-made objects. Manipulating these hand-held objects also supports student learning in spatial visualization [10]. This finding was consistent with past studies that physical objects exhibited a positive effect on students' development of spatial visualization skills [11-12].

IV. CONCLUSION

This study explored the effect of Google SketchUp on students' learning achievements in spatial visualization. Based on the statistical results identified above, the research null hypothesis was rejected. A significant difference in students' learning achievements was found among three experimental groups. Compared to two other groups, students in Google SketchUp (with full features) group achieved a better learning outcome. Therefore, Google SketchUp (with full features) can be an effective learning tool to support students in developing spatial visualization skills.

Even though students in the Google SketchUp (with limited features) group used computers to facilitate their mathematics learning regarding spatial visualization, students' learning outcomes were the lowest among the three experimental groups. From a statistical perspective, Google SketchUp (with limited features) and traditional instruction (hand-held objects) achieved similar learning outcomes. When one major feature (object transformation) was disabled, Google SketchUp might not effectively benefit student in learning fundamental engineering concepts.

Although the study was conducted in a K-12 learning context, the findings of the study may still provide an implication for engineering educators at higher educational institutions. In engineering colleges, when given an opportunity to adopt advanced technologies in classrooms, instructors tend to choose commercial-based software and

spend time developing specific tools for classroom instruction. From the results of our study, Google SketchUp as open source software showed its benefits in engineering learning. While developing visualization-training programs becomes popular in higher education, Google SketchUp may offer an alternative instructional solution to support engineering students in developing spatial visualization skills.

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Learning about Engineering Education Research: What Conceptual Difficulties Still Exist for a New Generation of Scholars?

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Abstract – In 2007, Borrego published her groundbreaking work “Conceptual difficulties experienced by trained engineers learning educational research methods”[1] that described five conceptual difficulties engineering faculty encountered as they began to learn about rigorous research in engineering education. Since Borrego’s research was published the engineering education departments have been formed and a new generation of engineering education researchers has emerged. These researchers must tackle the same paradigm shift that faced the engineering faculty in Borrego’s study. The research question that guided this study was: “What conceptual hurdles still exist for the new generation of engineering education researchers?” PhD students in Engineering Education were asked to reflect on their conceptual difficulties during the first semester of their PhD courses and write an end-of-semester reflective paper that summarizes their cognitive journey. The summative reflections were coded using Borrego’s conceptual hurdles as a framework. The results of the present study can inform those entering the engineering education research community by highlighting areas that remain problematic and offer strategies that emerging scholars have used to make sense of educational theories and methods.

Index Terms –Conceptual difficulties, Rigorous Research in Engineering Education, Paradigm shift, New Generation of Scholars

INTRODUCTION

In the past two decades research in engineering highlighted the fact that engineers were being educated in a manner that would probably be no longer applicable by the time they exit school [2]–[4]. Hence there was a reported need for innovative approaches to educating engineers aimed at developing adaptive people and organizations

tasked with designing learning experiences to leverage students’ strengths and experiences [5]. Similarly, there were increased calls for a systematic approach to research in engineering education that saw the development of what is now an established engineering education research initiative. Felder, Sheppard and Smith discussed this as “pressures on engineering education to adapt and change that were not going to go away. The impetus for engineering schools and faculty to develop new curriculum structures and improved teaching methods and materials is only likely to grow in the coming years, and the need for high-quality scholarship to assess the new developments and archival venues to chronicle the work will grow concurrently” [6, p. 8]. The main idea behind this initiative was to conduct research aimed at identifying tools capable of defining and transforming learning experiences as well as to provide opportunities for collaboration among engineering and science fields [3], [7]. Radcliffe described this move as “a need for a broader conception of engineering and of engineering research, one that includes the practice of engineering and which takes account of other types of knowledge” [8, p. 263]. Consequently, the important questions of what constituted engineering education research and how this research was to be conducted would eventually emerge.

A. Defining What Constitutes Engineering Education Research

The Rigorous Research in Engineering Education: Creating a Community of Practice (RREE) funded by the National Science Foundation (NSF DUE-0341127) was one of the first programs designed to increase the number of faculty who could conduct high quality engineering education research. The idea behind this project was to bring together a wide array of engineering faculty, educational practitioners and other research scientists through a five day workshop aimed at exposing these engineering faculty to the world of educational research [9]–

[11]. Having an executive committee comprising of members from the American Society for Engineering (ASEE), American Educational Research Association (AERA) Division I and the Professional and Organizational Development Network in Higher Education (POD) “the purpose of the RREE project was to prepare faculty to conduct rigorous research in engineering education” [12, p. 103]. The term “rigorous” as defined by the authors aligned with the National Research Council’s [13] six steps for conducting scientific research which were:

1. Pose significant questions that can be investigated empirically.
2. Link research to relevant theory.
3. Use methods that permit direct investigation of the question.
4. Provide explicit, coherent chain of reasoning.
5. Replicate and generalize across studies.
6. Disclose research to encourage professional scrutiny and critique.

B. Conceptual Difficulties Associated with Conducting Engineering Education Research

The work of Borrego [1, p. 91] based on data collected at the RREE project identified five conceptual difficulties experienced by the participants specifically the engineering faculty, involved in this project as they learned and engaged with the materials presented at the workshops. These were:

1. Framing research with broad appeal – research questions on the “why” and “how” of a phenomena.
2. Grounding research in a theoretical framework – using the theoretical framework as a guide for conducting the research.
3. Fully considering operationalization and measurement constructs – how to determine measurement of constructs outside of their area of expertise.
4. Appreciating qualitative and mixed-methods approaches – how these research approaches can be just as valuable as quantitative approaches.
5. Pursuing interdisciplinary collaboration – the importance of having a diverse group of researchers to foster collaborative work.

However, in 2005 when Borrego collected the data for the “conceptual difficulties” paper, engineering education research was just being “born” as a discipline [7]. One of the conceptual difficulties she describes specifically addresses this state of affairs. “In the absence of individuals trained in both engineering and social science methods, a team of collaborators with diverse disciplinary backgrounds is required to provide the necessary expertise for rigorous engineering education research” [1, p. 95]. Since 2005, engineering education departments have been created based on the recommendations for relevant skills researchers in this field would need to possess [14]. To this end a new generation of engineering education researchers has emerged. However, this new generation of researchers must

tackle the same paradigm shifts that faced the engineering faculty who participated in the RREE – they begin as trained engineers and need to understand the similarities and differences between technical research (dealing largely with the physical world) and educational research (which focuses on human learning and behavior). The purpose of this paper is to investigate, based on the conceptual difficulties identified by Borrego, what conceptual hurdles still exist for the new generation of engineering education researchers.

METHODOLOGY

Research Questions

The research question guiding this study was: “What conceptual difficulties still exist for the new generation of engineering education researchers?”

Participants

The data used for this study were collected from 16 PhD students in the Engineering Education department at a large research intensive University who were enrolled in a one-credit introductory engineering education research seminar in their first semester in the PhD program.

Study Context

The course is aimed at introducing new students to the profession of being an engineering education researcher. The purpose of the course explicitly outlined in the course syllabus discusses the fact that unlike engineering education, other more established disciplines possess areas of research and research methodologies that are well-defined and relatively stable. This being the case, the activities employed in the course centered on providing the new students with the ability to transition into new bodies of knowledge, research methods, jargons and concepts direct related to this new and still emerging field. A requirement of the course was that students, having read the paper by Borrego, were to summarize what engineering education concepts were difficult for them to understand and strategies they used to make sense of the difficult information. To be able to better understand the experience making the paradigm shift, a subgroup of students were invited to further reflect on their journey and be co-authors on this paper. Their reflections serve as case studies that strengthen our understanding what it is like to experience this paradigm shift and what strategies might be used to make the transition.

Data Analysis

The summative reflections written by the students based on the two guiding questions given at the beginning of the course were coded using Borrego’s conceptual hurdles as a framework. The number of instances of the five conceptual hurdles identified by Borrego were noted and examples of each hurdle presented in the following section of this paper.

RESULTS

A. Coding based on conceptual hurdles framework

Of the five categories, theoretical framework and qualitative and mixed-methods approaches were reported as the most problematic areas faced by the students. Illustrated in Table I below, theoretical frameworks were reported 11 times, qualitative and mixed-methods approaches nine times, transferability of results five times, interdisciplinary collaboration twice and operationalization and measurement of constructs once. Much like the participants at the workshop, the new PhD students spoke about difficulties

they experienced writing research questions that would fit this research paradigm, being completely overwhelmed by the idea of a theoretical framework, the uncertainty associated with being able to measure what their new research questions were intended to find, their doubt in the usefulness of qualitative research as well as why they needed to foster collaboration between two seemingly dissimilar fields. Specific examples of these difficulties taken directly from the students' reflection documents are shown in Table II.

TABLE I
NUMBER OF COUNTS FOR CONCEPTUAL DIFFICULTIES REPORTED BY PARTICIPANTS

Conceptual Difficulties	Number of instances
Transferability of results	5
Theoretical Framework	11
Operationalization and measurement of constructs	1
Qualitative and mixed-method approaches	9
Interdisciplinary collaboration	2

TABLE II
EXAMPLES CONCEPTUAL DIFFICULTIES FROM PARTICIPANTS REFLECTION DOCUMENT

Conceptual Difficulties	Examples from participants reflection document
Transferability of results	--While I might see the difficulty in moving away from the scientific closed-form question "yes" or "no," my own initial struggle was writing a research question that truly articulated the knowledge I wished to create or unveil. The challenge was not starting a question with "why" or "how," rather it was the difficulty of capturing the essence of what I wished to discover. -- If we did not ask questions that could be answered empirically, if we did not link the research we are doing to theory, if we did not follow the other characteristics of what is rigorous engineering education research, then how can we ever ensure disciplinary progress?
Theoretical Framework	--The concept of " <i>theoretical framework</i> ", which immediately pulled the ground from under my feet and I started to grapple with an entirely new concept. --When I would read papers I would find myself thinking: "Why are you telling me what framework this is based on? Why can't you just explain what you did and what you found? Why is a 'framework' even important?"
Operationalization and measurement of constructs	--Given my large foundation in ECE courses the utility of the course is contained in the courses name. Such is not the case for me with philosophy. The philosophical underpinnings of why we're engineering software is not something we readily discuss in ECE. Finding utility in these new ideas or some way of applying them to the world I already knew was something I yearned for
Qualitative and mixed-method approaches	--What we perceive as humans is not always what actually happened, so how could we trust this data? We are also not reliable. Personally, if I answered questions one day versus another day, I might respond differently depending on my mood or my experiences just prior to the questions. For these reasons, I was suspicious of qualitative methods and I clung to quantitative ENE research. -- Qualitative studies were not considered true research so the thought of doing qualitative research didn't even cross my mind. I did not believe it had validity (how could a study of 6 people be valid?) nor did I believe it added value to the field.
Interdisciplinary collaboration	--We were three engineers from distinct fields attempting to conduct a qualitative study with First Year Engineering students. We had no experience or expertise with regards to this research at any level. We had our own experiences on which to lean on, but we were pushing ourselves to do more than what we already knew. -- It's not the idea of diverse collaboration that confuses me; instead it's the requirement that one needs technical engineering training to perform engineering education research. I realize that originally engineering educators were trained engineers with an interest in engineering, but people with diverse backgrounds are now entering the field of engineering education

B. Expanded example from Avneet

While reading Borrego's paper, the first conceptual hurdle that I came across was transferability of results. She wrote about how engineering faculty have difficulty understanding the importance of framing research questions that have a broad appeal, because they assume transferability. As I read this section, I found myself perpetually thinking about how that wasn't the case, and in my experience with engineering research, framing a broad research question was imperative to make any sort of contribution to the field. From my research work in the field of aerodynamics, one of the most important lessons that I had learnt was that one needed to research situations that could be commonly reproduced in more pragmatic situations. Even though fluid dynamics theories and experiments are considered easier, and are even taught before at educational institutes, as an aeronautical engineer it was always important for our results to be applicable to compressible fluids (like air). Thus to deal with this difficulty, I drew an analogy between the broader transferability of engineering education research, and my prior experience of moving from incompressible to compressible fluids to make a real impact in the field of work.

Working on engineering education research seemed like a great idea, and I saw how it would help me satiate my inner sense of purpose. However, I was unsure about how most of the research was being carried out. Research always meant numbers to me, one way or another. I just could not see how numbers could be used to understand how students learn, and consequently help them learn. The big turning moment occurred in a professor's office, who is now my advisor. He shared with me one of his projects in which he along with his colleagues studied students solving engineering problems presented in fictional books. There was a clear research question, method, and even big real-world implications, even though it involved absolutely no numbers! This is when I realized the power of qualitative research. I couldn't think of a way in which the aforementioned research study could be carried out by quantitative methods.

C. Expanded example from Juan

To better understand a theoretical framework I mentally compared to it to a protocol in that I see a protocol as a set of agreed-upon general rules that guide practice on a particular field, or toward a particular objective. A protocol, as I interpret it, is not a detailed instruction on *how* to do something thing, but a higher level description or narrative of what the thing *should do* or how it *should look* like. It is for the practitioner to overcome the gaps from description to execution, bringing in her/his own expertise, beliefs, and evidence. In my analogy, the theoretical framework becomes the overarching set of rules, descriptions, and indications that guide the actions of the researchers in order

to help them produce something that other people—and they themselves can make sense of. A framework in this sense serves not only for the researchers to frame and orientate their work, but also for the interested community to look at the finished product, understand the underlying principles and intentions that shaped it, and assess its utility accordingly.

D. Expanded example from Hector

As we were studying the sources of information students used in choosing a major, we looked at their previous experiences, sources of information used, and influence from adults/peers, etc. Throughout discussions within our research group we arrived at this idea that students were motivated in some way to choose engineering, and then to choose a major within engineering. Through the reading assignments of other classes one member found a paper that used Eccle's expectancy value theory. We all looked at the framework and concluded that it sounded very applicable to what we were doing. We felt we ought to ground ourselves in a framework because otherwise we were just conjecturing based on what we had seen in the data. In our classes we were talked to about frameworks. In papers we saw people using frameworks. We knew we used the scientific method as a framework in other engineering work. And here was this framework that fit very nicely into the work we were doing.

Throughout the examination of the data words like 'values' and 'beliefs' would pop up in our research group discussions. When we adopted a theoretical framework that seemed to fit our research study (to the best of our knowledge) the biggest change I remember happening was that our vocabulary changed. We felt more at ease being able to point at something [the theoretical framework] as a way of labeling the phenomena we were observing. Using the framework bolstered our confidence. We were using a tool our community of practice encouraged and endorsed, and the tool made me feel thorough, empirical, objective, more 'scientific'.

DISCUSSION

The coding of the summative reflections (shown in Table I) indicates the three most reported areas of difficulty still perceived by the new PhD students were using a theoretical framework, the issue of qualitative research being a "real approach" to research and transferability of results. This was similar to the group of engineering faculty observed by Borrego in the RREE project. A common theme that was repeated throughout the participants' explanation of strategies they used to deal with the conceptual difficulties they faced while learning about engineering education research in the course was the ability to use their prior engineering knowledge or experiences. Regardless of the difficulty, the students would speak to

another educational experience or aspect of working as an engineer that could relate to the current difficulty.

I. Using a theoretical framework

The participants who discussed theoretical framework being an area they had to wrestle with collectively questioned why this was something they need to use. However, in their reflection document as some the participants described the kinds of “scientific” work they were used to doing it was found that they actually aligned their work with a framework except it was not called a framework at the time. This indicates that the students had a misconception of what the term theoretical framework meant. In discussing strategies used to deal with this difficulty, one of the co-authors described using a theoretical framework in a trial-and-error approach. Not having any idea what a theoretical framework was or how to use it when faced with a new research project in engineering education they “just chose a framework and hoped it would work”. Borrego writes about a similar analogy was made by the facilitators of the RREE workshop when they emphasize that there is no one *correct* theoretical framework just as there is no one correct answer when attempting to solve an engineering design problem. Rather, it is a case of choosing the framework that is most *appropriate*. Another co-author discussed having done technical work in which they did not have to be explicit about a framework “likened it to a having a protocol that governed how a task was to be completed”.

II. On qualitative research approach being “real” research

The participants who attended the RREE workshop expressed a preference for research approaches that were absent of ambiguity and that lessened the possibility of being misconstrued. However, as the RREE participants refined their research questions they reported appreciating the level of depth qualitative approaches provided them. Initially, both the RREE participants and the PhD students in our study found the notion of small cases or conducting research dependent on human interpretation was a culture shock. The PhD students discussed not trusting a qualitative approach primarily on the grounds that perception about an event can change as people reflect or time passes. One student explicitly discussed being “suspicious” of any method that does not allow for the same results to be achieved when the study is replicated by a different researcher. However as they reflected on what benefits a qualitative approach provides, their level of wariness slowly subsided. One co-author described the process of their conversion as the point in time when they really got to read about a research project being conducted using qualitative research methods and came to the realization that the research questions being posed could not have been answered using a purely quantitative approach. Numbers would not provide the data they needed.

III. Transferability of results – framing the research question

Participants spoke about the challenge of wording research questions “just right” in order to uncover what it was they were hoping to find. All the students who raised this concern described this the essence of the difficulty as knowing when they had a question that captured the *purpose* of the research. This difficulty was even further compounded by the fact that they had to be able to answer the question empirically. From questions being too broad to becoming too narrow, these participants discussed being challenged by advisors or professors mechanism whereby they were finally able to come up “acceptable” research questions.

CONCLUSIONS

Based on the research question that guided this study the following important conclusions can be drawn:

Conceptual difficulties identified by Borrego are still an issue for new engineering education PhD students

Ten years after Borrego collected her data, Engineering Education departments are an established reality, and students are able to receive PhDs in Engineering Education. However, based on the results of our study the conceptual difficulties highlighted by Borrego are still prevalent in the new generation of engineering education researchers. This finding has significant implications for the design of current and emerging engineering education programs in that introductory courses for newly admitted students should provide materials necessary for a successful transition to the discipline. Research projects new PhD students engage in their first year of study should also be a good representation of the type of the research that characterizes this field.

Students linked their prior knowledge and experiences to the new information being learned

Interestingly, while it was students’ prior knowledge and experiences that lead to conceptual difficulties in their first exposure to engineering education research, our participants used their previous engineering and scientific knowledge where applicable to make sense of the new material they were learning. The participants spoke of the different analogies they used or how they compared the current information to other educational or social interest in a manner that helped them to understand the new concepts. Documenting and sharing these analogies is the next stage of our work. These results can be shared with others who want to enter EER community to help make sense of this new way of looking at things.

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Apprenticeship of Observation

Implications for the adoption of evidence-based instructional practices

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Abstract— This work explores the relationship between faculty descriptions of how they currently teach and how they were taught in similar courses during their undergraduate experience in order to understand how faculty choose to adopt evidence-based instructional practices in light of signature pedagogies in engineering education. Twenty-one one-on-one structured interviews were conducted with faculty members in a College of Engineering who teach courses in the first two years of the engineering curriculum. Interviews were analyzed using thematic and axial coding approaches to understand faculty's educational experiences as a student and how this relates to how they currently teach. Findings indicate that the current inclusion of evidence-based practices in undergraduate engineering courses positively relates to the adoption and persistence of usage by engineering educators. By this we can begin to understand the gestalt shifts that lead faculty away from signature pedagogies and towards more progressive and research-based approaches.

Keywords— *Signature pedagogies; faculty beliefs; evidence-based instructional practices*

I. INTRODUCTION

Studies have drawn contrast between teacher-centered and content oriented to student-centered and learning-oriented [1] instructional techniques. Entwistle et al. [1] note intermediate categories ultimately describing developmental trends in thinking and conceptions of teaching (Figure 1). This model identifies that faculty epistemological levels align with a focus on instructional techniques and the focus of their course. A dualistic instructor imparts knowledge to his/her students through teacher-centered and content-oriented instructional methods. As his/her epistemological beliefs advance to a more relativist approach, the instruction becomes more student centered. Regarding this progression, Entwistle et al. [1] assert, “more sophisticated conceptions emerge out of the earlier ones, while retaining certain elements of them.”

For engineering faculty, earlier conceptions such as how they were taught have the potential to influence not only how they teach, but whether they stick to using traditional teaching practices (ex. lecture) or adopt evidence-based instructional practices (EBIPs). Thus, this work seeks to explore the relationship between faculty descriptions of how they currently teach and how they were taught in their fundamental engineering courses. Additionally, this work seeks to

understand how faculty choose to adopt evidence-based instructional practices in light of signature pedagogies in engineering education. Thus, this study explores the following research questions:

1) *How do faculty describe their current general pedagogical practices in comparison to their own learning experience?*

2) *What evidence-based instructional practices occur in faculty teaching that have carried over from their own learning experiences?*

II. SIGNATURE PEDAGOGIES

Throughout the training of those who participate in professional practice, signature pedagogies can be identified across the disciplines from science and engineering to law. Signature pedagogies inform students on how to think, perform, and act and can be recognized as the first thing that comes to mind when thinking about professional preparation in a field [2]. The signature pedagogies of engineering have been recognized to change depending on the context of the course; whether it is an engineering analysis course or a design studio reflects the signature pedagogy. As summarized by Shulman [2], signature pedagogies represent a history and pervasiveness of practice that defines the role of knowledge in a field:

“Signature pedagogies are important precisely because they are pervasive. They implicitly define what counts as knowledge in a field and how things become known. They define how knowledge is analyzed, criticized, accepted, or discarded. They define the functions of expertise in a field, the locus of authority, and the privileges of rank and standing. As we have seen, these pedagogies even determine the architectural design of educational institutions, which in turn serves to perpetuate these approaches.”

Many faculty who teach in higher education rarely receive direct training to teach, instead they rely on an “apprenticeship of observation” where they most often model their own teaching from their prior experiences as a student [2, 3]. In order for faculty to adopt the practices they observed as a student they must be attentive to the process of the practices, be able to repeat the practice, and be motivated to repeat it [4, 5].

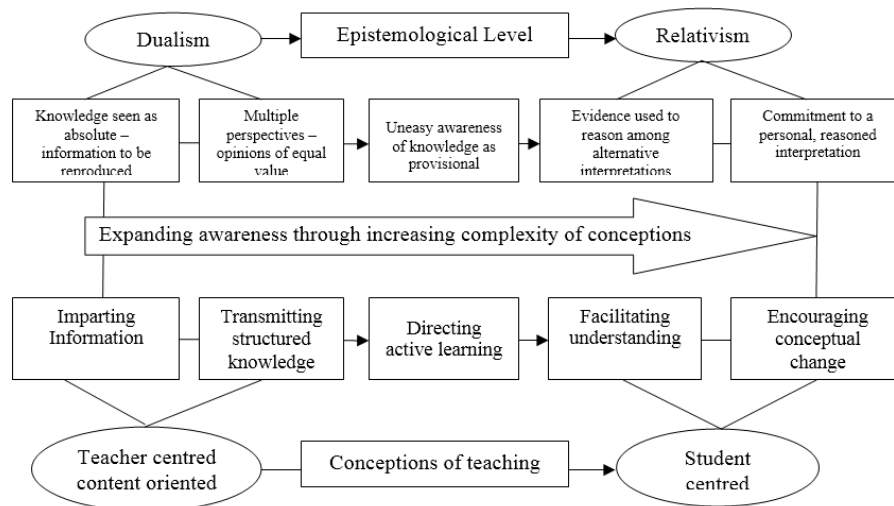


Fig. 1. Developmental trends in thinking and conceptions of teaching [1]

III. BELIF STRUCTURES AND PEDAGOGICAL PRACTICE

In part, signature pedagogies persist because they simplify the practice of professional education. As faculty learn an instructional practice and internalize it, they become more comfortable with its implementation [2]. These practices then begin to imbed themselves into the belief structures of the faculty. Pajares [6] notes that in studies examining teacher beliefs, the construct is not normally clearly defined. He uses the definition provided by Rokeach [3] where he defines beliefs as any simple proposition, conscious or unconscious, inferred from what a person says or does, capable of being proceeded by the phrase ‘I believe that...’. Additionally Rokeach [3] noted that all beliefs have cognitive, affective, and behavioral components. Attitudes are the holistic organization of beliefs around an object or situation. Values are the evaluative, comparative, and judgmental functions of beliefs. Together beliefs, values and attitudes form a person’s belief system [6]. When applied to teaching, these belief structures influence the perceptions faculty have regarding their students, the instructional practice, and how it should be carried out. These beliefs are first structured from their experiences as a student, and later as an instructor based on their in-class experiences, feedback, and interactions with other instructors [5].

Nespor [7] suggested that the structure of beliefs are comprised of four primary features that differentiate beliefs from knowledge. The first is that beliefs contain existential presumptions. One’s belief system contains assumptions regarding the existence or non-existence of an entity like the teacher’s perception of the student’s ability and maturity. These presumptions represent deeply personal beliefs of the physical and social reality and are very difficult to change [6]. The second feature pertains to the alternativity of beliefs. This refers to the conceptualization of an ideal situation as a result of concerns and the recognition of short comings in current realities [7]. The third feature is the role of affective and evaluative qualities. These qualities involve subjective evaluations and feelings that can be distinguished from cognition. This feature differentiates between the knowledge

of a domain and the feelings toward a domain and can directly impact the effort a teacher gives toward teaching a particular subject [7]. The final feature of belief systems is that they are composed of memories and experiences stored in the episodic memory, whereas knowledge is stored semantically. This type of storage provides a quick recall of rich descriptions that can influence faculty practices [7].

Belief structures are primarily characterized by their non-consensuality and unboundedness [7]. The non-consensuality of beliefs refers to the fact that belief systems are debatable, generally inflexible, and unchanging. This makes altering beliefs, and therefore signature pedagogies, a difficult task, requiring a restructuring of the belief system for it to occur, also referred to as a gestalt shift. The unboundedness of belief systems indicates that they are highly variable allowing their inferences to be applied in a wide variety of phenomena and settings [7]. Contrary to belief systems, knowledge systems are capable of being altered given adequate reasoning and their applications are contextually bounded to appropriate applications. Faculty beliefs and the use of their belief structures aids in the development of engineering pedagogical practices by providing a means to deal with the ill-defined nature of the classroom and providing a source of pedagogical practice to pull from that can be quickly accessed.

Within the academic context and environment that faculty function in, faculty frequently encounter ill-defined and deeply entangled problems [7]. By nature of the environment of teaching, faculty have interpersonal contacts and must be able to function on impulse rather than reflection [6]. The use of knowledge to solve these complex and varied problems requires a clear definition of the problem as well as the identification of a multitude of courses of action [7]. Due to the nature of the entangled domain, faculty are ill-equipped to deal with problems through cognitive and information processing strategies alone as they do not work [6]. Instead faculty are required to rely on their belief structures to solve these problems.

Nespor [7] provides a description of how teachers can use their belief structures to deal with ill-defined problems. As belief structures are unbounded, faculty can utilize the quick retrieval of detailed memories and past experiences that have been episodically stored, and apply them to a wide variety of scenarios. These solutions are also relatively immune to contradiction as belief structures are non-consensual and involve the alternativity of the situation being addressed. The use of existential presumptions further stabilizes the problem as it imparts absolute and concrete entities into the ill-defined problem.

The resources available to faculty in their episodic storage consist of memories and experiences throughout their lives. One of the most common sources of these experiences resides in the teachers own experience as a student [8]. As a large portion of the teachers' youth is spent in the classroom observing teachers, they begin to develop beliefs about the practice of teaching. Pajares [6] acknowledges that early experiences, like those in elementary education, are very influential, and beliefs because of these types of experiences are difficult to change. The limitation of this perspective is that students only observe the action of the faculty from the student perspective, and therefore what they learn about teaching is intuitive rather than empirical; it does not represent all of the aspects of teaching. Despite this, data from Lortie's study [8] indicates that faculty realize their current practices reflect those of their teachers. Stice et al. [9] discuss the future of engineering education and the qualification of future teachers, noting that future teachers may not know much about teaching, but will "teach the way they were taught", thus supporting the findings presented by Lortie [8].

If this model persists, then the current engineering pedagogical practices that involve more traditional and dualistic perspectives will persist, limiting the opportunity for the adoption of evidence-based instructional practices. By understanding which evidence-based instructional practices carry over from faculty's own education, further emphasis can be added to those practices that will require a substantial gestalt shift to alter faculty belief structures regarding their implementation.

IV. METHODOLOGY

This study utilizes a qualitative exploratory design. The study explores the relationship between how faculty describe the way they teach and how they were taught in similar undergraduate engineering course. This study will address which evidence-based instructional practices carry over as signature pedagogies and why faculty choose to adopt new evidence-based instructional practices in lieu of signature pedagogies in engineering education.

A. Participants

This study involved twenty-one faculty members who teach core courses within the first two years at a medium-sized, private, primarily undergraduate institution. Participants included both tenure and non-tenure track faculty with varying teaching experiences and course loads (Table I).

Participants had an average of 8 years teaching experience. Of the twenty-one participants, six faculty members taught design courses, eight taught lab courses with major class projects, and seven taught courses involving fundamental engineering theory (ex. Statics).

TABLE I. PROFILES OF PARTICIPATING FACULTY

Academic Rank	Instructor	1
	Adjunct Professor	6
	Visiting Assistant Professor	1
	Assistant Professor	5
	Associate Professor	7
	Professor	1
Sex	Male	12
	Female	9
Course Category	Design	6
	Theory	7
	Lab	8

B. Data Collection

Each of the twenty-one one-on-one interviews were recorded and transcribed. Interviews lasted an average of 62 minutes. The researchers modified Cutler's [10] interview protocol for her assessment of the use of EBIPs (coined *Research-Based Instructional Strategies*, or RBIS, in her work). During each interview faculty members were asked to walk the interviewer through a typical class session in their course, describe the purpose of the course in their own words, and describe what the course was like if they took it during their undergraduate program:

- 1) *What course or courses are you currently teaching?*
 - a) *How many sections?*
 - b) *How long have you been teaching those courses?*
- 2) *Could you please walk me through a typical class session in your course? What does it look like?*
 - a) *In your own words, what is the purpose of the course?*
 - b) *Did you take a course like this in your undergraduate program?*
 - c) *What was the course like when you took it?*

In addition to the questions above, participants completed a survey regarding their use of EBIPs outlined in Table II [14]. Participants were asked to provide a rich description of their implementation of the EBIP if they indicated they currently used it, how they learned about the practice, and why they decided to use that particular strategy. This line of questioning was used to determine whether their decision to use a practice was based on their past learning experience. Interviews were used as the primary source of evidence as the researchers could include additional probing questions that would prompt the participant to provide critical incident descriptions in order to validate the implementation of the EBIP. While video recordings of class room practices were

collected for each of the participants, these observations did not ensure that a currently implemented EBIP would be used that day and provided little insight into the belief structures of the participants in comparison to the in-depth interviews.

TABLE II. EVIDENCE-BASED INSTRUCTIONAL PRACTICES AND DESCRIPTIONS [14]

EBIP	DESCRIPTION
Active Learning	A very general term describing anything course-related that all students in a class session are called upon to do other than simply watching, listening, and taking notes
Collaborative/ Cooperative Learning	Asking students to work together in small groups towards a common goal; A structured form of group work where students pursue common goals while being assessed alone
Think-Pair-Share	Posing a problem or question, having students work on it individually for a short time and then forming pairs and reconciling their solutions. After that, calling on students to share their responses
Inquiry Learning	Introducing a lesson by presenting students with questions, problems, or a set of observations and using these to drive the desired learning
Just-in-Time Teaching	Asking students to individually complete homework assignments a few hours before class, reading through their answers before class, and adjusting the lessons accordingly
Problem-Based Learning	Acting primarily as a facilitator and placing students in self-directed teams to solve open-ended problems that require significant learning of new course material
Concept Tests/Peer Instruction	Asking multiple-choice conceptual questions with distracters (incorrect responses) that reflect common student misconceptions. / A specific way of using Concept Tests in which the instructor poses the conceptual question in class and then shares the distribution of responses with the class. Students form pairs, discuss their answers and vote again.

C. Data Analysis

Interviews were transcribed by an undergraduate research assistant and professional transcription service. The interviews were then coded by the lead researcher, first comparing the participants' description of their course to their description of how they were taught. These learning experiences included any experience a faculty member had as an undergraduate and in graduate school. The described instructional practices were categorized for pedagogical practices through thematic analysis to provide generalized descriptions to compare practices.

The analysis was then examined in-depth for descriptions to categorize their learning experience as an evidence-based instructional practice through the a priori codes identified in Table II. These classifications were then compared to their descriptions of their own teaching practices; providing a point-to-point comparison of the practice. The codes were validated for confirmability through negotiated agreement of two interviews [13].

V. FINDINGS

Each of the participants indicated that they utilized several EBIPs they experienced in previous learning experiences, and secondarily from other sources such as workshops and other professional development opportunities. These findings emphasize that as a result of their prior experiences as a student, faculty develop belief structures that relate to their use of specific pedagogical practices. These belief structures are developed as a result of favorable educational experiences that translate to their own practice or through modifications to practice and improve the experience for their students. Overall student-centered approaches are identified as current signature pedagogies among participants.

A. Student-Centered Learning as Engineering Signature Pedagogy

Faculty members described the courses they currently teach, whether they took a course like it in their undergraduate program, and how the course they teach compares to when they took it as an undergraduate student. Comparing faculty pedagogical practices with their own learning experiences, we find that teaching has moved from traditional teacher-centered lecture style (how they learned), to faculty serving as more of a facilitator, implementing EBIPs (how they teach). Faculty comparisons parallel the stages in the evolution of teaching styles (Figure 2) [14].

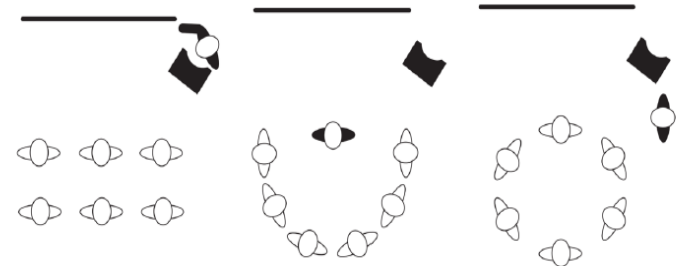


Fig. 2. Stages in the evolution of teaching styles. [14]

Stage 1 consists of the course instructor lecturing from the front of class, serving as an authority figure solely delivering material, with minimal instructor-student engagement, as noted in the following interview excerpts:

“He sat at the front of class. Didn’t stand, didn’t walk around, wasn’t engaged, [and] didn’t really give examples. Just kind of went through what the steps of the design process were and then he gave us projects to work it out on our own so it was not engaging at all. I was very turned off by that class.”

“Ok so at [institution], 500 students in a lecture hall, [and] one professor lecturing in the front. The chances of getting a question in or even wanting to ask a question, much lower than if we were to have, say 100 students in a large lecture hall. Also the room, being so much larger, you felt such a far distance from the class. So it’s less personality

connection. In fact the professor, we almost never spoke with him outside of lecture.”

In each of these situations, faculty developed belief structures regarding the level of interaction with faculty and engagement in the course. In these instances these faculty participants perceived their experience negatively; choosing to alter their practice in order align their practice with their own beliefs.

In stage 2 the instructor serves as a demonstrator or coach, incorporating several lecture formats including demonstrations and multimedia presentations. One faculty member in the sample described learning in this way as seen in the following interview excerpts:

“Yeah, it was the same thing: activities, labs, projects. But we were always in teams of two.”

As a result, this faculty member teaches using a similar approach since their belief structure aligned with the positive outcomes of the approach:

“They get the code sheet. Usually they read the first two lines and try to code so you just stop them and tell them to finish reading and then they start coding again and then they make mistakes and we stop them and they fix it and then they get stuck and they raise their hand and then the teaching assistant or me just walks and tries to make them find a solution to the code, again.”

Stage 3 describes how several of the participants in this study currently teach, and how this differs in comparison to how were taught. The model is a learner-centered teaching style where the instructor serves as a facilitator promoting self-regulated learning, as evident in the following interview excerpt:

“I think the whole course is structured around this collaborative learning. We have three projects in which students have to work towards [a] common goal. I had groups of four or five students. Pretty much the entire class is collaborative learning essentially. The students are given the assignment and they’re asked to decide who’s going to be responsible for parts of the project. I basically split them into team leaders, into let’s say the project manager, the engineer, and basically the timekeeper. They have roles in the teams so everybody [is] supposed to have a specific task and we come together as a group to reach a successful final design. As a teacher basically [I’m] making sure that they’re on the right path, the issues they’re having are resolved and assisting them in any way I can.”

Throughout the interviews a common theme emerged: participants self-identified that the signature pedagogies for engineering were focused on student-centered approaches or at least should be. Through their reflection of their own learning experiences, faculty developed beliefs regarding instruction and the necessity for student-centered approaches.

While the findings presented here are associated with faculty descriptions of their own learning experiences, it is important to note that the development of the faculty belief structures were not solely developed as a student. Student-centered instructional approaches were either experienced in one of the courses they took as a student that they chose to adopt because of a desire to increase student engagement, through collaboration with other faculty, and traditional professional development activities. These experiences align with those of Oleson and Hora [5] indicating that a faculty’s prior learning is not the only source of educational training that promotes the usage of certain pedagogical practices. Further, there are broader experiences aligned with their belief structures that support their adoption of pedagogical techniques.

B. Evidence-based instructional practices as signature pedagogies

When examining which evidence-based instructional practices carry over from their learning, there was a common theme of active learning, problem/project-based learning, and inquiry learning. While faculty were not aware of the terminology, which has been recognized in prior studies [9], their descriptions of their own learning experiences identified these EBIPs.

However, in their descriptions of the course they were currently teaching as compared to what it was like when they took it, there was little indication of carry over. Instead much of the carry over about specific EBIPs came from other learning experiences. During the examination of their usage of these practices, faculty were asked “where did you learn about this practice”. The source was recognized from a general perspective of their own educational experience that they could not specifically identify. Instead, it manifested as a norm or belief about the course. For example common responses to this question included:

“I guess my own experiences as a student.”

“I just copied my way of learning.”

“I guess that’s how I learn things, so I figured that’s the way to teach it.”

These statements provide an insight into a belief structure that was developed by the faculty participant when they were a student.

Active learning was the most common EBIP occurring in faculty teaching that carried over from faculty members’

own learning experience. This practice was described as being used where faculty taught theory-based courses. Common signature pedagogies in this context included question-answer periods, discussions, and guided problem solving, as evidenced in the following interview excerpts:

“I would present the students with a topic and have them come out with the answers, and then kind of guide them to an answer.”

“The primary mechanism for me is through discussion.”

“I actually have the students try to solve problems in class. I have them present it up on the board, as they're learning it as they go.”

In design courses, active learning is heavily dependent upon group work, as described in the following interview excerpts:

“Sometimes they have to go out of the way and actually go on the internet and do research. I have them going through groups. The way I implement it is I have them in groups. I have them talk amongst themselves—have them go outside. Sometimes I'll set a class in the library, et cetera and work on it and they come back. Answering their questions, anything that they have, some issues with the problem and stuff.”

“My next activity is [an] impromptu vehicle building activity, so I'm going to give them some stuff and ask them to build something, depending on constraints, cost constraints and item constraints.”

Teamwork and hands-on activities were the primary pedagogies used in lab courses. Faculty described their usage of active learning as having students help each other and “learn by doing” in the following interview excerpts:

“I give them problems and then explain to them, so that they have a moment to think to themselves, and then work with other team members. If they've already completed any [software task], they help their other friends, and so they're actively telling others—I mean it's one thing to know material, but teaching others kind of [reinforces] what you know, so I encourage that as well.

“It could be even, just anything with learning by doing— just going through the tutorial and then trying to apply the tutorial-the lessons from the tutorial to a less scaffolded assignment.

“When the information is presented in different ways and different terminologies are used I will deliberately give them tutorials from different style textbooks and then they are allowed to work with each other.”

Faculty who taught design and lab courses also included aspects of problem-based learning and inquiry learning as a result of their previous learning experience. These courses involved computer programming and semester long design projects. Signature pedagogies can be summarized as facilitating group learning and project-based learning, as noted in the following two interview excerpts from faculty who taught design and lab courses:

Design course:

“I gave them seven to eight different case studies, divided the class into small groups and asked them to look at the case study, brainstorm a solution, look at the NSPE code of ethics, see which code of ethics is violated, which code of ethics they stuck to and what they should have done ideally in that situation, and then I asked them to present their solution to the class, and then the classmates asked them questions.”

Lab course:

“They need to pick up an existing product on the market and to look for the sustainable design solution so they are not just designing an existing product. They need to look for any particular weaknesses of the product and see how to improve it. And so they need to make sure they define their problem and they tell me what problem they have and how they are going to seek the solution to stop the problem and they need to do the cost analysis to demonstrate their design (if it's functional and applicable). And they need to show me the final design so they need to first give me a model based on the current existing product and they also need to show me an improved model based on their problem statement.”

Although several faculty members mentioned using think-pair-share, concept tests, and just-in-time teaching, it was not as a result of these practices carrying over from their previous learning experiences. Instead they were associated with other experiences that included professional development activities, collaborating and observing other faculty, and industry experiences. In many instances, the faculty interviewed in this study had never heard of these practices (Table III).

TABLE III. SOURCES OF ADOPTION OF EVIDENCE-BASED INSTRUCTIONAL PRACTICES

<i>EBIP</i>	<i>Prior Learning</i>	<i>Other Source</i>	<i>Not Adopted</i>
Active Learning	Design Theory Lab		
Collaborative/ Cooperative Learning		Lab Design	Theory
Think-Pair-Share		Lab	Theory Design
Inquiry Learning	Lab Design		Theory
Just-in-Time Teaching		Design	Theory Lab
Problem-Based Learning	Design Lab		Theory
Concept Tests/Peer Instruction		Lab	Design Theory

IV. CONCLUSIONS & IMPLICATIONS

Faculty belief structures have a strong impact on the persistence of educational practice and the ultimate recognition as a signature pedagogy in the field. These practices are initially experienced by faculty through their own experiences as a student, but persist due to their perception and implementation of the practice. Despite a focus on lack of implementation of evidence-based instructional practices utilized in engineering education, there appears to be some movement towards a focus on student-centered teaching across several engineering education course contexts.

While it has been identified by several authors that past experiences as a student are not the only source of inspiration to implement an evidence-based instructional practice, it does represent a first experience that can have a lasting belief in a faculty member's own practice. As more students have positive experiences with these implementations and faculty experience success implementing them, they will have the potential to redefine signature pedagogies in engineering.

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Ambiguity During Engineering Problem Solving

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Abstract—Work place engineering problems are recognized as being complex and ambiguous. However, most of the problems students are asked to solve during their degree programs are classroom problems. Most studies of ambiguity in problem solving have defined ambiguity as a characteristic of the problems. We are interested in understanding how students interpret engineering problems, either creating or resolving ambiguity during their problem solving process. The research question that guides this study is: How is ambiguity manifested by engineering students as they solve problems? This study is part of a larger project examining engineering students' engineering problem solving across different types of engineering problems. Twenty materials engineering students were asked to solve four materials engineering problems during a think-aloud session. For the analysis, points of ambiguity during the problem-solving process were identified as periods in which the students specifically verbalized uncertainty. The points of ambiguity in the transcript were then analyzed through script analysis. More specifically textual instances of ambiguity were linked with three main periods and situational categories: a) the situation that caused the ambiguity, 2) what happened during the point of ambiguity, and 3) the reaction of the student after reaching the point of ambiguity. Results indicated that students experienced points of ambiguity in both closed- and open-ended problems. Several motifs were common to both types of problems, including confusion over how to use given values, not having necessary content knowledge, lack of self-confidence, and difficulty conceptualizing the problem. The lack of constraints inherent in the open-ended problems also caused additional ambiguity among some students. Our findings show that ambiguity can take many forms and is not just a function of the problem structure. Students reach points of ambiguity (e.g., points where they do not know what to do next), due to many factors. Some of these factors represent aspects of their academic and epistemological development. Our analysis to date suggests that students need more comprehensive training and practice to be prepared in facing problems that reflect the work in engineering practice. We are currently examining the data further to identify patterns in their response to ambiguity, which may help in developing pedagogical strategies and tools to support students' ability to successfully solve engineering problems

Keywords—*ambiguity; qualitative analysis; problem solving*

I. INTRODUCTION

Engineers have been seen as problem solvers, yet the kind of problems students solve in classroom environments are different than what they will face in their professional careers [1,2]. Most classroom exercises involve application of content knowledge in well-defined situations to obtain a single correct solution. Walther and Radcliffe argue that engineering graduates may not have the competencies required for their practice, even though program outcomes are designed to meet the needs of industry [3]. Along similar lines, Atman et al believe engineering education falls short of the goal of adequately preparing students for professional practice [4]. Where the traditionally taught classes permit the efficient delivery of basic content knowledge, they fail to provide an opportunity for the synthesis of knowledge, development of skills, and possibility of finding innovative solutions to engineering problems [8].

Previous research has demonstrated that to promote flexible thinking and to furnish students with skills that will enhance their chance of being successful in their workplace, educational institutions should introduce students to complex, ill-structured and open-ended problems [5-7]. Ill-defined problems are problems with many possible answers [9]. The difficulty of these problems lies in evaluating multiple viable solutions, and choosing the best one. Ill-defined problems require more information to understand the problem than what is provided, have multiple solution paths, may change as new information is acquired, often elicit additional questions, are open-ended, and are complex enough to require collaboration and thinking beyond recall.

In past studies, the difficulty of a problem has always been analyzed as an external factor [10]. According to Schrader most empirical research has considered the degree of ambiguity as a characteristic of the problem independent of the problem solving process (i.e. exogenous to problem solving) [11]. However, the level of ambiguity in the problem that is

acknowledged by the problem-solver is often made implicitly, based on the problem solver's mental models that are brought to bear on the problem. An individual's mental models are derived from a host of factors such as their educational background and experiences. Ambiguity is defined as the decision maker's lack of understanding of the critical parameters or variables in a given problem, and/or the nature of the relationship between variables.

The level of ambiguity endogenous to problem solving is positively correlated with the level of experience. Novices strictly accept the rules until they progressively reach an expert level through experience; proficiency at a subject matter is arrived only after substantial reflective practice. In our initial study of problem solving we witnessed the consequences of being a novice [12]. Students with little or no experience with the problem type and a lack of content knowledge struggled to make decisions to move forward during problem solving. Thus, we undertook this study to answer the research question: How is ambiguity manifested by engineering students as they solve problems? This Work in Progress paper provides some preliminary results of our study.

II. METHODOLOGY

The qualitative study presented in this WIP paper is part of a larger study aiming to understand how students interpret problems, creating ambiguity or unambiguity as part of the problem solving process.

Twenty undergraduate materials science students from a large research university in the southeastern region of the United States participated in the study. Although participation was voluntary, students were required to be materials science students and seniors. The reasoning behind the criteria was to equalize the domain knowledge and level of experience in the subject area. We also wanted to select advanced students in order to examine how they dealt with ambiguity at the end of their degree program.

Data collection included video-recordings of problem-solving through the think aloud method. The think aloud method allows the researchers to gain insight into mental operations and observe the processes underlying the performance of a task in addition to the final product [13]. During the think-aloud sessions, participants were provided with a problem statement on a single page of paper, blank paper to work out their solution, a calculator, and a reference textbook [14].

Students were asked to solve four problems during the think aloud sessions. The problems varied in their complexity and whether they were open- or closed- ended. For this study, we analyzed think aloud data from the more complex closed- and open- ended problems. The two problems are presented in the Appendix.

During think-aloud sessions students were asked to verbalize their thinking process no matter how irrelevant it seemed. The role of one of the researchers was to prompt participants during extended periods of silence. Some of the prompts used were: "What are you thinking now?", "How are you deciding what to do now?". Prompts were never used to provide information to students.

Recordings of the think aloud sessions were transcribed verbatim and transcripts were treated as a data set for the analysis process. Fonteyn et al argue that script analysis allows for the investigation of the types of information that participants attend to during problem solving in terms of their method of structuring the problem, justification of the decisions they make, and their problem-solving plan [15]. Analysis continued with identifying points of ambiguity as periods where students were unsure of how to proceed. Those instances in the transcript were categorized based on the situation that caused the ambiguity, what happened during the point of ambiguity, and the reaction of the student to resolve the ambiguity.

To ensure the distinction between filler words and words that represent ambiguity, we watched the videos a second time and incorporated factors such as the participants' body language and the amount of time they took so that we could differentiate ambiguity words from filler words. For example, the word "hmm..." could be used as either a filler word or as a word indicating ambiguity, depending on the situation.

III. PRELIMINARY FINDINGS

In this study we analyzed three instances of when students dealt with ambiguity: a) the situation that caused the ambiguity, b) what happened during the point of ambiguity, and c) how the student responded to that ambiguity. As an example, Table 1 shows a sample of part of the coding for participant 39.

TABLE I. EXAMPLE OF PART OF THE CODING FOR PARTICIPANT 39.

Problem Type	Participant 39		
	<i>Situation that causes ambiguity</i>	<i>During the point of ambiguity</i>	<i>Reaction of the student after point of ambiguity</i>
Closed-ended Many decisions	Trying to manipulate equations	Cannot solve the problem due to missing initial length	Accessing book for Poisson's ratio and connecting it to strain in different dimensions
Open ended, Many decisions	Revisiting the problem	Failing to solve the problem due to missing information	Making assumptions to move forward

The coded text for the closed-ended many decision problem for this student is:

...Um, I'm just trying to still manipulate, you have this set of 3 values that are equal to each other. You know that the stress is equal to the force over area which is also equal to the modulus times the um, change in length over the original length. (Looking at paper) So what's throwing me off is which values, like before and after values, to plug in for the dimensions.

The solution to this problem does not require knowledge of the length, as the only relevant quantity for the length of the cylinder is the strain. However, because this student knows that strain is defined as change in length over original length, she believes that the initial length is needed as part of the calculation. This point of ambiguity is an example of the student not

understanding the relationship between variables. Eventually the ambiguity is resolved when she accesses the textbook and finds the definition of Poisson's ratio, which then allows her to move forward without knowing the initial length.

The coded text for the closed-ended many decision problem for this student is:

"...I'm just trying to see if I'm missing something in terms of um, maybe that the, the cross-section element is also, it's a, a cube so the 12 feet would apply not only for the length but for the cross-section value, too"

Here again the student is confused over missing information. In this case the problem is open-ended in that the cross-sectional area is not defined in the problem; rather she must select a cross-sectional area on her own. In this case she makes an assumption about the cross-sectional area, which is the correct approach, and is able to continue.

The examples above are for the motif *failing to make connections between different variables and/or between values and variables*, which is one of the primary reasons students faced ambiguity. Fig. 1 shows an example of the categories for this motif. In this figure we can see the patterns of responses that led to ambiguity. For example, three different situations led to the category "cannot solve problem due to missing initial length". Participants demonstrated many different approaches to the problem, some resulting in ambiguity and some resulting in unambiguity. Also we have seen cases where the same situation led to a different ambiguity category, and different situations that led to the same ambiguity category. Examples of these cases are shown in Fig. 2, which is for the motif *misconceptualization of the problem*.

At this preliminary stage of analysis we have identified four motifs that represent major areas of ambiguity: *unclear approach to problem solving*; *misconceptualization of the problem*; *uncertainty over what is being asked*; and *failing to make connections between different variables and/or between values and variables*.

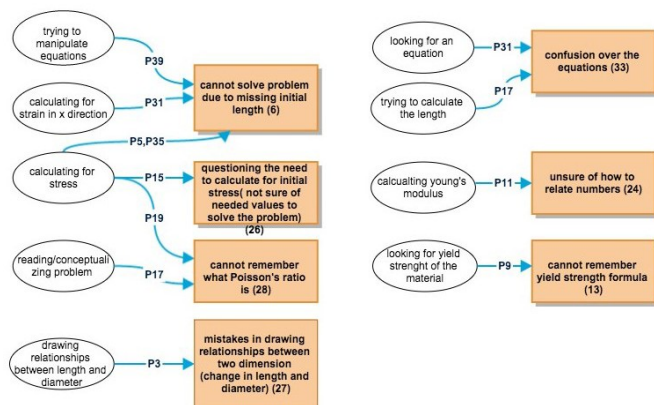


Fig. 1. Codes and categories in the *failing to make connections between different variables and/or between values and variables* motif. White circles are the initial codes and orange boxes are the resulting categories. Px indicates the participant number that had that particular coded text. Numbers in parentheses are a unique identifier associated with each category.

IV. CONCLUSIONS

Our preliminary results to date confirm Shrader et al's assertion that ambiguity is not only a characteristic of a particular problem, but also can be imposed by the problem-solver. This is most clearly seen in the closed-ended problem, which was designed explicitly to avoid ambiguity. An expert could solve it easily in a step-by-step fashion without any need to make assumptions or decide between alternatives. However, the students in our study found many points of ambiguity in this

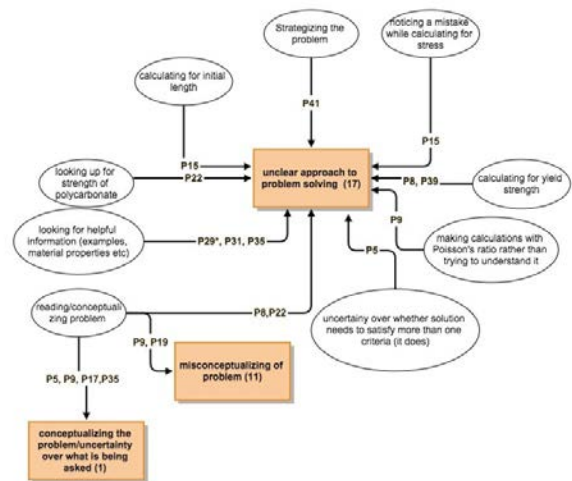


Fig. 2. Examples of different situations leading to the same ambiguity and the same situation leading to different ambiguity for the *misconceptualization of the problem* motif. White circles are the initial codes and orange boxes are the resulting categories. Px indicates the participant number that had that particular coded text. Numbers in parentheses are a unique identifier associated with each category.

problem, as illustrated in Table 1. The open-ended problem also elicited points of ambiguity. In this case, the point of ambiguity shown in Table 1 was a deliberately designed ambiguity, and participant 39 handled it in much the same way we would expect an expert to. However, there were also places in the problem-solving process where students experienced or even created imposed ambiguity where ambiguity was not intended.

A number of factors may be responsible for the ambiguity seen in this study. Lack of content knowledge is clearly one factor. Students who do not have the needed content knowledge will reach a point where they do not know how to proceed. The ambiguity for the closed-ended problem shown in Table 1 is at least in part a result of lack of content knowledge. Once the student was reminded of the definition of Poisson's ratio and how it could be used to calculate strain in directions normal to the applied stress she was able to continue.

Another factor causing ambiguity may be the students' epistemic beliefs. In our previous work [12] we described the problem-solving processes used by students and related those processes to the stages described in the Reflective Judgement Model [16]. In this model, the stages of epistemic beliefs are as follows:

- Pre-reflective: All knowledge is certain and comes from authority.
- Quasi-reflective: Knowledge is uncertain and there is no definitive way to select between competing knowledge claims.
- Reflective: Knowledge is uncertain, but different knowledge claims can be weighed against each other and an appropriate choice made.

We believe that the differences in ambiguity seen in this study may in part reflect different stages of epistemic beliefs. For example, some students had difficulty choosing a material for the open-ended problem. These students could not identify a justification for choosing one material over another, believing that any of several options were equally appropriate. This type of ambiguity is suggestive of a quasi-reflective epistemic belief. A reflective student, faced with the same situation, would be able to justify a choice. In our future work we intend to combine think aloud protocols with additional measures of epistemic beliefs.

Our results, while preliminary, in combination with our previous work have potential implications for engineering education. First, even these fourth year students faced ambiguity due to lack of content knowledge, suggesting a need to use research-based instructional practices to improve learning. Second, in order to become comfortable in dealing with ambiguity students need practice and guidance in solving complex, open-ended problems. However, students are generally not exposed to these types of problems in traditional engineering programs [1-4]. While many programs include design experiences in the freshman and senior years, the problems students are given in the bulk of engineering topics in the middle years are generally closed-ended. In order for students to develop the problem-solving skills needed in engineering practice, traditional classes such as statics, thermodynamics, and kinetics should incorporate authentic, open-ended engineering problems that include ambiguity.

ACKNOWLEDGMENT

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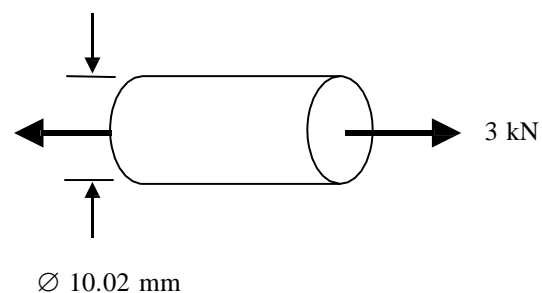
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APPENDIX

A. Closed-Ended, Many Decision Problem

A cylindrical piece of polycarbonate with the diameter shown below is subjected to equal and opposed uniaxial forces of 3 kN as shown. With these forces applied will the polycarbonate piece be able to pass through an opening 10.00 mm in diameter without breaking due to the applied stress?



B. Open-Ended, Many Decision Problem

A truss bridge requires 40 members of square cross-section each of which is 12 feet long and experiences its maximum load in tension. The bridge is designed so that the maximum load experienced by each member is 500,000 lbs. You are bidding on the contract to provide these 40 members. The weight of each member cannot exceed 350 lbs as this is the lifting limit of the crane that will be used to construct the bridge. Provide a recommendation as to the specifications for these members and the cost for the job.

Background and demographic factors that influence graduation:

A comparison of six different types of majors

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Abstract — How are engineering students different from other students? This study determined which demographic and background variables influenced graduation for engineering students, as well as education, business, psychology, health, and social science students. Once determined, a comparison between disciplines was made to discover if or how engineering students differ from other students. To perform the analysis, logistic regression with backwards elimination was used. The results showed that high school grade point average was a significant influence with respect to graduation for each discipline except psychology and business. A student's American College Test (ACT) English score was a significant and positive variable for both business and engineering majors while ACT math scores were only statistically significant for engineering students. These findings could potentially be used for recruiting as well as retention.

Keywords—graduation factors; engineering; ACT scores; Input-Environment-Output model; logistic regression

I. INTRODUCTION

Multiple studies have declared that engineering students are different from students majoring in other disciplines. Potvin, Tai, and Sadler found measurable differences between science and engineering majors in certain aspects of their backgrounds, such as SAT scores, level of mathematics preparation, and other high school aspects [1]. Another study stated that engineering students are more persistent than other college students when persistence is defined as students who matriculate in engineering and are still enrolled in their eighth semester [2]. However, little information is available about how engineering students are different from other students with respect to factors that influence graduation.

Abundant research has been conducted analyzing only engineering or STEM students and graduation. At least one study has found that both high school GPA and math SAT were positively correlated with graduation rates for each of the six universities tested, along with factors such as gender, ethnicity, and citizenship for some universities [3]. The study used a single pooled model to incorporate all the data, but used dummy variables to compare the results for each institution from an unpooled analyses. Moller-Wong and

Eide, also studying engineering students, reported that students with higher high school rank and ACT math score, among other factors, were more likely to graduate in engineering [4]. On the opposite end, they also found that being African American or having an ACT composite score of 35 or 36 puts a student at risk for not graduating with an engineering degree [4]. French, Immekus, and Oakes determined that high school rank, SAT Math scores, and GPA were related to persistence in engineering [5]. Using slightly different variables, some studies connected persistence and achievement in engineering with students' self-efficacy [6,7].

Scott, Tolson, and Huang, studying math and science majors, discovered that high school rank and combined mathematics and reading SAT scores positively correlated with retention [8]. A separate study sampling business, education, and STEM majors found that “students with higher high school rankings, no matter their race..., gender... or which school district they are coming from, should be encouraged into STEM majors” [9, p. 23].

II. RESEARCH QUESTION AND PURPOSE OF THE STUDY

Using data from Louisiana Tech University, this study aims to identify the demographic and background variables that significantly influence a student's graduation and determine if those factors are different across types of majors. More specifically, the question guiding the research is, “What factors that correlate with graduation are unique to engineering students?”

The purpose of this study is to discover the strongest influences on graduation by category of major. This information can then be used for both recruiting (to identify students who show great potential) and retention (to better design pre-college interventions).

Based on previous studies, it is expected that all categories of majors will show a positive correlation between high school GPA and graduation. Extrapolating from other results already published, such as Moller-Wong and Eide as well as Thompson and Bolin, it is expected that high school

rank will have a strong correlation with graduation for engineering students.

At Louisiana Tech University, as well as many other engineering programs, engineering students must have a certain ACT math score to enroll in non-remedial mathematics classes. Other majors, such as education and psychology, do not have such requirements. Therefore, regarding only engineering students, it is suspected that ACT math and science scores will positively correlate with graduation while neither of these variables will show significance for the other categories of majors. While ACT science scores do not directly affect enrolling in a class, it is likely that engineering students also show an affinity for science.

III. THEORETICAL FRAMEWORK

The theoretical framework guiding the study is Astin's Input-Environment-Outcome (I-E-O) model, which takes into account incoming characteristics of the student as well as environmental variables of the institution or program [10]. The input variables studied include high school GPA; high school rank; Louisiana residency, Math, Science, English, and Reading ACT scores; race; and gender. The different educational environments are engineering programs and five categories of non-engineering programs. Specifically, non-engineering majors will be broken into five separate categories: business related majors, social science/history majors, health related majors, psychology majors, and education majors. The outcome of interest is graduation in any major. We define graduation as a positive outcome if within six years of starting college.

IV. RESEARCH METHODS

Data for this study come from a single source: Louisiana Tech University's academic records, which included demographics and admission information. To analyze the data, logistic regression with backwards elimination is used.

A. Participants

The participants in this study consist of first-time-in-college (FTIC) freshmen who started at Louisiana Tech University in the fall of 2008. This group of students was chosen because a six-year graduation rate is used and 2008 is the most recent cohort with six years of data available. The students were split into six different groups according to the major declared when they began their studies. The first five major categories are reflective of the majors with the largest percentage of bachelor degrees according to the Condition of Education 2014 [11]: psychology, social sciences and history, business, health professions, education. The sixth group is engineering. Engineering students were not contrasted against other math and science majors because of insufficient sample size. Classification of Instructional Programs (CIP) codes were used to determine which majors offered at the university fit under each category. Not all

degree programs at Louisiana Tech fell into one of these categories, notably Mathematics, Physics and Chemistry. The list of specific majors that fall under each major category is given in Appendix A.

UNIV 100 is a university seminar class which all FTIC freshmen are required to take. Enrollment in this course was used to identify FTIC students, so transfer students are not included in the study. In total, 909 students were enrolled in the required class for the fall of 2008 that declared majors within the aforementioned categories. A total of 74 students were in the psychology majors, 84 in education, 91 in social sciences/history, 112 in health-related majors, 184 in business, and 364 in engineering.

The students were followed from the fall of 2008 until the spring of the 2013/2014 school year. This allowed for students to graduate within six years of their initial quarter attended.

B. Descriptive Statistics

As with most universities, at the time of data collection, race, ethnicity, and international status were confounded into one variable. The options were: White, Black/African American, Hispanic, Pacific Islander, Asian American, non-resident alien, and decline to identify. The population of students used in this study are not representative of all college students in the United States. The records indicate that the percentage of students in each race who started at Louisiana Tech majoring in the aforementioned disciplines are as follows: 82% White, 13% Black/African American, 1% Hispanic, and 1% Asian. Less than one percent of students were Pacific Islander. Two percent of the population declined to report a race and 1% of the students were non-resident alien. Unfortunately, cell sizes limited the study to those who reported their race as White or Black/African American. As for gender, forty percent of the students were female and sixty percent were male. A breakdown of percentages for each major group is given in Table I.

TABLE I. SAMPLE BY RACE AND GENDER

Major (Abbreviation)	White	Black	Female	Male
Psychology (Psyc.)	72 %	27 %	69 %	31 %
Social Sciences (S.S.)	79 %	16 %	53 %	47 %
Health (Health)	86 %	13 %	80 %	20 %
Business (Bus.)	83 %	12 %	39 %	61 %
Education (Ed.)	87 %	6 %	56 %	44 %
Engineering (Engr.)	81 %	12 %	15 %	85 %
Total	82 %	13 %	40 %	60 %

To identify differences between major groups, a model was created for each major group. Comprehensive data sets were compiled for each group of students. Each major group had similar average high school rank, high school GPA, and ACT scores with two exceptions – engineering students had a higher ACT Mathematics score and therefore higher ACT composite on average. The detailed information for each discipline's averages are shown in Table II.

TABLE II. GPA, RANK, AND ACT BY MAJOR

Major	GPA	Rank	ACT			
			<i>S</i>	<i>M</i>	<i>E</i>	<i>R</i>
Psyc.	3.28	70	22.9	21.5	24.9	25.1
S.S.	3.27	65	22.5	21.2	22.8	24.4
Health	3.47	44	22.5	21.8	24.0	24.4
Bus.	3.40	61	23.0	22.9	24.2	24.7
Ed.	3.39	65	20.9	22.0	22.2	22.2
Engr.	3.43	60	23.1	25.4	23.4	23.7

As noted, ACT scores rather than SAT scores were used for this study. According to research, high school students from Louisiana have an 80 – 100 percent chance of taking the ACT at least once, and Louisiana Tech University's students are primarily from Louisiana [12, 13]. Furthermore, after reviewing the data for the students in the study it was revealed that a very small percentage of the population had recorded SAT scores.

C. Definition of Graduation

For this study, graduation is defined as graduating from Louisiana Tech University within a six year time period with any undergraduate degree. In the logistic regression model, graduating from Tech was indicated with a 1 and not graduating with a 0.

Although the data for this study came from a single source, multiple files held different pieces of information. These files were merged to obtain all of the variables for each student. Once compiled, a logistic regression analysis with backwards elimination was completed for each cohort to determine the variables which had a statistically significant relationship with graduation. The procedure for backwards elimination involved removing the least significant variable from the model each time until only statistically significant variables remained. After the logistic models were run for each major group, the odds ratio for each statistically significant variable was calculated. The software R Studio was used to perform these operations.

For the purpose of inputting variables into the logistic regression, all symbols or letters were transformed into a numerical value. For example, gender was transformed into binary numbers; 0 for male and 1 for female. Louisiana Residency was transformed as well. If a student was from out of state or out of country, it was indicated with a 0, and a 1

TABLE II. VARIABLES

Variable (Abbreviation)	Range/Values
Sex (Sex)	0=Male 1=Female
Race (Race)	0= White 1= Black/African American
Louisiana Residency (State)	0= Non-Resident 1= Resident
High School Rank (HS Rank)	1 – 533
High School GPA (HSGPA)	1.59 – 4.0
ACT component scores	
Science Score (ACT S)	14 – 36
Mathematics Score (ACT M)	13 – 36
English Score (ACT E)	10 – 36
Reading Score (ACT R)	13 – 36

for students within state. High school rank ranged anywhere from 1 to 533 with 1 being top of the class. High school grade point average ranged from 1.59 to 4.0. Race was separated as seen in the table; again, the values rearranged

TABLE I. PRELIMINARY RESULTS (ALL VARIABLES LEFT IN MODEL)

Model	Coefficient	p-Value
Psychology		
Race	1.108	0.120
ACT M	0.034	0.780
ACT E	0.083	0.389
ACT R	-0.095	0.287
ACT S	0.121	0.275
HSGPA	1.798	0.201
HSRank	1.266	0.178
State	-16.005	0.992
Sex	0.529	0.444
Social Sciences		
Race	-1.375	0.091
ACT M	-0.038	0.762
ACT E	-0.191	0.084
ACT R	0.113	0.178
ACT S	0.006	0.957
HSGPA	1.798	0.134
HSRank	0.001	0.890
State	-0.495	0.607
Sex	0.137	0.820
Health		
Race	0.416	0.562
ACT M	-0.106	0.282
ACT E	-0.018	0.812
ACT R	0.003	0.705
ACT S	0.003	0.759
HSGPA	3.060	0.002
HSRank	0.001	0.054
State	-15.340	0.993
Sex	-0.248	0.703
Business		
Race	-0.674	0.198
ACT M	-0.054	0.384
ACT E	0.112	0.078
ACT R	0.005	0.928
ACT S	-0.111	0.152
HSGPA	0.719	0.276
HSRank	0.002	0.505
State	0.943	0.186
Sex	-0.333	0.420
Education		
Race	-0.239	0.891
ACT M	0.149	0.230
ACT E	-0.094	0.326
ACT R	0.108	0.256
ACT S	-0.255	0.043
HSGPA	2.508	0.041
HSRank	0.004	0.593
State	-0.180	0.878
Sex	1.386	0.031
Engineering		
Race	-0.170	0.668
ACT M	0.070	0.121
ACT E	0.095	0.029
ACT R	-0.050	0.195
ACT S	-0.050	0.333
HSGPA	1.320	0.004
HSRank	0.003	0.259
State	0.391	0.932
Sex	0.391	0.296

· p<0.1, *p<0.05, ** p<0.01, *** p<0.001

into binary numbers for each student. The variables obtained and analyzed in this study are presented in Table III with the abbreviations and range.

V. RESULTS

A snapshot of the initial results when each major had all nine variables left in the model (before backwards elimination) is given in the Table IV as a reference to how variables were eliminated and retained.

Backwards elimination was complete when only statistically significant ($p < 0.1$) variables were left in the model. The final results for each discipline are displayed in Table V. Table V displays the coefficient, odds ratio, confidence intervals, and level of significance for each for each variable included in the final models.

The *odds* of an event (such as graduation) occurring are the ratio of the probabilities of the two outcomes. If for example, a typical student has a 75% chance of graduating, there is a 25% of not graduating, then the odds of graduation are $75\%/25\% = 3$ (sometimes written 3/1, 3:1, or 3 to 1). The typical effect size used with logistic regression is a ratio of the odds of an event occurring under certain conditions compared to the odds of the event occurring under a reference set of conditions. This *odds ratio* represents the percent change in the odds of the event for a one unit increase in the variable. So if a variable has an odds ratio of 2, we would say that the odds of a students with that characteristic are twice that of a similar student without it. In our example, that would make the odds $2 \times 3 = 6$, or 6 to 1 odds, and therefore the probability of graduation $6/7 = 85.7\%$. An odds ratio near unity means the variable has a negligible effect on the outcome.

TABLE III. FINAL GRADUATION MODELS

Model	Coeff.	Odds Ratio	Conf. Interval		p-value
			2.5%	97.5%	
Psychology					
HSGPA	0.796	2.217	0.773	6.788	0.146
Soc.Sci.					
HSGPA	1.263	3.535	1.207	11.338	0.026 *
Health					
HSGPA	2.690	1.474	3.308	80.086	<0.001 ***
HSRANK	0.013	1.013	1.0018	1.026	0.049 *
Business					
ACT E	0.079	1.082	1.001	1.175	0.053 .
Education					
HSGPA	1.818	6.160	1.742	25.095	0.007 **
Sex	1.061	2.890	1.086	7.904	0.035 *
Engineering					
ACT M	0.076	1.079	0.994	1.173	0.073 .
ACT E	0.068	1.071	0.999	1.150	0.056 .
ACT S	-0.080	0.923	0.846	1.006	0.071 .
HSGPA	0.941	2.564	1.344	4.990	0.005 **

. $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

We can interpret odds ratio in a similar way for the given models in Table V. For example, if there is a one unit increase in high school GPA for an engineering student, the odds of graduating only increase by a factor of 2.564. However, if there is a one unit increased in high school GPA for a social science student, the odds of graduating increase

by a factor of 3.535 [14]. The larger the gap between 1 and number given for odds ratio, the more impactful the variable is. The odds ratio is an estimate of effect size. Table V also gives the 95% confidence interval. There is a 95% chance that the true odds ratio is within these limits. The formula for confidence interval is

$$\text{Estimate} \pm \text{Confidence Coefficient} * \text{Standard Error}$$

Confidence intervals can also be used to determine if a variable is or is not statistically significant at $p < 0.05$ level [15]. If the two confidence interval numbers include 1, the variable is not significant at that level. For example, the gender variable for education students has a confidence interval that starts at 1.086 and ends at 7.904; therefore, it is statistically significant because 1 is not included in the span. This is verified by the given p-value.

In the case of psychology majors, no variables were concluded to be significant through the logistic regression; the last variable in the model was high school GPA, but it was not statistically significant, even at $p < 0.1$. Every other discipline showed at least one significant variable. For social sciences, health, education, and engineering students, graduation had a positive and significant relationship with high school GPA. For students within business and engineering majors, ACT English scores were also positive and significant. The results for engineering students also showed that ACT Math was a positively significant variable while ACT Science was a negatively significant variable. The analysis for education also revealed that gender, specifically being a female, was a significant variable.

VI. DISCUSSION

To answer the initial research question, “What factors that correlate with graduation are unique to engineering students at Louisiana Tech University?”, the logistic regression analysis showed that engineering students are the only discipline to have a positive, statistically significant correlation to ACT math scores and a negative, statistically significant correlation to ACT science scores. It was expected that ACT math scores would be a strong influence on graduation for engineering students given previous research and the mathematics involved in obtaining such a degree, but it was not expected that ACT science scores would show a negative relationship with graduation. This may be due to the collinearity of ACT Math and ACT Science. When entered into the model as a lone predictor, ACT Science has a non-significant, yet positive effect.

Surprisingly, high school rank was not a significant variable in terms of graduation for engineering students as some previous research has shown. As expected, almost all models displayed high school GPA as a significant indicator of graduation.

Another unexpected result was ACT English score being a significant variable for both business and engineering majors. Neither of these majors require a large number of English classes in order to graduate nor do they require a

specific score on that portion of the ACT to be admitted to the programs.

A lack of relation between race and graduation is another finding that does not concur with the majority of previous research. However, it is possible this is because race and ACT are confounded. The differences in ACT scores between the two races of students, using the entire sample, can be seen in the table below. The average score for White students in the sample is about three points higher than for Black students on each part of the ACT.

TABLE IV. AVERAGE ACT SCORES BY RACE

Race	Comp.	M	E	R	S
Black	21.5	20.2	21.7	22.5	21.0
White	24.6	23.8	24.9	25.3	24.0

Another issue is the small sample sizes. Only two categories of race were included in the study, White and Black; furthermore, only thirteen percent of the students in the study identified as Black.

Psychology students, according to the model, are not significantly affected by demographic or background variables. However, this discipline did have the smallest sample size ($n=74$) and this may have influenced the results.

A factor that could have been significant to any of the majors in the study, but was not used is the socioeconomic status (SES). Multiple studies have found that low-income students or ones from low SES schools are at a disadvantage in terms of graduating from a postsecondary institution [16, 17]. Unfortunately, the authors did not have access to this data and that variable was not included in the study.

These results could be used to help universities identify students that may need more assistance in order to graduate. The findings of this study could also potentially assist high schools in advising students about career choices.

VII. LIMITATIONS

The primary limitation is that the study only used data from a single institution, and therefore the results cannot be broadly generalized. These particular findings may not translate to other schools. The quality of data used in this study also limits the generalizability. For example, high school rank was only given as a number for each student; it was not possible to calculate the percentile rank. Also, neither SES, marital status, nor number of credits a student obtained before coming to the university were a part of the data available. It is possible that including these variables could produce differing results. Moller-Wong and Eide found that engineering students who were married were less likely to graduate [4]. As for diversity, some students had to be left out of the analysis due to small cell sizes.

As previously mentioned, another limitation within the data is the use of ACT scores. Using college readiness standards, ACT reported that at least 50% of Caucasian and Asian students meet the standard for three of the four subjects while African American students typically struggle

meeting the standards [12]. However, the difference between genders is minimal with female students' averages about two-tenths of a point less than males' composite scores [18].

VIII. CONCLUSION

Using logistic regression, separate analyses were done to determine what factors influence graduation among psychology, social sciences, health, business, education, and engineering students respectively. A total of 909 participants were involved in the study with forty percent being female and sixty percent being male. Concurring with previous research and literature, high school GPA held a significant relationship with graduation for social science, health, education, and engineering majors. Sex was a significant variable for education students. For business majors, ACT English scores were slightly significant while engineering students' graduation positively related to both ACT English and math scores. The main limitation of the study is that the data came from a single university; an analysis using data from multiple institutions would be helpful in determining the generalizability of the results. This study could be useful in helping colleges and universities recruit as well as retain students in engineering.

ACT math scores showed significance in predicting graduation for engineering students, but not other majors studied herein. As ACT math scores are commonly used for math placement, further research is needed on the interactions between math ACT score, math placement, and graduate rates.

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APPENDIX: MAJORS WITHIN EACH GROUP

Category	Major
Psychology	Psychology
Social Sciences	Geographic Information Science Political Science Sociology History
Health	Health Informatics and Information Management Medical Technology Nutrition and Dietetics Nursing Pre-Professional Speech-Language Pathology
Business	Business Administration Management-Business Management and Entrepreneurship Sustainable Supply Chain Management Accounting Business Economics Finance Management- Human Resources Management Computer Information Systems Marketing
Education	Elementary Education (1 - 5) Elementary Education and Special Education Mild/Moderate (1 - 5) Middle School Education Math (4 – 8) Middle School Education Science (4 – 8) Agricultural Education (6 – 12) Business Education (6 – 12) English Education (6 – 12) Family/Consumer Science Education (6 – 12) Mathematics Education (6 – 12) Social Studies Education (6 – 12) Biology Education (6 – 12) Chemistry Education (6 – 12) Physics Education (6 – 12) Earth Science Education (6 – 12) Art Education (K – 12) Health and Physical Education (K – 12) Early Childhood Education (PK - 3)
Engineering	Biomedical Engineering Chemical Engineering Civil Engineering Electrical Engineering Mechanical Engineering Industrial Engineering Nanosystems Engineering Cyber Engineering

Undergraduate experiments with aperiodic gratings based on the Fibonacci sequence

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Abstract— We present a simple diffraction experiment with Fibonacci gratings as a motivational strategy for students of physics and engineering to learn the potential applications of aperiodic systems. The Fraunhofer diffraction patterns were obtained with the standard equipment present in most undergraduate physics labs and compared with that obtained with conventional periodic gratings. It is shown that Fibonacci gratings produce a splitting of the diffraction orders which positions are related to the Golden mean involved in the Fibonacci sequence. A very good accuracy is obtained between experimental and numerical results.

Keywords— *Laboratory Experiences, Approaches to Student-Centered Education, Teaching & Learning Experiences in Engineering Education, First and Second Year Program Introduction*

I. INTRODUCTION

Most of basic Physics courses for science or engineering students include the study of interference and diffraction as fundamental properties of all wave phenomena [1]. This phenomenon appears when light interacts with an obstacle or aperture with a size comparable to its wavelength. It plays an important role, for instance, in image forming systems due to the finite sizes of lenses and other optical components. This fact makes the image of a real point object does not be a point but a diffraction spot whose dimensions limit the resolution of the imaging systems. This includes the diffraction effects caused by the pupil in the human eye.

Even the undoubtedly importance that in many real systems the study of the diffraction of light waves has, it is usually perceived by the students as something of purely academic interest that requires of a complicated mathematical treatment and very specific elements for the observation, such as, monochromatic light sources, apertures, slits of very small size or diffraction gratings. However, nothing is more away from reality either in terms of interest or in the difficulty to make experiments. For this reason, some creative works have been published to increase the interest of students. For example, the tracks of a compact disc [2], the spiral element of a spider orb-web [3], the cells of the onion epidermis [4], and the array of pixels in CCD image sensors or LCD screens [5] are used as diffraction gratings.

In our opinion, other non-conventional aperiodic diffractive objects such as fractals are also very motivating because it is a

way to students to basic research activities [6]. Fibonacci gratings are also one of the most common examples of aperiodic structures exhibiting two incommensurate periods (i.e., it is quasiperiodic) [7]. The ratio of these two periods is equal to an irrational number known as the golden mean. This number has been historically associated with the subjective concepts of equilibrium, harmony, or beauty and can be found profusely in nature [8] and technology [9]. In Physics teaching, some interesting examples where the Fibonacci sequence and the golden mean appears include the study of network of resistors [10] or the coupled-oscillator problem [11].

We present here a simple experiment (from a didactic point of view) to verify the discrete Fourier spectra produced by Fibonacci gratings. The experiment has been developed at the *Escuela Técnica Superior de Ingeniería del Diseño* at the *Universitat Politècnica de València* (Spain) as a new laboratory practice for electronics engineering students, but may be easily reproduced with the standard equipment present in most undergraduate Physics laboratories. For comparison, the diffraction patterns produced by regular periodic gratings are also obtained. We show numerically and experimentally that the diffraction peaks generated by Fibonacci gratings are related to the golden mean.

II. BASIC THEORY

A Fibonacci grating is defined as a set of slits distributed aperiodically according to the following recursive procedure. Starting with two elements (seeds), $F_0 = 0$ and $F_1 = 1$, the Fibonacci numbers $\{F_j\}$ are obtained by the iterative rule and $F_j = F_{j-1} + F_{j-2}$ with $j > 1$, so $F_j = \{0, 1, 1, 2, 3, 5, 8, 13, \dots\}$. The golden mean or golden ratio is defined as the limit of the ratio of two consecutive Fibonacci numbers

$$\varphi = \lim_{j \rightarrow \infty} \left(\frac{F_j}{F_{j-1}} \right). \quad (1)$$

Taking into account that the Fibonacci can be expressed as the sum of the two preceding numbers, it is easy to prove that the above limit results in the transcendental equation

$$\varphi^2 - \varphi - 1 = 0. \quad (2)$$

Solving this equation we obtain $\varphi = \frac{1}{2}(1 + \sqrt{5}) \approx 1.618$.

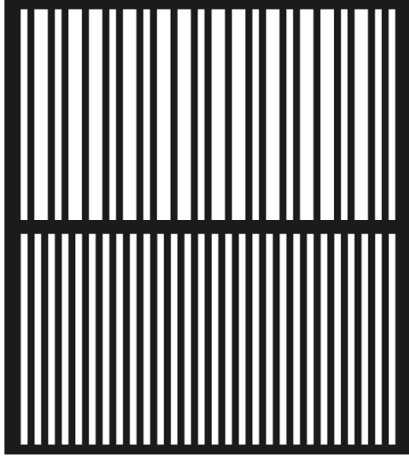


Figure 1. Fibonacci grating (top) at stage of growth $S=9$ with $F_{10}=55$ slits ($F_9=34$ transparent slits) and the equivalent periodic grating (bottom) with the same number of slits.

In a similar way, a binary Fibonacci sequence can also be generated with two seed elements, $t_0 = \{0\}$ and $t_1 = \{1\}$, and the successive elements of the sequence are obtained as the concatenation of the two previous ones $t_j = \{t_{j-1}t_{j-2}\}$ with $j > 1$, so:

$$\begin{aligned} t_2 &= \{10\}, \\ t_3 &= \{101\}, \\ t_4 &= \{10110\}, \\ t_5 &= \{10110101\}, \\ t_6 &= \{1011010110110\}, \dots \end{aligned} \quad (3)$$

Note for example that t_6 presents $F_6 = 8$ type-1 elements and $F_5 = 5$ type-0 elements, being the total number of elements $F_7 = 13 = 8 + 5$. In general, the Fibonacci sequence at an arbitrary generation level S contains F_S type-1 elements and F_{S-1} type-0 elements, so the total number of elements is $F_{S+1} = F_S + F_{S-1}$. Then, the ratio between the number of type-1 and type-0 elements is $F_{S+1}/F_S \approx \varphi$ when $S \rightarrow \infty$.

With this encoding, a Fibonacci grating at a given generation level, S , can be constructed as a sequence of F_{S+1} slits with the same width a , but defining the transmittance $t_{S,j}$ of the j -th slit as the j -th element of the binary array t_S , where $t_{S,j}=1$ for transparent zones (slits) and $t_{S,j}=0$ for opaque zones. Then, a Fibonacci grating presents F_S transparent slits and F_{S-1} opaque zones aperiodically distributed, as shown in figure 1. In mathematical terms, the transmittance function $T_S(x)$ of a Fibonacci grating of order S is given by

$$T_S(x) = \sum_{j=1}^{F_{S+1}} t_{S,j} \text{rect}\left(\frac{x - a(j-1/2)}{a}\right). \quad (4)$$

The Fraunhofer diffraction pattern is generated at the back focal plane of a lens placed against the grating when a monochromatic plane wave is used as illumination. Within the scalar approximation, the focal irradiance is given by the Fourier transform of the transmittance function [12]

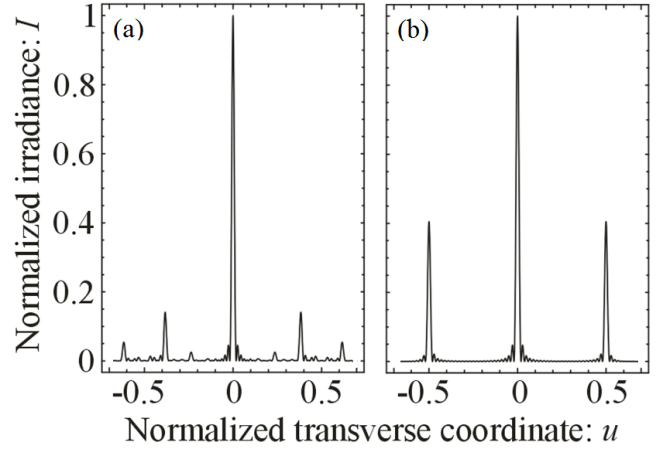


Figure 2. Normalized Fraunhofer irradiance versus the normalized transverse coordinate u for the (a) Fibonacci grating and (b) for the periodic grating shown in Fig. 1.

$$I(x) = \left(\frac{A}{\lambda f}\right)^2 \left| \int_{-\infty}^{\infty} t(x_0) \exp\left(-i \frac{2\pi x x_0}{\lambda f}\right) dx_0 \right|^2, \quad (5)$$

where λ is the wavelength of the light, A is the amplitude of the incident plane wave, and f is the focal length of the lens.

To determine the diffraction properties of Fibonacci gratings, we will obtain analytically the Fraunhofer patterns by replacing in the above equation the transmittance function $t(x)$ by $T_S(x)$ given by equation (3). By using the dimensionless transversal coordinate $u = \frac{ax}{\lambda f}$, equation (5) can be rewritten as

$$I_S(u) = \frac{1}{F_S^2} \left| \sum_{j=1}^{F_{S+1}} t_{S,j} \exp(-i2\pi u j) \right|^2 \text{sinc}^2 u. \quad (6)$$

Note that the above equation has been normalized to have $I_S(0) = 1$.

By using Equation (6) we have computed the Fraunhofer diffraction pattern provided by the Fibonacci represented in Fig. 1 and for comparison purposes the corresponding to a conventional periodic grating. The results are shown in Fig. 2. It can be seen that the main diffraction peaks in both cases coincide. However, the aperiodic distribution of zones according to the Fibonacci sequence produces a symmetrically distributed splitting of the first diffraction order with two irradiance peaks located at $u_I=0.6165$ and $u_{II}=0.3831$. Thus, the ratio of the transverse distances satisfies $u_I/u_{II} \approx \varphi$. Higher diffraction orders with a lower irradiance also appear. However, only the transverse distances associated to the first diffraction order of the Fibonacci grating are related through the generalized golden mean φ .

III. EXPERIMENTAL RESULTS

To experimentally check the above results, the gratings shown in Fig. 1 were built on graphic arts film [13] by using a photoplottter AGFA with 2400 lpi resolution. The basic zone width was $a=50 \mu\text{m}$ in all cases.

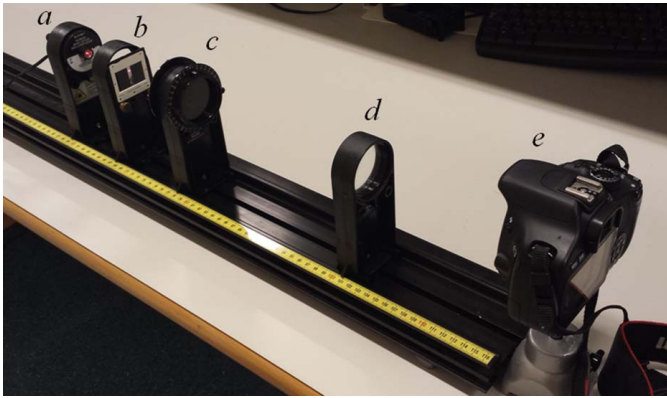


Figure 3. Experimental setup: a) collimated laser diode; b) diffraction grating; c) variable density filter, consisting in a couple of linear polarizers (one rotatable); d) thin lens; and e) camera body (CMOS sensor).

Figure 3 shows the setup used in our experiment. We only considered the standard equipment present in most undergraduate Physics laboratories. From left to right, the first element was a light source (a conventional laser diode with a wavelength $\lambda=650$ nm). The laser source was adjusted to provide a plane illumination onto the object grating. Next, a set of two linear polarizers controlled the irradiance level of the registered pattern by in-plane rotating one respect to the other.

The Fraunhofer diffraction patterns were obtained on the back focal plane of a thin lens (focal length 200 mm) and registered with an digital camera (Canon EOS550D, with a 18 Mpx 22.3×14.9 mm sensor). The registered irradiance patterns are shown in Fig. 4. These results are in full agreement with the theoretical predictions in Fig. 2. From the diffraction pattern generated by the periodic grating, a splitting of the first diffraction order is clearly seen in the Fibonacci case. Moreover, the splitted orders are symmetrically distributed around the original position. Furthermore, from a quantitative point of view, it is easy to check that the ratios between their distances to the zero diffraction order follow the relationship presented above. Actually, these distances can be measured to be $x_I=268$ pixels and $x_{II}=166$ pixels in the Fibonacci pattern, following that $x_I/x_{II}=1.614$, which is in good agreement with the theoretical value for $\phi=1.618$.

IV. CONCLUSIONS AND OUTLOOK

We have presented a simple optical method to analyze the Fraunhofer diffraction properties of one-dimensional gratings based on the Fibonacci set. With this method we have shown that optical processing can be performed using the standard equipment available in most undergraduate physics laboratories. In fact, the diffraction patterns can be easily observed and recorded with this setup and measurements of the mathematical properties of the Fibonacci are also possible from experimental results. It is worth to be mentioned that with this method other one-dimensional aperiodic structures, such as the Thue-Morse gratings, can be studied. In our opinion this result could be a strong motivation for the students to go into the field of optical processing in depth.

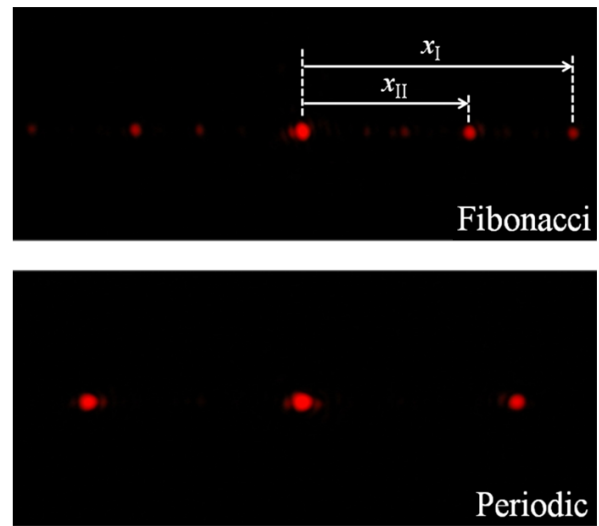


Figure 4. Experimental Fraunhofer diffraction patterns of a Fibonacci grating ($S=9$) and a equivalent periodic grating shown in Fig. 1. The basic zone width was $a=50$ μm in both cases.

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An Interactive learning environment for assisting students in solving problems on designing of logic digital circuits by using Multiple Representations

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Abstract—In this paper, we propose a Web-based interactive learning environment with a knowledge-based assistant for helping undergraduate students in solving problems on designing digital circuits, focusing the relationship between Boolean algebra and Digital Logic. Particularly, we have addressed problem solving situations that essentially consist of mapping a logic expression into another equivalent, for example, the task of simplifying digital circuits. To do that, we have considered to operate on two symbolic linked representations: Boolean Algebra and Logic, connecting these two representations to a visual one with logic gates. This integration comes from the importance to involve students in three equivalent representations, permitting them to make connections between them. The learning environment contains a knowledge-based assistant that works on a collection of scenarios with several associated problems, where the students are placed in a problem-solving situation. To each problem, there are pedagogical resources needed to provide the students with feedback and knowledge support based on their performance and identified needs. Furthermore, there is an adaptive mechanism that is responsible for how problems should be sequenced or ordered, and even we have designed a switcher mechanism, which permits the students to change from one to another representation. We evaluate our approach by using scenarios and conclude that the system is feasible.

Keywords— *interactive learning environment; multiple representations; Digital Logic; Boolean Algebra*

I. INTRODUCTION

The little motivation and dedication observed in undergraduate students when take courses in foundational formal disciplines of the curriculum of computer science and computer engineering, is causing some difficulties to such students to learn the subjects in those disciplines. Particularly, Mathematical logic and logic digital circuit's courses contain many abstracts concepts and, at the same time, they are strongly related and share the same essence, but often they are not seen on this way. The first one is inherently abstract and the second, frequently, is less abstract, but always more directly referring to concrete situations, for instance: a traffic light design. Here, one important question is on how approximate abstract and concrete approaches in order to help the students to have a unified view between these two abstraction levels.

One alternative to alleviate this problem is to provide those students with software tools that allow them to link concepts and results, that occur, in these two disciplines, appreciating that abstract and concrete aspects may be adequately connected. In fact, in a broad sense, some studies have presented arguments in favor of the use of multiple representations of a given domain knowledge, considering its potential to cause positive effects on the learning process [1]. Additionally, they state that during the learning process, switching among different methods may cause more effective learning [2].

Taking into account the above motivations, questions and discussions, in this paper, we propose a Web-based interactive learning environment for assisting undergraduate students in solving problems on designing digital circuits, focusing the relationship between Boolean algebra and Digital Logic. There are many reasoning tasks associated with digital circuits. Particularly, here we have addressed problem-solving situations on how to design some smaller logic circuits, performing operations on them that consist of mapping a logic expression into another equivalent represented in a symbolic language. For example, it is often the situation in which one need to deal with the task of simplifying digital circuits represented as a boolean expression, where you need to reduce the number of logic gates required to implement it. To approach these problem situations, we have considered operating on two symbolic linked representations: Boolean Algebra and Logic, connecting these two representations to a visual one with logic gates dealing with the basic three types: AND and OR gates and NOT gates (inverters). From the two first representations, we have considered Digital logic with their three basic operators: the AND, the OR and the NOT, expressed in their correspondent notations. Therefore, the suggested integration comes from the importance to involve students in three equivalent representations, permitting them to make connections between them.

The proposed learning environment contains a knowledge-based assistant, with the basic modules of a typical Intelligent

Tutoring System (ITS)[3], including modules, such as: a problem solver, a diagnoser and a pedagogical planner, as well as, a learner model representing cognitive information about a given learner. This assistant works on a collection of scenarios with several associated problems, where the students are placed in a problem-solving situation. To each problem, there are pedagogical resources needed to provide the students with feedback and knowledge support based on their performance and identified needs. Furthermore, there is an adaptive mechanism that is responsible for how problems should be sequenced or ordered, and even we have designed a switcher mechanism, which permits the students to change from one to another representation. A functional view of the proposed assistant may be summarized in four steps as follows:

(i) The assistant to selects and to present to the student a problem from a given scenario;

(ii) The student choices in what representation, between algebra or logic, he prefers to start the problem solving process, and

(iii) As the student is going to operate the logic circuit by repeated application of the rules and laws of boolean algebra or classic logic, according to the choice done to operate;

(iv) To each step, the assistant will create a third view on logic gates: one correspondent digital circuit to that current expression, as well as, this is done to the other symbolic representation.

Alternatively, the step (i) may be changed to one where the student selects and poses a problem to be solved by the assistant. In this case, the system will solve the problem according to the selected symbolic approach, showing step by step of the developed solution, as well as, mapping each yielded step in the other two representations.

Through scenarios with adequate problems coverage, we evaluate the value of the proposed approach and conclude that the assistant is feasible and useful.

The remainder of this paper is organized as follows. Section II presents some background knowledge and discusses some related work. Section III describes the proposed learning environment with its main requirements, its overall architecture, and its main functionality, as well as an illustrative scenario with the main interactions provided by the assistant. Section IV presents an evaluation for the proposed approach, offering comments on the initial results. Finally, section V summarizes our research work, offers conclusions and discusses the next steps to be taken.

II. BACKGROUND KNOWLEDGE AND RELATED WORK

In what follows, we present a brief background knowledge with respect to two kind of knowledge employed in our proposal. Firstly, we provide a brief coverage of digital logic with boolean algebra and propositional logic, that are important

to clarify what we have used in our approach. Secondly, we describe some related work.

A. Boolean Algebra and Propositional Logic

We summarize here some important aspects in Boolean Algebra and Propositional Logic, which serve to clarify what has been directly used in our work. To this end, it is important to remember that we can approach digital logic according to different ways of representations, and in our case we have considered Boolean Algebra, Propositional Logic and Logic Gates. There is a one-to-one correspondence between each two of these three representation ways, as well as, there is a one-to-one correspondence between one of these three representations and its physical implementation using electronic circuits. For instance, Boolean functions are implemented in digital computer circuits, that is, gates. A gate is an electronic device that produces a result based on two or more input values.

Boolean algebra is a kind of algebra that manipulates variables that can take on only two values, typically true and false. It has operations that can be performed on these variables, in such a way that when one combine the variables and operators, yields Boolean expressions. As mentioned earlier, three common Boolean operators are AND, OR, and NOT. As in arithmetic expressions, Boolean operations have rules of precedence, where the NOT operator has highest priority, followed by AND and then OR. There are different ways to manipulate these expressions, for example, reducing one to another that is equivalent, including simplification of a given expression that is not in its simplest form. To perform reduction operations on expressions there are a collection of identities or laws to be applied to the expressions, as for instance in boolean expressions.

Most boolean identities have an AND (product) form as well as an OR (sum) form. In what follows we present some identities using two forms. More information about boolean algebra and digital logic can be found in Gregg [4].

Identity Name	AND Form	OR Form
Identity Law	$1x = x$	$0 + x = x$
Null Law	$0x = 0$	$1 + x = 1$
Idempotent Law	$xx = x$	$x + x = x$
Inverse Law	$x\bar{x} = 0$	$x + \bar{x} = 1$

Fig. 1. Rules 1

Identity Name	AND Form	OR Form
Absorption Law	$x(x+y) = x$	$x + xy = x$
DeMorgan's Law	$\overline{(xy)} = \bar{x} + \bar{y}$	$\overline{(x+y)} = \bar{x}\bar{y}$
Double Complement Law	$\overline{(\bar{x})} = x$	

Fig. 2. Rules 2

Identity Name	AND Form	OR Form
Commutative Law	$xy = yx$	$x+y = y+x$
Associative Law	$(xy)z = x(yz)$	$(x+y)+z = x+(y+z)$
Distributive Law	$x+yz = (x+y)(x+z)$	$x(y+z) = xy+xz$

Fig. 3. Rules 3

The same construct is verified in classical logic with its logical expressions, as well as, is verified in logic gates. The mentioned three ways of representing expressions are equivalents, only having different languages. Therefore, the boolean identities presented above have correspondent, one-to-one, in the other two representations: Propositional Logic and Logic Gates.

B. Related Work

Learning environments with support to multiple representations have been the focus of some studies in the literature. Part of them concentrate on examining the potential benefits of supporting multiple representations by analyzing the main influences on learning process. In particular, Steiner, and M. Stoecklin [5] showed that learners acquire a deep understanding only if they are able to link multiple representations of the same concept and to coordinate between them. At the same time, we have seen computer-based learning environments for propositional logic with focus on solving problems by generating proofs have been considered in some works in the literature. One of them was selected to be discussed here, because it is closely related to the present work. On the other hand, we selected one paper that has invested in multiple representations for a given formal domain.

The work proposed by Rau, Aleven and Rummel [6] shows an Intelligent Tutoring Systems that uses multiple graphical representations as support to teaching mathematical fractions. In this sense, the authors propose that students use self-explanation, aiming to improve the students' comprehension about the relation between the different graphical representations and the symbolic representation. The results indicate that that approach is promising and the use of multiple representations coupled together with better understanding of the relation between them can enrich the teaching of fractions. This approach uses multiple representations with support only to visualization and does not offer a proposition where the student can solve a problem based on different ways.

The work proposed by Lukins, Levicki and Burg [7] shows an ITS to teach students basic concepts of propositional logic and theorem-proving techniques. The work can be summarized with the following contributions: i) an ITS to teach the student how to use truth tables, equivalence rules and inference rules to proof the validity of an argument; ii) a learning mechanism to improve the capacity of the tutoring system in proving theorems. One limitation in this work is that it offers just one representation of this domain. Our approach differs from this mainly on dealing with multiple representations on the knowledge domain.

III. PROPOSED LEARNING ENVIRONMENT

In what follows, we describe the modelling of the proposed domain and we present the architecture of the learning environment, where we highlight the Expert, Student and Pedagogical Modules.

A. Domain Module: Curriculum Structure

A curriculum is composed by a set of pedagogical units, which have a sequencing that will be followed by the tutor to guide the student in their studies. Each one of the three representation languages adopted in our work has an associated curriculum structure. That is, one for boolean algebra, one to logic, and another to logic gates.

In Figure 4, there is an abstract curriculum structure that we have adopted in our approach.

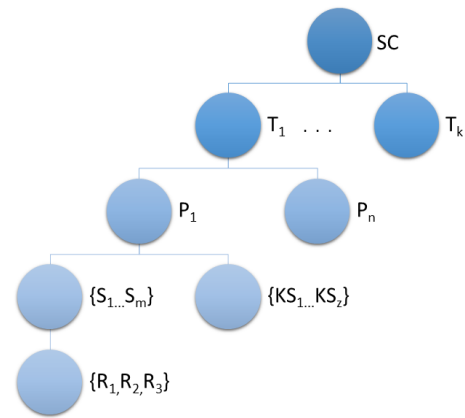


Fig. 4. Curriculum Structure

In this structure, SC stands for Structure of curriculum that is formed by a collection of topics. To each topic is associated to a set of problems, where each problem may be abstractly defined as a triple, as follows:

$P = \langle I, F, Op \rangle$, where I is an initial state of the problem (in this case, an expression), F is the final state or goal (a particular expression), and Op is a set of operators to be applied to the involved expressions.

KS: Knowledge Support, including several resources, for example hints.

Solutions: Set of possible solutions for a particular P .

Representations: Each solution may have more than one representation. The assistant works on three representations: boolean algebra, logic and logic gates.

B. Architecture

The architecture of the proposed system, as in Figure 5, is based on the classic architecture of an intelligent tutoring system involving an expert module, a pedagogical module,

model student and a user interface. The expert module contains the expertise of the system in propositional logic and digital circuit, composed of four sub-modules: Problem solver, Profiler, Solution Reviewer and Diagnoser module. Each sub-module works as a traditional expert system that contains a knowledge base, an inference engine and an explanation module.

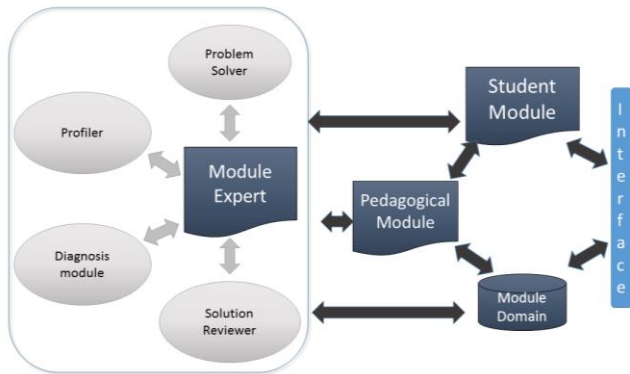


Fig. 5. Architecture of the Learning Environment

Student Model: is an open student model, where for each pedagogical unit there is a concept associated. In the model of the problems submitted by the student are stored one evaluation and one diagnostic for each solution, the support used by the student, for example, tips, didactic materials or others problems representation (for example: to resolve a deduction natural problem, the student could have some doubt about any rule application and request to the system a truth table about the current problem).

Expert Module: The expert module contains the expertise of the system in digital logic, composed of three sub modules (Problem solver, Evaluator (evaluates solutions proposed by students) and Diagnoser (diagnosis mistakes of the students)). Each sub-module works as a traditional expert system that contains a knowledge base, an inference engine and an explanation module. To implement this module, we have used the Inabit shell [8].

Pedagogical model: responsible for the management of the student-tutor interaction, playing different pedagogical roles in that aspect, including task sequencing over the curriculum structure and a knowledge-based assistant that requires services from the Expert Module. This assistant poses problems to students waiting for detailed solutions, and then the system evaluates the provided solution, eventually providing suitable feedback.

IV. SCENARIOS AND EVALUATION

The purpose of this section is to evaluate the proposed approach through some example scenarios for which different examples were performed. Despite being hypothetical, it shows the value of the proposed approach in terms of the adequate behavior demonstrated by the assistant, by connecting one resource to another.

A. Dynamic Interactions

The proposed system is designed to help students learn to solve problems on digital logic involving the manipulation of Boolean or logical expressions, making the links between the representations adopted. Here, the student starts a session, getting a problem to be solved. Each problem is presented as an expression to be turned into a target expression, for example, its simplified form. In this case, the student is required to declare explanations of their steps troubleshooting, showing each step and the corresponding justification. If the student answers incorrectly or tip application, step-by-step guidance is provided for him.

As shown in Figure 2, the system can interact with the student based on a troubleshooting scenario, such that: (1) the system selects and puts problem for the student, considering their current cognitive profile, or (2) alternatively, the student poses problems to be answered by the wizard, showing step by step solution with their justifications. From (1), when the wizard proposes a problem for the student, it can ask for a hint, or present a solution to the problem posed. In this case, the system provides the student with a suggestion or an evaluation.

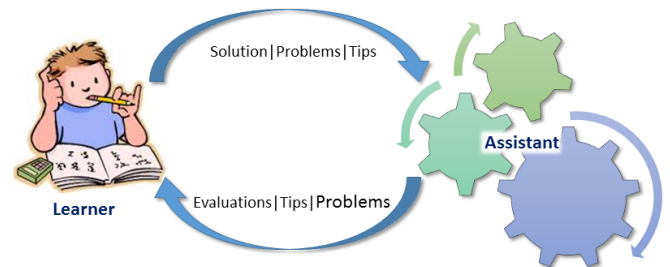


Fig. 6. Learner-assistant Interaction

To summarize, a functional view of the tutor system proposed by interacting with the student, can be summarized in four steps, as follows:

- (I) the system, via sequencer, selects and presents the student with a problem of a given scenario;
- (Ii) The student chooses which representation you want to start to solve the problem from the available options, then the student provides a comprehensive solution, displaying every step;
- (Iii) The student operates the logic circuit by repeated application of the rules or laws of Boolean algebra and propositional logic, according to the choice made to operate
- (Iv) For each step, the system creates a vision of the logic gates language: a corresponding digital circuit for the current expression, the same being done for another symbolic representation, if that is the one. In addition, the system (evaluator) evaluates the step-by-step solution, what if there is an error, the troubleshooter tries to detect errors and their causes in the solution presented by the student, using a incorrect rule base. The evaluator or diagnostician, sends information to be processed by the student modeler, updating the student model. Where appropriate, the system, via

educational module, provides assistance with tips or other educational resource, as the situation of difficulty presented by the student.

Alternatively, step (i) may be changed to a situation in which the student would be responsible for choosing the problem and then request the system (via resolver) that resolves the problem through an approach, showing each step of the solution, and also explain the use of each step, but mapping each step in the other forms of representation.

As can be seen, the Figure 3 system screens comprises:

- 1- System Options: Problem solver, Evaluator (Evaluator) and Rule (Rules);
- 2 Problem descriptions: Problems are described in natural language or directly in a symbolic language;
- 3 Desktop: Where the student can observe each step of solving a problem. In this part of the system are shown to simplify the form of the expression or logical path algebra, each step of simplification with the corresponding rule and system feedback;
- 4- Issue expression: area reserved for the choice of the rule, editing sending the partial solution;
- 5 A. area made up of the complete solution submit button or the button "did not understand" where the student can tell the system that did not understand the problem;
- 6 Help: In this area, the student can seek help system asking for a tip or watching a video.

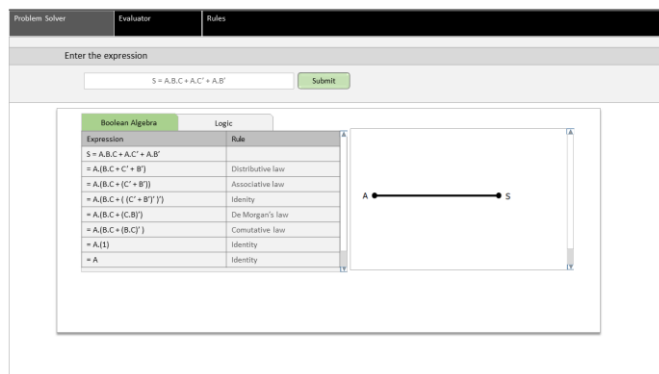


Fig. 7. Screen – Solving a Problem

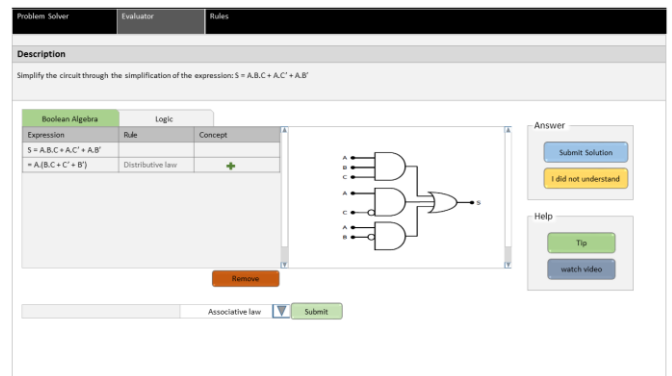


Fig. 8. Screen – Solving a Problem

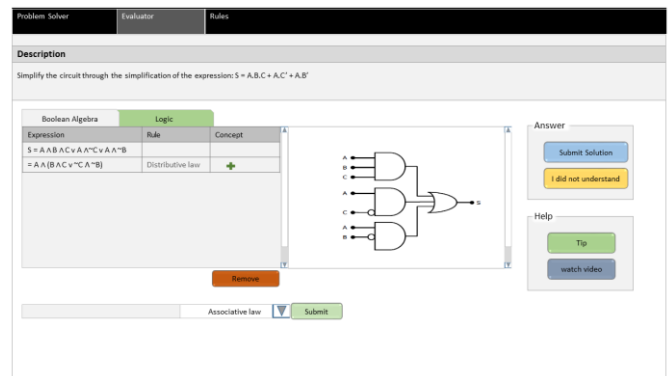


Fig. 9. Screen 1 –Evaluating a Solution

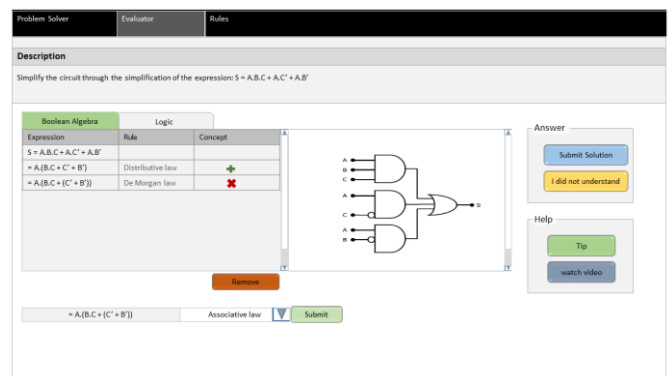


Fig. 10. Screen 2 –Evaluating a Solution

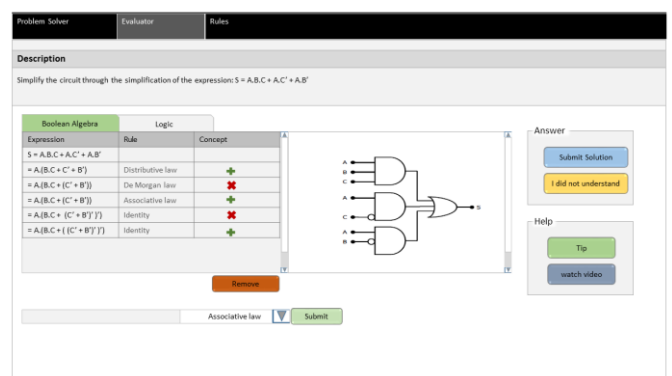


Fig. 11. Screen 3 –Evaluating a Solution

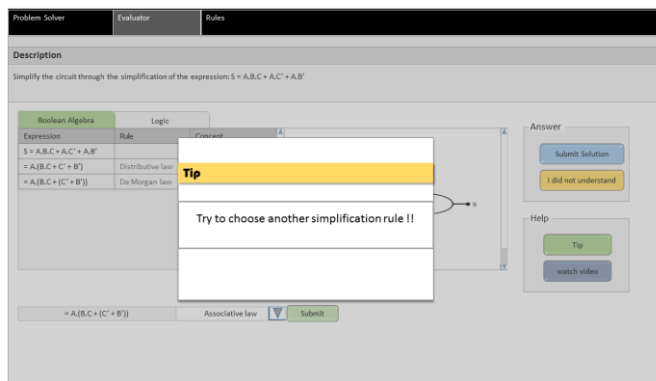


Fig. 12. Screen – Tip

V. CONCLUSIONS AND FUTURE WORK

In this paper we presented the proposal and implementation of an interactive learning environment with a knowledge-based assistant designed for helping students to learn digital logic using multiple representations, taking into account a problem-based learning approach, especially focusing on logic expressions problem solving. The preliminary results using this assistant are positive, mainly with regard to its feasibility. Another conclusion is that our work is, to the best of our knowledge, the first in the literature to present a large in scope and concrete solution for problem solving with multiple representation in Boolean algebra and classical logic. Therefore, this work set out to answer the following question:

”How to provide multiple representations for digital logic domain”, having an assistant to accomplish this domain knowledge. For immediate future work, we will invest in interface aspects as well as performing more experiments, this time, as part of a regular digital logic course.

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Adaptive Vision Studio – Educational Tool for Image Processing Learning

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Abstract—In this paper, we present Adaptive Vision Studio (AVS)—a novel tool for creating image processing and analysis algorithms. AVS has been applied in post-graduate computer vision course for students of Automatic Control and Biotechnology at Silesian University of Technology. This software is a powerful environment with ready-for-use image analysis filters for computer vision experts as well as for engineers, who are beginners in this field. AVS has been published as a freeware version for non-commercial and educational purposes recommended for students and engineers, who want to learn how to develop complex image processing algorithms. Lite version of AVS is freely available at <https://adaptive-vision.com>.

I. INTRODUCTION

The use of cameras and automated image processing methods is widespread in industry and applications, in which we would like to enable computers to understand and interpret visual information from static images and video sequences [1]. The applications are of a wide range and significance, including robot vision, face recognition, image denoising, medical imaging, object recognition and many others. However, a large variability in data (varying lighting condition, pose, orientation, scale, color calibration) causes that it is not possible to prepare an universal algorithm for various engineering applications. Therefore, all vision problems have to be solved individually. To limit the time that is needed to prepare a full vision system, an advanced flow-based software called Adaptive Vision Studio (AVS) has been developed. This software has been created by Future Processing company in cooperation with the scientists from Silesian University of Technology.

This software uses visual programming language and is designed for rapid prototyping and building advanced vision systems. AVS software is the most powerful graphical environment for machine vision engineers. It is based on dataflow and comes with a comprehensive set of powerful, ready-for-use image analysis filters. It is also successfully used in post-graduate courses in Automatic Control and Biotechnology at Silesian University of Technology.

Understanding vision algorithms requires using a variety of images and test the effect of applying various parameters. Transfer of personal experience to students during laboratory classes with only a few test images is a challenge. It could be even more difficult to explain how video processing algorithms

work. In an ideal situation, students should be able to understand the described algorithms and their parameters influence on the final result. Due to time constraints during laboratory classes, students are able to implement only some vision algorithms. It seems therefore reasonable to use interactive tools to help them understand the nature of other machine vision algorithms, often too complex to implement in the classroom laboratory.

According to the literature, there are several environments applied in image processing courses. The review and comparison of several tools for learning computer vision can be found in [1], [2]. In this group there are several commercial software packages. The most popular commercial tool seems to be Matlab with Image Processing Toolbox, which is widely used in the scientific community for fast prototyping and in educational process [3], [4]. Image processing courses have also been conducted with other commercial software such as Mathematica [5], LabView [6]. There are also many non-commercial solutions based on C [3], [7], [8], Java language [4] or Python [9].

In this paper, we present a novel tool useful for image processing learning that allows resolving a real life computer vision problems without specific programming skills and experience in image processing. We present also the exercises prepared for students of Automatic Control (focused on aspects of quality control in manufacturing) and Biotechnology (focused on aspects of medical image processing). The presented exercises can be used at other universities in image processing course.

The exercises are based on improving the quality of the analyzed image, image segmentation and features finding of the objects such as: location, size, shape, average color or intensity etc. Based on these features, we performed counting identified objects, classification of objects etc. AVS allows to work on images acquired before starting the program and on images acquired in real-time for example from GigE vision cameras. Lite version of AVS is available free of charge at <https://adaptive-vision.com/>. The next Section provides a brief description of AVS and concept of programming in this environment. In Section 3 we present exemplary real-world problems and finally we conclude the paper in Section 4.

II. INTRODUCTION TO ADAPTIVE VISION STUDIO

AVS is a dataflow-based software designed for machine vision engineers. AVS does not require the user to have any experience in low-level programming. Nevertheless, it is a highly specialized tool for professional engineers and a fully-fledged visual programming language. It could be an ideal tool supporting education of future engineers. AVS facilitates the understanding of the basic computer vision algorithms, and allows them to quickly create complex projects.

Adaptive Vision visual programming is based on its 4 core concepts: Data, Filters, Connections and Macrofilters.

Data—AVS supports different data types starting from simple ones like integers, reals, by image-related types (Image, pixel etc.) to geometric ones. AVS also supports arrays, i.e. variable-sized collection of data items that can be processed together. For each data type, there is a corresponding array type. For example, just as 4 is a value of the Integer type, the collection 1, 5, 4 is a value of the IntegerArray type. Nested arrays are also possible. Filters—the basic data processing elements in the data flow driven programming. Figure 1 depicts a typical Adaptive Vision filter which usually has several inputs and one or more outputs. Each of the ports has a specific type (e.g. Image, Point2D etc.) and only connections between ports with compatible types can be created. Values of unconnected inputs can be set in the Properties window, which also provides graphical editors for convenient defining of geometrical data. When a filter is invoked its output data can be displayed and analyzed in the Data Preview panels (see Figure 2). It should be also pointed that some data types can be automatically converted at filter inputs (e.g., real and integer numbers to strings).

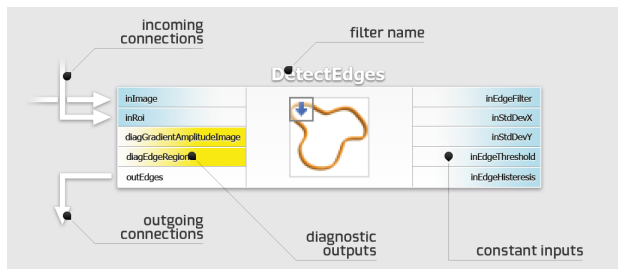






Fig. 1. Example of AVS Filter

Connections - transmit data between filters, but they also play an important role in encapsulating much of the complexity typical for low-level programming constructs like loops and conditions. Below are the types of supported connections and their symbols:

-  basic flow of data,
-  automatic data type conversions,
-  for-each processing—successive array elements are processed,
-  conditional processing.

Macrofilters—reusable subprograms with their own inputs and outputs. Once a macrofilter is created it appears in the

Project Explorer window and since then can be used in exactly the same drag-and-drop way as any regular filter. Most macro-filters (we call them Steps) are just substitutions of several filters that help to keep the program clean and organized. Some other, however, can create nested data processing loops (Tasks) or direct the program execution into one of several clearly defined conditional paths (Variant Steps).

AVS environment enables not only the graphic design of complex machine vision algorithms, but it is also a powerful tool for testing of developed solutions—all intermediate results can be viewed and analyzed, and parameters can be adjusted in real time as presented in Fig. 2.

Final solutions created in AVS can be exported to C++. The generated code uses Adaptive Vision Library and compiles to a native EXE file. Another option to use created program outside the studio application is export to run-time executable file which can be used with the special run-time module.

Although image analysis algorithms are usually the most crucial, a Human-Machine Interface (HMI, end-user's graphical interface) is most often also a very important part of a machine vision application, especially in the industrial setting. AVS comes with an integrated graphical designer, which allows for creating nice looking user interfaces in a quick and easy way. Its capabilities encompass composing highly customized "front panels", where the end-user will be able to set selected parameters and see or verify the inspection results.

AVS comes with a comprehensive set of powerful, ready-for-use image analysis filters. The library of image analysis filters that come with Adaptive Vision Studio can be described as composed of two sets:

- a set of well-known general image processing and computer vision algorithms,
- a set of ready-for-use tools specialized for industrial inspection systems.

There is a special type of filter in AVS commonly used in our examples, namely the **Formula** filter. A formula block makes it possible to write down operations on basic arithmetic and logic types in a concise textual form. Its main advantage is the ability to simplify programs, in which calculations may require use of a big number of separate filters with simple mathematical functions. Formula notations consist of a sequence of operators, arguments and functions and are founded on basic rules of mathematical algebra. Their objective in Adaptive Vision Studio is similar to formulas in spreadsheet programs or expressions in popular scripting languages. Below are two examples of the formulas used in the 'Vehicle Speed' application:

```
outToDraw = ( inSpeed > inMinSpeed )
             and ( inSpeed < inMaxSpeed )
             and ( inVehicleCenter.X > inMinX )
             and ( inVehicleCenter.X < inMaxX )
outSpeed =
    inDistance * ( 1 / inReversePixelSize )
    * inFPS / ( inFrames - 1 ) * 3.6
```

AVS includes a variety of powerful filters, but it is possible to integrate your own C++ code using so-called user filters if

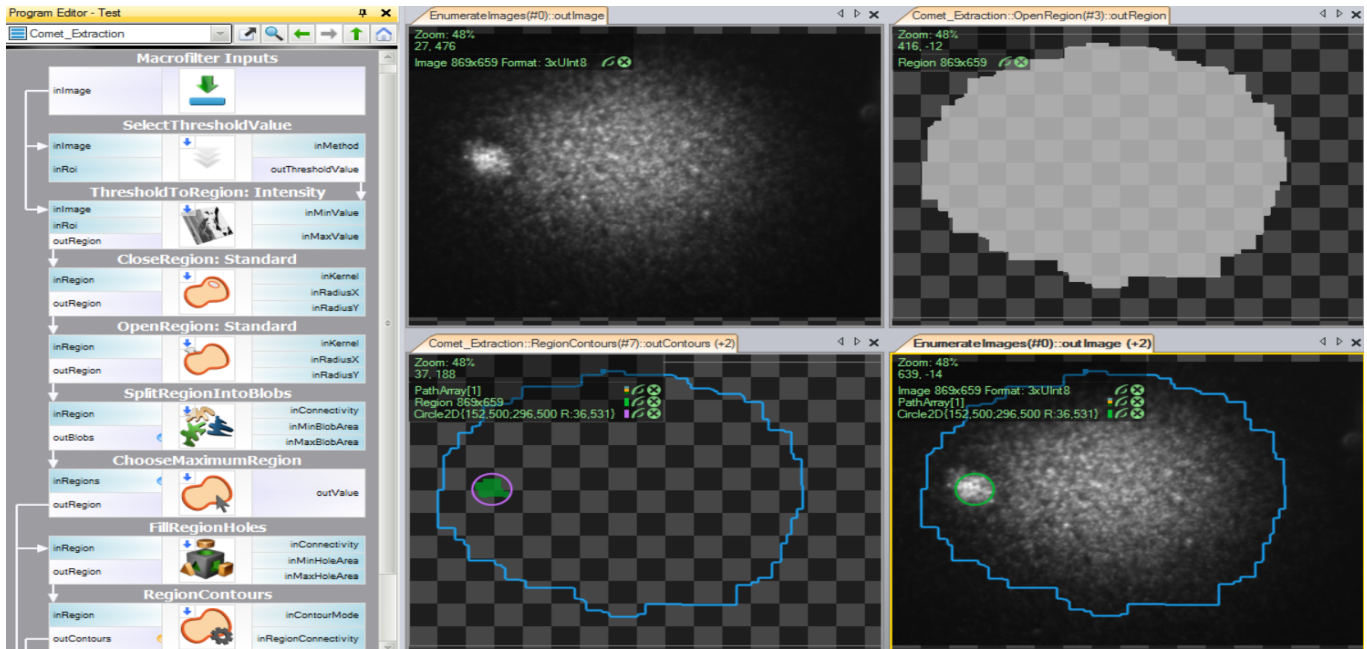


Fig. 2. A part of automatic comet extraction algorithm developed in AVS.

necessary.

III. PRACTICAL EXAMPLES OF LABORATORIES REALIZED IN ADAPTIVE VISION STUDIO

At our university, we realize some image processing courses for students in Automatic Control and Biotechnology with specialization in Bioinformatics. The introduction to image processing during an undergraduate course is realized in Matlab, but on master study, we propose the students to solve the real-life problems in their preferred image processing environment. For last five years, we have proposed the students to realize this laboratories in the AVS environment.

Below, we present three problems and our exemplary solution in AVS that are solved by students during the computer vision laboratories at master level curriculum.

A. Biomedical image analysis

The comet assay is a useful method for assessing DNA damages caused by different genotoxic agents described in [10]. The main aim in this problem is to properly localize the comet and segment its head, and measure some characteristics. The damage is quantified by measuring the amount of the genetic material, which migrates from the nucleus to form the comet tail. One of the most widely used comet's parameter is the percentage of DNA in the tail. It is calculated as the ratio between the total intensity of the tail and the total intensity of the comet (head and tail together). The foremost advantage of the comet assay is that it analyses individual cells, thus allowing the measurement of the heterogeneity of response within a cell population. The images used in this exercise were observed using a fluorescence microscope and gathered from Molecular Biology Laboratory at Silesian University of Technology.

Recently, several automatic methods of comets extraction have been proposed [11]–[14]. However, biomedical images are quite interesting for analysis due to their complexity and the students will become aware of difficulties connected with medical image analysis. To simplify the analysis, the images prepared for the laboratory exercise contain only single comet.

In this approach, we presented a two step solution, in which the comet regions are detected based on the simple thresholding methods. In the first step the comet is segmented using Otsu method and post processed using morphological operations. Then, the regions in obtained binary image are labeled and the biggest blob is chosen for later analysis. Finally, the possible holes are filled and the contour of the comet extracted. In the second step, the head is extracted in similar manner, but instead of Otsu method entropy based thresholding was applied only for pixels that belong to the previously selected comet ROI. A part of automatic comet assay analysis with temporary results in AVS was presented in Fig. 2. Exemplary results of properly detected comets and their head are depicted in Fig. 3.

B. Object detection and recognition

Object detection and recognition is one of the main tasks in computer vision systems. The objects may vary with regards to many features such as color, size, shape, texture, orientation, number of holes etc. [15]–[17]. The main goal of this exercise is: in static color images find standard six-sided red dice and recognize the number of white dots on a visible side using AVS software.

The images containing dice were acquired by a mobile phone camera in the resolution 2016x3584 pixels. Figure 4 shows two examples of these images and below enlarged

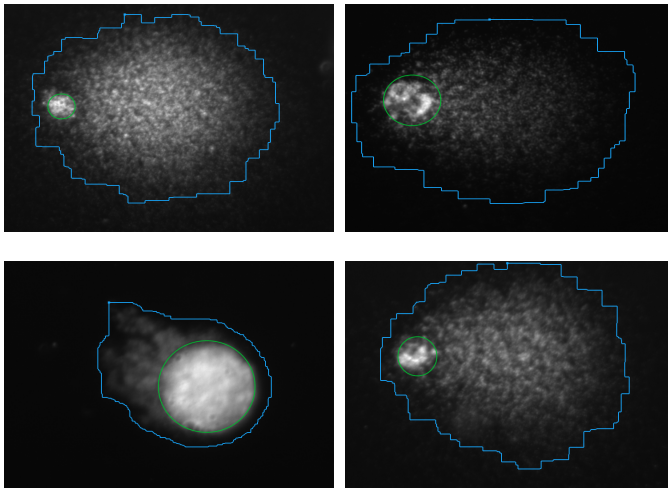


Fig. 3. Results of comet tail and head extraction.

details showing the dice. The background is simple gray, but the scene contains many objects that are not a dice, which makes the task more difficult. Some objects have similar color, area and shape. Also, the objects cast shadows and cause reflections which additionally complicates the task.



Fig. 4. Two samples of acquired images and dice in detail view.

The most characteristic features of the dice are color, shape and area. The dots located on a dice also can be characterized by color, shape and area. Students who solved the task proposed many different solutions. One of the best is based on several stages of image processing and based on knowledge about the seeking object. First, the area which may be a dice is found, and then in this area the dots are sought. The main application built in AVS is divided into four parts as shown in Fig. 5:

- **EnumerateImages**—scans a disk directory for image files and then returns the images one by one in consecutive iterations,
- **Dice_Segmentation** (macrofilter)—applies a threshold to the input image in *HSV* color space, performs morphological postprocessing, region labeling and classifies them by area,
- **Dots_Segmentation** (macrofilter)—operates in the region of interest (ROI) obtained from **Dice_Segmentation**, applies a threshold to extract almost white objects that can be the dots, performs morphological postprocessing, region labeling, classifies the regions by area and circularity features,
- **Results_Drawing** (macrofilter)—computes the number of dots, displays a string on the top of images presenting the number of calculated dots and draws a cross in the dice center.

The parameters and detailed view of each operation of used main macrofilters are shown in Fig. 6-7. For example, the dice region thresholding in *HSV* may be performed for $H = (200, 255)$, $S \geq 140$, $V \geq 40$ as shown in Fig 6, the dots regions must have circularity [18] higher than 0.42 and area belongs to the interval (34, 150) in pixels as shown in Fig. 7.

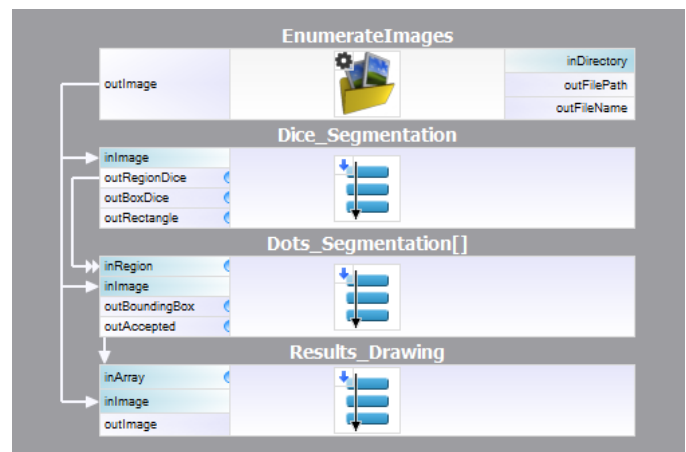


Fig. 5. Dice and dots detection main application.

The results for the four test images are shown in Fig. 8-9. In any case, the number of dots (5, 3, 6, 4) was correctly identified, also for different orientation of a dice in relation to the surface (Fig. 9—5 dots). The proposed solution is not sensitive to shadows and light reflection. Sometimes, the

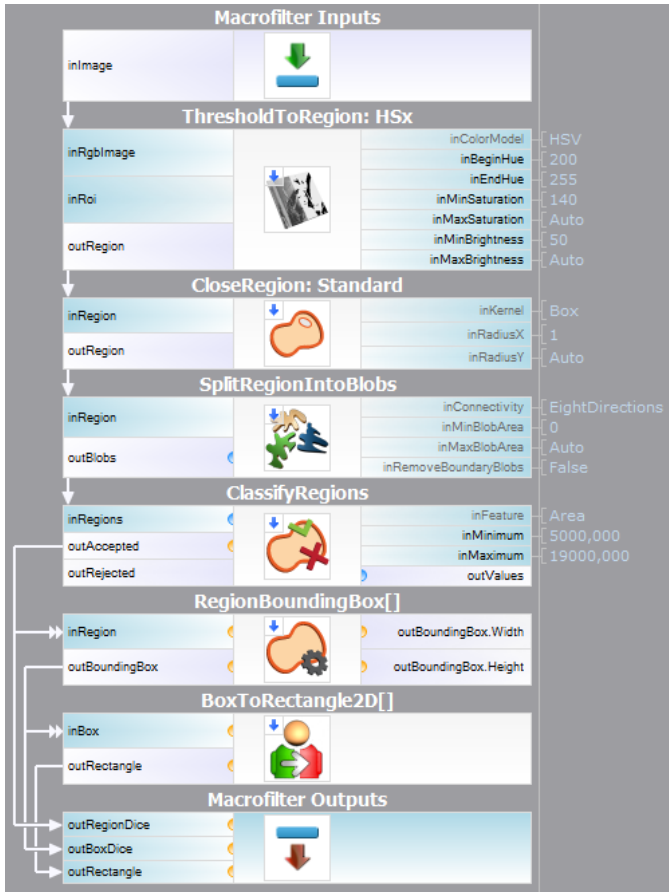


Fig. 6. **Dice_Segmentation** macrofilter—detail view with parameters.

initially segmented area of the dice is too large (Fig. 9—4 dots), but the second Dots_Segmentation macrofilter locates the dots in the right place and the center of the dice is correctly set. The test images in this task are quite difficult. In practice, in computer vision systems, the background is usually much simpler and lighting is better.

C. Video sequences processing

In practical applications, instead of performing operations on individual images, more often it is necessary to process video sequences, taking into account the relationship between successive frames. For this reason, modern automatic control engineer should have basic knowledge and skills for such operations.

During the computer vision courses conducted at our university, the students solve the problem of measuring the speeds of vehicles based on the sequence of surveillance cameras using the AVS environment.

The main issue to be solved in this task is the correct segmentation of moving objects. In this work, a hybrid version of background subtraction and thresholding of temporal frame differences was used. In this solution, the attempt was made to make the system insensitive to scene selection and environmental changes, so the running average background adaptation

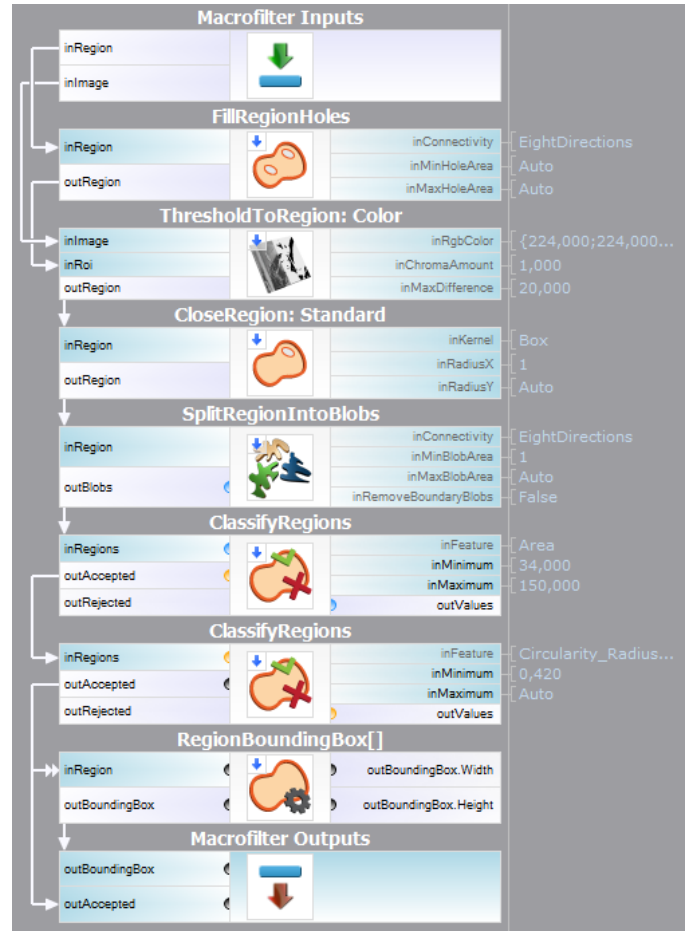


Fig. 7. **Dots_Segmentation** macrofilter—detail view with parameters.

model was used [19]:

$$B_{i+1} = \begin{cases} \alpha F_i(x, y) + (1 - \alpha) B_i(x, y) & \text{if } F_i(x, y) \in \text{Background} \\ B_i(x, y) & \text{if } F_i(x, y) \in \text{Foreground} \end{cases} \quad (1)$$

where F_i and B_i denote the current video frame and the background image, respectively, α is the learning factor, typically $0.05 \dots 0.1$.

The analyzed problem can be divided into several tasks that are reflected in the logical structure of the program which is shown in Figure 10.

- **Read_Video**—reads a frame sequence from a video file and generates main program loop (could be replaced with camera acquisition block).
- **Preprocessing** (macrofilter)—performs filtering and color to gray-scale conversion.
- **Background_adaptation** (macrofilter)—one of the two main tasks for this application, performs background detection and adaptations based on equation 1, detailed macrofilter diagram with parameter used is presented in Figure 1. It should be noted that *Background* variable is passed between consecutive iterations by special AVS structure called *register*.

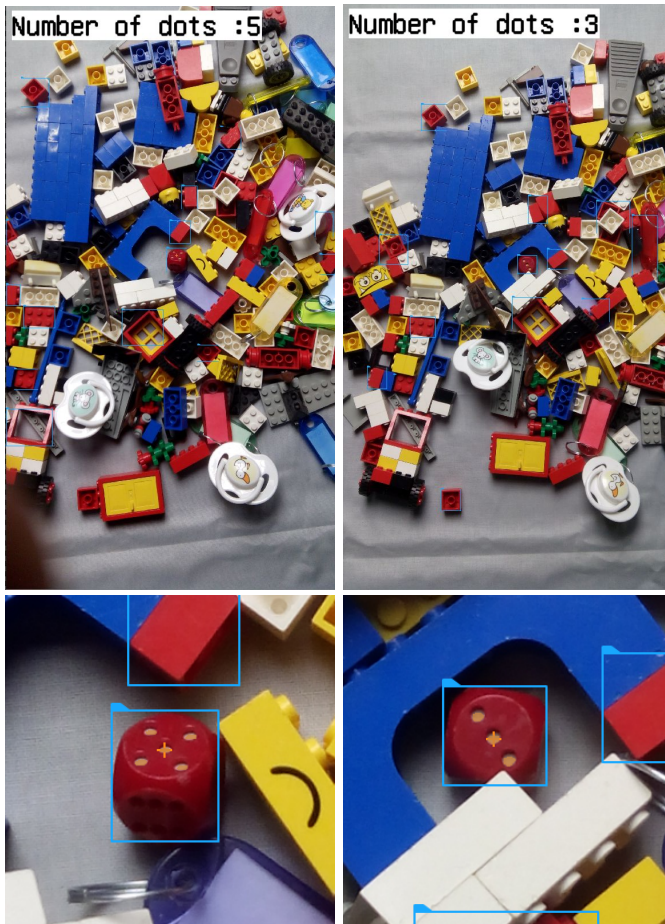


Fig. 8. Results of dice detection and number of dots calculation.

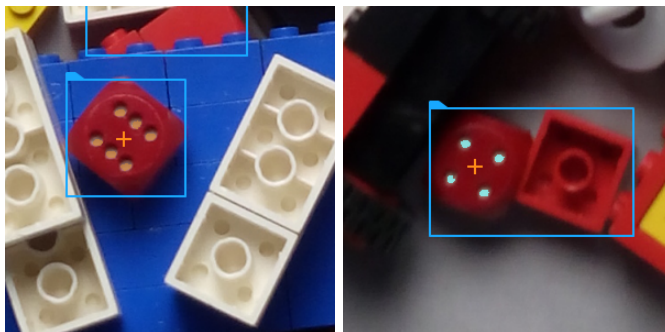


Fig. 9. Results of dice detection and number of dots calculation.

- **Vehicle_detection** (macrofilter)—segmentation of moving vehicles based on background subtraction combined with thresholding of temporal differences and region morphological processing (Fig. 12).
- **Speed_calculation** (macrofilter)—computes vehicles speeds based on their displacement between consecutive frames, scaled based on real length of observed area (Fig. 13). This macrofilter uses a typical filter for video processing **LastObjects** which aggregates objects between consecutive program iterations. The main

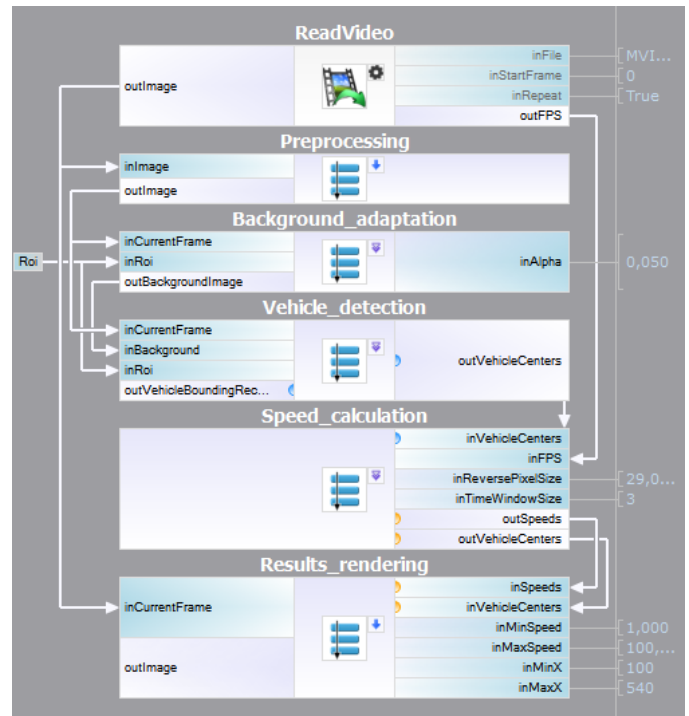


Fig. 10. Vehicle Speed—main application.

problem encountered in this task was to match the corresponding points in successive frames belonging to the same vehicle. The proposed solution is based on the special data structure of paths, available in AVS environment which allows grouping adjacent paths and direct path length calculation.

- **Results_rendering** (macrofilter)—renders speeds of tracked vehicles on the input frames with some restrictions (only valid speed values near the frame center are displayed).

In order to improve the efficiency and robustness of the proposed solution, image analysis is limited to the preselected region of interest (ROI). Adaptive studio supports any-shape ROIs in majority of image processing filters, so we can fit ROI to cover only the road area. The ROI mask used in our solution is shown in Figure 14(a). Examples of velocity measurements are shown in Figure 14(c) and the visualization of detected vehicles in Figure 14(b). Detected objects are visualized using the built-in AVS features, which allow presenting graphical objects such as blobs, rectangles, paths, etc. in the form of overlays in the output image. Verification of the accuracy of speed measurement is not fully possible, however, on the basis of comparative tests, we can assume that the results are reliable. Tests carried out on several video sequences show that apart from a few exceptions, the detection of moving vehicles is running flawlessly. In addition, it is possible to fine-tune the parameters of the algorithm so that the results were even better.

However, the presented solution is still not complete, e.g., there is no analysis of occlusions and due to the small area

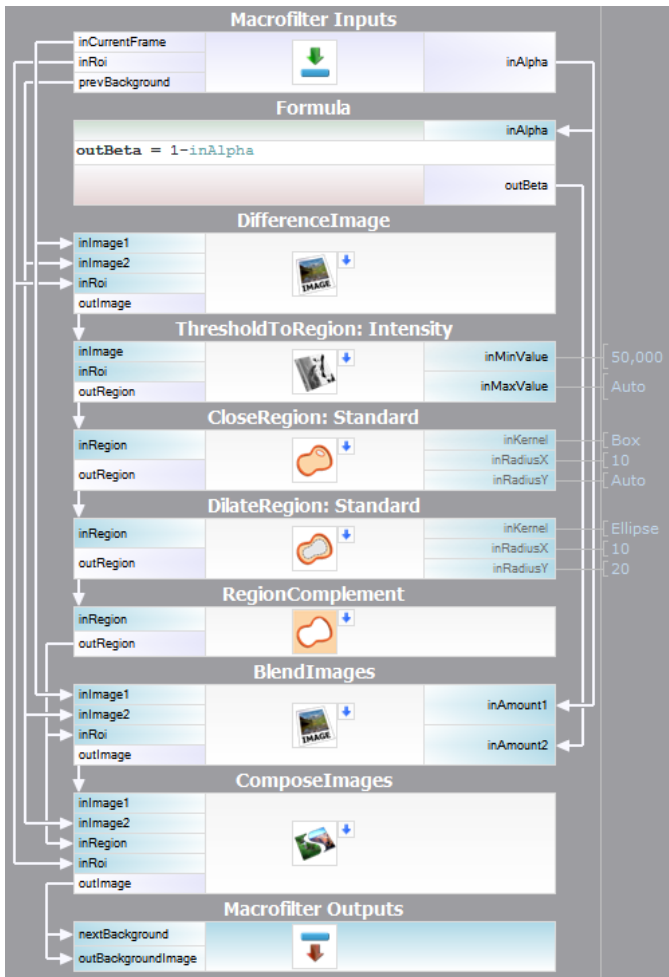


Fig. 11. **Background_adaptation** macrofilter.

covered by the camera, it is not possible to measure the speed of large trucks.

IV. CONCLUSIONS

Most students enjoy the visual nature of the project and were surprised that they could write a program to accomplish so much after just one programming course. A few students wrote very creative programs within the time limit of a single laboratory (1.5 hours) without any previous knowledge of AVS.

The effectiveness of using this software in teaching image processing was evaluated in several steps. First, a student at introduction laboratory has to work in a new environment, but on later laboratory exercises the students have the possibility to use other programming software that they have used in the previous courses, such as Matlab or OpenCV in C++. All students choose the AVS as they environment to work. We also ask about their experience in using this software and they outline its simplicity and easiness in viewing the temporary results of image processing steps in their application. The students were also confident that the exercises have more practical form and will be more useful for them in their future

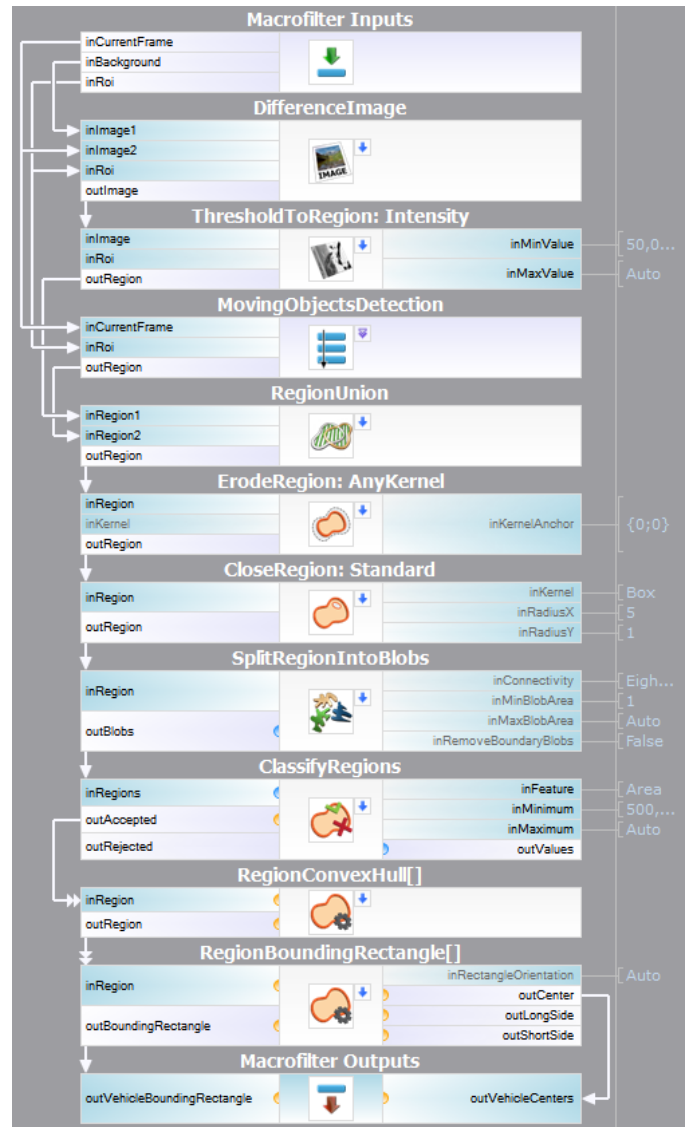


Fig. 12. **Vehicle_detection** macrofilter.

work. These facts prove that the proposed AVS studio can be effectively used in image processing learning process.

Another advantage observed by the teachers was the fact that students were able to realize more exercises during the laboratory time. When these exercises were realized in Matlab environment, the students very often have to finish their work at home and present their work in the form of a laboratory report. It sometimes causes some plagiarism in their work, but now their work is evaluated during the laboratory and this issue is not observed any more. The students were also more engaged in their work and the solutions of the proposed problems are more creative than those created in Matlab.

The main assumption is that the students have a basic knowledge about digital image processing and are familiar with the idea of algorithms and their possible applications. However, in our opinion it can be an ideal software for demonstrating the practical aspects of computer vision algo-

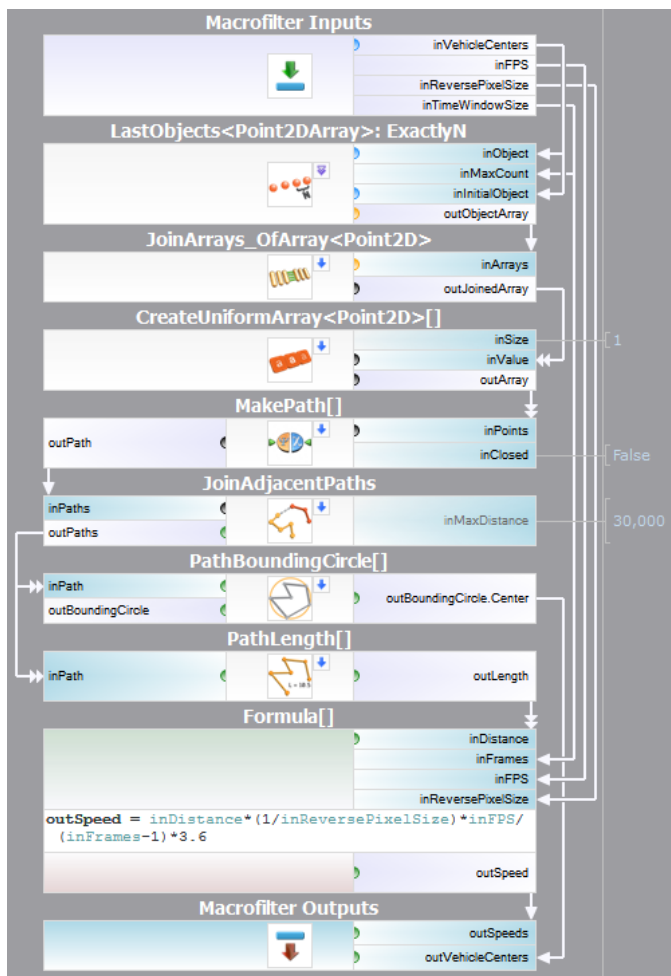


Fig. 13. Speed_calculation macrofilter.

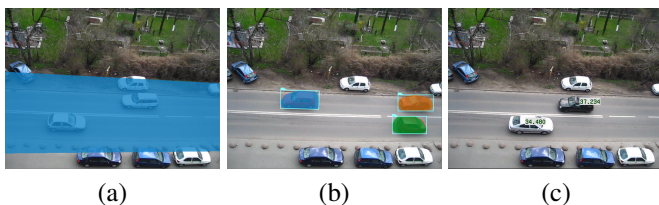


Fig. 14. Results of car detection and analysis: (a) selected ROI, (b) detected cars and (c) estimated speed values.

ritms even for students not familiarized with programming, such as those who study biotechnology, chemistry or biology. Using AVS, the students also can quickly and thoroughly understand the operation of advanced algorithms without the need of implementing them. The students focus on proposing a ready solution to the problem, which increases their creativity. Last, but not least, the AVS software is a powerful complete environment which can also be successfully used for learning machine vision engineers.

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Analysis of Opportunities and Challenges of the Electronic Dual-board in Instruction

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Abstract - Recently, a brand new instructional system named the electronic dual-board (EDB) was created and put into practice in China. To find out the opportunities and challenges of the system in the instruction, the research was conducted in a primary school and a university from March to June in 2013. The results indicated that most of the participants' attitude towards the EDB was positive. Especially, the primary school students preferred to attend the class with the EDB. However, there were some technical problems in the EDB. Moreover, using the EDB, the teacher should face up to some challenges, such as how to create the new resource, how to adjust the teaching plan and how to carry out teaching design. In order to make full use of the EDB, the suggestion of using the system was collected from both the students and teachers in the end.

Index Terms –evaluation of CAL systems; interactive learning environments; country-specific developments; elementary education; adult learning

INTRODUCTION

During the rapid progress in the application of information technology in education, new instructional systems were introduced into the classroom constantly to improve the effect of instruction. Recently, a brand new instructional system which was based on dual coding theory was invented. The system was called the Electronic Dual-Board (EDB) which consisted of a control center, two electronic whiteboards and a suite of software for editing and presentation. Its main functions included presentation, writing, drawing graph, highlighting, annotating, drag-and-drop activities, screen shade, zooming and the introduction of digital resources made the teaching colorful. It looked like the interactive whiteboard (IWB), but it was different from the IWB in many aspects. For instance, with two whiteboards the area of presentation was enlarged, which could support presentation of different contents at the same time. The content of text and video corresponding to the same topic, or the current page and the former page in PowerPoint (PPT) could be rendered simultaneously. Moreover, the specific software and hardware of the EDB were developed to enhance the functions of edit, presentation and interaction.

Since April in 2011, the EDB has been put into practice in a primary school named No.1 Chang-Qing primary school. This system was also introduced into other primary schools and high schools such as the affiliated middle school of Central China Normal University and Tibet high school. Besides, the system was practiced in some universities in

China, including the Central China Normal University, Hubei Normal University etc. Because the EDB was a brand new instructional system, the teachers and students might have encountered many opportunities and challenges when they used the system. But to our best knowledge, the most research focused on the using pattern of the EDB. However, the challenges and opportunities of using the system had been an open issue left.

Facing the music, the research was proposed to analyze the opportunities and challenges of the EDB by employing the interview method. Throughout half a year more than twenty-four students and ten teachers were monitored and investigated in a primary school and a university. Actually there were really many challenges and opportunities that the teachers and students faced when they used the EDB in their classes.

The rest of the paper is organized as follows: the related works on the EDB and The IWB are presented in section 2. The scheme of the research is rendered in section 3. The findings and discussions are described in section 4 in details. Section 5 concludes with a summary and future research plans.

RELATED WORKS

Basically, the literature related to the EDB could be divided into two categories. One was to discuss the design and realization of the EDB from the perspective of technology. The other was to find the effective pattern of teaching and learning from perspectives of teachers and students.

With the development of two-track teaching mode, the dual-split screen device started to apply in classrooms because it can support various display modes easily. Yang (2012) launched the dual-split screen device design research. It was proposed that the overall design of the framework as well as specific implementations from the actual application needs.

Wang (2011) discussed how to conduct “Dominant-the Main” in the EDB environment. With combining theoretical and empirical research, “Dominant-the Main” teaching mode was integrated into the EDB environment. Zhang (2012) focused on how to design, implement and analyze Clicker, an interactive tool of the EDB, assessment project. Based on case studies of electronic boards and Clicker, the paper pointed out an overall strategy about designing Clicker classroom assessment in the EDB environment.

The research of the subject-related teaching and learning with the EDB had been conducted by other scholars. For instance, Wu (2012) presented functions and characteristics of the EDB. Then a Chinese lesson was designed by utilizing this platform and discussed the applications of the EDB in the Chinese subject. Similarly, Du and Lu (2012) investigated the EDB application in the subject of history

and put forward to three pieces of advice about using this platform. That was to define the teachers' position, manage properly the process of instruction and "act according to actual circumstances" in instructional design.

Due to the lack of literatures related to the EDB until now, the works on the IWB were reviewed in this part as well. Over the last decade, the IWB had been applied in many countries such as Australia, Italy, Mexico, the Netherlands, New Zealand, Turkey, the UK, and the USA. Specifically in the UK, the government invested a huge amount of money in the IWB in 2004 because the government was in the belief that their use in the educative process would raise attainment among British school children (Hall & Higgins, 2005). In order to support the use of the IWB, they even set up the national whiteboard website and gave teachers more assistance in the resources and technologies.

Numerous studies mostly focused on investigating the use of the IWB in classroom environments. These studies addressed the issues from a variety of perspectives. For example some focused on the use of the IWB in particular subject areas (Glover, Miller, Ave-ris, & Door, 2007; Merrett & Edwards, 2005); some paid more attention to teachers' perspectives (Loveless, 2003; John, 2005); and others minded learners' perspectives (Hall & Higgins, 2005; Wall, Higgins, & Smith, 2005).

Bruce and Rose (2010) conducted a treatment/control research. The main aim of this research was to determine the extent to which the use of interactive whiteboard technology was associated with upper elementary students' self-reported level of motivation in mathematics. A similar research was carried on in Turkey for determining the attitudes and evaluating the views of 10th grade students towards the IWB in mathematics classes, which was a part of a quasi-experimental research (Tataroglu & Erduran, 2010). In this research, qualitative and quantitative data were collected. The research revealed that students were positive toward using the IWB in classroom.

Moloney (2011) discussed instruction of Chinese subject under the environment of the IWB. The research verified the IWB could provide help for all aspects of Chinese learning through organizing and implementing instruction in the high schools in Sydney, Australia (Moloney, 2011).

Sad and Ozhanb(2012) designed an empirical approach to investigate the views of primary students about the use of the IWB in their classes from attitudinal and pedagogical perspectives (Sad & Ozhanb, 2012). The research conducted group interviews to fifty primary students who had about two years of experience regarding the use of the IWB in their lessons. Results showed that the students like instruction with the IWB. Aydinli and Elaziz (2010) investigated the use of the IWB in the field of foreign language learning in Turkey. The conclusion indicated the vast majority of students had positive attitudes and perceptions towards using the IWB in their courses (Aydinli & Elaziz, 2010).

Bakadama et al. (2012) designed a questionnaire including ten items to identify the teachers' perceptions about the benefits of using the IWB in instruction. The research combined qualitative and quantitative approaches. The questionnaire was distributed to fifty teachers, and three teachers were interviewed. The result of the research revealed that the majority of teachers use the IWB as an

overhead projector and for internet research but they did not make use of the many other advanced s features of the IWB (Bakadama & Asiri, 2012).

SCHEME DESIGN

In order to find the opportunities and challenges that the students and teachers faced up to when they used the EDB, an empirical approach was conducted which involved interviewing the students who took part in the class with the EDB and the teachers whose duration of regular teaching experience with the EDB was no less than one year. By analyzing, summarizing and sorting the results of the interviews, this paper aimed to give a comprehensive description of authentic experiences in terms of the opportunities, problems, challenges, and suggestions.

✧ Interview outline design

A series of semi structured interviews was designed in the research. The interviews focused on the teachers' and students' overall attitudes and views towards the usage of the EDB in their classes during the past and current semesters. Four open-ended questions were prepared for the interviews to guide the interviewees and to probe into the participants' views deeply. Due to the different role of the teachers and students, some questions were divided into different pieces according to the role. Reference to the subjective evaluation of the image, the scale for some answers was defined to make the numerical analysis. The specific questions were as follows:

- 1) What were your attitude towards the instruction with Electronic Dual-Board. (One a scale of 1-5, rate the attitude towards the EDB. 1 being rejection, 2 being indifference, 3 being acceptance partial, 4 being acceptance full and 5 being preference) (for both teachers and students)
- 2) What were the advantages of Electronic Dual-Board compared to the traditional blackboard or interactive whiteboard when you were teaching or learning? (for both)
 - 2.1) What was the convenience that the EDB brought to you? (for teachers)
 - 2.2) Could the EDB have some impact on motivating your interest in learning? (One a scale of 1-4, rate the degree of interest motivation. 1 being negative, 2 being no impact, 3 being a little, 4 being remarkable) (for students)
- 3) What were the disadvantages of Electronic Dual-Board in the actual instructional process? (for both)
 - 3.1) What were the barriers when you organized a class with the EDB? (for teachers)
 - 3.2) Did the EDB have some side-effects on you when you attended the class with the EDB? (One a scale of 1-4, rate the number of side-effect of the EDB. 1 being zero, 2 being less than 2, 3 being less than 4, 4 being more than 6, 5 being lots of) (for students)
- 4) What suggestions would you propose to improve course instruction and enhance students' engagement in classes with Electronic Dual-Board? (for both)
 - 4.1) Provided your suggestion had been accepted and realized, would you like to keep on teaching with the EDB? (for teachers)
 - 4.2) what would be your attitude towards the EDB if your suggestion had been accepted and realized? (One a scale of 1-5, rate the new attitude towards the EDB after suggestion accepted. 1 being rejection, 2 being indifference, 3 being

acceptance partial, 4 being acceptance full and 5 being preference) (for students)

To smoothly carry out this interview and collect effective data, it was necessary to design interview outline. According to each question, some guided words were provided. For example, to the second question, Screen Lock, N-Function, Dual-track teaching, Serialization of the teaching process design, and supporting multiple teaching methods were offered to inspire the interviewees to think of the question completely.

✧ Participants

Sampling for this research was divided into two steps. First, according to a purposive sampling approach, two schools, the No.1 Primary School of Chang-Qing and Central China Normal University, were selected. The participants included the students and teachers who had more than one year of experiences in learning and teaching with the EDB. Next, based on random sampling, the final interviewees were selected from the candidates of teachers and students in step 1. Ten teachers and twenty-four students from the two schools participated in this research finally. In the teacher group, three of them were primary teachers (teachers in the No.1 Primary School of Chang-Qing) and the rest teachers were from the Central China Normal University. In the student group, half of the students were from the No.1 Primary School of Chang-Qing. They were divided into two groups. One was from year 4 and the others were from year 5. There were 12 students from the Central China Normal University. Similarly, they were divided into two groups randomly with equal members.

✧ Data collection and analysis procedures

In order to collect rich data, focus group interviews were utilized instead of individual interviews. Focus groups can be used “to gain unique insight into existing beliefs, behaviors, and attitudes” (Byers & Wilcox, 1991, p. 71). The interaction focus groups provide high quality data in a social context where people can consider their own views by hearing the views of others (Fraenkel et al. 2012; Patton, 2002). Thus one can “promote talk on a topic that informants might not be able to talk so thoughtfully in individual interviews” (Bogdan & Biklen, 2007).

At the beginning of the interview, we introduced the purpose of the interview and told the interviewees what they should talk about. We played the role of a moderator and interviewer. We not only needed to open ears to the words what the interviewees said but also guided the interviewees to clarify their answers. It took at least 50 minutes for every interview.

Besides, the details of these interviews were recorded by using a recorder pen to identify and analyze commonalities throughout the interviews. After the interviews, we transcribed and sorted the results into four themes. In order to summarize the contents of the recording, we listened to the recording again and again, constructed and named categories to capture some recurring contents. Based on the inductive approach, the categories mentioned would be grouped in the four themes. Then, the numbers about each category were counted. The categories would be ordered by the statistic numbers from the most frequency to the least.

FINDINGS AND DISCUSSIONS

From March to June in 2013, six interviews were held and ten times of the class with the EDB were participated in to observe the usage of the EDB. The example of a class employing the EDB was shown in Figure 1. Figure 2 indicated the presentation interface using software of the EDB.



Figure 1 A Class Using The EDB

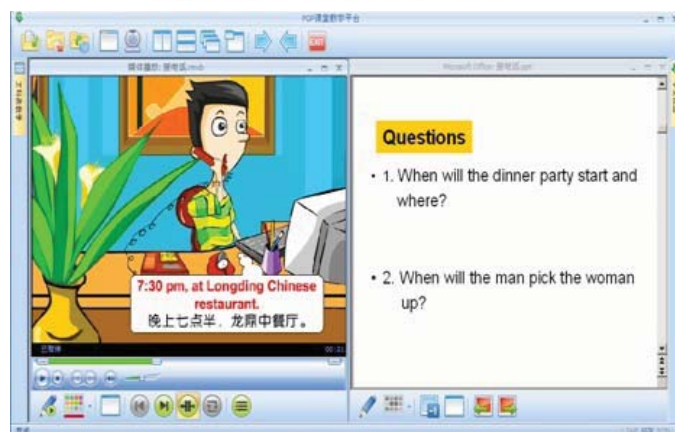


Figure 2 Presentation Interface of The EDB

Six audio files of the interviews and three video files about the classes with the EDB were collected. After distilling and analyzing the data, we generated the following results.

✧ Attitudes towards the instruction with the EDB

The students' attitude to the EDB was shown in figure 3.

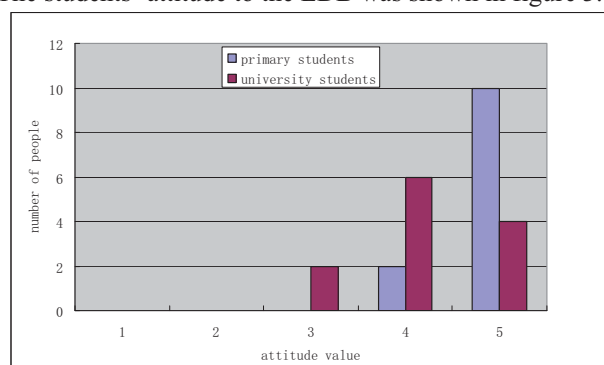


Figure 3 Attitude towards The EDB

Most of the participants' attitude towards the instruction with the EDB were very positive. Especially, the primary students stated that they wanted to have classes with the EDB extremely compared to the traditional classroom with blackboard. They thought the classes with the EDB were interesting and efficient. For the university students, they remarked that they were able to accept the EDB completely.

For the teachers, one of the primary teachers said that he could accept the EDB. However, when he was asked whether he would like to continue to teach with the EDB, he stated that the difference between the EDB and the IWB was little ["If I can use the IWB properly, the IWB can also enhance our teaching efficiency. Why should I change to the EDB"]. The other teachers expressed that they would like to proceed to organize the classes with the EDB.

✧ *Advantages of the EDB compared to the traditional blackboard or the IWB*

The analysis revealed the basic categories of the advantages of the EDB. The categories were listed in Table 1.

Table 1 Advantages of The EDB

Categories	Numbers of references				
	University Teachers	Primary Teachers	Under-graduates	Primary Students	Total
Double-screen display	4	2	5	6	17
Facilitate learning	2	2	6	2	12
Better visual presentation	0	1	3	4	8
Total	6	5	14	12	37

The most mentioned advantage about the EDB was the double-screen display including N-1 Function, Lock screen and Dual-track teaching. The N-1 Function was referred to as that current page of courseware (such as courseware of PPT) was shown on one of the two boards. The previous page was shown on the other board at the same time. The contents of the two boards were relevant. Four university teachers stated that they often used this function. Some undergraduate students also praised this function. Additionally, in the process of teaching, when you (who is 'you'?) needed to show the details of the structure or content about some knowledge, you could use the "Lock screen". When you locked the screen of content, the courseware could proceed on the other board. ["I like to use this function of the EDB in the process of teaching structures of plant."(a primary school teacher)]. In the opinion of students, in this way they could have an entire understanding of knowledge and promote the construction of knowledge. ["Dual-track teaching is not only beneficial to our research, but also saves time and improves teaching efficiency. So, we can learn more knowledge." (the primary school students)]. The Dual-track teaching mode based on the dual coding theory means that teaching contents are presented in the form of double-picture, which can promote the learner's brain language system and non-verbal reinforcement for the reception of information. According to the theory, the left and right sides of the EDB could exactly present relevant contents at the same time.

The second most outstanding advantage mentioned was to facilitate learning. Some of undergraduates highlighted that on the one hand, it was convenient for them to take notes. On the other hand, by comparing the relevant knowledge, it was helpful for them to understand and remember what they were learning. Moreover, the function of the geometry sketchpad could draw the regular graphics, avoided the limitations of traditional teachers' freehand graphics such as inaccuracy. In addition, a few students said that the teachers' writing on the EDB could be saved as it was required, which were good for them to review after classes.

Additionally, a few students referred to as that the form of the EDB to present resources was no longer a monotonic projection screen. Two boards enlarged the space of presentation and allowed a variety of related teaching resources to be accessed at the same time. Several college students mentioned that using the EDB to watch courses with videos was better than using the projection. Moreover, the one side of the EDB could play the video, and the other side could present the corresponding text, which mobilized their left and right brains fully. In this way they not only understood what they were learning but obtained more knowledge to expand their horizons.

Besides the advantages of the EDB in instruction, the degree of interest motivation was investigated. The results were depicted in figure 4.

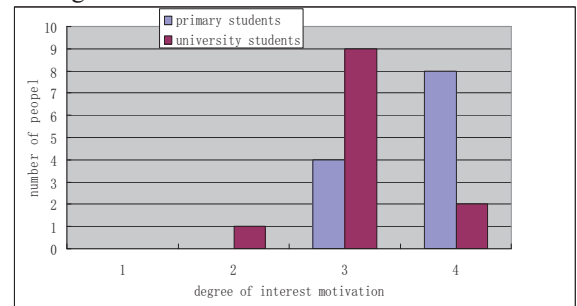


Figure 4 Degree of Interest Motivation

Based on the results, it was concluded that most of the primary students thought the EDB had impact on the studying interest significantly. And most of the university students thought the impact was a little. Therefore the EDB could have influence on studying interest to some extent.

✧ *Disadvantages of the EDB in the actual instructional processes*

The analysis of the data revealed basic categories about the disadvantages of the EDB in the actual instructional processes. Specific categories were listed in Table 2.

Table 2 Disadvantages of The EDB

Categories	Numbers of references				
	University Teachers	Primary Teachers	Under-graduates	Primary Students	Total
Writing questions	7	3	5	3	18
Technical problems	4	1	2	2	9
Resource constructions	1	3	0	0	4
Health problems	0	2	0	0	2
Total	12	9	7	5	33

The disadvantage mentioned most about the EDB was writing problem. If the pen was not in the precise position, the writing was delayed and not fluent. The interviewees, almost all, believed that the writing function of the EDB was a barrier for the classes owing to its insensibility because the board writing was the necessary for a class. Therefore, the writing problem degraded the effect of the EDB in classes remarkably. ["In the math or similar courses, the formula and calculation occupies a large proportion. So the writing is an essential part. Once the writing problem appeared, the class would not be able to continue" (a university teacher)].

The second most mentioned disadvantage was the technical problems category. The teachers were annoyed with the

interruption and inefficiency caused by technical problems. In general, the technical problems consisted of software and hardware problems. For example, the software was lack of minimum function ["The software has no function of minimum, so the teacher cannot run other programs on the computer simultaneously. It isn't comfortable." (a university teacher)], the system shut down inexplicably ["When the system collapses, the teacher must restart the computer. To do so, it is not only to waste the time, but also to distract the students' attention. It is not good for teaching" (a undergraduate student)], the arrangement of wire for the EDB was outside, which might cause many evitable troubles ["The outside wiring are harmful to students. Moreover, it is easy to appear problem" (a primary school teacher)].

Resource constructions were mentioned many times in the interviews. It was referred to as that there were few matched resources for the EDB. Though the dual board was very convenient for making courseware and supported many types of resources, many teachers still felt difficult to create resources by themselves. Some teachers believed resource constructions had to be considered ["Not all teachers master the skills of creating resources. For them it is a waste of time to make resources oriented to a specific platform." (a university teacher)].

The health problems to use the EDB was another minor but very important category. Some teachers felt that it was not good to look at screen for a long time ["When the students watch the screen for a long time, it is likely to have side effect" (a primary school teacher)]. Previous research also reported primary school students' concerns about the similar health problems caused by the IWB including "headaches, sore eyes, and epileptic fit" (Wall et al, 2005).

Besides the disadvantages investigation, the degree of inconvenience of the EDB was investigated. The results were shown in figure 5.

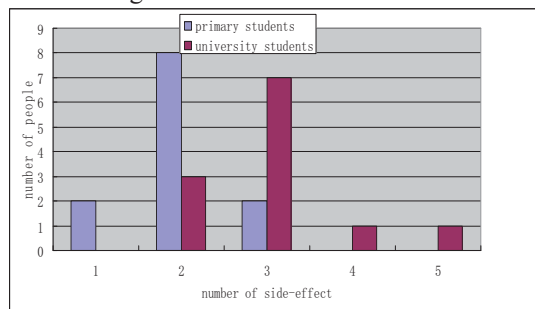


Figure 5 Number of Side-effect

Based on the investigation, it could be concluded that most of the primary students thought the number of side-effect of the EDB was less than 2, and most of the university students thought the number of side-effect was more than 3. It could be found out that there were certainly a few side-effect brought to the students by the EDB.

✧ suggestions for improving instruction with the EDB

At the end of every interview, the interviewees were asked for some suggestions for improving course instruction with the EDB. Resulting categories were listed in Table 3 from the most frequency to the least across the different interviewees.

The top suggestion given by the interviewees was to splice the two boards seamlessly or reduced the gap between them. On the one hand, the technique of seamless splice had been

achieved in other fields. On the other hand, the seamless splice was convenient and helpful. Some teachers believed it would help to teach ["Only in this way, it is the perfect combination of single and double board. Teachers have the right to choose the use form of dual board based on the teaching design."(a university teacher)]. Some students agreed with this idea and highlighted the change would offer the better visual effect ["If we are in a big classroom, the characters on the each board are too small to see when we are at the back of the classroom. So, decreasing the gap between the two boards will enlarge the space of presentation, and sometimes we can use them as a single big board" (a undergraduate student)].

Table 3 Suggestions towards The EDB

Categories	Numbers of references				
	University teachers	Primary teachers	Under-graduates	Primary students	Total
seamless splice	5	1	5	2	13
Auxiliary blackboard	4	2	2	0	8
Matched resource	2	3	0	0	5
Training teachers and students	0	2	1	1	4
Total	11	8	8	3	30

The second most proposed suggestion was to add an auxiliary blackboard. Many interviewees, especially the science teachers, thought the dual board could not be the substitute to the blackboard completely. A dual board was not suitable for all the situations in a class ["Like science course, formulas appear more frequently. Many formulas need to write during teaching, but not to just show by the PPT. Though blackboards are regarded as the traditional medium, we have got used to them. Why should we change?" (a university teacher)]. In addition, some courses of arts also needed to combine the dual board with the blackboard ["I have learned paleography course, the teacher writes ancient words on the dual board. These words look very weird. If he can write on the blackboard, the result will be much better. And those words are marvelous on the blackboard"(Undergraduate)]. Because the EDB was still at the initial stage and it was not suitable for all the circumstances as well, combining two boards could be helpful.

Providing more resources was another important suggestion. Many teachers felt difficult to design lessons using the EDB ["When teaching with the dual board, we need the resources supported. However, the dual-board provides limited resources. So, we must create them by ourselves. But doing it all by ourselves is difficult and unrealistic"]. With the matched resources, teachers could concentrate on the teaching design.

At last, several students believed training on how to use the EDB should include both teachers and students. In a class, interaction was very important. If students did not know how to use the EDB, troubles would appear in interaction. ["If we ask a few students to show their ideas on the dual board, we will have to teach them the correct way of using it.

Otherwise, incorrect operations are a waste of time or cause the crash of the system” (a primary teacher)]. The students accepted new things faster than some of teachers and they might help teachers to use the EDB in classes. Therefore, it was necessary to provide EDB training for students as well. Besides the collection of the suggestion for using the EDB, the attitude towards the EDB had been investigated again if the suggestion should be accepted. The results were shown in figure 6.

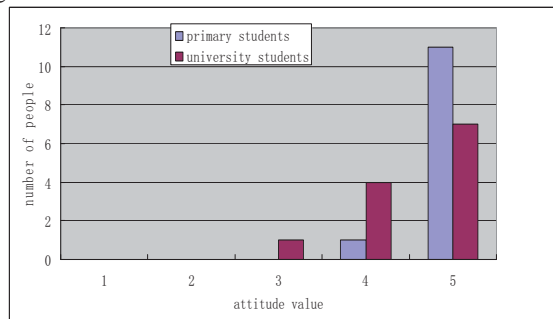


Figure 6 New Attitude towards The EDB

Based on the investigation, it could be found out that the attitude of the university students was changed obviously. Most of them thought they would accept the EDB fully, even prefer to using the system if the suggestion had been taken. And most of the primary students prefer to taking the class using the EDB. Therefore, It could be foreseen that the EDB would have a bright future in instruction if some improvements should be made.

CONCLUSIONS

The purpose of this research was to analyze the opportunities and challenges of the EDB. The results indicated that the students' and teachers' attitudes towards the EDB were positive because the system was convenient for teaching and learning, because of the features of double-screen display, learning facilitation, and better visual presentation. However, many challenges of the EDB should have to be overcome, such as the writing problem, the technical problem, and lack of the resource, if the EDB should spread over China even more widely. In addition, the suggestion had been collected to improve the course instruction with the EDB. In the next step, some researches will be conducted to find out the solution to the other challenges, such as what on earth shall be prepared for, how to adjust the teaching plan, how to carry out teaching design and how to intervene in the teaching process.

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Aesthetics and Expanding Perception in Fluid Physics

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Abstract— Flow Visualization is both the practice of making fluid physics visible and a course that focuses on the practice of making those images, as short video and stills. Since 2003, this course has been cross-listed as a mechanical engineering elective and a fine arts studio course, and brings together mixed teams of engineering and fine arts photography or film students. With its focus on the production of aesthetically pleasing and scientifically useful images of fluid flows, it is one of the few course offerings that explicitly calls upon engineering students to use an aesthetic sense in their studies. In prior work, this course was associated with a positive shift in affect toward fluid flows, which we measured through the Fluids Perception Survey (FluPerS) [1]. In the same survey, students expressed a greater awareness of fluids. This outcome was in contrast to the survey results from Fluid Mechanics, a traditional engineering core course, with a highly analytic, mathematical approach. Exit surveys of students in Fluid Mechanics reveal a negative shift in affect, which is typical of other technical courses, with no comments about awareness of fluids. The increased awareness of fluids can be termed an expansion of perception – when learners see everyday objects, events, or issues through the lens of the content [2]. Expansion of perception is often associated with deeper conceptual understanding and the ability to transfer learning to new settings. Building on the prior survey work, we conducted interviews with students from Flow Vis, both engineering students (n=4) and art/film students (n=5), in addition to Fluid Mechanics students (n=3), at the beginning and end of a semester. Their comments, along with open responses in the survey (n=86), are being analyzed using an iterative process to develop an emergent coding scheme. We want to discover what about Flow Vis helps students, both from engineering and art, internalize and apply their understanding of fluids. What role does the emphasis on aesthetics, so familiar to the art students, so uncommon in coursework for the engineers, play? Finally, how can we adapt the teaching practices from Flow Vis for other courses, other content areas? Analysis of data and future course suggestions are discussed.

Keywords—aesthetics; flow visualization; fluid mechanics; pedagogy; perception; student engagement; transformative experience

I. BACKGROUND AND SIGNIFICANCE

Student engagement has been found to be a complex problem, relating to multiple constructs such as motivation, goals, self-efficacy, and emotion or affect [3]. As a result of this complexity, engagement is often assessed broadly, using data such as persistence in a major or degree attainment as proxies. Yet, we know that constructs like engagement are

impacted at the course level. In particular, technical courses in math and science tend to cause a negative shift in affect [4]–[8]; students emerge from a course less interested in the content than when they began, and they report believing the content less useful and less important. This effect is largely immune to varying pedagogy. To investigate the content-related shifts in affect, we use a lens called the transformative experience.

The transformative experience is a learning experience with three hallmarks. Students: 1) apply course content in everyday life without being required to (also called *motivated use*); 2) see everyday objects or situations differently, through the lens of the new content (*expanded perception*); and 3) value the content in a new way because it enriches everyday affective experience (*affective value*) [2]. The transformative experience stems from John Dewey’s seminal theory of experiential learning, and is influenced by his work on the value of aesthetic experiences [9], [10]. In brief, we want students to be able to perceive concepts they have learned in the larger world, put those concepts to work, and derive meaning or satisfaction from that experience.

While prior studies have cataloged a wide range of influential student characteristics both extrinsic and intrinsic [11], aesthetics and perception have not been considered. Our broad investigation of the impact of aesthetics and perception on student learning was prompted in part by unsolicited student comments such as “I’ll never ignore the sky again” or “I see examples of flow vis all the time now.” The present investigation centers on the course that elicited those student remarks, Flow Visualization (Flow Vis), and demonstrates the utility of the Deweyan transformative experience as a framework for capturing aesthetics and perception.

II. COURSE DESCRIPTION

Flow Vis brings together engineering and fine arts photography or film students to produce aesthetically pleasing and scientifically useful images of fluid flows. This includes both undergraduates (mostly juniors or seniors) and graduate students. Engineering majors use the course as a technical elective, and the art/film majors count it as part of a studio requirement. There are typically 40-50 students in the class, which has been offered annually since 2003. Figures 1 and 2 show sample images from the course.

Some sessions are lecture-oriented, especially early in the semester, when topics include imaging basics, light-matter

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interaction, and fluid mechanics. Later class sessions focus on students presenting their work. There are six projects over the course of the semester that can be still photographs or short videos. For the first assignment, students work independently,

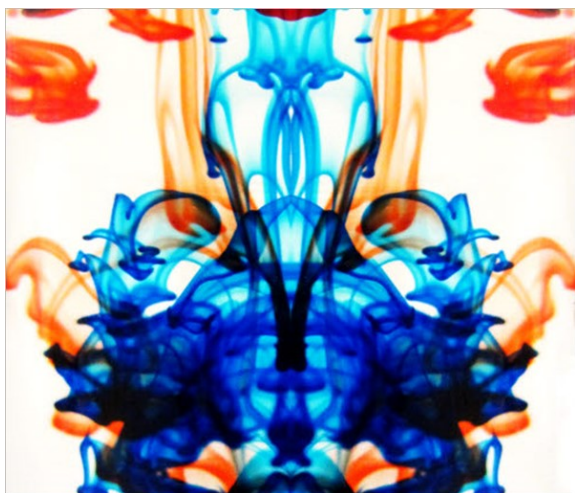


Fig. 1. Image by student Trevor Beatty; Food dye exhibits the Rayleigh Taylor instability, forming toroidal vortex rings in a mirrored image, 2013.

partly to demonstrate the challenge of controlling a flow while documenting it visually. Students also independently photograph cloud formations throughout the semester for two assignments. Aside from the cloud images, the only specification for image content is that it must document fluid mechanics. Students are assigned to teams using CATME [12] to share resources and expertise for the last three assignments. For each team assignment, students have individual creative control of their images, while supporting teammates.

The images are presented during class. The professor and other students comment on the image. To foster honest, encouraging critique and ensure all students participate, students may bring their laptops and can log in anonymously to offer comments. Discussion spans fluid physics and aesthetics. The professor often supplies keywords that can be used to research the phenomena present in the image.

The written explanation of the image is due one week later. In one to four pages, students provide the context for their images such that someone else could attempt to re-create them. The paper includes apparatus, materials, and photographic techniques used, and an explanation of the phenomenon demonstrated. Art students write generally about the physics involved, while engineering students should estimate the appropriate non-dimensional properties (such as the Reynolds number) and provide time and spatial resolution based on flow speed and field of view. All students are expected to cite references. Graduate engineering students cite technical, refereed literature and write at a professionally publishable level.

The course culminates in a show in the Engineering Center lobby. Students are encouraged to submit their work to various competitions, and their work is displayed on the course website (www.flowvis.org). The grading standards emphasize taking

each assignment seriously (including the written explanation), collaborating in groups, and providing thoughtful feedback.

III. PRIOR WORK

In order to gauge student affect in the Flow Vis course, the Fluids Perception Survey (FluPerS) was developed in Fall 2008. The survey design uses an item response modeling approach [13], often used in the education research community. The survey defines “appreciation of fluid flow”, as well as a continuum on which an individual’s responses are mapped. The survey was administered and refined over several semesters. Validation results were published in 2012 [1]. The survey offers statements such as “Visualizations of fluid flow are very beautiful” and “the study of fluids is useful to me as an engineer.” Students respond on a five-point scale of agreement.

As a control during this work, students from the Fluid Mechanics course, as well as another thermofluids elective, Sustainable Energy, were also surveyed. Fluid Mechanics students demonstrated a negative shift in affect; Flow Vis students showed a positive shift; and those in Sustainable Energy were neutral. To investigate the aspects of these courses influencing shifts in affect, our current study was initiated.

IV. METHODS

Three courses were included in the current research: Flow Vis, the technical elective described above, Fluid Mechanics, the required, more traditional course, and Sustainable Energy, another thermofluids elective. Students were invited to participate in the research during class and via email. All students were asked to complete both pre- and post-course surveys. Interviewees replied to an email invitation that went directly to the research interviewer, not through the professors. Thirteen students were each interviewed twice, once early in the course, and once after the course had completed. See Table 1 for a summary of data collected.

These were individual, semi-structured interviews intended to cover both known research interests and to allow students to convey other ideas they felt were important about their experiences. Early course interviews were conducted after the first assignment had been turned in. The researcher guided the early course interviews to deliberately address: engineering (or artistic) identity, past work in visualization, past collaboration experiences (especially outside of their disciplines), and preconceived notions about the course. Post-course interviews addressed identity, collaboration within the course, specific logistics of the course, as well as overall impressions. For the most part, subjects did not have to be asked about visualization as it was central to the course. These interview data are undergoing an open-coding analysis, where new themes emerge along with evidence for the a priori claims of the researcher [14], a multi-step, iterative process [15].

The most recent survey data included 31 pairs of responses from Flow Vis students (that is, the same student completed both the pre-course and post-course survey). Fluid Mechanics provided 55 pairs of responses, and Sustainable Energy

provided 13. The survey contained both numerically scored items (on a Likert scale), and open response items. Numerical items will be evaluated statistically. Open response items will be coded with an emergent coding scheme similar to that of the interviews.

TABLE I. DATA COLLECTED

Data Type	Courses		
	<i>Fluid Mechanics</i>	<i>Flow Visualization</i>	<i>Sustainable Energy</i>
Interviews	3	4 engineering 5 art/film	1
Surveys	55	31	13

V. PRELIMINARY FINDINGS

In the interviews, students conveyed their attitudes about the Flow Vis course, revealing traces of what impact the course has, and why. Preliminary coding of the interviews has focused on identifying the hallmarks of the transformative experience: *motivated use*, *expanded perception*, and *affective value*, as related to the fluid physics content.

Engineering interviewees described using their fluids knowledge in new ways, even in early course interviews (labeled int 1). We might call this scaffolded *motivated use* of the content. Scaffolded, because the use of content is assigned not spontaneous, yet still in a new context:

- Every single time we talk about photographic technique, or develop a flow product or a combustion project, those are all backed up with examples from the real world.... It's not just this is a problem from the book or 'ignore friction here'. All these things are real applications, all factors are considered. –Eng. student (Sub 03, int 1)
- [Flow Vis] is like Fluids 2. Now that you know the basics, you can apply them to making cool artistic pictures. – Eng. student (Sub 01, int 1)

Later in the same interview:

- I feel like [art students] are going into the dark trying to find art, and I am going in dark trying to take pictures of my ideas. –Eng. student (Sub 01, int 1)

This last excerpt points to the openness of the assignments, which was associated with a sense of exploration, instead of finding existing answers. Often *motivated use* takes the form of tinkering with ideas. Students commented on this mostly in their second interviews (labeled int 2):

- You can modify your pathway [in Flow Vis]. In math there's only one way, but in [Flow Vis] it was more along the lines of this experiment is how you choose to direct it. –Eng. student (Sub 03, int 2)
- In Flow Vis, the end is so variable, that it was very dependent on the person. –Eng. student (Sub 01, int 2)
- [in other courses] you create such a rigid thought process rather than a really flexible, dynamic space. – Eng. student (Sub 09, int 1)

- [experimental film] is such a lofty term and it's used a lot, [but] here we were truly experimenting, which is the most beautiful part about it. You are producing something through experiment. –Art student (Sub 16, int 1)
- I love the open-endedness of pretty much everything in that class. –Art student (Sub 16, int 2)

Among the art students, some identified as experimental film makers, and commented that capturing images such as the ones in Flow Vis are important for adding texture and evoking emotions in their work. One film student commented that he had learned as much about using his camera in the first two weeks of Flow Vis as he had in a whole semester of a photography course. This highlights the concentrated nature of the early sessions of the course, which enable students to begin finding and capturing flow images quickly. Getting to hands-on assignments swiftly may be worth replicating, as it supported the scaffolded motivated use of content.

While engineering students commented on the way Flow Vis showed them fluids content in a new context, the art students commented on *expanded perception*:

- In terms of appreciating flows and keeping a keen eye out for it, that's totally improved drastically... I don't want to make another film without including one flow vis. –Art student (Sub 07, int 2)
- I learned to investigate texturally ... It's right under your nose, bubbles in the dishwasher, water under your feet by the creek... it opened up a more microscopic kind of beauty. –Art student (Sub 16, int 2)

This motivated use and expanded perception of the content was also connected to *affective value*. Students felt excited, were engrossed, and took pride in their work:

- I feel like I'm out of my element, which is fun and exciting. –Eng. student (Sub 01, int 1)
- I just had a blast. I was really proud of what I did.... I'm excited to see [the final exhibit]. My family is going to come. –Art student (Sub 07, int 2)
- One of my projects, I noticed I can do this and it will look much more interesting. I spent three times as long. I didn't even know it. –Eng. student (Sub 03, int 2)
- I took more pride in [my Flow Vis work]. Just because I didn't feel that any of it was, pardon my language, absolute bulls***. I feel at times [professors] assign work because they have to, we need it for grades or something. [In Flow Vis] you were actually doing something. – Eng. student (Sub 09, int 2).

Some trends in the interview data surfaced unexpected similarities between the two groups and the benefits of collaboration between them. This included acknowledgement of the other group's expertise:

- [The engineer's explanation] went whoosh, right over my head. I didn't understand the physics and

mathematics, but I understood why that reaction occurred in simple terms. –Art student (Sub 02, int 2)

- There were a lot of things that [the film maker] pointed out that I wouldn't have thought of when taking photographs, certain angles, certain lighting... all this art technical stuff. I had no idea what he was talking about. – Eng. student (Sub 03, int 2)
- The engineers were looking deeper into what we were seeing. I wouldn't have done that before. I think it's cool. I do value it. –Art student (Sub 07, int 2).

This mutual respect contributed to the collaborative work by the teams:

- We played off of each other perfectly because they were just interested in making the experiment and I was interested in capturing it. –Art Student (Sub 16, int 2)

Another point in common: both groups expressed a dislike for the papers with a begrudging appreciation for what they learned through the process:

- There's times I'm really interested in something and I don't know why... But to have it thought out and put down on paper really helps me think about it creatively. – Art Student (Sub 16, int 2)
- [the paper] backs the image up, gives a secondary way to understand what is going on, maybe more in depth. Maybe the video brings you and makes you want to understand it, and then you can read that and figure out what you just watched. – Art Student (Sub 05, int 2)
- The only thing that I didn't like was writing the papers. The engineering part, I wrote like I normally write any experimental paper. But for the artistic side I felt like I was telling more of a story. I didn't expect that. I liked the storytelling part of it. –Eng. Student (Sub 03, int 2)
- I think I have a better understanding about what the Reynolds number actually means from [writing the papers]. After my fluids class, you think it's just this number. It can actually tell you a lot. –Eng. Student (Sub 09, int 2)

However, the requirement of the paper did discourage at least one art student from taking more risks with the work:

- If I could omit the scientific part [of the paper], I would have liked that. It made me reluctant to try things more complex, because I'm like, oh s*** after I do this, I'm going to have to explain this scientifically. –Art student (Sub 16 int 2)

Among the engineering majors, some chose Flow Vis precisely because they are or were photography hobbyists. This could be viewed as a source of bias in the investigation of positive affect; however, others cited past fascination with ocean waves or other natural fluids phenomena as guiding their choice to take the course. We view both types of past experiences as a potential indicators of the latent desire among engineering students for an aesthetic experience relating to their work.



Fig. 2. Image by students Emily Howard, Preston Wheeler; Colliding water jets result in a 'fishbone' instability, 2012.

VI. RELATED AND FUTURE WORK

In ongoing analysis, we hope to discover the most relevant features of Flow Vis for developing a positive shift in affect, and the role of aesthetics in that process. Our initial work has focused on comparing engineering and art students within Flow Vis. Future analysis will 1) compare Flow Vis engineering student responses to those from Fluid Mechanics and Sustainable Energy courses, and 2) identify possible shifts in attitude between early-course and post-course responses.

As part of our study of how certain pedagogical methods influence positive affect, we have adapted features of Flow Vis, including an emphasis on aesthetics, and applied them to a new course, Aesthetics of Design. In it, students designed and built projects as they developed a *design aesthetic*. While the course did not feature the mix of students present in Flow Vis, three instructors with varying expertise offered insights from fields such as mechanical and electrical engineering, computer science, photography, and music. Similar to our findings with Flow Vis, most students relished the opportunity to design with fewer constraints and were able to articulate their aesthetic in a final paper accompanying the project [16].

Ultimately, using courses such as Flow Visualization as a guide, we would like to develop a pedagogical model that enables instructors to incorporate aesthetic dimensions into their courses. Aesthetics, with its potential to initiate and sustain student engagement, represents an untapped resource for improving engineering education experiences.

ACKNOWLEDGMENT

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Step-Based Tutoring System for Introductory Linear Circuit Analysis

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Abstract—The development, expansion, and assessment of a step-based computer-aided tutoring system to teach linear circuit analysis is described. Circuit problems and fully worked, error-free solutions to same are created automatically and randomly with any desired characteristics, varying both the layout and numerical values. Students therefore have access to an unlimited source of both examples and practice problems of variable difficulty. A unique feature is that students input each stage of their work in a variety of forms including redrawn circuit diagrams, equations, matrix equations, numerical answers, multiple choice answers, and sketches of time-dependent waveforms. Students receive immediate feedback on the correctness of each step of their work. The solutions use analytical methods, rather than the numerical methods used in a tool like PSPICE. A total of 15 tutorials are now available, including DC and AC circuits and two on Laplace transforms. The system has been used by over 1950 students to date. A randomized, controlled laboratory-based study finds a statistically significant learning gain of 1.21 standard deviations compared to working conventional textbook problems. Another randomized, controlled classroom study found a strong preference of students for this system over a widely-used commercial publisher-based homework system, as well as higher scores.

Keywords— *linear circuit analysis; computer-aided instruction; step-based tutoring*

I. INTRODUCTION

Linear circuit analysis is a key topic in electrical engineering curricula, and is also studied by many other engineering majors. At Arizona State University (ASU) for example, we currently teach about 19 large sections (~70-80 students) each year using a large number of faculty. Student retention and graduation rates can be significantly impacted by their experience in this course. To improve that experience and help teach the course more efficiently, we are developing computer-assisted instruction as a substitute for conventional homework [1-4]. By providing immediate feedback on every step of a student's work, we expect to enhance learning, promote complete mastery of the topics, and reduce the time required to grade student homework manually. Student frustration should be reduced by avoiding their spending many

hours to solve equations that are incorrectly written in the first place, or that are based on an incorrectly re-drawn circuit diagram in a multi-step solution process.

II. DESIGN PRINCIPLES AND NOVEL APPROACHES

A wide variety of computer-aided instruction or intelligent tutoring strategies have been employed previously to help teach linear circuit analysis topics [5-21]. However, the only systems that are currently widely deployed are those that accompany circuits textbooks on publisher web sites such as McGraw-Hill's Connect®, Pearson's MasteringEngineering®, Wiley's WileyPLUS, and others, which provide mainly algorithmic problems where a few element values are randomly varied and the student is asked to input numerical answers. A meta-analysis of different types of tutors by VanLehn found that the typical effect size for such answer-based tutoring systems is a Cohen d -value of 0.31 standard deviations (σ). However, step-based tutors, such as the one we are developing, average d -values of 0.76, nearly as good as the average effect of expert human tutors ($d = 0.79$) [22]. This difference is considered to be a major reason that the controlled, randomized laboratory-based study discussed below, which compared use of our tutorial exercises to working conventional textbook problems, found a large and statistically significant effect size of $d = 1.21 \sigma$.

Our system differs from previously described and publisher-based systems in the following ways:

1. An unlimited number of topologically different circuit diagrams can be generated on demand, where both the circuit layout and element values vary randomly. The complexity of these circuits can be varied at will. Existing publisher-based systems and other web-based systems [18, 19, 23-25] only vary a few element values randomly, and a given problem is essentially the same regardless of specific numerical values. If a fully worked solution is provided to students for a given set of values, it is essentially trivial to modify that solution using a different set of values. Also, when such systems allow multiple attempts and supply the correct answer after a failed attempt (without providing the full solution), students have been reported to fail their first attempt deliberately to get an answer

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they can use to check their method [23]. Our system avoids these problems by creating a completely new circuit diagram after showing students correct answers and fully-worked solutions. Further, virtually all prior systems have used a finite bank of pre-created problems and circuit diagrams (even if some element values are varied) [6, 10, 12, 16-20, 23-27]. In such a case, the answers must be pre-computed by the tutorial authors, which is a very laborious and time-consuming process [25] (which one of the authors can himself attest, having done so for the publisher site of a popular circuits textbook!), and is also prone to human error. Moreover, if a student completes all of the available pre-generated exercises, and still does not understand a concept or procedure, they are left with nothing that is fundamentally new on which to practice. Further, a finite bank of problems means that there may not be problems available over a wide range of difficulties or complexities, which some students may need to be able to progress at a pace that is comfortable or appropriate for their individual needs.

Very few systems have attempted to generate circuit problems randomly. Yoshikawa *et al.* did so, but only for series/parallel combinations of resistors, inductors, and capacitors, and not in more general cases [8]. Cristea *et al.* described a more general algorithm to create AC circuit problems whose solutions are integer values, but it is not clear if the resulting circuit graphs and element values were translated into actual circuit diagrams, as none are illustrated [9, 28]. It is also not clear if worked solutions (as opposed to numerical answers) were generated.

2. Fully worked solutions and answers to the randomly generated problems are produced automatically, using the same methods used in textbooks, such as node and mesh analysis, superposition, source transformations, and Thévenin and Norton equivalents. Most prior systems require manual solution generation by developers or instructors as noted above, which can be subject to error. Existing tools such as PSPICE, etc. typically used modified nodal analysis for solutions, which is not a method normally taught in introductory circuit analysis courses.

3. Very importantly, our system is step-based, and accepts a large variety of student input types. Equations are accepted and evaluated using a special template-based system, and simplified forms of the equations and matrix equations can also be entered (with both real and complex values). Numerical answers and multiple choice answers are also accepted. Important unique features are the interactive waveform sketcher (which is currently being adapted to sketch asymptotic Bode plots also) and circuit drawing and editing modules described below. We do not currently use any natural language dialogs, provide for virtual laboratory experiments or simulations [6, 11, 12, 29], or accept algebraic expressions as final answers [17-19, 25], though a generalization to the latter is possible.

Most existing systems accept only multiple choice or short answers [5, 6, 11-13, 16, 27], numerical answers [6, 18, 19, 23-25, 30], or equations [10-12, 17-19, 25, 26, 31]. Solution of complex circuit analysis problems may however involve re-drawing the circuit diagram (as in superposition, source transformations, Thévenin and Norton equivalents, etc.). A

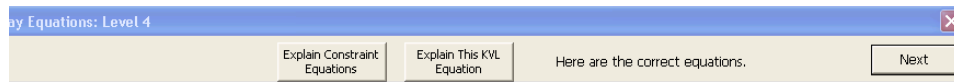
complete step-based tutor therefore requires that students have the ability to do that interactively, as we provide. Further, certain problem types involve sketching expected waveforms or Bode plots, so the ability to accept those inputs is also important.

4. Another unique feature of our system is the use of certain pedagogical devices, such as color coding of nodes to facilitate identification of elements in parallel, and color coding of equation terms and placement of correspondingly colored arrows or voltage drops on a circuit diagram to help show the origins of KCL or KVL equations. The integration of equations into circuit diagrams [32] and the use of color-coding for different quantities such as currents and voltages [33] has been studied, but we know of no other software that uses these devices.

5. A special feature of our system is that we offer both fully worked examples (with detailed explanations) as well as interactive problems of the same type, where the student must supply all steps. Both examples and problems are typically available at several progressively increasing levels of difficulty. This feature avoids the typical student complaint for textbook examples that the “problems are nothing like the examples!” The student is typically allowed to select an appropriate starting level (within certain limits), so that strong students are not required to solve problems that are trivial for them, and weaker students can progress at a gentler pace. The system advises (but does not force) students to view examples or descend to an easier level if they make too many mistakes. Further, any problem can be converted to a fully worked example by “giving up” at any point, after which a new problem of the same type and difficulty will be offered to the student. Most existing systems seem to offer only problems, without examples. It is well established that inclusion of both examples and corresponding isomorphic practice problems improves learning [34-36]. In particular, learning from examples is important in the early stages of learning, specifically in the first stage and early part of the second of four stages in the schema of Anderson *et al.* [37]. In later stages, problem solving practice becomes more important [37]. While it is not currently implemented, we could incorporate a fading strategy into our program, where worked examples gradually become less and less complete and require students to fill in the missing portions [38].

6. Our system aims to cover essentially the complete content of a typical introductory linear circuits course, though a number of areas are not yet included. Many other systems have been limited prototypes, sometimes covering only a narrow range of topics [16, 26], though some systems have been more comprehensive [6, 18, 19, 25].

7. A number of prior studies have developed intelligent tutoring systems in this area, which generally feature both an expert system and a student model (ideally including typical “bugs” or mal-rules) [5, 6, 8-10, 27, 28, 31]. Such a system typically adjusts the problems and content according to the student model, to adapt to individual students. Our system currently uses a limited amount of adaptation, but it logs and stores all student actions in the system to a central server, and it can automatically generate problems of any desired difficulty



Each colored +/- symbol pair corresponds to a term in KVL equation #1 of 1.

Current constraint equations:

$$I_1 - I_2 = 3\angle 0^\circ \text{ A}$$

KVL equations for each mesh or supermesh:

$$I_1(9\ \Omega) + I_2(3\ \Omega) + (3\ \Omega)I_x + I_2(-j5\ \Omega) + 2\angle 0^\circ \text{ V} + I_1(j2\ \Omega) = 0$$

Equations for control variables of dependent sources:

$$I_x = -I_1$$

Simplified mesh equations:

$$\begin{array}{rcl} 1\ I_1 & -1\ I_2 & +0\ I_x = 3\angle 0^\circ \\ (9+j2)\ I_1 + (3-j5)\ I_2 & +3\ I_x & = 2\angle 180^\circ \\ 1\ I_1 & +0\ I_2 & +1\ I_x = 0 \end{array}$$

Matrix form of mesh equations:

$$\begin{bmatrix} 1 & -1 & 0 \\ 9+j2 & 3-j5 & 3 \\ 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_x \end{bmatrix} = \begin{bmatrix} 3\angle 0^\circ \\ 2\angle 180^\circ \\ 0 \end{bmatrix}$$

Sought variable equations:

Finding the voltage V_o across the I_1 current source is tricky, because the voltage across a current source is whatever it needs to be. Therefore, we need to sum all voltage drops from one end of this source to the other using a path that does NOT go through the current source, and use KVL.

The drops are considered positive if they have the same polarity as the desired voltage, or negative if they are reversed. We choose to do this on the side where the resulting expression will be the simplest, using mesh #1.

$$V_o = I_1(9\ \Omega) + 2\angle 0^\circ \text{ V} + I_1(j2\ \Omega)$$

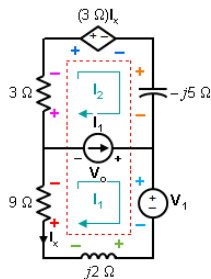
Solution:

$$V_o = 17.78\angle -30.41^\circ \text{ V}$$

$$I_1 = 1.745\angle -46.55^\circ \text{ A}; \quad I_2 = 2.201\angle -144.9^\circ \text{ A}; \quad I_x = 1.745\angle 133.5^\circ \text{ A}$$

Compute the following quantity for this circuit:

V_o



$$V_1(j\omega) = 2\angle 0^\circ \text{ V}$$

$$I_1(j\omega) = 3\angle 0^\circ \text{ A}$$

Fig. 1. Automatically generated steady-state AC circuit problem, showing the computer-generated equations and solution and the interface where the student can request detailed explanations. The dashed red line illustrates a supermesh, and the voltage drops around it are currently labeled and color-coded to match the terms in the corresponding KVL equation.

and complexity. Thus, a more intelligent system could later be built on top of our problem generation and user input engines. Such a system would then feature a wide “bandwidth,” in the language of intelligent tutoring systems, because of the highly detailed inputs it is able to accept at each stage of a student’s work.

8. A key distinguishing feature of our study is the use of controlled experiments using random assignment of students to different conditions and rigorous tests for statistical significance of our results. No formal evaluation has been described for many existing systems [5, 8, 9, 16, 23, 27, 28, 30], and in some cases they do not appear to have been tested with students. Weyten *et al.* found no statistically significant effect on performance [17]. Oakley performed a quasi-experimental study of his system that found improved course grades and lower drop rates, but did not report statistical significance or any measure to ensure that the experimental and control sections of the class were equivalent in terms of average GPA or test scores [19]. Butz did report detailed statistical analysis in a quasi-experimental study on several cohorts, and found significant improvements on several output measures [6, 7]. It is unfortunate that Oakley’s and Butz’s systems are no longer apparently in use. However, no prior study of a practical computer-aided instruction system in this

area has reported a controlled, randomized trial of their system, which is the most reliable way to validate effectiveness.

In comparison to prior work, our system therefore has some significant distinguishing features such as random generation of an unlimited supply of problems of any desired difficulty, automatic solution generation, a user interface that accepts a fully variety of student inputs for step-based tutoring, special pedagogical features, wide planned scope, and evaluation using controlled, randomized experiments.

III. PROBLEM AND SOLUTION GENERATION

For randomly generated problems to be useful, they should have characteristics similar to those usually found in textbooks. Those characteristics have been described in detail elsewhere [1], but involve ensuring that the problems are soluble (not inconsistent), do not typically contain elements that are shorted or “dangling” (except when desired for specific pedagogical purposes), and do not contain elements that are “redundant” (i.e., whose presence has no effect on the rest of the circuit). Elements in series with ideal current sources or in parallel with ideal voltage sources are in the latter category. More generally, we do not normally want a circuit to be “hinged,” meaning that we should not be able to draw it in a way that two or more

portions are connected only by a single wire. In that case, the separate portions are essentially independent circuit problems (unless connected by dependent sources whose control variables are in the other portion, or by magnetic coupling). The “sought quantity(ies)” or unknown variables for which the student is asked to solve should further usually be chosen in a way that they are not trivial to determine. For the sake of graphical convenience, we allow only planar circuits, and require that they be laid out on a square grid.

For even moderately complex circuits, random placement of elements on such a grid will produce a valid circuit only an extremely small fraction of the time, which is not a practical method. The algorithm of Cristea *et al.* can generate valid netlists [9, 28], but a suitable layout must then be devised, and there does not appear to be any guarantee that the circuit will be planar as required for mesh analysis. We have instead opted to generate the layout directly rather than the netlist, which is a

The goal is to find the inverse Laplace transform of the function,

$$\mathbf{F}(s) = \frac{5(s+40)}{(s+10)(s^2+10s+29)}.$$

The first step is to factor the quadratic terms in $\mathbf{F}(s)$. For the general quadratic equation $as^2 + bs + c = 0$, the roots are given by:

$$s_{1,2} = \frac{-b}{2a} \pm \sqrt{\left(\frac{b}{2a}\right)^2 - \frac{c}{a}},$$

which implies

$$(s - s_1)(s - s_2) = 0.$$

For $s^2 + 10s + 29 = 0$, we have

$$\begin{aligned} s_{1,2} &= \frac{-(10)}{2} \pm \sqrt{\left(\frac{10}{2}\right)^2 - 29} \\ &= -5 \pm j2. \end{aligned}$$

So,

$$s^2 + 10s + 29 = (s + 5 - j2)(s + 5 + j2).$$

Therefore, $\mathbf{F}(s)$ can be written in factored form as

$$\mathbf{F}(s) = \frac{5(s+40)}{(s+10)(s+5-j2)(s+5+j2)}.$$

The inverse Laplace transform is obtained by expressing $\mathbf{F}(s)$ in a partial fraction expansion:

$$\mathbf{F}(s) = \frac{k_0}{s+p_0} + \frac{\mathbf{k}_1}{s+\mathbf{p}_1} + \frac{\mathbf{k}_1^*}{s+\mathbf{p}_1^*},$$

where $p_0 = 10$, $\mathbf{p}_1 = 5 - j2$, and $\mathbf{p}_1^* = 5 + j2$.

Note: * denotes the complex conjugate of a complex number and $-p_0, -p_1$, etc. are the poles of $\mathbf{F}(s)$.

The values of \mathbf{k}_i 's are obtained as follows:

$$\mathbf{k}_i = (s + p_i)\mathbf{F}(s) \Big|_{s=-p_i}.$$

Therefore,

$$\begin{aligned} k_0 &= \cancel{(s+10)} \frac{5(s+40)}{\cancel{(s+10)}(s+5-j2)(s+5+j2)} \Big|_{s=-10} \\ &= \frac{5(-10+40)}{(-10+5-j2)(-10+5+j2)} \\ &= \frac{5(30)}{(-5-j2)(-5+j2)} \\ &= 5.1723 \end{aligned}$$

Fig. 2. Portion of an automatically, randomly generated and worked example of an inverse Laplace transform (web-based).

bit more complex but avoids the layout step. The layout generation is performed in three separate steps as described elsewhere [1]. **Step 1:** We start with a “topology” composed only of open and short circuits, where some of the shorts later become circuit elements but the opens remain open. The topology may not be hinged or have dangling segments, and determines the number of meshes. **Step 2:** Generic circuit elements are then substituted for the required number of short circuits, taking care to place at least two elements on each mesh, including the “outer mesh,” so that nothing is shorted. A second check for hinging is made. **Step 3:** A tree of the resulting layout is chosen at random, and voltage sources and inductors substitute for generic elements on the twigs of that tree, while current sources and capacitors are placed on its links. Resistors (or all passive elements, in the AC case) can be placed anywhere. Sought quantities and dependent source control variables are then selected randomly in accordance with desired specifications and certain rules. This procedure is a sufficient but not necessary method to avoid situations that might violate Kirchoff’s laws and create inconsistencies (other than those due to dependent sources). Since dependent sources can still cause problems, the circuit is checked for solvability and rejected if necessary, but few iterations are usually needed.

Node and mesh equations are then generated automatically, using supernodes and supermeshes as needed, and can be re-written for any user specified choice of ground in the nodal case. Equations for the sought branch currents, branch voltages, branch powers, and/or non-branch voltages are also generated. Doing so can require the use of KCL or KVL in the case of current sources in node analysis or voltage sources in mesh analysis, respectively, for which a complete textual explanation is generated. Users can select any particular KCL or KVL equation to highlight, in which case individual current arrows leaving a node or supernode or individual voltage drops around a mesh or supermesh are placed on the diagram and color-coded to match specific terms in the equation, as illustrated in Fig. 1 for an AC circuit. Note that AC circuits can be generated directly in the phasor domain, or starting in the time domain. In the latter case, the student is first required to convert element values to impedances at the specified frequency before

proceeding with the analysis. We are currently extending the analysis routines to handle reactive elements appropriately for DC circuits, as a pre-requisite to solving transient problems in the $t < 0$ or $t = \infty$ steady-state cases.

IV. NEW WEB-BASED MODULES

A. Laplace Transforms and Inverse Transforms

A recently added module in our system addresses the mathematical aspects of performing direct and inverse Laplace transforms. This module is entirely web-based, using PHP for the server portion with HTML5 and JavaScript for the client side and no plug-ins of any kind. The entire module can be accessed from mobile devices as well as PCs. The first portion involves an interactive tutorial (with multiple choice questions at each step), illustrating the definition and application of the transform integral, along with an explanation of the transform concept as that of an “avatar” that represents the time-based function in a parallel universe, the s -domain. The student is led through a typical derivation of a transform, and supplied with a detailed transform table, where clicking on any entry in the table leads to a detailed derivation of a given transform pair. A second table summarizing the properties of the transform is provided, and the two tables can be invoked in a separate browser tab for reference at any time. The student is then led to an example generator, which creates fully worked examples for all of the common transform types. We have provided a high level of detail so that students can readily understand the procedure.

For the inverse transform case, the system again generates fully worked examples showing partial fraction decompositions in great detail, as partially illustrated in Fig. 2. Both simple and complex conjugate poles are handled automatically (multiple poles to be added soon). The process is spelled out in a higher level of detail than in most textbooks.

The next step is interactive exercises, where students are asked to work similar problems themselves. The equation entry interface will be template based,

similar to what we use in the VB6 portion of our system, and is currently under development. The student will then be required to complete a certain number of exercises of gradually increasing complexity of each type, leading to mastery-level comprehension.

B. Waveform Sketching

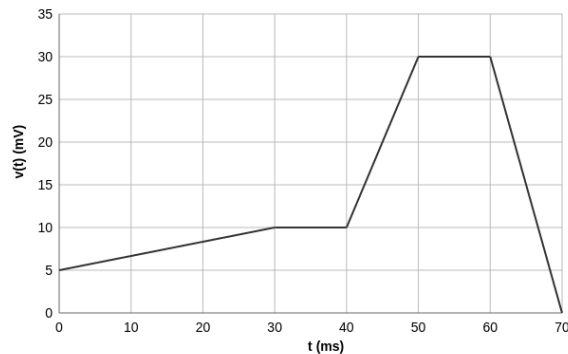
In studying reactive elements such as capacitors and inductors, students are often asked to relate the current or voltage as a function of time to the opposite quantity. This process involves graphical integration or differentiation, which often poses significant problems for students. To help them overcome this difficulty, we provide examples of such

Capacitors and Inductors

Question 2.7.1 (ID 225)

Section 2 of 3

The voltage across a $20\ \mu\text{F}$ capacitor is shown below. Find the current through the capacitor from 0 to 70 ms.



Solution:

First write the expression for the above graph:

► Expression Details

- The voltage is a ramp from 0 to 30 ms with a slope

$$m = \frac{\Delta v}{\Delta t} = \frac{10\text{ mV} - 5\text{ mV}}{30\text{ ms} - 0} = 0.167\text{ mV/ms} = 0.167 \times 10^{-3}\text{ V}/10^{-3}\text{ s} = 0.167\text{ V/s} = 0.167\text{ V/s}.$$

The voltage intercept is 5mV. Thus,

$$v(t) = (0.167\text{ V/s})t + 5\text{ mV} \quad 0 \leq t \leq 30\text{ ms}.$$

- The voltage is constant from 30 ms to 40 ms, so

$$v(t) = 10\text{ mV} \quad 30\text{ ms} \leq t \leq 40\text{ ms}.$$

► Detailed Solution

For $0 \leq t \leq 30\text{ ms}$,

$$\begin{aligned} i(t) &= C \frac{dv(t)}{dt} \\ &= (20\ \mu\text{F}) \frac{d}{dt} [(0.167\text{ V/s})t + 5\text{ mV}] = (20\ \mu\text{F}) (0.167\text{ V/s}) \\ &= (20 \times 10^{-6}\text{ F}) (0.167\text{ V/s}) = 3.34 \times 10^{-6}\text{ C/s} \\ &= 3.33\ \mu\text{A}, \end{aligned}$$

because $C = \text{F V}$ and $\text{A} = \text{C/s}$.

For $30\text{ ms} \leq t \leq 40\text{ ms}$,

Fig. 3. Portions of a web-based example in the waveform sketcher module. (Several portions have been omitted for brevity. The actual solution describes every portion of the waveform.)

randomly-generated problems of various types, worked in great detail as illustrated in Fig. 3. The problem was created and solved automatically by the system, including the final sketch of the current waveform (not shown). Once students have viewed examples, they will be asked to work very similar problems using the interactive waveform sketcher module we described previously [2-4]. At any point, they will be able to give up if necessary and view the computer generated solution, but then be given a different problem of the same type to solve. More generally, the student can be asked to sketch a waveform for various quantities like charge, current, voltage, power, or stored energy.

V. CONTROLLED, RANDOMIZED EVALUATIONS

To date, two separate evaluations of software effectiveness have been performed. In the first, we used 33 student volunteers in a laboratory setting, all of whom were currently enrolled in our EEE 202 class at ASU or who had completed it within the last year. One qualitative and one quantitative topic were selected for study, namely identifying elements in series and parallel, and writing DC node equations, respectively. All subjects were administered a pre-test and post-test covering these areas, randomly assigning them to one of two similar test forms for either the pre-test or post-test. They were then randomly assigned to work problems from the textbook we normally use, selected to correspond as closely as possible to the subject areas, or to use our series-parallel identification or node equation tutorials for the same periods of time (25 minutes and 35 minutes, respectively). This test is an authentic one as assigning textbook problems is the method most often used now in our course. The pre- and post-test data is shown in Table I for the both experimental and control groups. The learning gain was about 10 \times higher for the group using the software. The difference was significant, $t(19.7) = 3.303$, $p < 0.05$ without assuming equal variances, and the Cohen d -value (effect size) was 1.21 pooled standard deviations (σ), a large effect. A motivational survey administered in this experiment also yielded better results for the software condition, with an effect size of 0.91 σ ($p < 0.05$).

To further compare our software with existing algorithmic homework systems, we randomly assigned students in one section of EEE 202 at ASU in Fall 2014 to either a) use the step-based Circuit Tutor system for node analysis problems (using both the node equation writing tutorial and a second tutorial in which they must perform a complete numerical solution of the node equations as well), and use a commercial answer-based homework system to work mesh analysis problems; or b) use Circuit Tutor for mesh analysis problems (using both the mesh equation tutorial and a complete equation solution tutorial), and the commercial system for node analysis problems. The problems in the publisher-based commercial system were algorithmic versions of end-of-chapter problems in the corresponding textbook, and were selected to be very similar to the problems assigned in the Circuit Tutor tutorials. The above required assignments counted towards their homework grade (20% in total of the course grade). There were five required problems on each topic in the commercial system, and six or more required problems in Circuit Tutor (depending on the level at which students start, and how many

Table I. Controlled, Randomized Laboratory-Based Study of Learning Gains.

	Exptl. Group	Pre-Test Score	Post-Test Score	Gain
Average	Textbook	58.6	61.6	2.9
Median	Textbook	60.5	67.0	1.5
Std. Dev.	Textbook	25.3	28.0	14.1
Average	Software	57.8	86.4	28.6
Median	Software	57.0	85.0	30.0
Std. Dev.	Software	22.1	11.5	14.9
Std. Dev.	Pooled	23.0	20.5	14.1

problems they give up on), though they had to work out complete numerical solutions in all of the commercial system problems but only in two or more of the Circuit Tutor problems. In the commercial system, students were allowed up to four attempts to enter the correct numerical answer (with the same element values each time), and received full credit for any correct answer. Circuit Tutor gives feedback after every step (an equation has been entered, simplified equations have been entered, the matrix equation has been entered, or the final numerical answers have been entered), and allows multiple attempts on numerical entries. It provides a fully worked solution to any problem if a student gives up, with no penalty (but requires working a new problem of the same type). It further allows students to view any number of worked examples at any level of difficulty.

The average assignment scores, taken as a measure of successful completion, were 40.2/50 on Circuit Tutor and 33.6/50 in the commercial system, with standard deviations of 16.2 and 15.9, respectively. (These figures combine the node and mesh assignment scores.) The difference is significant with $p < 0.008$, and the effect size is $d = 0.41 \sigma$. Further, a full 64% of the Circuit Tutor users obtained 100% of the credit on their assignment, whereas only 26% of the commercial system users did. Moreover, after the due date of the required assignment, both groups (each of whom had used Circuit Tutor for one of the two topics, and the commercial system for the other) were given access to the system they were not originally assigned to use for each topic, to permit additional voluntary work (for no additional credit). Of the group assigned to use the commercial system for a given topic, fully 32% or 34% of them voluntarily completed at least one tutorial level in Circuit Tutor, and of those doing so, the average number of levels completed was 6.5 of an available 10. Further, 16% or 17% of the students completed all available levels in Circuit Tutor voluntarily. On the other hand, no students at all completed any voluntary work at all in the commercial system. This difference indicates a clear preference of students for the Circuit Tutor system over the commercial one. Students were not specifically surveyed about their relative opinions of Circuit Tutor and the commercial system, but in open-ended comments, seven of them volunteered such a comparison, and all strongly favored Circuit Tutor over the commercial system. A sample comment was that "I like this much better than [commercial system name]!!! I feel like I learn more going through the circuits than being told I'm wrong for one flat answer." However, we consider a preference expressed by

Table II. Sample Verbatim Student Comments on Software from Spring 2014.

Series-Parallel Tutorial

- Wish Unit Games were available. Also wish that there were versions of circuit tutor for superposition, and other concepts. This Program taught me these concepts quickly and well.
- I understand the difference between series and parallel so much better now! Thanks!
- This game was brilliant and really helped me in understanding how to spot parallel and series circuit elements. I think there needs to be more resources like this.
- I really liked this game and the tutorial before the game. I think the tutorial explained things really well and I was able to get through the game quite easily. I learned a lot of series and parallel circuits that I didn't fully understand before doing this exercise. Very helpful! We should do more of these!
- If there were video tutorials, that'd be great instead of reading through textual information.
- Coloring the nodes was EXTREMELY helpful. I honestly would have never thought about doing that. Thanks for the help

Nodal Analysis

- More chances to write out an equation, as sometimes just making a simple sign error was the issue and could have been resolved on the following guess.
- I thought I had a good understanding of Nodal Analysis but this exercise really helped
- Could have used this to study before exam.
- A tutorial at the beginning, like with the first module, would have been helpful.
- I liked how there was an option to view new circuits without penalty.

Mesh Analysis

- Cleared my confusion on Mesh Analysis. Thanks again! I hope you do other exercises on other circuit's topics (Thevenin .. etc)
- I like these games! They help drill the concepts in too :)
- More enjoyable than a standard HW.
- These are awesome!
- This was also very helpful in understanding this topic. Lots of great practice.

doing extra work to be much more significant than any survey response.

VI. CLASSROOM USAGE AND SURVEY STATISTICS

Our current system includes 15 tutorials that are available to students, covering identification of elements in series and parallel, writing both AC (phasor) and DC node equations

(including voltage constraint equations, supernodes, and dependent sources), and writing AC and DC mesh equations (including current constraint equations, supermeshes, and dependent sources). Another covers the effects of different types of terminals on series relationships (such as those used to measure voltage, "view" input impedance, or connect an arbitrary subcircuit). Others then teach students to combine resistors, inductors, capacitors, and general impedances in series and parallel, including complicated multi-step simplifications. Two new web-based tutorials focus on the mathematics of Laplace transforms, teaching students to perform direct and inverse transforms, including partial fraction decomposition with simple or complex conjugate poles. As of Spring 2015, our tutorials have been used (usually as required homework exercises) by over 1950 students in 42 class sections at Arizona State University, University of Notre Dame, University of the Pacific, Morgan State University, Messiah College, South Mountain Community College, and Chandler-Gilbert Community College. Testing has therefore involved a diverse set of institutions.

Each time a student completes a tutorial, we administer a simple two-question survey about their experience. First, we ask them how useful the software was in learning the assigned topic, with possible responses of "very useful," "somewhat useful," "not very useful, or "a waste of time." The percentage of each response has remained roughly constant at 70%, 25%, 2%, and 2%, respectively, for data from Spring 2013 through Fall 2014. The percentage of students rating them as very or somewhat useful is therefore about 96%. We also collect open-ended comments, which have mostly been very favorable (Table II). Students particularly like the coloring of the nodes and the way in which that helps them visualize the circuit nodes. The main request has been to expand the topical coverage, which we are in the process of doing. Students often comment that the system helps build their confidence, that they like the gradual increase in exercise difficulty, that they appreciate not being penalized for wrong answers, and that they appreciate the detailed explanations that are available.

We also administered a more detailed, 12 question survey to those who used the software in Fall 2013 through Fall 2014. The survey used a four-point Likert scale to gauge whether the software was useful and well-designed, whether the difficulty and coverage are appropriate, and whether it is preferred over conventional homework assignments. The average favorable ratings in these categories were 87%, 85%, and 78%, respectively. Ratings by students at Notre Dame were uniformly higher than those at ASU, suggesting that the software can be employed usefully at institutions of different types. Favorable results were also found for Morgan State University students, though they tended more to feel that the difficulty and length of the exercises was too high.

VII. CONCLUSIONS

Our computer-based interactive tutorial system now includes 15 tutorials and features an improved, highly capable graphical circuit editor, the ability to generate and solve AC circuits using phasor analysis in addition to DC circuits, and a fully developed web-based waveform sketching tool that can assess the correctness of student drawings. At the same time,

usage of the system has been expanded to many more class sections both at ASU and several other universities and community colleges. High levels of student satisfaction have been achieved. A large quantity of log file data is being analyzed and used to iteratively refine the existing tutorials, with the eventual objective of achieving “perfect learning” of the covered topics by all students. New tutorials are also under development.

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Implementation of an Intelligent Tutoring System using Moodle

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Abstract—The paper presents the implementation of an Intelligent Tutoring System. The paper consists of two sections. The first section describes the framework of the Intelligent Tutoring System. In this framework, the elements of course design are identified as competencies, instructional activities and assessments. These elements are aligned using a tool called the Taxonomy Table. The second section describes the implementation. The system has been implemented on top of the Learning Management System Moodle. Prior to implementation, a study of the parameters required in a Learning Management System to build an Intelligent Tutoring System on top of, was carried out; and an evaluation of two open source Learning Management Systems was performed, which led to the decision to build the tutoring system using Moodle. Subsequently, the implementation of the expert, tutoring and student modules using Moodle are presented.

Keywords—Intelligent Tutoring Systems, Learning Management Systems, Moodle

I. INTRODUCTION

Intelligent Tutoring Systems (ITS) are computer applications that provide one-on-one instruction to students and aim to identify their shortcomings.

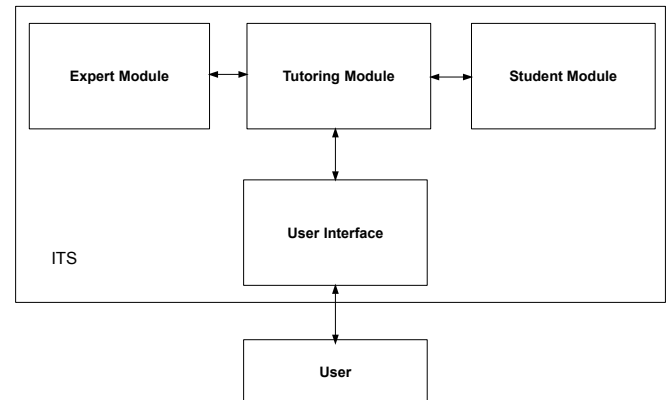


Fig. 1: Structure of an ITS

ITS typically consist of four modules as shown in Figure 1: [3] the Expert Module, which comprises of facts and rules of the particular domain to be conveyed to the student; the Tutoring Module, which designs and regulates instructional interactions with the students; the Student Module, which is a dynamic representation of the students current state of knowledge; and the User Interface, which controls interaction between the student and the system. Implementation of ITSs have been carried out in numerous ways, using technologies such as LISP, CGI and others. In this paper, we present the implementation of an ITS built upon the Learning Management System Moodle. Learning Management Systems take care of creation, delivery and management of content and assessments. They help to manage grades more consistently and efficiently. They also help in ensuring compliance of the e-learning content to standards such as SCORM, AICC and IMS. While the initial learning curve in using an LMS can be high, instructors soon realize that this is a one-time effort. Effective usage of an LMS can reduce the effort spent on administrative activities, thereby enabling the instructor to put increased focus in teaching and associated core activities. For example, with the right LMS content creation (both

instructional content and assessments) for a course can be a one-time activity, with incremental updates to content during subsequent offerings of the course. Because of these advantages, the use of such systems has become nearly ubiquitous, and institutions and corporates support them for both their pedagogical and administrative benefits [2].

Some of the popular LMSs are Blackboard, Desire2Learn, Moodle, ATutor and Sakai among others. The decision as to which LMS to use can be a challenging one and is based on many factors. Different organizations have different needs from an LMS. These needs dictate the factors that govern the choice of a LMS and the relative priorities of these factors. For example, corporates use LMSs typically to conduct training programmes that last between a day and a month, whereas educational institutions typically have courses which last for longer duration (e.g., a semester). Even within educational institutions, different kinds of institutions have different needs. For example, a medical institution would need to store specialized content such as videos of surgery and radiology images [4], where an engineering college would require content which would include presentations, documents and so on.

The paper has been divided into two parts, an overview of the framework of the ITS and the implementation based on the stated framework.

II. FRAMEWORK OF ITS

In this work, framework for an ITS has been defined. The framework is based on the premise that good course design consists of three elements: competencies, instructional activities and assessments [8]. A competency, also referred to as learning outcome, learning objective, instructional objective etc., is defined as an effective ability, including attributes, skills and knowledge, to successfully carry out some activity which is totally identified [8]. Instructional activities are activities used to facilitate students to acquire the competencies. Assessment Items are used to collect information about the students acquisition of the competencies. It utilizes a tool called the Taxonomy Table [7], which checks alignment of the elements based on Cognitive Level and Knowledge Category [8]. Tutoring rules have been designed based on the alignment of the elements. Tutoring rules are course-specific. The course on which the student is tutored is developed based on this framework.

The tutoring system consists of an instructional activity, presenting a formative assessment instrument of the lesson, evaluating the response of the student, and guiding (tutoring decision) the student to the next stage based on her performance. Taxonomy table is a table of six cognitive levels and eight categories of knowledge. The competencies of a course are located in the cells of its taxonomy table. Instructional activities and assessments aligned with competencies are located in the same cells or cells associated with lower cognitive levels and the same category of knowledge.

As discussed, the course is defined in terms of competencies. Each competency has associated with it a single Unit-of-Learning. Therefore, Competency C_i has associated with it UOL_i , where 'i' indicates the index of the competency. For example, consider competency C_1 . C_1 will have a Unit-of-Learning UOL_1 . This is as depicted in Figure. UOL_i consists of 'k' Units-of-Study ('k' varying from two to six) that

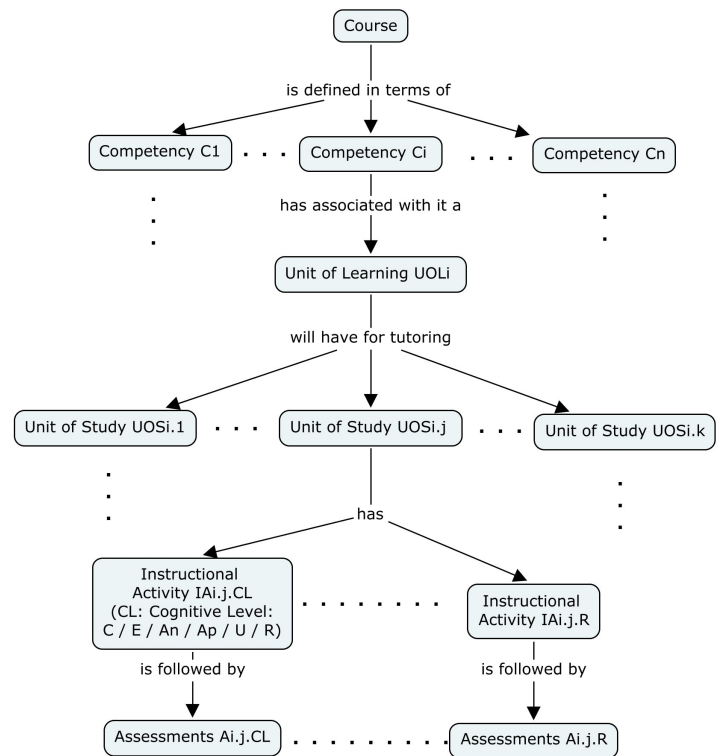


Fig. 1. Expert Module of ITS

are denoted as $UOSi,j$, where 'j' indicates the index of the Unit-of-Study. The Units-of-Study may belong to different cognitive levels than that of the Unit-of-Learning. $UOSi,j$ consists of several Instructional Activities for all cognitive levels pertaining to $UOSi,j$. These Instructional Activities are denoted as IAi,j,CL where i,j is the index of the Unit-of-Study and CL is the cognitive level that the Instructional Activity addresses. For example, assume UOL_i has associated with it Units-of-Study $UOSi.1$ belonging to Understand / Procedural, $UOSi.j$ belonging to Apply / Procedural, $UOSi.k$ belonging to Apply / Procedural. Each of these have associated with them Instructional Activities as follows:

- 1) $UOSi.1$ has Instructional Activities $IAi.1.U$ belonging to Understand and Instructional Activity $IAi.1.R$ belonging to Remember.
- 2) $UOSi.j$ has Instructional Activities $IAi.j.Ap$ belonging to Apply, Instructional Activities $IAi.j.U$ belonging to Understand and Instructional Activity $IAi.j.R$ belonging to Remember.
- 3) $UOSi.k$ has Instructional Activities $IAi.k.Ap$ belonging to Apply, Instructional Activities $IAi.k.U$ belonging to Understand and Instructional Activity $IAi.k.R$ belonging to Remember.

Figure 1 describes the framework of the Expert Module of the ITS.

We have taken into consideration the course Data Structures designed for an undergraduate course in engineering.

III. DETAILS OF IMPLEMENTATION

Moodle is a Free and Open Source LMS. Moodle is designed to provide educators, administrators and learners

with a single robust, secure and integrated system to create personalized learning environments and is guided by social constructionist pedagogy. As it is an Open Source System, Moodle allows a high level of extensibility at all levels. Moodle is implemented using the LAMP stack with the front end using PHP, back end using MySQL and the web server Apache. The following sections explain the implementation of the Expert, Tutoring and Student Modules using Moodle.

A. Expert Module

In this framework of the Intelligent Tutoring System, the Expert Module consists of representation of the competencies, instructional activities and assessments and their alignment. Each of these elements are represented in Moodle as follows.

1) *Competencies*: Moodle incorporates a module called the "Outcomes" Module. Outcomes are specific descriptions of what a student has demonstrated and understood at the completion of an activity or course. They may also be termed as Competencies or Goals. Outcomes can be enabled using the Site Administration > Advanced Features. Specific Outcomes can be added under Course Administration > Grade Administration > Outcomes as shown in Figure 2. Figure 3 is the list of complete outcomes uploaded to the course.

2) *Instructional Activities*: The Expert Module consists of Instructional Activities which are named and tagged appropriately. Instructional Activities may be of several different types, including Webpages, Files, Books, IMS content packages, Labels, Pages and URLs. Not all aspects of instructional activities may be accessed by the student at all times. In fact, some aspects of instructional activities may never be accessible to students. Therefore, instructional activities which are not to be accessed at a particular time are restricted from access by the student. Internal information such as cognitive level, knowledge category are added to the description section. This information is not revealed to the student so as to avoid confusing the student with too much information.

3) *Assessments*: The Expert Module consists of Sets of Assessment Items, pertaining to every cognitive level of each Unit of Study. Assessments are represented using the question types amenable to automatic assessment available in the Question Bank (available in Course Administration > Question Bank). The Sets of Assessment Items are represented using the Categories feature of the Question Bank Module, available in Course Administration > Question Bank > Categories. For the sample course on Data Structures, at the highest level namely the competency level a category is created for each Competency / Unit of Learning as shown in Figure 4.

Further, each Unit of Learning consists of several Units of Study. A category is created for each Unit of Study as shown in Figure 5.

Subsequently, each Unit of Study consists of several sets of items. Each set at the first level in the UOS consists of several sets of items pertaining to a particular cognitive level. Let us consider UOS1.1, UOS1.2 and UOS1.3, which belongs to the cognitive levels Understand, Apply and Apply respectively. Therefore, UOS1.1 has categories [A1.1U] and [A1.1R]; UOS1.2 has categories [A1.2Ap], [A1.2U] and [A1.2R], and UOS1.3 has categories [A1.3Ap], [A1.3U] and [A1.3R] as follows in Figure 6.

Subsequently, each set of assessment items consists of several sets that consist of items of a similar type. For example, let us consider the sets of problems in [A1.2Ap].

[A1.2Ap] consists of 9 sets of items, namely {A1.2Ap1}..{A1.2Ap9}. These are stored as separate categories as shown in Figure 7.

Each category at the lowest level consists of questions (items) which belong to a similar type.

B. Tutoring Module

The tutoring rules are implemented primarily by restricting access to different instructional activities and assessments based on the current performance of the student. In order to do that, the "Restriction" settings must be enabled under Site Administration > Advanced features > Enable conditional access and Site Administration > Advanced features > Enable.

1) *Sets of Assessment Items*: Subsequently, each Unit of Study consists of several sets of sets of items. Each set at the first level in the UOS consists of several sets of items pertaining to a particular cognitive level. Let us consider UOS1.1, UOS1.2 and UOS1.3, which belongs to the cognitive levels Understand, Apply and Apply respectively. Therefore, UOS1.1 has categories [A1.1U] and [A1.1R]; UOS1.2 has categories [A1.2Ap], [A1.2U] and [A1.2R], and UOS1.3 has categories [A1.3Ap], [A1.3U] and [A1.3R] as in Figure 8.

Subsequently, each set of assessment items consists of several sets that consist of items of a similar type. For example, let us consider the sets of problems in [A1.2Ap]. [A1.2Ap] consists of 9 sets of items, namely {A1.2Ap1}..{A1.2Ap9}. These are stored as separate categories.

Each category at the lowest level consists of questions (items) which belong to a similar type.

2) *Tutoring Rules*: Assessments are delivered using the "Quiz" module. Using these settings, quizzes may be restricted based on the level upto which the student has completed a task. Each set of assessment items at the lowest level of hierarchy has a quiz associated with it. Let us consider the set of items {A1.2Ap1}, which belongs to the superset [A1.2Ap], which is a set of sets of items belonging to cognitive level Apply associated with UOS1.2. An assessment instrument is created to deliver a representative problem $a \in \{A1.2Ap1\}$ by creating a Quiz from the activity menu.

Upon creating the quiz, prior to adding items to the quiz, the following settings are set appropriately.

- *Adaptive settings*: The adaptive settings ensure that the students' previous items of a quiz are taken into account while delivering representative items of a set. For example, if a student attempts a representative problem $a \in \{A1.2Ap.1\}$, and does not perform satisfactorily, he is redirected to attempt a representative problem from the pre-decided set {A1.2U.1}. Upon performing satisfactorily in the representative item $a \in \{A1.2U.1\}$, he is redirected back to {A1.2Ap.1} but this time, must attempt a different representative item from the item attempted earlier. Enabling these settings (in combination with the random question selection explained subsequently) ensures that the student

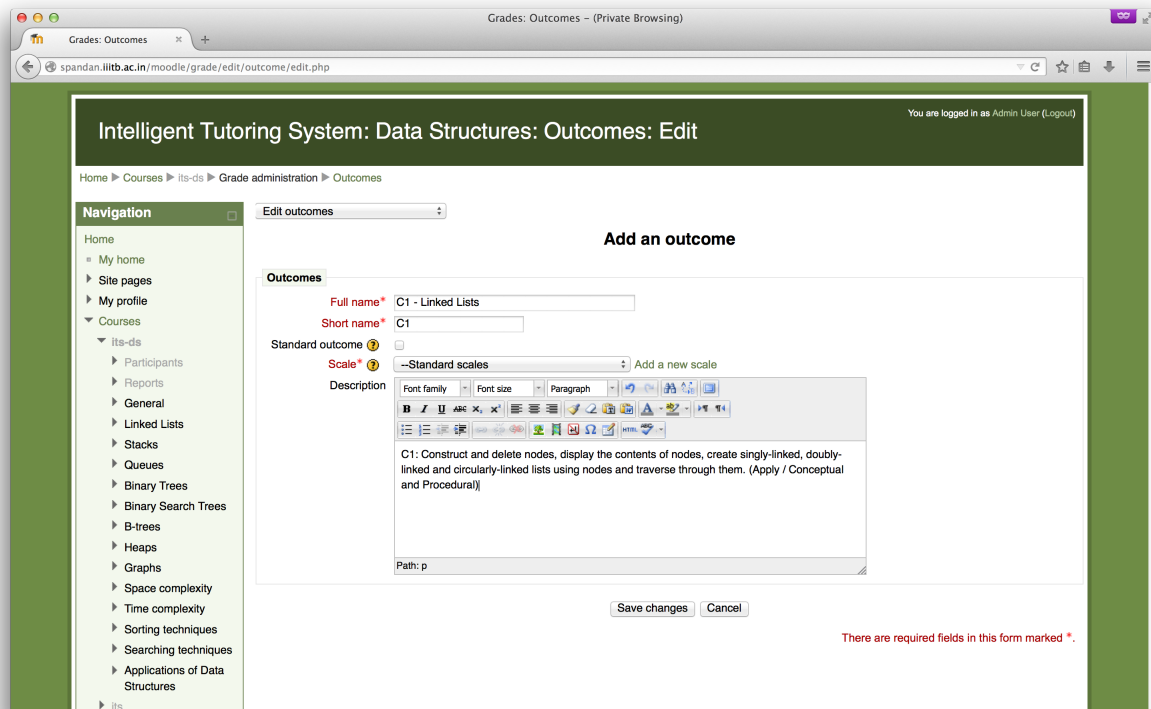


Fig. 2. Adding Competencies/Outcomes to Moodle

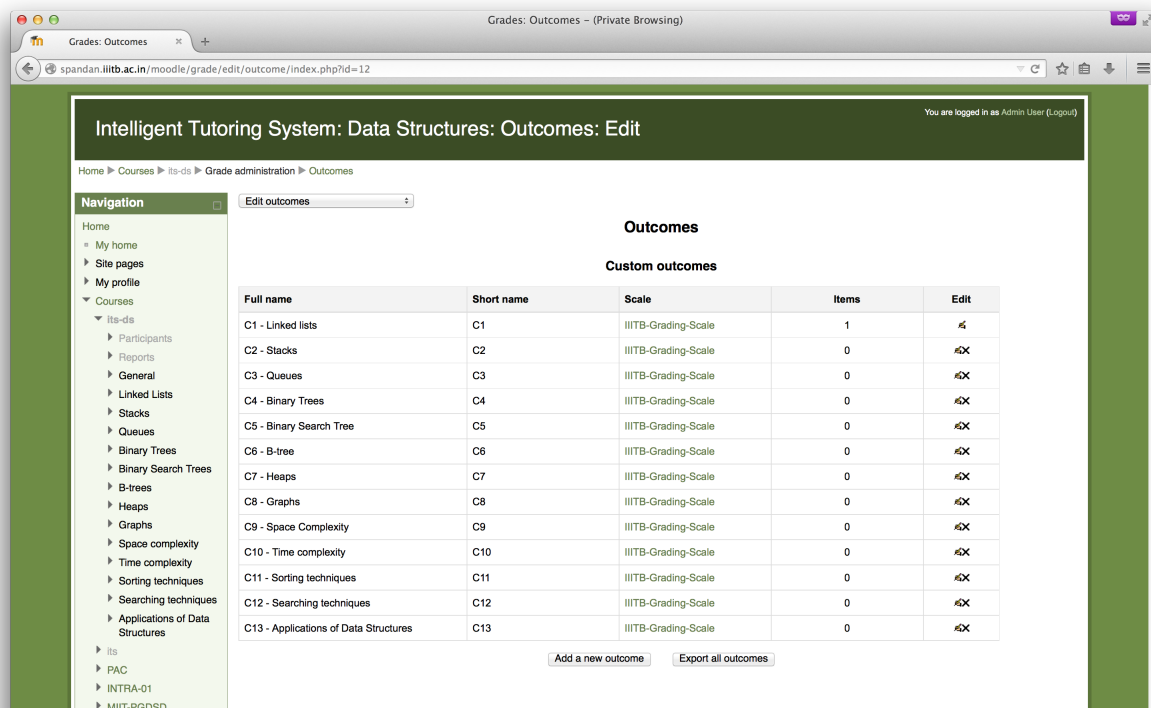


Fig. 3. List of Outcomes/Competencies

- C02 (0)
 - All sets pertaining to C02 - UOL02
 - C02: Construct, delete, push, pop values on stacks. (Apply/ Conceptual and Procedural)
 - ✕ ↻ ↕ ↗ ↘
- C03 (0)
 - All sets pertaining to C03 - UOL03
 - C03: Construct, delete, push, pop values on queues. (Apply/ Conceptual and Procedural)
 - ✕ ↻ ↕ ↗ ↘
- C04 (0)
 - All sets pertaining to C04 - UOL04
 - C4: Construct, modify, insert and delete nodes in a binary tree and perform pre-order, in-order and post-order traversal on the same. (Apply/ Conceptual and Procedural)
 - ✕ ↻ ↕ ↗ ↘
- C05 (0)
 - All sets pertaining to C05 - UOL05
 - C5: Construct, modify, insert and delete nodes in a binary search tree and perform pre-order, in-order and post-order traversal on the same. (Apply/ Conceptual and Procedural)
 - ✕ ↻ ↕ ↗ ↘
- C06 (0)
 - All sets pertaining to C06 - UOL06
 - C6: Construct, modify, insert and delete nodes in a B-tree and perform pre-order, in-order and post-order traversal on the same. (Apply/ Conceptual and Procedural)
 - ✕ ↻ ↕ ↗ ↘
- C07 (0)
 - All sets pertaining to C07 - UOL07
 - C7: Construct, modify, insert and delete nodes in a heap and perform pre-order, in-order and post-order traversal on the same. (Apply/ Conceptual and Procedural)
 - ✕ ↻ ↕ ↗ ↘
- C08 (0)
 - All sets pertaining to C08 - UOL08
 - C8: Model graphs in different forms including incidence and adjacency lists, and incidence and adjacency matrices. (Apply/ Conceptual and Procedural)
 - ✕ ↻ ↕ ↗ ↘
- C09 (0)
 - All sets pertaining to C09 - UOL09
 - C9: Determine the space complexity of different data structures. (Apply/ Conceptual)
 - ✕ ↻ ↕ ↗ ↘
- C10 (0)
 - All sets pertaining to C10 - UOL10
 - C10: Determine the time complexity for a specific operation on a data structure. (Apply/ Conceptual)
 - ✕ ↻ ↕ ↗ ↘
- C11 (0)
 - All sets pertaining to C11 - UOL11
 - C11: Implement sorting techniques including bubble, insertion, selection, merge, quick, heap sort. (Apply/ Procedural)
 - ✕ ↻ ↕ ↗ ↘
- C12 (0)
 - All sets pertaining to C12 - UOL12
 - C12: Implement searching techniques including linear, binary and hashing. (Apply/ Procedural)
 - ✕ ↻ ↕ ↗ ↘
- C13 (0)
 - All sets pertaining to C13 - UOL13

Fig. 4. Categories of Competencies

- C01 (0)
 - All sets pertaining to C01 - UOL01
 - C01: Construct and delete nodes, display the contents of nodes, create singly-linked, doubly-linked and circular lists using nodes and traverse through them. (Apply/ Conceptual, and Procedural)
 - ✕ ↻ ↕ ↗ ↘
- UOS1.1 (0)
 - All sets pertaining to UOL01 - Unit of Study UOS1.1
 - UOS1.1: Understand data types, pointers to memory locations and the parts of a node. (Understand / Conceptual)
 - ✕ ↻ ↕ ↗ ↘
- UOS1.2 (0)
 - All sets pertaining to C2 - UOS1.2
 - UOS1.2: Construct and traverse through linked lists. (Apply / Procedural and Conceptual)
 - ✕ ↻ ↕ ↗ ↘
- UOS1.3 (0)
 - All sets pertaining to UOL01 - Unit of Study UOS1.3
 - Use linked lists in various applications. (Apply/Factual, Procedural, Conceptual)
 - ✕ ↻ ↕ ↗ ↘

Fig. 5. Categories of Units-of-Learning

- C01 (0)
 - All sets pertaining to C01 - UOL01
 - C01: Construct and delete nodes, display the contents of nodes, create singly-linked, doubly-linked and circular lists using nodes and traverse through them. (Apply/ Conceptual, and Procedural)
 - ✕ ↻ ↕ ↗ ↘
- UOS1.1 (0)
 - All sets pertaining to UOL01 - Unit of Study UOS1.1
 - UOS1.1: Understand data types, pointers to memory locations and the parts of a node. (Understand / Conceptual)
 - ✕ ↻ ↕ ↗ ↘
 - A1.1U (0)
 - All sets of items pertaining to UOS1.1 at cognitive level Understand
 - ✕ ↻ ↕ ↗ ↘
 - A1.1R (0)
 - All sets of items pertaining to UOS1.1 at cognitive level Remember
 - ✕ ↻ ↕ ↗ ↘
- UOS1.2 (0)
 - All sets pertaining to C2 - UOS1.2
 - UOS1.2: Construct and traverse through linked lists. (Apply / Procedural and Conceptual)
 - ✕ ↻ ↕ ↗ ↘
 - A1.2Ap (0)
 - All sets of items pertaining to UOS1.2 at cognitive level Apply
 - ✕ ↻ ↕ ↗ ↘
 - A1.2U (0)
 - All sets of items pertaining to UOS1.2 at cognitive level Understand
 - ✕ ↻ ↕ ↗ ↘
 - A1.2R (0)
 - All sets of items pertaining to UOS1.2 at cognitive level Remember
 - ✕ ↻ ↕ ↗ ↘
- UOS1.3 (0)
 - All sets pertaining to UOL01 - Unit of Study UOS1.3
 - Use linked lists in various applications. (Apply/Factual, Procedural, Conceptual)
 - ✕ ↻ ↕ ↗ ↘
 - A1.3Ap (0)
 - All sets of items pertaining to UOS1.3 at cognitive level Apply
 - ✕ ↻ ↕ ↗ ↘
 - A1.3U (0)
 - All sets of items pertaining to UOS1.3 at cognitive level Understand
 - ✕ ↻ ↕ ↗ ↘
 - A1.3R (0)
 - All sets of items pertaining to UOS1.3 at cognitive level Remember
 - ✕ ↻ ↕ ↗ ↘

Fig. 6. Categories of Units-of-Study

```

o UOS1.2 (0)
All sets pertaining to C2 - UOS1.2
UOS1.2: Construct and traverse through linked lists. (Apply / Procedural and Conceptual)
X <=> + ->

o A1.2Ap (0)
All sets of items pertaining to UOS1.2 at cognitive level Apply
X <=> + ->

o A1.2Ap1 (0) X <=> + ->
o A1.2Ap2 (0) X <=> + ->
o A1.2Ap3 (0) X <=> + ->
o A1.2Ap4 (0) X <=> + ->
o A1.2Ap5 (0) X <=> + ->
o A1.2Ap6 (0) X <=> + ->
o A1.2Ap7 (0) X <=> + ->
o A1.2Ap8 (0) X <=> + ->
o A1.2Ap9 (0) X <=> + ->

```

Fig. 7. Categories of Assessments

```

o C01 (0)
All sets pertaining to C01 - UOL01
C01: Construct and delete nodes, display the contents of nodes, create singly-linked, doubly-linked and circular lists using nodes and traverse through them. (Apply/
Conceptual, and Procedural)
X <=> + ->

o UOS1.1 (0)
All sets pertaining to UOL01 - Unit of Study UOS1.1
UOS1.1: Understand data types, pointers to memory locations and the parts of a node. (Understand / Conceptual)
X <=> + ->

o A1.1U (0)
All sets of items pertaining to UOS1.1 at cognitive level Understand
X <=> + ->

o A1.1R (0)
All sets of items pertaining to UOS1.1 at cognitive level Remember
X <=> + ->

o UOS1.2 (0)
All sets pertaining to C2 - UOS1.2
UOS1.2: Construct and traverse through linked lists. (Apply / Procedural and Conceptual)
X <=> + ->

o A1.2Ap (0)
All sets of items pertaining to UOS1.2 at cognitive level Apply
X <=> + ->

o A1.2U (0)
All sets of items pertaining to UOS1.2 at cognitive level Understand
X <=> + ->

o A1.2R (0)
All sets of items pertaining to UOS1.2 at cognitive level Remember
X <=> + ->

o UOS1.3 (0)
All sets pertaining to UOL01 - Unit of Study UOS1.3
Use linked lists in various applications. (Apply/Factual, Procedural, Conceptual)
X <=> + ->

o A1.3Ap (0)
All sets of items pertaining to UOS1.3 at cognitive level Apply
X <=> + ->

o A1.3U (0)
All sets of items pertaining to UOS1.3 at cognitive level Understand
X <=> + ->

o A1.3R (0)
All sets of items pertaining to UOS1.3 at cognitive level Remember
X <=> + ->

```

Fig. 8. Sets of Sets of Assessments for UOS1.1, UOS1.2, UOS1.3

is delivered a different item each time he attempts the quiz.

- **Outcomes:** The outcome (competency) to which the quiz (representative problem, in this case $a \in \{A1.2.Ap.1\}$) is associated with is selected in the Outcomes section of the quiz. This ensures the proper tracking to deliver the snapshot of the students' performance required in the Student module. As $\{A1.2Ap1\}$ is associated with C1, the outcome is appropriately selected.
- **Common Module Settings:** So as to keep the details of the assessment opaque from the student, the details pertaining to the Set ID are stored in the common module settings.
- **Completion Settings:** These settings indicate whether a student has completed a quiz or not. They are set so that a student may not manually mark an activity to be complete, and must receive a grade in order to indicate whether the activity is complete or not.
- **Restriction Settings:** These settings are critical for proper execution of the tutoring rules. Once again, let us consider the same example set $\{A1.2.Ap.1\}$. If a student performs unsatisfactorily on representative

problem $a \in \{A1.2.Ap.1\}$, he is redirected to a quiz that delivers representative problem $a \in \{A1.2.U.1\}$. This quiz remains hidden unless the student has performed unsatisfactorily on representative problem $a \in \{A1.2.Ap.1\}$. Therefore, the settings for a quiz delivering representative problem $a \in \{A1.2.U.1\}$ are defined as shown in the Figure 12.

- **Random question settings:** Subsequent to defining the appropriate settings listed above, the representative item from the appropriate category needs to be added to the quiz. In order to ensure that the student is delivered different representative items for each attempt of the quiz, a random question from the appropriate category is added as follows. On the empty quiz, of the two options of "Add a question" and "Add a random question", the option "Add a random question" is selected.

Subsequently, the appropriate category from which the random question is to be generated is chosen. In this case, that category is $C1 > UOS1.2 > A1.2.Ap > A1.2.Ap.1$.

C. Student Module

The student module consists of a snapshot of the students' progress at any given point in time. In this framework, the

Fig. 9. Adaptive Settings

Fig. 10. Outcomes Settings

Fig. 11. Common Module Settings

Fig. 12. Completion Settings

Student Module would consist of the instructional activities / assessments completed by the student, which would thereby indicate which competencies have been attained by the student. Progress is measured according to the Competencies and Units-of-Study completed by the student, which are uploaded in the form of Outcomes. Therefore, first "Completion tracking" is enabled for the course under Course Administration > Edit course settings.

Further, a snapshot of the student's progress at any point in time is available in the gradebook, under Course Administration > Grades.

IV. CONCLUSION

A framework for an Intelligent Tutoring System has been described. The framework consists of the three elements of course design competencies, instructional activities and assessments. The framework for the Intelligent Tutoring System is implemented using the Learning Management System Moodle. The representation of the Expert Module (broadly, the competencies, instructional activities and assessment items), the Tutoring Rules in the Tutoring Module and the snapshot of the

student's progress in the Student Module were implemented for a course on Data Structures in an undergraduate engineering programme.

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Restrict access

Allow access from 30 July 2014 00:00 ☐ Enable

Allow access until 30 July 2014 00:00 ☐ Enable

Grade condition C1 - Linked lists must be at least 95 % and less than %

[Add 2 grade conditions to form](#)

Activity completion condition Quiz on Linked Lists! Test your knowledge... must be marked complete

[Add 2 activity conditions to form](#)

Before activity can be accessed [Show activity greyed-out, with restriction information](#)

Fig. 13. Restriction Settings

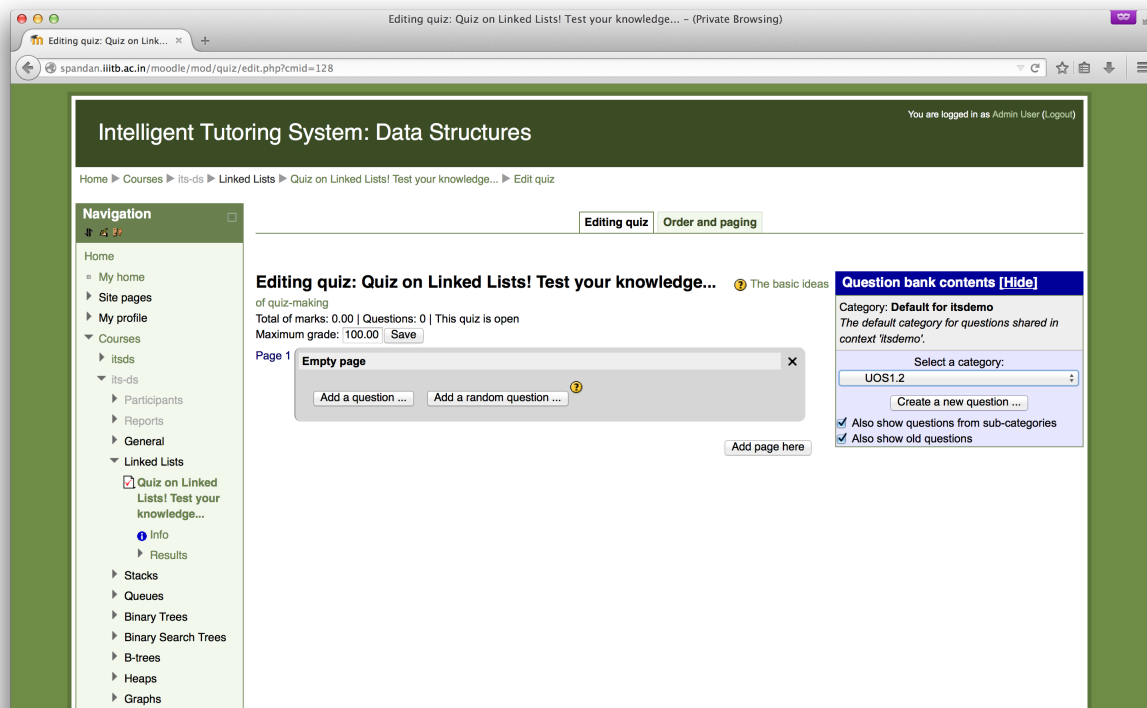


Fig. 14. Randomization settings

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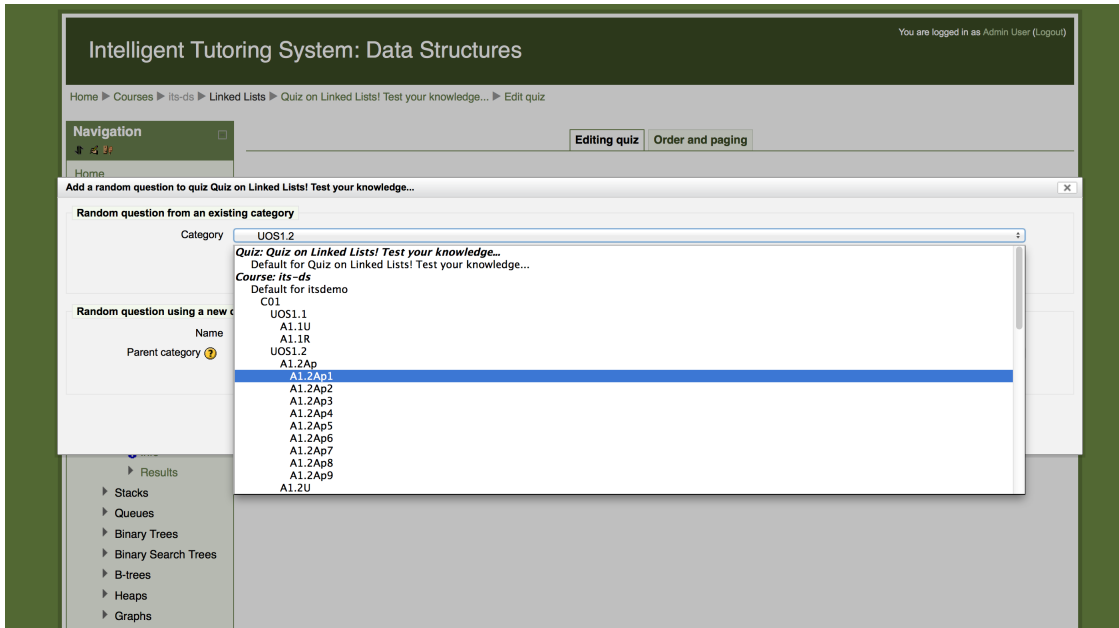


Fig. 15. Adding a random question



Fig. 16. Completion Tracking in Student Module

A User Profile Definition in context of recommendation of Open Educational Resources. An approach based on Linked Open Vocabularies

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Abstract—Open Educational Resources include a diverse range of materials making it the most representative icon arisen within the Open Content movement. Users who access and use OERs could be classified into one of these three groups: instructor, student and self-learner. To provide personalized lists of OERs according to the user profile and personal preferences, the user should be characterized by an open and scalable model. In this paper, an open linked vocabulary is proposed to describe user profiles of the open educational resources, which take into account the challenges and opportunities that an open and extensible platform as the Web can provide to learn about the OER users, and from this knowledge, offer the most appropriate resources.

I. INTRODUCTION

Different projects arising under the philosophy of Open Access (OA) have helped to facilitate and to make accessible to all users the online learning. The OA initiatives framed in the educative context have "significant implications, and allows distance educators to play an important role in the fulfillment of the promise of the right to universal education" [1]. Open Educational Resources (OER) include a diverse range of materials making it the most representative icon arisen within this movement.

Considering the personal interests of people that access to the open educational resources, OERs are not only useful for students of educational institution, but also they are used by self-learners or who are part of a kind of informal learning.

The most used tools to find the resources in the Web are the search engines. However, due to the huge amount of available resources, and because the traditional research systems does not consumption the users knowledge, thousand or millions of results are returned. The failure to find relevant material to support a teaching and learning process can be an inhibiting factor in the process of formal or informal learning.

Unlike the search engines, the recommender systems filter the resources taking into account the users interests, and they are able to give a better user support when the users are trying to find the resources they need. The issue is that these systems to be effective require big amounts of data; in closed or specific e-learning environments there is the possibility of modeling a wide range of users variables such as; preferences, styles, goals, learning aims between others. Considering that one of

the OER users profiles is the self-learner or people who do not belong to a formal education system, thus, the collection of interaction information that helps to build a user profile is limited.

In this paper, an open linked vocabulary is proposed to describe user profiles of the open educational resources. As is known, the platform on which OER users are identified, participate and contribute is the Web; in this regard, there are challenges and opportunities that an open and extensible platform can provide to learn about the OER users, and from this knowledge, offer the most appropriate resources.

The user's representation is based on computable schemes, and it fed on Web data structured and organized through systems of open knowledge. The usage of vocabularies and formal languages of the Semantic Web enables to reuse and interoperability of user's data between several applications. Moreover, the modeling of user interests through knowledge organization systems will allow to implement query and support services so that they can understand the topics and relations around the domain and finally, people will know how to better conduct the search of material.

Continuing with this paper, the main proposal to describe Web users, and their main constraints when modeling heterogeneous users in a open learning environment are put forward in the section II. The design and preliminar validation of the User Profile for OER recommendation tasks are put forward in the section III, and the section IV. Finally, in the section V, the conclusions and future work are appeared.

II. THEORETICAL BACKGROUND

A. Standards and data models to represent users

In order to represent a learner, a widely know specification is PAPI Learner Standard (Public And Private Information) proposed by the IEEE Learner Model Working Group. PAPI was launched in 2001 and has served as a reference to some proposals as [2], [3].

PAPI defines different elements to record descriptive information about students' knowledge and preferences, as well as personal contact information, security settings and general privacy, among others. The draft 8 from the specification lets

us to specify different views of learners' information, this way, those using this model can choose the parts that are appropriate for their application.

Moreover, the consortium IMS GLC (IMS Global Learning Consortium) created the specification, IMS LIP (IMS Learner Information Package)[4]. An initial draft specification appeared in 2001 and, in 2005 the final specification was formalized.

The IMS LIP standard has been used in the construction of student models and some applications like: Elena¹, L4All², EPET³, Europass CV Application⁴, among others. The specification divides the learners information into eleven categories or data structures, these categories include: biographical and demographical students data, objectives and competencies, accessibility, degrees, activities and relationships.

One of the cons of these two specifications is that they are not extensible, in other words, they have not evolved to consider features and user preferences that arise in an open online learning environment. Another problem identified in [5] is that IEEE PAPI and IMS LIP do not facilitate the sharing and reuse of profiles stored on different servers.

Nowadays, in order to improve interoperability and scalability of user profiles between different systems, most proposals are based on representations based on ontological models. There are implementations of models using OWL or RDF(S) languages. Among the related works about semantic models proposed to represent the user profile, we can highlight the following:

Among the high-level specifications to describe Web users, there are: i)FOAF (Friend Of A Friend)⁵, and ii) vCard⁶ standard proposed by the IETF and currently published in RDF/OWL format by the Semantic web Interest Group. Both FOAF and vCard propose identification metadata and contact as: names, age, nickname and email. FOAF also allows the description of some professional information and user interests. Finally, we can name the collection Person⁷ of the Schema.org specification, driven by major Web search engines.

Another proposal that defines the profile of a Web user shows up in [6], although in this case, the profile is projected in order to incorporate it in recommender systems based on content, for it models the profile based on words of the pages visited by the user.

For purposes of personalization of content and specifically for adapting Web content, the ontology GUMO (General User Model Ontology) [7] defines individual characteristics of a person, as: physical and emotional states, characteristics and personality; in addition, in [7] the Markup Language (UserML) is proposed to manage the communication between different applications to share the user model. Another proposal to facilitate the development of e-learning systems is presented in

[3] custom, where a model student profile based on the IEEE PAPI specification is proposed.

To provide personalized access to documents, [8] defines a domain ontology that organizes the Web documents so that each document is classified as a particular concept in the domain of ontology, then, according to the history of user navigation is the interests of users are collected and recorded in the user model.[9]

Another group of user profiles, focus on ensuring portability and reuse of profiles between systems that adopt the same metadata schema: [2], [5], the LLO ontology (Learner Ontology for Planning of Lifelong Learning), the ontology U2MIO [10].

Although, the proposals mentioned try to model the users profile in a wide spectrum of dimensions, in a Web context, by the dynamics of users data, it seems to be useful to focus in such aspects that in a mid-term will capture the nature of the users interest. To sum up, in order to model the users interest and preferences, the authors have found the following proposals.

- A model to describe the users preferences (local and global) expressed in terms of resources and domain of interests; the learning of users interest, getting trough data mining methods is based on the characteristics or attributes of an object which is graded by a user. [11]
- The experimental vocabulary WI (Weighted Interest Vocabulary) which was developed in 2009 in order to cover the requirements of the Project NoTube; WI models the users preferences inside an environment o determined context; the relevance of significance for the user can be established through weight which value can change depending of the context.
- The STOUN ontology (Spatio-Temporal Ontology of User Preference) defines three types of preferences (positives or negatives) and the dimensions that can affect them such as activities, devices, localization, time, and event.
- CC/PP (Composite Capability/Preference Profiles) allows describing a devices capacities and the users preferences; this information can be used to guide the content adaptation that is presented in a determined device.
- The FRAP ontology (Framework for Ratings and Preferences)⁸ allows the open interchange of the users preferences. The framework is independent from the domain. [12]
- The same organization that developed FRAP, which is called CTIC, proposes the ontology RECO⁹ that differs in the objective and in the proposal of the ontology FRAP. RECO represents a ordered list of elements given by a recommendation system, whereas FRAP captures the users preferences. The RECO ontology defines a vocabulary to represent preferences and ratings as restrictions through a RDF graph.

¹elena-project.org

²lkl.ac.uk/research/l4all/

³eportfolios.ac.uk/ePET/

⁴europass.cedefop.europa.eu/

⁵<http://xmlns.com/foaf/spec/>

⁶<http://www.w3.org/TR/vcard-rdf/>

⁷<http://schema.org/Person>

⁸<http://purl.org/frag#>

⁹<http://vocab.ctic.es/reco/reco.owl>

TABLE I. REQUIRED CHARACTERISTICS OF THE USER PROFILE

Feature of the OER User	Current proposals	Requirements of the User Profile
The user can have different levels of knowledge. On the other hand, one of the forms that a user uses to express their learning information needs is through interest expressed as concepts.	Works such as [12], [10] define a model of web user independent from the domain, i.e. they are re-usable in any field; but, they are too general to determine the knowledge of the user in a determined subject; this can affect the performance of the personalization task.	The model must capture the current state of knowledge of a user in a specific field and it must be able to be used to interpret with open knowledge repositories; so that, it can enrich the user profile from these sources. Therefore, recommender systems can take advantage of the potential of the semantic relations, which are expressed, in open systems of organization of knowledge.
An OER user does not center his or her participation in a specific learning system or in a unique material repository; actually, he or she will not be register in any platform.	A considerable number of approaches for users modeling as [14], [11] have focused on the identification of profiles of teachers and students based on their preferences and needs as users of a determined system or a controlled environments.	The model must be flexible to characterize users who little is known, i.e., the profile should model the user preferences depending on the educational material distributed in different repositories, in order to take advantage of the OERs metadata.
OER user can participate in learning communities that emerged spontaneously. Since it has become massive the use of social networks, people use these services to share material, data and preferences.	Approaches as [15] y [16] are experimenting with public data from social sources since they provide an acceptable way to identify user interests. To infer user behavior, techniques based in learning machine are applied; they can be intensive in data processing.	The model should distinguish user profiles from heterogeneous systems (including social services); therefore, it must capture the user data dynamics and model the shared communitys interests of users using techniques applicable to the Web. [9]

Another dimension in which some founded Jobs are centered is the characterization of the user as a part of a network. In [13] is proposed an approach for a multi-layer building of communities of interest (COI), which is based on the analysis of the users individual preferences that are described in the profiles. The method builds users profile interests based in specific concepts with the purpose of find similarities between users; the profiles are divided in groups of interest, based on this, some layers of COI are found. Another work that deserves to be named is one presented in [9] in which a model based interest ontology is proposed, it can be used to determine the close neighbors by calculating the semantic similarity of interest models of two users.

B. Characterization of the User of the Open Educational Resources

In this section are analyzed the main conclusions of the present state of users profile modeling against the nature and characteristics of an open learning environment user, supported by oERs; as well as how this relation affects the recommender systems which should provide customized listings according to the users interests and preferences.

From the information in Table I, the authors can conclude that a OER users profile should be flexible; so, it should allow represent users under contrary scenarios: anonymous users or reserve ones with little known information vs. active users in

the web, generally with presence in networks or communities. Also, the model should be extensible and interoperable, so that, it can connect with other representations in order to take advantage of the large amount of open data that are published in different knowledge systems and in OERs open repositories of metadata.

III. DESIGN OF THE OER USER PROFILE

A. User profile requirements

In order to ensure the successful our proposal and according the findings that were found in the literature review, the model of user of OER should keep the following design principles:

- 1) Based on semantic structures, i.e., the model must be able to be combined with controlled vocabularies and open systems of knowledge organization. This feature enables the enrichment and inference of new user profile data and above all enables the organization and classification of users according to common interests. Taking advantage the potential of different knowledge domains they are encoded on the web as linked data. The knowledge about the domain of interest to the user, allow to do better recommendations according to the level of knowledge the user has on an issue.
- 2) Support distributed information: the model should facilitate the representation of user profiles from heterogeneous and distributed systems, which are enabled to share information about learner or teacher.
- 3) Privacy and data protection: In order to ensure the integrity and privacy of user data, the attributes that the user has decided to share in your public profile have to be considered. You must also take into account other information, both personal and critical, which should not be shared with others external agents.
- 4) Personalization. The data model of OER's user must be flexible to support adjustments in two ways: i) extension through the addition of new user features and its environment, and ii) personalization according to specific purposes or environments.

B. User Profile Dimensions

The organization of user characteristics and the environment in which he/she interacts, encapsulating the attributes in different dimensions allows to build a interoperable model of the user, so different applications can share the model with different purposes. The Figure 1, shows the different categories of data that could characterize an OER's user.

In addition, as shown in Figure 1, different categories of user data may influence others: i) due to the exercise of academic and professional activity, the user can acquire different skills and abilities; ii) the previous experience and the current user activity can determine their learning objectives and motivations; iii) finally, i) and ii) more the context information can influence the interests and current decisions of the user.

Although the user profile can be used for different purposes, on this paper, the user preferences constitute the fundamental dimension of our design. The following reasons justify this decision: i)) the users background both academic as

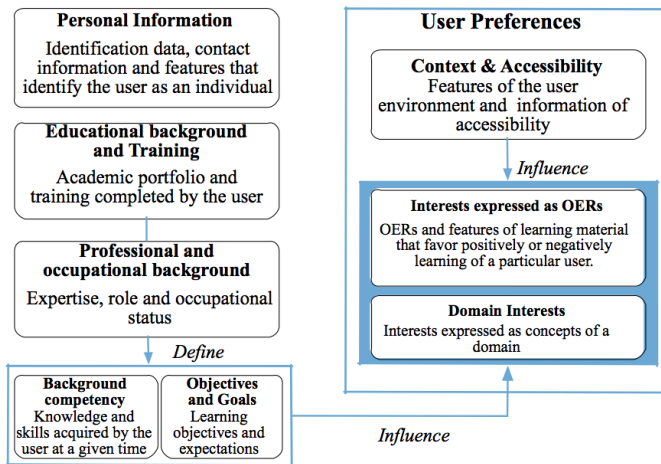


Fig. 1. Dimensions of the User Profile

professional have an important role in customization tasks oriented to content adaptation [17], this differs from our primary purpose, the recommendation of OERs. ii) The collection of information about the objectives and expectations of learning, in an open learning environment can be complex or limited.

C. User's Preferences

A preference is a mental state of an individual respecting from a subset of items from a universe of alternatives.

To provide lists of relevant OERs according to the interests of a particular user, it is proposed to specify a grade or rating for each user preference through a quantitative or qualitative scale; the value that is assigned to represent the importance of this element to the user.

In order to support different methods of filtering information, the user model has been designed to withstand at least three types of user preferences:

1) *User Interests expressed as concepts of a domain of knowledge*: The interest model of the user, being based on thesaurus or other knowledge organization systems, it can be used to exploit hierarchies of concepts and provide the necessary support the user can define in more precise interests. [9]

Example 1: Topic recommendation. An user (:User1) has expressed interest by the subject of Software Engineering (:SoftwareEngineering). Open Sources of Knowledge as DBPedia¹⁰ enable the automatic extraction of the subtopics of this discipline, which can be recommended to the user to refine their interests, if it is required.

```

IF
[ type (:Software_Engineering . :Concept) AND
  interest (:User1 . :Software_Engineering) AND
  narrower (:Software_Engineering . :Software_design) AND
  narrower (:Software_Engineering . :Software_requirements) AND
  narrower (:Software_Engineering . :Software_architecture)
]
THEN
[ recommends (:User1 . :Software_design) OR
  recommends (:User1 . :Software_requirements) OR
  recommends (:User1 . :Software_architecture)
]

```

¹⁰<http://dbpedia.org/About>

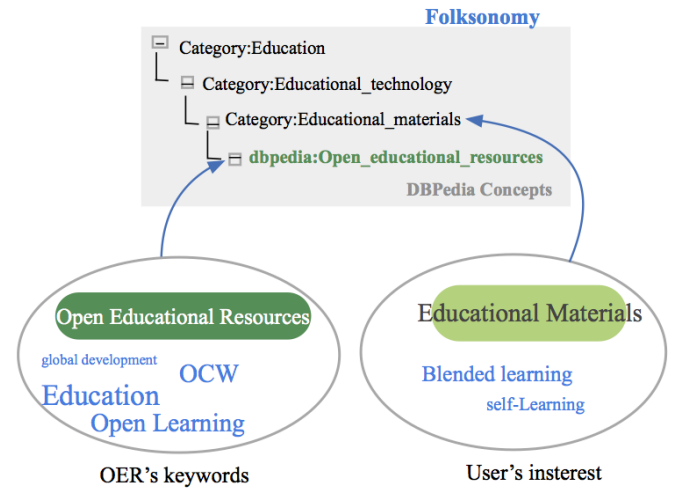


Fig. 2. Mapping between OER concepts and User interests

Another application of interest expressed as linked concepts by semantic relations is the location of the resources related to given subject and their variations or derivations.

Example 2: OER recommendation. In Figure 2, it can see that it is possible to map user interests expressed as concepts and keywords of OERs, thus, systems can provide recommendations for resources without them having the same words of the user. The same approach can be used to find similar users and provide recommendations based on collaboration.

2) *Documents and/or preferred attributes of OERs*: The user's preferences for a particular group of OERs, or their features that describe it, they can be used to apply approaches based on content filtering, in order to take advantage of the large amount of metadata exposed by open repositories of learning material.

3) *Demographic information and accessibility*: This information is useful to filter the most appropriate items of information according to user context. This dimension includes: location, language, age, and information accessibility and user device used to access the educational content. The PAPI [18] specification also adds metadata such as learning style and physical limitations.

By including this information in the user profile, systems sensitive to the context could be created according to the particular tastes of each user; for example, for a student who manages one language, it may result a priority to find the resources that are in her/his mother tongue.

D. Conceptual Model of the User Profile

The design of the OER user profile begins with the construction of the conceptual model. Therefore, at this point, our goal is to identify and describe the terms of the user model to improve the discovery and recommendation of open educational resources

One of the fundamental tasks of the conceptualization of the model is building the terms of the glossary, which specifies the metadata and user variables and concepts related. Table II

TABLE II. EXCERPT OF THE TERMS GLOSSARY

User Concept		
Metadata	Description	Range of values
names	User names	Text
description/summary	Resume or information descriptive of the user	Text
e-mail	Email preferred for the user	email
Localization	User location, i.e. a city, region or country	URL
Language	Source language of the user	URL
Web page	URL of the user's home page	URL
Profile Concept		
Metadata	Description	Range of values
Identifier	User profile ID	URL/string
User	Social account user	URL
Source	Source address of the user profile information	URL
Creation date	Date of the profile creation	Date
Published date	Date of the profile published	Date

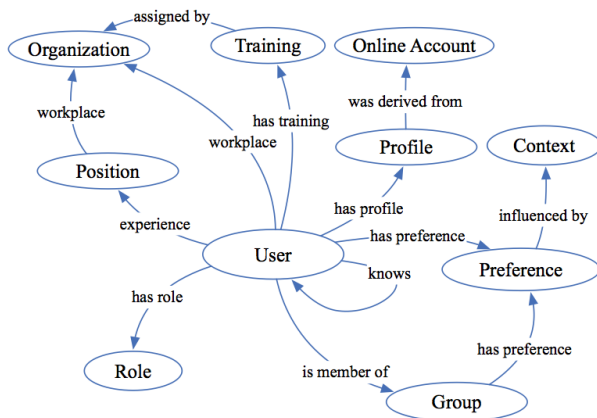


Fig. 3. Conceptual Model. A top level view

shows an extract of the terms identified for concepts User and Profile shown

As shown in Table II, to build the glossary terms may appear new terms, such as Concept Profile. This concept includes the information necessary to identify the web profile of an user, and it is used to identify the source and provenance of the user's information.

From the glossary of terms, the next step was to build the diagram of binary relations between concepts. In the Figure 3 it is presented the high level conceptual model resulting from this process.

E. Reuse of ontological and non-ontological resources

The reuse of ontological and non-ontological resources reduces the time for creating an ontology and associated costs; also it contributes to the quality of ontology. citeVillazon2011

From the analysis of the proposals referred to in paragraph 2.1, it was selected those models that offer greater coverage of the terms identified in the Glossary of Terms and ensured a high probability of interoperability and semantic consistency with the conceptual definition of the model chosen. Main vocabularies that are selected are listed:

- Simple Knowledge Organization System (SKOS)¹¹ vocabulary used to organize the users interest defined by concepts.
- FOAF¹² y vCard¹³ are used to describe the basic information of people and organizations.
- Dublin Core (DC)¹⁴ y Dublin Core Metadata Initiative (DCMI) Metadata Terms¹⁵ provide needed metadata to describe the users preferences depending on of OERs.
- VIVO¹⁶, ontology for describing different concepts in academic and scientific domain.
- Open Provenance Model Vocabulary¹⁷ to describe the origin of the data from Web users.
- Schema.org¹⁸, set of metadata schemes that improve the discoverability of an appeal by Web agents.

Attributes, properties and entities that are not considered in these vocabularies, were designed and created as part of our proposal.

IV. REPRESENTATION AND VALIDATION OF THE USER PROFILE

Once built the ontological model, various user profiles were defined in order to determine the capacity of representation of the model designed. Namely, three user profiles are considered: i) a person who regularly uses digital educational resources to support their work and acquire the skills required in their occupational tasks; ii) a student of an educational program, who want to supplement the study material provided in class; and iii) an instructor who want to find the material related to a particular subject.

The first type of user could well correspond to a self-learner profile. In e-learning, self-learner is an active user on the web that is not necessarily enrolled in an educational institution and supports their learning processes using resources found on the Web.

Then, certain characteristics that could distinguish to a self-learner when interacting and search online material are described: i) is professional and entrepreneur, ii) generally set their own learning objectives; iii) it subscribed to some social networks such as Facebook, twitter and LinkedIn; iv) regularly, publish and share relevant material that he/she has been used in his/her training process; v) his/her interests are related to different knowledge areas and topics; vi) dominates

¹¹<http://www.w3.org/2004/02/skos/>

¹²<http://xmlns.com/foaf/spec/>

¹³<http://www.w3.org/TR/vcard-rdf/>

¹⁴<http://dublincore.org/documents/dces>

¹⁵<http://dublincore.org/documents/dcmi-terms/>

¹⁶<http://vivoweb.org/ontology/core>

¹⁷<http://open-biomed.sourceforge.net/opmv/ns.html>

¹⁸<https://schema.org/>

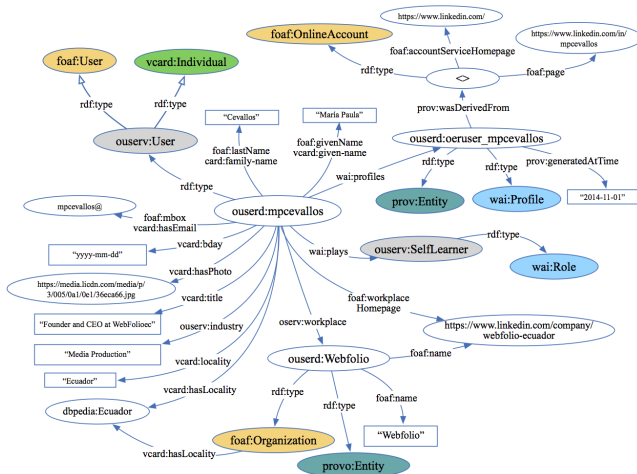


Fig. 4. User Data Representation. Personal Information

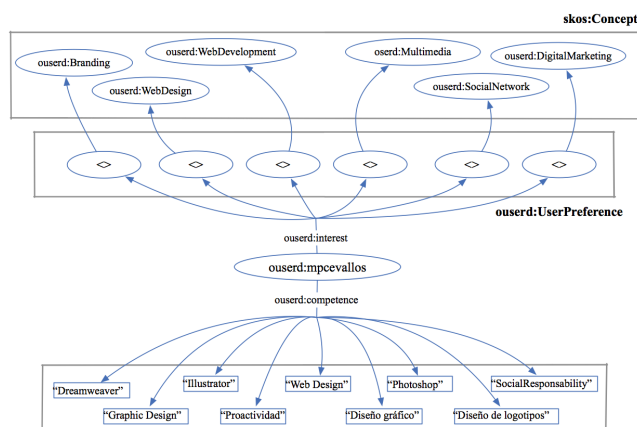


Fig. 5. User Data Representation. Preferences based-on concepts

certain subjects but can also be beginner in emerging issues; and vii) user is enrolling in courses and other free online learning resources. Figure 4 shows the semantic representation of the personal data of a user corresponding to the profile described, and Figure 5, the user preferences and their skills are presented.

As shown in Figure 5, the ratings or weights of each topic of interest are unknown. To complete the profile, the system can explicitly request this information to the user via a Web form or implicitly the interests can be updated when the user interacts with the system.

V. CONCLUSION

In this paper, authors have proposed a User Profile for the OER recommendation, which take into account i), the constraints and opportunities that an open learning environment could offer in real time to obtain users information; and ii), the general characteristics that identify a OER user; and iii) the particular characteristics that can make it possible to differentiate one group of users from other.

The creation of the model has been addressed by a set of requirements that the online learning and open demand and the current proposals do not cover. Part of the proposal

validation was made considering a set of scenarios; concretely, in this work was exposed the representation of an self-learner because in this group is more likely to find the widest range of OERs users; they can be beginners or highly qualified in a topic, they can have the ability to handle bibliographical resources or they can ignore the research mechanisms and tools. Therefore, the user profile has been designed to support these features and to provide sufficient knowledge to recommender systems because they have to differentiate the types of users and satisfy the needs of both beginners and advanced users.

Currently, the authors continue evaluating and validating the created model, before publishing it according to the Best Practice Recipes for Publishing RDF Vocabularies ¹⁹. The usage of the profile in recommendation tasks will be key to the feedback this work. In this moment a knowledge-based recommender system is being implemented considering the present approach.

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¹⁹<http://www.w3.org/TR/swbp-vocab-pub/>

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Supportive Environment for Teaching and Learning Digital Image Processing

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Abstract—Digital Image Processing (DIP) consists of a set of techniques to acquire, represent and transform digital images. Through these techniques, it is possible to extract and identify information of images and improve the visual quality by facilitating human perception and interpretation by computer systems. However, the Digital Image Processing teaching is hindered by the complexity of implementation of many techniques, on several occasions is not possible that student visualize the results of DIP techniques when are discussed during the course. This paper presents an experiment over a web platform to support the teaching of digital image processing. The goal of this platform is not replace coding techniques, but allow rapid visualization and experimentation of studied methods, without be necessary to install software or previous knowledge of a specific programming language.

keywords: Digital image processing, teaching/learning platform, web platform

I. INTRODUCTION

The increase of computing devices performance and the advances in image acquisition methods have made the Digital Image Processing (DIP) an important way for solving problems of different areas [1].

The Digital Image Processing has become an important tool to several organizations from different areas, which uses solutions based on DIP; in academy is a research subject; and in daily life with the popularization of multimedia applications [1] [2].

DIP applications use several algorithms, highlighting: image acquisition, enhancement, filters, transforms, segmentation, border detection and classification. Thereby, the discipline of Digital Image Processing became subject of teaching in many higher education courses, such as computer science and engineering, mapping science and engineering, geology, agronomy, electrical engineering, electronics engineering and agronomic engineering [1].

However, the strong mathematical background necessary to understand DIP algorithms and the time for development of those algorithms hamper the development of classes and homeworks. In that way, it is infeasible on several occasions to visualize the results of DIP techniques as they are discussed during the course. These issues might make the teaching and learning of DIP discipline demotivating for the students [1].

Thus, it is important to use tools to assist in teaching and learning DIP techniques and methodologies, through execution of algorithms and display results dynamically. Nevertheless, the most popular tools available have drawbacks as the high-value of commercial license, operating system dependence or necessity of to learn a specific programming language.

In this paper it is presented a web platform to support teaching of Digital Image Processing. Through this platform the user can create image processing streams and view the result without writing code. In addition, the web platform offers facilities, such as independence of operating system and hardware.

In order to evaluate the web platform, it was conducted an experiment with a group of students. Initially, the students developed the same activities using the web platform and MATLAB (commonly used tool in introductory courses of DIP). Next, the students filled a form to evaluate and discuss both approaches.

This paper is organized as following. Section II presents basic concepts of Digital Image Processing, in particular the steps that make up a digital image processing system; Section III presents related works to this; Section IV presents the web platform, and brief comments about implementation aspects; Section V describes the experiment and presents results obtained; in addition, in Section VI the conclusions and future work are presented.

II. DIGITAL IMAGE PROCESSING

The Digital Image Processing consists of a set of techniques to capture, represent and transform digital images with computer assistance. Those techniques seek identify and extract information from images and improve visual quality, facilitating human perception and automatic interpretation by computer systems.

The schema of Digital Image Processing system is depicted in Figure 1. There are four stages: *acquisition*, *processing*, *storage* and *output* [2].

A. Acquisition Stage

The first step consists in image acquisition using a device to capture signals from different source (i.e. light and X-ray).

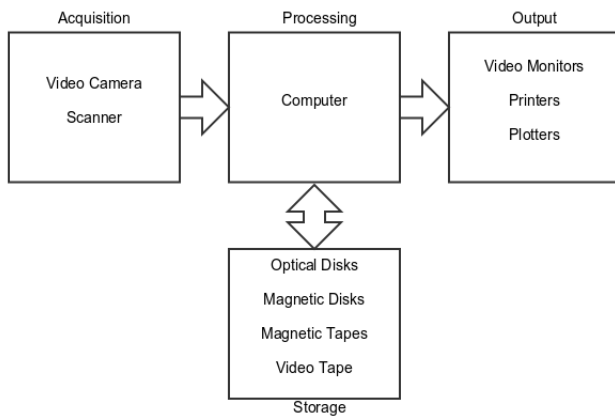


Fig. 1. Digital image processing system stages: acquisition, processing, storage and output – Adapted from [2]

Also, it is stored into files according to formats defined to image for later processing. Among the acquisition instruments are video cameras, scanners and embedded sensors on satellites.

It is important to note that the resulting image has imperfections, which demands specific treatment before applying the processing technique.

B. Storage Stage

The storage stage is one of difficulties in the design of a Digital Image Processing system. This stage can be divided into three models: short period storage, which occurs when the image is being used for processing; mass storage, responsible for operations that require relatively quick recoveries; and storage for future recovery [2].

C. Processing Stage

The **processing** stage refers to algorithms to handle images. This stage can be partitioned into two steps: pre-processing and segmentation. The pre-processing is useful when the images obtained from the acquisition stage have imperfections due to poor lighting conditions or capture device characteristics. In turn, *segmentation* seeks to partition a set of input data in structures with relevant semantic content for the activity in question.

1) *Pre-processing*: This step aims to improve the image quality and prepare it for the subsequent processes. Depending on the image in question, can be applied different techniques, because efficient methods for a given problem are not satisfactory in others [2].

The pre-processing can be performed both in space domain and frequency domain. This step is, also, divided into approaches to enhancement and image restoration.

The approach of enhancement is responsible for improving the image quality or emphasize any image particularity through any heuristic – such as changes in contrast or histogram. In the other hand, the restoration aims to recover or rebuild lost details during the acquisition stage with methods of smoothing noise and blurring.

2) *Segmentation*: The **segmentation** aims to partition a set of input data in structures with relevant semantic content for the activity in question. The structures refer to objects or parts of objects that help in the image interpretation. As result, for example, it is possible to extract objects that are merged with the image background, providing the basis for further processing.

The complexity of segmentation step depends on the interested image: it is low when the image of interest has few and well defined objects, especially when combined with a background with a good contrast; it is complex when one wants separate many noisy regions and low contrast.

There are different ways to perform the segmentation of an image, highlighting the methods based on threshold and active contour.

Threshold based methods can be classified into automatic global and adaptive processes. The global process utilizes histogram properties to perform the segmentation, while the adaptive performs a subdivision in the image and applies a threshold on each subdivision, resulting in multiples shades of cut that are interpolated to give the new pixels of the image. Threshold based methods have advantage of less sensitivity to background irregularities and local variations.

On the other hand, active contour based methods use techniques based on border detection, known as snakes. These methods are characterized by to try to adjust a curve on the border of an object of image and have a lower sensitivity to noise. In this way, such methods can be applied efficiently on images with a high noise level while maintaining a better continuity of the contour [3].

D. Output Stage

The last stage of a digital image processing system is the output, which aims to display the result presentation (show the obtained result to the user). Also, the obtained result can be used as input to another processing. The output can be through monitors, printers or even communication protocols.

III. RELATED WORKS

The teaching and learning of digital image processing is research and development target both in academia and business. Several appropriate tools for teaching and learning of digital imaging processing can be found, whether free or licensed commercially [1].

A software that we can highlight is MATLAB, a desktop tool widely spread in engineering courses and has a set of toolboxes for several areas, including differential equations, statistics, signal processing and image processing. It uses a proper programming language for the development of technical applications, C-like syntax. However, its main disadvantage is the high cost to obtain a license.

The GNU/OCTAVE is an alternative to MATLAB, a free tool originally created for design of chemical reactors. Just as the MATLAB, has a faster programming language than more conventional programming languages. Nevertheless, in

both tools is required previous knowledge of their particular languages for develop algorithms.

In contrast to MATLAB and OCTAVE, which require a previous knowledge of its programming language, we can cite Khoros. Among its features, there is a complete environment image processing consisting of an attractive visual programming interface, which makes it more practical the application of computational methods for image visual processing.

At first, Khoros was a free tool, open source and offered a system that allowed the extension of new functions within its toolbox. But, over time, did not follow the technological advances of software and ceased to be a free tool [4].

One environment of the Khoros platform is the Cantata (see Figure 2), and is intended for DIPs that have a high degree of abstraction. Whereas the output image of a processing can be used as input to another processing, this environment allows to create a process stream. This stream is described as a directed graph.

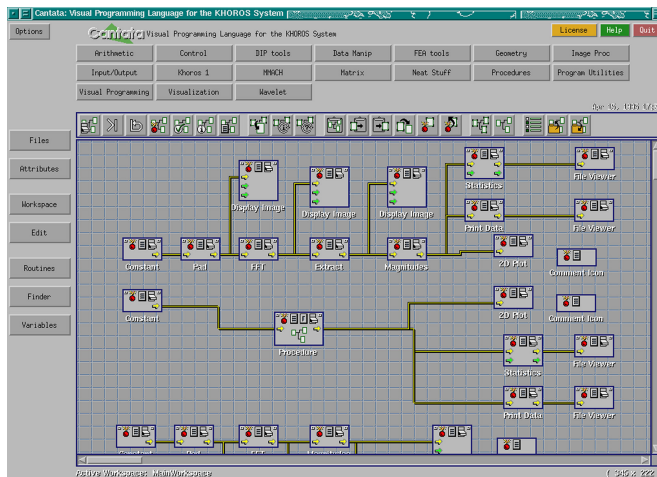


Fig. 2. Cantata environment of the Khoros platform - Source [4]

Based on Khoros, Cyclops has been developed. Cyclops is a platform that allows the modelling of stream image filters through a graphical environment. By the tool, the user can create filters streams, adjust parameters and view results. Furthermore, this tool allows streams to be saved for future use. The Figure 3 illustrates the Cyclops user interface with a created stream [5].

Adesso was developed in the 2000s, and is an authoring system of scientific programs based on the component/solution paradigm that uses a database and XML technology. For this platform, different toolboxes for image processing were created, including educational tools in Digital Image Processing [6].

Among these toolboxes, we can cite the "Toolbox of image processing using the python language". Through this toolbox teaching materials are available to DIP learning using the Python programming language [7].

PhotoPix is a tool developed in C++ and designed for Windows environment. It aims to separate the processing

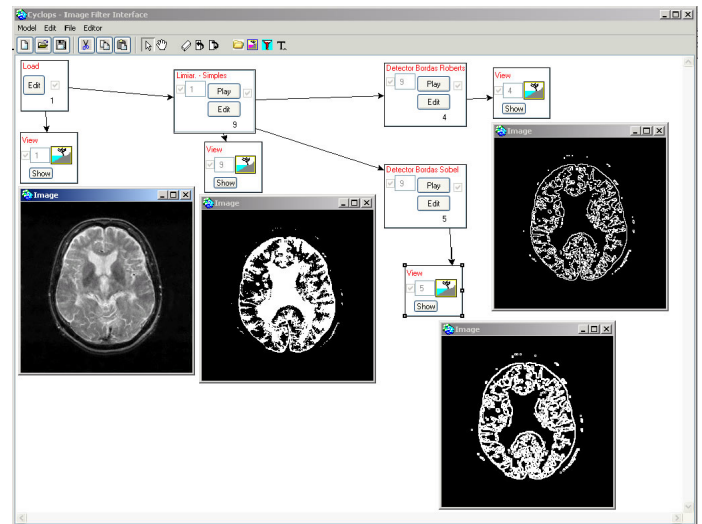


Fig. 3. Cyclops environment with a processing stream - Source [5]

algorithms of code in order to benefit portability across different hardware platforms and APIs. However, it is necessary previous knowledge of the language to add new algorithms [8].

Based on PhotoPix was developed PhotoPixJ, a tool that has a high degree of abstraction and facilitates addition of new algorithms. For being developed in Java, is independent of operating system, requiring only the installation of the Java virtual machine [8].

Another study found in the literature is the Image Analyser, which possess focus on statistical analysis of images in the frequency domain. The purpose of Image Analyzer is unite theory and practice of image processing using the DFT (Discrete Fourier Transform) [9].

Concerning the thermal images is highlighted the TermUV, a tool that allows acquisition, pre-processing and processing of thermal images. This process is performed by a graphical user interface, as illustrated by Figure 4. Through the tool can be created reports and the results are stored in a database [10].

Lastly, SimPle is an educational project developed in Java. In this tool, through the menu, is possible to apply filters and DIP techniques that are displayed in a new window. As the results of methods application are displayed in a different window, links are not displayed with the previous image, making hard the viewing of processing stream [1].

IV. THE SUPPORTIVE ENVIRONMENT FOR TEACHING AND LEARNING DIGITAL IMAGE PROCESSING

In a previous work entitled "Plataforma web para auxílio ao ensino de processamento digital de imagens" [11] was presented a platform to aid in DIP teaching. Similarly to Cyclops and Cantata, this platform represents the processing stream through a directed graph (digraph).

On this platform, three vertices represent acquisition, pre-processing and segmentation. However, there is no freedom for the user creates its own stream, since there is a limitation

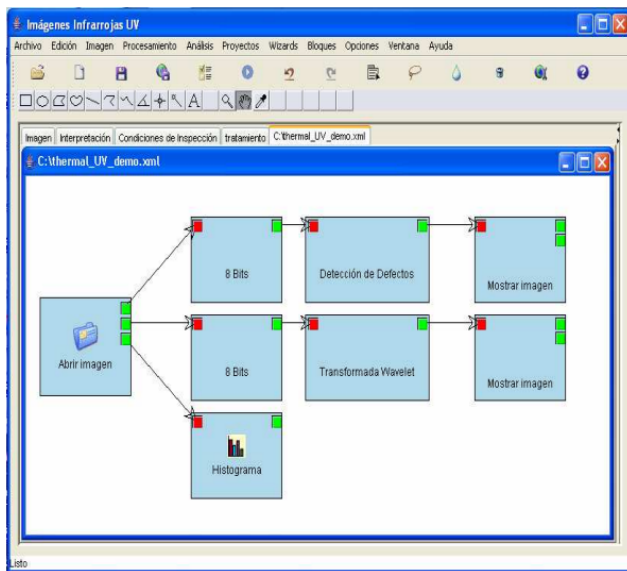


Fig. 4. TermUV's graphical interface - Source [10]

to apply only one filter in each process step (pre-processing and segmentation).

The Figure 5 illustrates a processing stream by this platform. The acquisition process consists of an upload of a digital image that will be processed (labeled by *a*). The pre-processing aims to prepare the image for segmentation and for this several techniques are available (such as grayscale, sepia, smoothing and so on). We can observe in Figure 5 the application of pre-processing methods: grayscale (labeled by *b*) and negative (labeled by *c*). From the resulting image of pre-processing, the segmentation is applied. From Figure 5 is possible see the application of segmentation in the resulting image of grayscale process, with border detection method (labeled by *d*) and mean removal method (labeled by *e*).

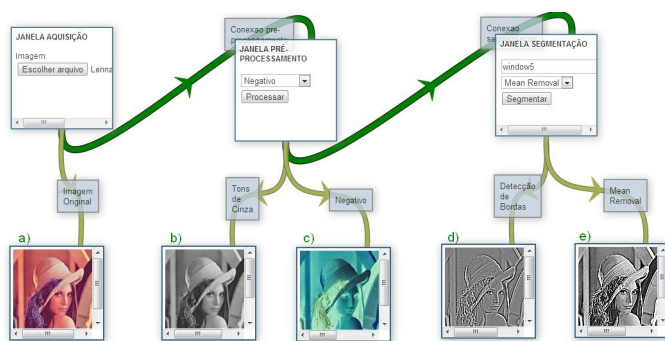


Fig. 5. Example of a processing stream by the Plataforma web para auxílio ao ensino de processamento digital de imagens

Starting with this platform, the goal is to develop a new platform based on web technologies to support teaching of Digital Image Processing. The features of this platform include:

- *Run in web environment:* The use of web technologies ensures operating system independence. To access the

platform only is need a browser that supports HTML5 with internet access;

- *Be visual:* The development of code is unnecessary, quickly showing result of applying the techniques offered;
- *Create Projects:* Possibility of the user to create and store projects, and starting from them create your own processing streams;
- *Be free:* To use the platform is only needed a previous registration for project management. Commercial license is not required.

A. Aspects of platform implementation

The user interface for image processing was built using HTML5 features, a modern mark-up language that allows graphical representation of information on the internet. This language has new tags compared to previous versions, which facilitate work with scripting languages such as JavaScript, and the canvas element that allows graphics manipulation. In order to produce dynamic and attractive content to the user is used the javascript language.

A MySQL database is used for persistence of project data, users, and resulting images from the application of processing methods available on the platform. The choice of MySQL is justified because it is a free and cross-platform tool.

The PHP is used as back-end language and is responsible for project and users management, image processing, organization of the processing stream, and communicate with database. The PHP scripts run through AJAX (Asynchronous Javascript and XML) calls performed via javascript by the user interface. The use of AJAX makes unnecessary the page refresh to view new processing results.

B. Digital Image Processing Methods

The processing functions of digital images present on this platform have been developed using the PHP language together with the *imagemagick* library. The *imagemagick* allows, among other features, to create, delete and resize images, draw geometric figures and text manipulation.

Imagemagick procedures are performed through terminal commands. The syntax for manipulate an image is similar to follow: `convert lenna.bmp -bias 50% -morphology Convolve LoG:0x2 lapgauss.bmp`. In this procedure on an input image (*lenna.bmp*) is applied the method to obtain the Laplacian of Gaussian, resulting the output image (*lapgauss.bmp*).

To create the histogram is used the tag canvas together javascript language. This choice was made because the *imagemagick* had unsatisfactory results in performed tests.

We can highlight among the methods in platform the RGB conversion filters for grayscale, image blurring, border detection, histogram generation, thresholding, and morphological segmentation filters. For latter, for each mathematical morphology operation, a structuring element is required or an element whose shape and size are previously known [12].

C. Platform Operation

The platform is available through identification. The identification is used because it allows that projects can be organized by the user and that the processing to be reused.

After identification, it is possible to load and manipulate digital images by the user interface; the processing methods of the images are presented in a unified way. Among these features are: create a new project; open or delete an existing project; load an image; apply a filter; enlarge an image; apply zoom in an image; delete a stream; display the histogram of an image and display the processing stream.

In order to allow a better view of the processing stream, the results of the applications of the techniques are displayed in a digraph. In this way, whenever is applied a processing on the image, a new node appears in the digraph with an edge linking the node that contains the original image and the node that contains the resulting image. Thus, different streams can be observed simultaneously, which allows that the users compare the results obtained in the same view.

After loading an image by platform, this image will be represented as the first node of digraph and all other nodes will be connected to it by some path. A dialog box opens for the user configures the processing parameters before to apply a filter to an image. To apply a filter to image, a dialog box opens for user configure processing parameters.

Figure 6 illustrates the platform interface after an image has been loaded. The digraph has only one node and on image contained on this node can be performed any available processing by platform.

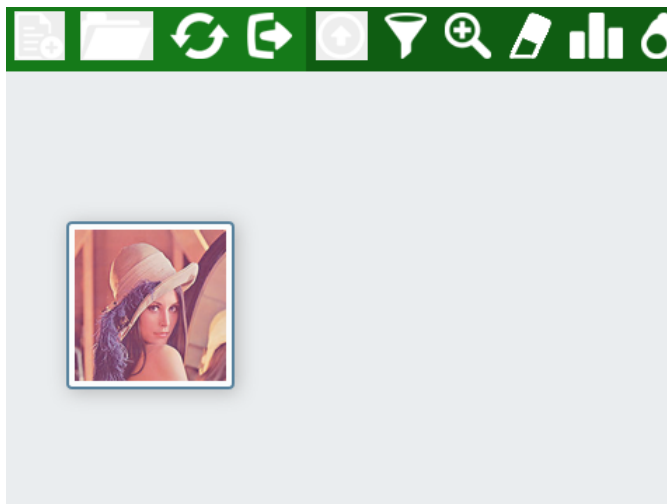


Fig. 6. An initial image loaded by the platform

In Figure 7 is illustrated the same digraph of Figure 6 after several processing. For each processing has added a new node containing the resulting image. In this Figure we can observe two processing sub-streams. The operation performed between the label 1 and 2 is common to both streams and displays the grayscale operation. In sub-stream composed by labels 2, 3 and 4 are performed the operations of thresholding with

isovalue 20% and aperture using a disk as structuring element, respectively. In sub-stream composed by labels 2, 5 and 6 are performed the operations of thresholding with isovalue 50% and aperture using a disk as structuring element, respectively. It is noted that on resulting images of processing may be applied new processing, creating a combination of processing.

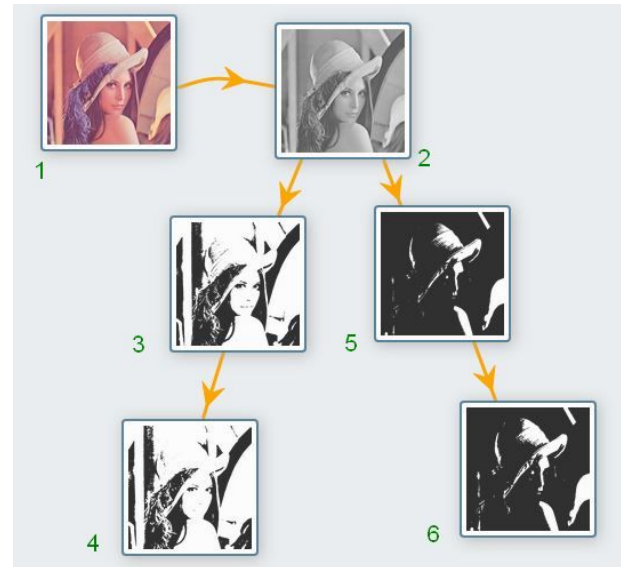


Fig. 7. Digraph created by the platform after several processing

In addition, nodes of digraph can be moved and deleted, and over the images can be performed zoom operation, facilitating the visualization of the results. Thus, the objective is that the user experience becomes more attractive and facilitates the learning process of DIP techniques.

V. EXPERIMENT

A. Experimental context

A good way to evaluate a teaching tool is through an experiment [13]. The experiment allows collecting feedback from a group of participants about a new tool or approach. Through this feedback it is possible to have evidence about efficiency of a tool/approach or identify their weaknesses.

An experiment was conducted to evaluate the advantage of using platform in teaching and learning DIP. The experiment was executed at São Paulo State University (Universidade Estadual Paulista – UNESP), campus at Presidente Prudente, with undergraduate students in Computer Science ($n = 33$) from different academic years.

Commonly in introductory courses of DIP, the main tool used in teaching is MATLAB. The purpose of this experiment was to introduce to participants the platform as a visual tool that complements the educational concepts of DIP. Importantly, the tool is not intended to replace the MATLAB but offer a dynamic approach for rapid results visualization of methods covered in class.

Most of the participants had no contact with MATLAB ($\sim 76\%$) and also did not have DIP knowledge ($\sim 67\%$).

Furthermore, none of participants had previous contact with the proposed web platform.

B. Hypotheses

The main goal is to analyze whether the visual approach has benefits in understanding DIP concepts when compared to traditional approach. Thus, the hypothesis is: the proposed web based approach is more efficient than the commonly used.

C. Experimental design

The experiment was divided into four stages. In the first stage we presented basics of Digital Image Processing.

The second stage consisted in the presentation of MATLAB syntax, with emphasis on its toolbox dedicated to Digital Image Processing. At same stage, participants were asked to convert a color image to gray-scale using MATLAB. Still using MATLAB, participants applied the threshold on the image obtained from the previous process.

In third stage the platform was briefly presented and asked to the participants to reproduce the stream of operations performed in the second stage.

Finally, in the last stage we ask to the participants to fill a form with a set of assessing questions the platform and about the practicality of use as an auxiliary tool in DIP learning. Through this form it has also enabled participants to provide suggestions and critics to platform.

D. Experiment Data Analysis

The first aspect considered in the form filled out by the participants was the ease of viewing of the techniques presented to be used MATLAB and be used the platform. The participants had an answer with five alternatives (very easy, easy, medium, hard and very hard) for the assertion that the approach facilitated the results visualization obtained by the processing stream.

The Figure 8 shows the distribution of responses obtained by experiment for the first aspect considered. From the chart represented by Figure 8, we note that none of participants considered hard to visualize the processing stream through the platform, while 36.36% considered hard to visualize when used only MATLAB.

Still on the same chart, we can note that 72.72% of the students consider the visualization of the processing stream by the platform easy or very easy, while 15.15% consider the visualization easy or very easy with only MATLAB. Thus, we can say that the use of platform makes it easier to see the processing stream when compared with the only use of MATLAB.

The second aspect considered was the approval of use of MATLAB and platform to help in DIP learning. In this aspect the participants had alternatively five responses: strongly disagree, disagree, indifferent, agree and strongly agree.

The Figure 9 shows the distribution of responses to the approval of use of the tools to aid in DIP learning. Through the Figure 9, we can see that the vast majority of participants believed that the use of these tools assist in learning DIP

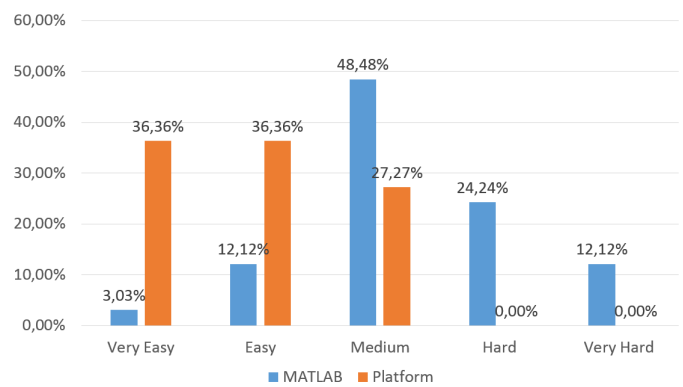


Fig. 8. Distribution of answers for easy viewing from the process stream

(75.75% agree to use the platform, while 84.84% agree to use of MATLAB). Thus, according to participants of the experiment is beneficial to use of MATLAB and platform to DIP teaching.

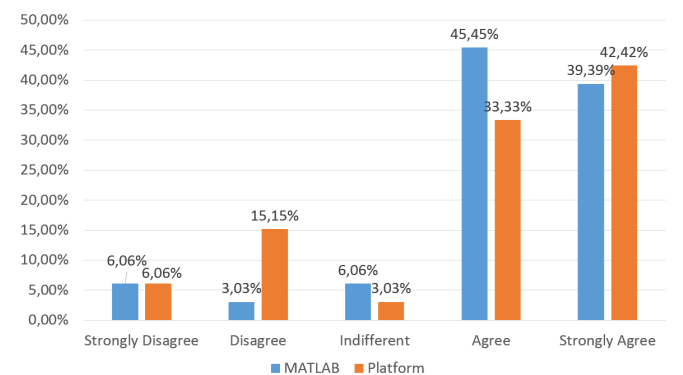


Fig. 9. Distribution of answers to the assertion that tools assist in teaching DIP

In a last aspect we asked to the participants to opt for a tool that they believe offer a better view of the processing stream. The Figure 10 illustrates the distribution of responses in choosing between the tools. The chart represented by Figure 10 shows that 46% participants prefer to use the platform. Note that 24% of respondents believe that the combination of tools is the best alternative for visualizing the stream, coming against the initial hypothesis.

Finally, the Figure 11(a) shows the distribution of preference for participants with previous knowledge of DIP, while the Figure 11(b) shows the distribution of preference for participants without previous knowledge in DIP. Note that for students with prior knowledge the use of the platform is well accepted.

VI. CONCLUSIONS AND FUTURE WORK

In this paper we presented a platform based on web technologies to aid teaching and learning DIP course. By using the web platform has been a gain in ease of access, since it can be accessed from any operating system through a browser that supports HTML5.

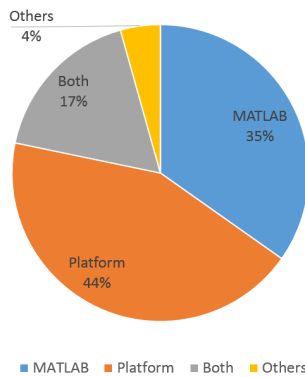
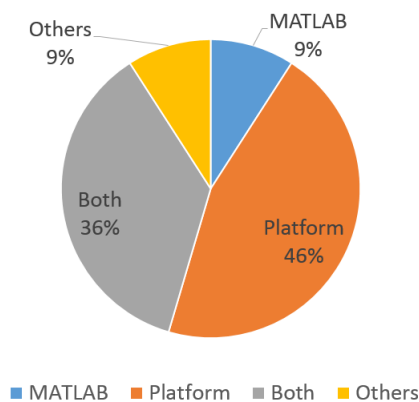
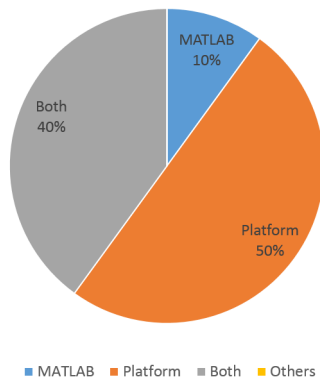


Fig. 10. Preferred distribution tool for visualizing the processing stream



(a) Participants with knowledge in DIP



(b) Participants without any knowledge in DIP

Fig. 11. Preferred tool to visualize processing streams for participants with or without knowledge of DIP

As the processing performed are displayed in a single view and the results are structured through a digraph, it is easy for students to view and understand processing streams. It is worth noting that the platform has not intended to replace the coding algorithms, but provide a dynamic experience of the covered techniques.

An experiment was conducted with a group of students in order to verify the acceptance of the platform. Through

the experiment was possible to see a good acceptance of the participants regarding the platform. Furthermore, a promising approach is to use the platform coupled with traditional tools (such as MATLAB).

With the feedback obtained from experiment, some possible refinements were identified and motivate other experiments in future. Among those refinements are the implementation of more processing techniques discussed in higher education courses and the availability of the processing pseudocode. Finally, it can be interesting to perform the processing on client-side (via browser), to reduce traffic on the internet, benefiting low speed connections.

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Adaptation Resources in Virtual Learning Environments under Constructivist Approach: A Systematic Review

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Abstract—Distance Education is a modality widely used in the teaching-learning processes. To support the distance education or blended courses there are educational environments called Virtual Learning Environments (VLEs). These environments support the process of communication between students, teachers, tutors, and the community, allowing everyone to participate in an interactive mode and with availability of teaching materials, both in academia and in the corporate environment. Also, there are several techniques for adaptation resources for students in VLEs found in literature like context-awareness, collaborative learning, and adaptation by Artificial Intelligence (AI) technologies, such as agents and ontologies. Thus, this paper aims to summarize the information obtained in the literature about educational adaptation to students in VLEs supported by a pedagogical theory. For pedagogical theory, Piaget Constructivism was chosen. To obtain this information in literature, a Systematic Review was performed in order to answer three research questions. The results and analyses of the review are also discussed. This study intends to contribute with designers and developers of educational applications, giving a broad view of the area of adaptation resources supported by Constructivism and making some recommendations.

Keywords—*Adaptation; Virtual Learning Environments; Constructivism*

I. INTRODUCTION

Distance Education is a modality widely used in the teaching-learning processes. To support the distance education or blended courses there are educational environments called Virtual Learning Environments (VLEs). These environments support the process of communication between students, teachers, tutors, and the community, allowing everyone to participate in an interactive mode and with availability of teaching materials, both in academia and in the corporate environment. So, many VLEs such as Blackboard [1], Brightspace [2], and Moodle [3] are in continuous process of development and testing in distance courses.

However, despite this huge use of educational environments, they usually offer learning resources in the same way for all students, resulting that the learning may not become effective for all because of several particular characteristics that each student has [4]. This therefore may create difficulties

of knowledge acquisition for some students or even lack of interest by the students in the use of learning environment. So, aiming to solve this problem, there are several techniques for adaptation resources for students in literature e.g., context-awareness [5], [6], collaborative learning [7], and adaptation by Artificial Intelligence (AI) technologies, such as agents and ontologies [8], [4]. In this paper, we considered the term “adaptation resources in VLEs” as the action of changing content (e. g., activities passed, learning objects delivered, and interface changing) in VLEs to adapt according to the students’ characteristics using some technology.

Thus, this paper aims to conduct a systematic review with the information obtained in the literature about educational adaptation to students in VLEs supported by a pedagogical theory. This study is considered relevant because of the importance of identifying, classifying and disseminating research in computer science and education areas, which aims to address the resource adaptation methods presented to the student in the teaching and learning processes. The scope of this research was restricted to Piaget Constructivism pedagogical theory [9]. This theory is applied in several works in the literature testifying the increasing of students’ effective learning [10], [11], [12], [13], [14], [15], [16].

To obtain this information in literature, a Systematic Review was performed. A Systematic Review “is a means of identifying, evaluating and interpreting all available research and relevant information on a research question, a topic or phenomenon of interest, and aims to present a fair assessment of a research topic, using a reliable methodology, rigorous and auditable” [17]. In addition, our Systematic Review was characterized by three research questions that will be answered in Section III:

- **Q1:** Which adaptation techniques shown to students in VLEs are most often currently used?
- **Q2:** From Q1 answer, which adaptation techniques shown to students in VLEs use a Constructivist approach?
- **Q3:** Which suggestions could be given for developers of educational systems aiming to use adaptation in VLEs in a Constructivist manner?

In the first question, the idea was to create a comprehensive study with the adaptation techniques most commonly used nowadays. In turn, the second question defines which adaptation techniques of educational resources in VLEs are within a constructivist perspective. With the results of these questions, the third question tries to make recommendations for developers of educational applications based on future trends evidenced from conclusions about the adaptation techniques found in the constructivist perspective.

This study intends to contribute with designers and developers of educational applications, giving a broad view of the area of adaptation resources supported by Constructivism. The text is divided into four sections. Section II presents related works and concepts. Section III describes the Systematic Review process and presents the results from this research, showing the adaptation techniques most used in VLEs under a Constructivist approach. Finally, Section IV presents final considerations.

II. ADAPTATION IN VLEs USING CONSTRUCTIVISM: THEORETICAL BACKGROUND

The definition of Constructivism is a conception of knowledge and learning, which derives from the genetic epistemology of Jean Piaget [9], that starts from the idea that the knowledge is constituted by the interaction of the individual with the social and physical environment, by virtue of its action and not by any prior endowment, nor the information that the student receives at classroom by the teacher. In Education area, this theory has a dissatisfaction with an educational process that consists of only repeat, recite, teaching what is already done, rather than making act, operate, exchange ideas, create, build from the reality experienced by students and teachers.

In the Systematic Review process conducted, several forms of implementation of Constructivist features in VLEs were observed. The Intelligent Open Challenges System (IOCS) [12] is a proposal for a multi-agent system to adapt some patterns of Piaget's Clinical Method. It has a strategist agent, performing mediation between the IOCS and the user. The proposed system aims to work learning through the application of challenges consisting by logical-mathematical proofs of open conception, worrying to acknowledge and document the reasons for the user compared to the solution, as well giving visibility to ongoing cognitive processes.

In turn, the work presented in [13] proposes "a general framework of multi-strategic learning environment" and analyzes in details each strategy in the VLE. This improves the interest of learning by students and promotes students to carry out personalized learning, improving the quality of teaching-learning processes. The Oscar Conversational Intelligent Tutoring System (CITS) presented in [14] is a system using natural language interface in order to allow learners constructing their own knowledge through discussions. Oscar CITS mimics a human tutor by detecting and adapting to student's learning styles whilst directing the conversational process.

In [15] a Constructivist approach to Adaptive Hypermedia Educational Tool is presented. The learning platform assesses user's knowledge and presents contents adapted according to

the characteristics of the student. This platform allows permanent automatic feedback and support, through teaching methodologies and educational activities. On the other hand, in [16] the study objective was built an e-learning system for a course of Programming Project using Constructivism. Based on this system, the authors conducted experimental teaching and presented how the Programming Course influenced the performance of university students. And in [18] an approach of case-based reasoning for Educational Adaptive Web-Based Systems using fuzzy logic to adapt e-learning contents according to the students learning styles and their individual needs is presented.

In the Systematic Review done, were found some research works dealing with Constructivism and collaborative learning described below. According to Dillenbourg [19], a wide used "collaborative learning" definition is "a situation in which two or more people learn or attempt to learn something together". And in some works dealing with collaborative learning we found the term "Computer-Supported Collaborative Learning" (CSCL). CSCL is a research field focusing on collaborative activities between students supported by computers. With the support of computer networks, students may do cooperative learning activities as "accompanied mutual education, group discussion, exercises and team projects, without the limitation of time and space" [20].

In [10] is presented Omega Network, a proposal to the social and adaptive e-learning areas. In particular, the authors want to distinguish the candidates that act as a point of help in an academic course of e-learning. This way, it was possible to use all the activities and features offered by VLE with technologies such as: adaptive presentation, collaborative filtering, and peer tutoring.

As way to overcome the feeling of isolation and consequent students' dropout in VLEs, the work presented by [11] presents an experiment with the model called i-Collaboration promoting collaboration between students in a VLE. This model is based on the use of Virtual Learning Companions (VLCs) agents as collaboration monitors based on Constructivist theory. These agents are integrated into collaborative tools to know each student profile and his behavior in the learning environment.

As examples of studies that use explicitly the term CSCL, we can mention [21], that is proposed an architecture that provides support for adaptive techniques of collaborative learning into a CSCL environment. The proposal combines adaptation rules and dynamic support through recommendations via a system of accessible and adaptive guidance. Another related work is [22], in which the authors used a multi-agent system in order to develop a CSCL application to form student groups improving collaborative learning. In [23] CSCL and Constructivism are used. Such research has a proposal of a theoretical framework that leverages attention guidance in a social approach to facilitating the process of central domain concepts, principles, and interrelations between them based on social interactions. In [24] is presented an architecture that facilitates the integration of features in a scenario of collaborative learning using the Moodle VLE. The proposal of [25] presents a pedagogical approach supported by a virtual environment to improve and

facilitate cooperative authoring in programming for Computer Science.

Also, in the work presented by [26] is proposed the integration of a set of CSCL tools in a VLE, as a complete sequence of learning activities based on a Constructivist approach. In [27], the authors want to explore the behavior patterns of collaborative learning of students in several simulation systems. Two CSCL learning environments (simulation of Augmented Reality and Traditional simulation) using mobile devices were designed in order to help college students in Physics.

In the conducted Systematic Review, some works that use mobile learning (m-learning) with Constructivist theory were found. The popularization of VLEs and the growth of mobile applications in education has emerged m-learning with a high degree of mobility anywhere and anytime. M-learning is frequently associated with context-awareness feature. This term means "the computer ability to sense and act upon the information provided by its environment, such as location, time, temperature, and user identity" [28].

The educational paradigm considered in COMTEXT project [5] is Interactionist-Constructivist. The tools within the learning environment COMTEXT aims to support the development of competencies in order to promote interaction among a community of students, focused on knowledge sharing and skills development. The authors consider four elements in the work: the knowledge about learner profile and his needs; the physical, temporal and social context that is moving around the learners; the educational paradigm; and the possibilities of wireless and mobile technologies.

In [29] is proposed an m-learning environment that can be used to provide customized learning, which uses the interaction of intelligent agents, which can improve the automated information gathering, planning lessons, customizing learning materials and collaboration between instructors and learners in a Constructivist perspective. Furthermore, the work in [30] describes an environment of personalized m-learning to the University College Dublin aiming provide content delivery to promote an efficient Constructivist learning anywhere/anytime for students. The VLE offers access both via desktop computers and mobile devices, an interactive tool, customized interfaces, reuse of learning objects, recommendation of educational resources, and similar peers.

The proposal presented in [31] consists in a proposal of collaborative learning objects under mobile devices technology allowing creation of teaching units for activities in a collaborative mode between students. The work uses three main approaches: learning objects, CSCL, and m-learning.

Regarding another works found in this Systematic Review using AI technologies, in [32] is presented an educational game for mobile devices based on multi-agent systems. In [33] the authors show courses adaptation according to the student's learning styles. In turn, in [34], an intelligent Java-based framework to provide mobile services (m-Services) in an Info-Station environment is presented. The environment is supported by an HTTP container. A multi-agent system

behaves as a bridge between m-Services applications and users using mobile devices.

We can thus see that there are several studies in literature that deal with educational adaptation technologies using Constructivist features applied to VLEs. The following section describes how the Systematic Review of literature was performed and its results.

III. EXECUTION OF THE SYSTEMATIC REVIEW

In the Systematic Review process, we seek to find answers to the research questions already presented in Section I. We used a search string with the following terms: "profile", "profiling", "profilng", "personalization", "personalisation", "adaptation", "adaptive", "adaptivity", "context-awareness", "VLE", "virtual learning environments", "constructivism", "constructivist", "CSCL", "computer-suported-collaborative-learning", "collaborative learning".

The retrieved publications by the search engines (IEEEExplore, ACM Digital Library, Scopus, Elsevier, Compendex) were organized by the manager references software Mendeley (<http://www.mendeley.com/download-mendeley-desktop/>). This software allowed indexing of items, i. e., a list with the names and other information for instant searches.

The criteria for publications be selected and analyzed in details are described below.

1. Exclusion Criteria:

- Publications whose full text is not available;
- Publications those are only available as an abstract;
- Publications those are a letter from the editor;
- Publications in which the context is not related to adaptation techniques in VLEs or not related to constructivist approach.

2. Inclusion Criteria:

- Publications presented as full papers; short papers and works in progress are counted if they are within the research scope;
- Publications addressing topics that are related to adaptation resources and Constructivist practices in VLEs.

A. Analysis and Discussion of Results

In the digital libraries searched, 951 publications were found in total. Of these, were finally selected 108, corresponding to 11.35% of publications found. To achieve this final number of publications, we used the inclusion criteria established above.

Table I summarizes all adaptation techniques found in the selected publications, ordered by the number of occurrences of adaptation techniques found. Thus, context-awareness was the technique with highest number of matches found (51),

followed by adaptation by agents (35), collaborative learning (33), and so forth. In Table I it is also possible to see further description of the adaptation techniques found. Importantly, in a publication may have occurred more than an adaptation technique. Therefore, the sum of all occurrences of adaptation techniques (218) is greater than the number of all selected publications (108).

TABLE I. ADAPTATION TECHNIQUES FOUND IN ALL SELECTED PUBLICATIONS.

Position	Adaptation Technique	Number of Occurrences	Definition
1	Context-awareness	51	Defined in Section II.
2	Adaptation by agents	35	Using software agents from AI. Agents are computational systems capable of autonomous action in some environment in order to achieve their project goals [35].
3	Collaborative learning	33	Defined in Section II.
4	Learning styles	19	A learner style is the distinctive and habitual way the learner acquires knowledge [36].
5	Fuzzy logic	12	Is a form of many-valued logic that deals with approximate, rather than fixed and exact reasoning [37].
6	Students' interests	10	Interests that students may have in the course.
7	Planning	8	Planning in AI is "the task of coming up with a sequence of actions that will achieve a goal" [38].
8	Competency-based adaptation	8	Related to the students' competencies.
9	Learner model	7	The learner model is made up of learner information considered most important for the adaptation and customization processes in VLEs in order to achieve a more effective learning by students, such as personal information, preferences, and academic information [39].
10	Ontologies	7	Is a formal naming and definition of the types, properties, and interrelationships of the entities that really or fundamentally exist for a particular domain of discourse [40].
11	Content recommendation	7	Recommendations according to students' characteristics.
12	Standards	7	Standards were used allowing content adaptation. The most cited were IMS LIP [41] for students' characteristics and CC/PP [42] for mobile devices.

13	Programmed instruction	3	It consists of self-teaching that presents material structured in a logical and empirically developed sequence [43].
14	Swarm intelligence technology	2	It consists on "the collective behavior of decentralized, self-organized systems, natural or artificial" [44].
15	Meaningful learning	2	Refers to "a learning way where the new knowledge to acquire is related with previous knowledge" [45].
16	Learning objectives	1	Learning objectives "should describe what students should know or be able to do at the end of the course that they couldn't do before" [46].
17	Adaptation by templates	1	Using predefined templates for adaptation in order to create a course.
18	Markov chains	1	A Markov chain is a stochastic process with the Markov property. The term "Markov chain" refers to the sequence of random variables such a process moves through, with the Markov property defining serial dependence only between adjacent periods (as in a "chain"). It can thus be used for describing systems that follow a chain of linked events, where what happens next depends only on the current state of the system [47].
19	Formative assessment	1	This process is "a range of formal and informal assessment procedures employed by teachers during the learning process in order to modify teaching and learning activities to improve student attainment" [48].
20	Genetic algorithms	1	Is a search heuristic that mimics the process of natural selection. This heuristic is routinely used to generate useful solutions to optimization and search problems [49].
21	Knowledge transfer	1	Knowledge transfer is "the process through which one unit (e.g., group, department, or division) is affected by the experience of another" [50].
22	Feedback messages	1	Feedback messages given to students on a Constructive manner, stimulating the students to achieve the correct answer.

A fact that has observed in this study was to find 58 studies (53.7% of total) which use m-learning approach from 108 selected publications. Moreover, for adaptation technique that

uses standards, which got 7 occurrences in Table I, the standards most cited were Instructional Management Systems Learner Information Package (IMS LIP) [41] for students' characteristics and the Composite Capabilities/Preference Profile (CC/PP) [42] characterizing the mobile device that the student uses. Importantly, regarding to the adaptation technique by learning styles (19 occurrences in Table I), the style that appeared more frequently was the Felder-Silverman [51]. Using Artificial Intelligence techniques for adaptation by agents, the most widely used framework was Java Agent Development Framework (JADE) (<http://jade.tilab.com>).

Another interesting information obtained from this systematic review was that of all selected papers, approximately 57% of them had their adaptation techniques tested. Meanwhile, the remaining 43% not tested their approaches or were papers of literature reviews or surveys. Regarding the VLE used, the most cited was Moodle [3] (approximately 14% of selected papers), although in most studies there was no VLE explicitly cited or even used (approximately 38% of selected papers).

The number of works that do not use Constructivist approach from the 108 selected publications was 59 (55% of total), but the 49 (45%) remaining use. Table II shows only the adaptation techniques in which a Constructive approach was used from all selected publications ordered by number of occurrences. In this situation, "collaborative learning" was the technique with the highest number of occurrences found (25), followed by adaptation by agents (17), fuzzy logic (10), context-awareness and learning styles (9 occurrences each), and so on.

TABLE II. ADAPTATION TECHNIQUES FOUND IN ALL SELECTED PUBLICATIONS USING A CONSTRUCTIVIST APPROACH.

Position	Adaptation Technique	Number of Occurrences
1	Collaborative learning	25
2	Adaptation by agents	17
3	Fuzzy logic	10
4	Context-awareness	9
5	Learning styles	9
6	Students' interests	8
7	Ontologies	4
8	Learner model	3
9	Content recommendation	2
10	Planning	2
11	Competency-based adaptation	2
12	Learning objectives	1
13	Markov chains	1
14	Formative assessment	1
15	Feedback messages	1

Returning to the research questions, based on information obtained from results of the Systematic Review, the answers found are described below.

- **Q1:** Which adaptation techniques shown to students in VLEs are most often currently used?
- **A1:** Table I shows all adaptation techniques in VLEs found in this research and the number of their occurrences. According to Table I, the three adaptation techniques found with the highest number of occurrences were: context-awareness, adaptation by agents, and collaborative learning, respectively with 51, 35, and 33 occurrences each. Thus, we can notice that context-awareness is the adaptation technique currently most common in the surveyed literature. In the research works read, context-awareness could be achieved through features in the students' equipment (e.g. GPS, RFID, wireless sensor networks) and student characteristics (preferences navigation, answered activities, frequency of students in VLEs and his learner model). Importantly, in some studies the context-awareness technique was used in combination with other techniques seen in Table I, as adaptation by agents, learner model, and standards.
- **Q2:** From Q1 answer, which adaptation techniques shown to students in VLEs use a Constructivist approach?
- **A2:** From all adaptation techniques found in Table I, Table II shows only adaptation techniques in VLEs using a Constructivist approach and the number of their occurrences. And from all the 22 adaptation techniques described in Table I, 15 of them have been used on Constructivist approaches. And all of 218 occurrences, 95 (43.5%) used adaptation techniques in VLEs with a Constructivist approach. In this case, collaborative learning had the highest number of occurrences (25), followed by adaptation by agents (17), and fuzzy logic (10). Importantly, although collaborative learning is often present in Constructivist approaches, not all studies that use Constructivism deal with collaborative learning and vice versa. This can be seen in Tables I and II. For example, although 33 occurrences have been found collaborative learning, 8 of them did not use Constructivist practices.
- **Q3:** Which suggestions could be given for developers of educational systems aiming to use adaptation in VLEs in a Constructivist manner?
- **A3:** Based on some studies with a greater emphasis on technology rather than the pedagogical aspects, the first suggestion is validate the pedagogical aspect, not only the technologies used. A good work within Informatics and Education area must have a good pedagogical foundation and not only technological innovations, without being supported by an educational theory. Another suggestion for

developers of educational systems is consider using the 7 adaptation techniques found in this study that does not use Constructivist practices (standards; swarm intelligence technology; meaningful learning; adaptation by templates; genetic algorithms; knowledge transfer; and programmed instruction). However, especially when dealing with programmed instruction, as this technique is opposed to the Constructivist practices, developers should check which can be availed from the Skinner theory [43]. Alternatively, developers can use some adaptation techniques based on Constructivism and also the same techniques based on programmed instruction, to compare which of the two approaches would bring better satisfactory results. Another suggestion is to integrate several techniques already using Constructivist practices, allowing VLEs more adaptable to the students' needs. For example, the VLE can provide activities that promote student reasoning and constructive feedbacks to students according to learning styles, skill levels of students, answers of activities and interests. Thus, through feedback that allows the dialogue with the student, he is not just a receiver of information. This dialogue can also mediated by software agents. Another suggestion is to develop applications and Constructivist strategies for m-learning environments, since many works (53.7% of 108 selected publications) using m-learning have been detected in this Systematic Review. For example, content adaptation techniques could stimulate collaborative learning between students and adapt the content shown to the students depending on mobile device features, such as screen size, processing power, memory, location, among others, but in a Constructivist manner. As another idea, according to the learner profile, some personalized activities could be passed to student execute in groups of recommended colleagues to discuss about a specific theme, constructing knowledge through interaction between students. The AI technologies such as agents, ontologies, fuzzy logic, and swarm intelligence could form the groups depending of the students' profile and the constructivist pedagogical theory would be applied to promote interaction between students through collaborative learning in activities passed by teacher.

IV. FINAL CONSIDERATIONS

In the distance education and blended courses, the common practice has been the use of VLEs. In the reviewed literature were found a summary of several techniques for adaptation resources applied in VLEs, in which they have the purpose of a higher degree of student satisfaction and a better effective learning by him, supported or not by a Constructivist theory. Thus, this paper aimed to characterize the state of the art on the adaptation resources in VLEs under a Constructivist

perspective, obtaining information such as which are the most commonly used techniques in the literature and which techniques are used in a Constructivist manner. Based on the research results, some suggestions were given to developers of educational systems who want to make their VLEs more adaptable to the students' needs.

With this study, we provide reflections on the research found that involve the concern with adaptation techniques in VLEs for students. In addition, with this systematic review, researchers can have easy access to research initiatives data in Informatics and Education dealing with this area.

Increasingly, with popularization of the use of mobile devices, the development and use of these devices adapted to educational systems will be more frequent. Furthermore, another fact observed is the adaptation technique of collaborative learning was often observed and thus the developers of educational systems may enhance this practice, also checking the effective learning of the student. In the Artificial Intelligence area, it was observed that there is a wide use of software agents and fuzzy logic. In this case, they may be responsible for an intelligence layer in VLEs, easing the process of content adaptation in courses. Therefore, all these facts found in this study contribute to give suggestions to the developers of educational systems that are interested in working with adaptation resources using a Constructivist approach, by concluding and perceiving that there is a promising future in this research field.

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Bridging the Divide: Strategies for College to Career Readiness in Computer Science

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Abstract— The conversations and debates concerning how a student's time on campus translates to better results upon graduation are not going away. Every day institutions of higher education are challenged to explicitly demonstrate and provide a clear articulation of the value of education as measured by post-graduation employment. We discuss strategies implemented in a computer science program to address the issue of student preparation for the workplace of the 21st century. We discuss the extension of more traditional experiential learning methods including project based courses, capstone courses, cooperative experiences and internships to assist students in developing the necessary skills required to transition from college to the workplace.

Keywords—*experiential learning, career readiness, computer science*

I. INTRODUCTION AND MOTIVATION

In 1976, the headline of Newsweek magazine was "Who Needs College?" [1]. The article's commentary is almost identical to that of today's politicians, pundits and the general public who question how a student's time on campus translates to better results upon graduation and debate the value of a college education. There is a shift in the perception of what the role of a university education is. As described in the Washington Post [2], "students and their parents increasingly view college as training for that first job out of college rather than a broad education for life that provides them with the ability to learn and move through multiple jobs and a career." Adding to the confusion, academia, government, industry, and the media make conflicting claims about the adequacy of the workforce: Is the supply and demand for workers in balance? Is there a particularly severe need to increase the supply and quality within the STEM workforce? Are there simply skills mismatches between employer needs and employee skills? Are students ready to transition to the workforce? No matter the answers, institutions of higher education are challenged every day to explicitly demonstrate and provide a clear articulation of the value of education as measured by post-graduation employment, and stakeholders must make decisions with contradictory, confusing or incomplete data [3].

Lumina Foundation's CEO Jamie Merisotis points out that the shift to a knowledge-based workforce has led to a general confusion about postsecondary education and what postsecondary credentialing means. Merisotis suggests that the confusion leads to an employer's lack of confidence in a graduate's readiness for the workforce. He proposes a

transformation of what he refers to as "today's fragmented postsecondary landscape" into one that is student-centered and learning based so that the meaning of the credential is clearer to employers and students [4][5].

In contrast to a traditional higher education model of transferring knowledge, there must be a shift in focus to learning and a shift in the responsibility for the management and direction of learning to the student [6][7]. The move towards making graduates career ready essentially amounts to finding ways to learn basic knowledge, and transforming these capabilities into deeper learning in order to create a flexible and adaptable individual with the appropriate skills to survive in the 21st century [8]. To survive, individuals must adapt and learn in ways that are unprecedented in the formal educational arena.

As university faculty, we have a vested interest in ensuring that our students are employable when they graduate, and we want to help the community understand the value of a college education. We also value a liberal arts education, and work to balance the principle of an education where students learn to become thinkers with the current trend towards an education that prepares students for a job. In this paper, we discuss the approaches we take in our curriculum to help students become well-rounded individuals, as well as prepared for the computing workforce.

We begin by discussing current marketplace factors faced by science and engineering majors. Next, we present the approach we take through our curriculum to help students develop marketable skills while learning to become lifelong learners. We end with a series of narratives based on capstone project experiences and discuss how the capstone project can be used as an opportunity for students to choose specific skills to refine.

II. MARKETPLACE FACTORS

Historically, the developed world benefited from an industrial economy that offered employment opportunities for all skill levels. However, the combination of globalization, pervasive technical advancements, and shifting demography has changed the employment equation. The knowledge economy, with flexible technology and high performance work systems, demands more skilled and autonomous workers [9]. Job requirements are extended beyond specific discipline based skills and knowledge to more general skill sets including learning, reasoning, communicating, and problem-solving with knowledge that cuts across domains [2][9][10][11]. As Kolb

and Yeganeh point out, "Expertise at learning has become a key capability necessary for survival, success and fulfillment" [7].

Though it is often thought that graduates should enter the workforce as a finished product, technical and scientific knowledge evolves so quickly that it is possible that a person's body of knowledge may become obsolete within a few years. In domains undergoing rapid development such as computer science, it is not whether a graduate is ready for the labor market that is most important, rather, upon completion of a degree, students must have not only useful and marketable knowledge and skills, but also the ability to adapt to a continually evolving workplace.

There are a variety of marketplace factors that have influenced our design of a university-level curriculum in computer science. We particularly consider the changing demands of the 21st century workforce. We look at employment rates and the perceived skills gap, the qualities that employers desire in recent college graduates, and we look at the transition from college to career. These issues guide our discussion of the strategies we implement to prepare students to become successful in their transition into the workforce.

A. 21st Century Competencies

The 21st century skills are defined as competencies required for present and future jobs and include knowledge, skills, abilities, work values, work contexts, and work interests, as well as key tasks and activities required by distinct occupations [9][12]. The U.S. Department of Labor's Occupational Information Network (O*NET) program has developed a database with detailed information on the competencies of workers by occupations [12]. Using the O*NET data, Carnevale and colleagues at the Georgetown University Center on Education and the Workforce identified competencies highly associated with occupations requiring computer science training [13]. These include cognitive competencies, such as knowledge of math, physics, and other scientific and engineering fields, as well as complex problem solving skills, technology design, and programming. Non-cognitive competencies include preferences for investigation and independent work [13].

In *Revisiting the STEM Workforce*, a companion report to *Science and Engineering Indicators 2014*, the National Science Board describes multiple pathways to these competencies. They identified a need to assess, enable and strengthen workforce pathways and suggested a heavy reliance on higher education in preparing students [3].

B. Employment Supply and Demand

Given the challenge of ever changing job requirements, Carnevale suggests that a 21st century worker's prospects "are increasingly grim" without a postsecondary education [3].

In 2012 6.2 million scientists and engineers were employed in the United States, representing 4.8% of the total United States workforce [14]. From 2008 to 2012, employment in these areas increased by an annual growth rate of 1.5%, while overall U.S. employment contracted by 0.9%. Although science and engineering employment was concentrated in two occupational groups, computer

occupations (56%) and engineers (25%), when viewed as an aggregate, the increase in employment hides the differential degrees of growth and decline in specialized occupations in these areas [14], an important element in fully understanding employment.

Because labor markets in science and engineering differ greatly across fields, industries and time, it is easy to identify a specialization that is in short supply. For example, employment in social media may be expanding, while other occupations shrink or are moved off shore. And though it is true that highly skilled professional occupations almost always have lower unemployment rates than the rest of the US workforce, there are surprisingly high unemployment rates for recent graduates such as engineering (7.0%), computer science (7.8%) and information systems (11.7%) during the first year [15].

This leads us to focus on how we can better prepare our students for the workplace. We looked at additional marketplace issues in an effort to determine what we can do to increase their competitiveness in the marketplace. Do they lack general 21st century skills, STEM competencies, or computer skills? What do employers want? Are there issues related to transitioning from college to the workplace?

C. A Skills Gap?

In a recent survey commissioned by the Chronicle of Higher Education and Marketplace, over half of the employers said they had trouble finding recent graduates to fill positions at their company or organization. Nearly one third gave colleges fair to poor marks for producing successful employees, criticizing degree holders for lacking basic workplace proficiencies [16]. A recent Bentley University study revealed that there are significant disconnects between students' perceptions of their preparation and employers' expectations of students' preparation, and a disagreement over who is responsible [17]. In a survey of 126 CEOs of major U.S. companies conducted by Business Roundtable and Change the Equation, 97% cited the "skills gap" as a problem [18].

Jeffrey Selinger in The Washington Post asserts, "As the price tag of college skyrockets and the job market for recent college graduates tightens, students and their parents increasingly view college as training for that first job out of college rather than a broad education for life that provides them with the ability to learn and move through multiple jobs and careers" [2]. He goes on to suggest that most college seniors are not ready for professional jobs. They either don't have the hard skills in computer coding and data analysis, or, more important, the soft skills employers are seeking such as problem solving and the ability to communicate and collaborate with co-workers and customers.

Conversely, Paul Krugman in the New York Times reports that multiple studies have found no support for claims that inadequate worker skills explain high unemployment [19]. Other discussions in the news media have suggested that the change in the relationship between job openings and unemployment denotes merely a mismatch due to geography and demography [20], or that it is not a skills gap that

employers are referring to, but rather an experience gap that is holding recent graduates back from the best jobs [6]. Following from this, it has been suggested that colleges should be closing this gap by ensuring that students get meaningful experiences preparing them for work long before they finish school [6].

D. *What Do Employers Want?*

The majority of employers say that possessing both field-specific knowledge and a broad range of knowledge and skills are important for recent college graduate to achieve long-term career success [21]. In broadest terms, demonstrated proficiency in cross-cutting skills related to communication, teamwork, ethical decision-making, critical thinking, and applying knowledge in real-world settings rank as employer's top priorities when hiring [9][22]. The ability to listen, interpret, follow instructions, and communicate with other people both orally and through writing are also listed [23], as are skills that demonstrate aptitude in a social setting and an ability to work in a team [24][25].

An Association of American Colleges and Universities survey found that employers place the greatest value on demonstrated proficiencies in skills and knowledge that cut across all majors; 88% of surveyed employers thought that it was important for colleges and universities to ensure that students are prepared to complete an applied learning project, and 60% thought that all students should complete a significant applied learning project before graduating [21]. The majority of employers stated that they were more likely to consider a job candidate who had participated in an internship, senior project, collaborative research project, or a field or community based project than a candidate who had not.

E. *Challenges for Transition from College to Career*

Currently, most students have opportunities to learn large amounts of domain knowledge and skills, but with few learning opportunities embedded in real work. Yet, when they graduate they are expected to be capable of applying knowledge and skills with flexibility. They must know what to use when, and they are expected to adapt their knowledge and skills to a variety of situations. We have found that even with project-based and capstone courses students may not be well prepared in domains outside of computer science. More importantly, they lack the skills to understand and remedy this situation. Though they should be ready for continued professional development, they may not be. Boshuizen's example of a software engineer who graduated and within five years had to not only stay up to date by learning a new language, but also adapt to completely new concepts and technologies with the introduction of the next disruptive technology [8] provides an example of the most sought after career skills – those skills related to job retention [26].

Smith and Gast [27] proposed, "There is a great myth that all seniors are ready for graduation and their impending transition into careers or graduate education." This is supported by research reported by Goleman, LaPlante, and Shivpuri and Kim suggesting that many students finish college or enter the workforce only to find that they are ill prepared for dealing with many aspects of both their personal and working lives [28] [29] [30]. Even though job-related domain

knowledge is critical for workplace success, there are other necessary skills needed for success in the workplace.

The transition to a career is often difficult because it requires the reorganization of self and the development of a new set of beliefs about life and career. Building on Erikson's theories of ego identity development in which he argues that establishing an ego identity (an understanding of who we are within the context of who we have been and our place in the social order) is the primary task of adolescence [31], Macia contends that college students are at the point of developing identity as a result of exploration and commitment [32]. Hansen talks about this as an identified point in an individual's life when they face anxiety and a sense of being adrift, lost [33]. After years of learning the system of how to succeed in school, the twenty something college graduates are thrown into the world of work with no real understanding of how to succeed in it [33]. They are forced to learn a new set of skills and attitudes that align with the workplace [34][35]. He identified critical issues that graduates face when making the transition from college to work [33]. Those that can be addressed in curriculum include:

- Time related issues - shifting from planning one's own schedule to working five days a week, eight hours a day,
- Learning everything you didn't learn in college and dealing with people of different personality types,
- Professionalism in the workplace based on who you are and what you want to do, and
- Developing a reputation as a valuable employee.

Another approach to address this transition is through internships. To develop mastery, students must acquire component skills, practice integrating them, and know when to apply them. Providing an opportunity to reflect on and integrate their academic experience into the workplace as a professional, quality internships focus on critical skills that employers value highly new employees will need to be successful: risk-taking, leadership, teamwork and collaboration, critical thinking and problem solving [6][36]. The National Association of Colleges and Employers reported that 63% of paid interns received at least one job offer post-graduation [21]. Lander reports that in 2012 69% of companies with 100 employees or more offered fulltime jobs to their interns and that interns had a seven in ten chance of being hired by the company they interned with [37].

III. ENHANCING DEVELOPMENT OF WORKPLACE READINESS

Degree programs in computer science are designed to prepare students with marketable expertise to enter the computing and information fields, as well as the skills and education required to adapt to the rapidly changing characteristics of the fields [38]. Anticipating shifts in skills and abilities, CAC (Computing Accreditation commission) within ABET (Accreditation Board for Engineering and Technology) provides guidelines that challenge faculty to prepare computer science graduates for careers and continuous learning in the ever changing knowledge-intensive workplace [39][40]. Thus, computer science education must cultivate a

wide range of capabilities that extend from current engineering and professional practice to those skills and knowledge sets that will result in the next generation of computer scientists with the abilities to lead and solve challenges well into the 21st century [41]. In this section, we describe the bachelor's and master's degrees that are offered by our department and discuss how various learning approaches are incorporated into our curriculum. We then discuss ideas for personalizing the curriculum based on the experiences and desired learning outcomes of individual students. The final section presents narratives as examples of how the capstone project has been personalized for our students.

A. Computer Science Curricula

The University of Texas-Pan American (UTPA) offers ABET accredited degrees in computer science and computer engineering, and master's degrees in computer science and in information technology. In Fall 2014, approximately 300 students were enrolled in the computer science bachelor's degree, 250 students in the computer engineering bachelor's degree, and 150 in the graduate programs. In addition to providing a core body of knowledge in the domain, the educational objectives for the degree programs include providing graduates with an understanding of social, professional and ethical considerations related to their disciplines. This paper discusses our use of deliberate practice, experiential learning, and the undergraduate capstone course and the graduate level master's project course to provide personalized opportunities for students to better prepare themselves for their careers.

The undergraduate curriculum for both the computer science and computer engineering degrees begins with a course to introduce the discipline. The course sets context for the remainder of the program, providing a foundation for the fundamental concepts of problem solving, algorithms and programming. Concrete exercises with limited solution spaces keep students focused on one or two issues at a time. For the last quarter of the course, robots are used to provide opportunities for students to integrate all of the course concepts with immediate and concrete visual feedback. Over the next two years, the curriculum focuses on skill development by introducing progressively more abstract concepts. It incorporates deliberate practice in both lectures and labs in which student performance is compared against an ideal model of performance to help students develop programming skills, as well as introduce problem solving and languages. The curriculum moves from concrete examples with demonstrations of concepts and constructs to more abstract levels of problem solving. This deliberate practice facilitates a "spiral of knowledge development" [36].

A junior level course in systems programming provides an opportunity to complete an individual semester long project in four well defined stages. This creates a space within the curriculum that allows students to transition from iterative practice to more experiential learning. This shift allows them to develop a knowledge framework that organizes both factual and domain knowledge. Students are able to increase their learning effectiveness through four modes of learning:

experiencing, reflecting, thinking, and acting, all of which are skills and abilities found in the 21st century competencies [36].

During the final year of the undergraduate curriculum, students typically take courses that have more open-ended projects, and students complete a capstone project.

The master's curriculum focuses on providing students with an opportunity to develop a deeper understanding of fundamental concepts of computer science, as well as broaden exposure to specialized topics. Through elective courses and a capstone project, students can choose to focus on a particular area of interest. Computer science master's students have two choices for the capstone project: a one-semester project or a two-semester thesis. The information technology master's curriculum is designed for students who earned a bachelor's degree in a field that is not computing based. The first semester courses provide a leveling experience for these students. At the end of the information technology degree program, students complete a one-semester project.

B. Project Based Courses

The deliberate incorporation of experiential learning in engineering and computer science education is common [36][42][43]. We suggest that a key is to give students project-based work or field studies earlier in their academic career. This provides students with more activities that integrate the lessons of the classroom with the real world [42]. These experiences can be used to address either false beliefs or potential gaps in knowledge and skills that might prevent graduates from successfully advancing their education, finding a job, and succeeding in their career.

We require a project based course in software engineering in each of the undergraduate degrees which may be taken after students have completed courses in advanced algorithms and data structures and in systems programming. The course provides a formal approach to the state-of-the-art techniques in software design and development with focused discussion on project planning, requirements, specification, system design, testing and implementation, and integration of the knowledge that students have learned in their other classes. Team projects are used to provide some experience in real world problem solving. The nature of the projects requires that students learn to not only apply software engineering principles, but, more importantly, develop collaborative and project management skills and expand their written and oral communication proficiency. Teams work on identified problems or challenges, most often involving concepts outside of the students' domains of expertise. This forces students to expand their existing knowledge base beyond the principles of their discipline and software engineering. Addressing a real problem adds value and motivation to the learning experience: the project becomes a challenge with multiple options for a solution, not just an exercise. Students take ownership, and the process to a solution results in identifiable learning outcomes [4][23][44]. At the graduate level, a similar course is offered for both of the degrees. The graduate software engineering course places more emphasis on issues of project management and resource management.

All of the software engineering courses provide an opportunity for students to experience a number of Hansen's critical transition issues. To successfully work within a team students must learn to shift their planning from self to that of the team, often resulting in concessions to schedules developed by the team. They must learn to deal with individuals with different skill sets and different personalities. On a team they must represent their skills and knowledge with honesty. If successful, they learn how to be a valuable team member.

Aside from a required theory course and a capstone senior project, the undergraduate curriculum provides the freedom for students to choose multiple paths through their upper division courses. Through discussion with faculty, students choose pathways that help them reach short term and long term career goals.

Both the undergraduate and graduate database courses include a semester-long project in which students work in groups to design and demonstrate the use of a relational database schema. Students select their own project topic and are encouraged to work with a real client or real problem. The project is divided into phases that are spread throughout the semester. Student teams receive feedback from the instructor on the deliverables for each phase and are encouraged to modify their design based on this feedback prior to progressing to the next phase. The structured phases of the database project help students to understand the software design process, while the open topic of the project provides students with the opportunity to customize the project based on their own interests and learning goals.

These example courses provide a formative learning environment where students can reflect on their experiences, assess their performance, apply feedback to improve their work, and identify their strengths and their weaknesses. Multiple presentations that address content and process allow students to refine communication skills. One of the critical skills desired by employers, and as Jarrett of KORU explains, communication is one of the easiest skill areas to improve in a short amount of time [2][29].

C. Internships

Though we encourage students to participate in internships, we are faced with two significant challenges. The first is that there are 21 million college students and only 2 million internships. The "simple" solution is to create 19 million more paid internships, but it seems highly improbable that this will happen. The second challenge is more closely aligned with our specific student populations. Many of the students have commitments that do not allow them to leave the region until after graduation. To address this challenge, we work with our local community to create opportunities for service learning and in this way create opportunities similar to those available through internships. For example, a student's volunteer work with a local nonprofit on social media can evolve into a paid position with the organization. Similarly, an unpaid internship at a local school district can lead to a permanent position. Recently, a project started in a software engineering course with a potential client turned into an opportunity for a team hire for the summer to complete the work.

D. Capstone and Master's Project Courses

The undergraduate curriculum includes a capstone senior project in which students construct a software product, following it through the stages from initial specification to the final completed project. The master's in computer science requires a thesis or final project, and the master's in information technology requires a final project. Those students who intend to extend their education beyond the master's level are directed towards the thesis option, while those students who intend to use the master's as their terminal degree are directed towards the final project.

The role of the capstone course is for students to integrate and synthesize learning from within the academic major to help students see the coherence across the discipline's body of knowledge. In the senior design and senior project courses in computer science, typically the goal is to promote coherence and relevance of general education and to foster conceptual connections between a student's general education and that in computer science. Design projects foster integration and synthesis within computer science and often require students to delve into other knowledge domains. The courses provide students many opportunities to explicitly develop skills, competencies, and perspectives that were either only tacitly or parenthetically introduced in other areas of the curricula (or missed altogether), improve their career preparation and facilitate their transition from an academic environment to the workplace.

E. Thinking about Career Readiness

We contend that it is important for student success to recognize the role that universities can play in helping students work on personal competence skills, social skills, and career and employment skills concurrently. Career development processes can be embedded in the curriculum and assist students in understanding, evaluating, and developing their personal competencies as they prepare to transition to the workplace. We can add focus on the time of transition from school to work, so that we might better prepare graduates to make this transition - to change their mindset from one geared toward freedom and autonomy to one of structure and teamwork [17]. Getting a job should not be something done after college, rather it should be a multistep process within the curriculum.

IV. EXAMPLE EXPERIENCES

Knowing that "context and continual integration across time" promotes the transfer of knowledge in new contexts, we have opted to go beyond traditional experiential learning methods including project based courses, capstone courses, cooperative experiences and internships to provide further opportunities to assist students in developing the necessary skills required to transition from college to the workplace. We began by developing a simulated corporate environment distributed over time and space to better assist students in transitioning from college to career [42]. Small group contexts provided opportunities for students to learn to communicate clearly in multiple media formats, deal with managing and applying large quantities of data, and making decisions with incomplete information. Students learn to transfer existing knowledge in changing contexts while simultaneously

implementing changes in the areas of personal growth and career development.

In an effort to more closely address the college to career transition, we then extended the simulated environment to support students in meeting academic goals and expectations, facilitating college and career planning and transition to the workplace. By scaffolding the learning experience, students had opportunities to master common skills while still allowing them to tailor individualized learning based on their post-secondary goals. Even though specific student goals and pathways varied, all students were expected to meet similarly rigorous standards. The specific student experiences were shaped by the students' goals, not their prior performance, and were also flexible, allowing students to alter programs to align with their changing post-secondary plans.

The following personal stories provide examples. The goals and expectations for students covered a wide range of knowledge and skills that extended beyond computer science and information technology domains. Their pathways reflect individual career interests and aspirations that were driven by state and national economic needs in conjunction with personal circumstances.

A. Lilia's Story

Though hesitant to accept an internship 864 miles from her family, Lilia was able to coordinate care for her two young daughters with her parents. So, after her junior year as a computer science major, she accepted a summer internship in the technology division of an international food processing company. With her daughters in trusted hands, she was able to focus on the experience and fully participate in a well-structured corporate internship program.

As with numerous other internships, at her internship exit interview, Lilia was offered a job upon completion of her degree. She had a corporate job waiting for her, with the potential for a long and successful career. It would have seemed that she would return to school, breeze through her classes, graduate, and move her daughters half way across the country to begin a career. Though she did return to school, and her classes went well, she returned from her internship, not doubting her computational skills, but rather concerned about her writing. Rather than completing a traditional capstone senior project, she worked with her faculty advisor to craft an experience that met the definition of the senior project, but more importantly focused her attention on honing her writing skills.

Lilia decided to complete a service learning project involving the creation of detailed and complete requirements and specific analysis documents for a software project supporting all organization of a local non-profit. By combining service learning, basic writing and software engineering, Lilia was able to practice professional writing in a situation that required her extant knowledge of the software development process. An unintended outcome of the experience was the opportunity for her to improve her evaluative and intentional listening skills as she elicited requirements from the non-profit's staff.

B. Salmon's Story

Salmon participated in a museum reservation system project as part of the graduate software engineering course. He also took the required database course, but worked on a different project. For the capstone project for the master's degree, Salmon decided to focus on the database component for the museum reservation system. His project expanded the project from the software engineering course by considering a database design for a more general-purpose system that could be used by organizations that handle reservations for a variety of types of events, including tours, room reservations, and reservations of resources. Additionally, the database provided for the storage and retrieval of membership information and staff assignment for events.

This project helped Salmon develop a variety of skills that he will use in the future. When planning the database design, he combined the requirements of the museum with those of another potential client. This required him to abstract the specific needs of each client and focus on how these specific needs could be met by a flexible and general database design. Additionally, he considered how the schema could adapt to new customers in the future. The ability to design a product that is flexible enough to meet the requirements of currently unknown customers is an important skill that is required in the corporate world. Additionally, Salmon wrote documentation for the database design that explained the design and provides a sample application with examples of how the database can be used for creating reservations and generating reports.

C. Victor's Story

Victor's master's project also evolved from the graduate software engineering class project, but with a quite different direction. His role focused on development of the prototype, and it was demonstrated for the class and the client at the end of the semester. The goal of Victor's master's project was to deliver a completed software application to the museum and assist the staff with setting up and rolling out the product.

Over the summer, Victor took control and responsibility for his own learning and engagement with the project. Victor worked on fleshing out the aspects of the system that the team had not included in the prototype. To enhance the functionality and usability of the software, Victor reviewed the requirements document, and incorporated several features that his class team had not included in their requirements.

By early fall semester, Victor thought that the product was nearly completed and looked forward to taking the application to the museum for testing. But the situation at the museum had changed over the summer. Personnel at the museum had changed, so the software would be delivered to a new client representative. As a result, Victor had to handle a number of changed and added requirements. Victor was able to deliver nearly all of the changes and make several adjustments to enhance usability. Near the end of the semester, Victor helped the museum's information technology specialist set up the software to run on the museum's server. Victor also created an extensive help/training video to support the software and offered to provide a rollout period for the software in case the client encountered problems.

In addition to his project, Victor served as a teaching assistant in the computer science department. Working closely with an experienced faculty member over two years, Victor took on more and more responsibility for the delivery of a freshman level computer science course. During his first semester, he assisted the faculty member with a structured lab component. During the second semester he volunteered to both lead lab and occasionally provide a lecture. Reflecting on his experience and the student outcomes, Victor experimented with novel methods for content delivery during his third semester. Finally, during his fourth and last semester, roles were reversed, and the faculty member served as his assistant.

Although Victor had considered a career in software development, upon graduation, Victor accepted an offer to teach at a local community college.

V. CONCLUSION

It is our hope that insights and stories we share will help others experiment with strategies leading to changes in the curriculum that accommodate the boarder landscape of learning required in computer science to maintain a strong, capable workforce, as the workforce needs of the country change. We suggest that these extensions to traditional experiential learning serve as strategies for deliberate and intentional cultivation of skill sets beyond those of the discipline. As a result, students are equipped to better articulate career goals, skills and abilities, and their relationship to the major. They are able to explain the connection between what they are learning in their discipline and the world of work. We propose that these experiences help students move beyond becoming lifelong learners; the experiences assist students to position themselves for lifetime employability. The experiences equip students to strategically and successfully navigate transitions. They serve to support their successful navigation of the path from college to the workplace with clarity, confidence and competence.

Finally, we suggest that although the strategies discussed have been successfully implemented at the faculty level, it is appropriate to intentionally embed career development skills that support the evolving economy into the fabric of the curriculum across the institution. The jobs are there; so is the perception of a "skills gap." There is also an experience gap - one that universities can help bridge.

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The Institutional Environment for Student Veterans in Engineering

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Abstract—Active military and student veterans navigate engineering education in ways both similar to and different from their civilian counterparts. This Work in Progress describes variation in institutional environments through interviews with campus administrators and inspection of university websites at four institutions. Three emerging themes are identified: 1) the presence/absence of key student policies, 2) variation in student support services, and 3) gaps in provision of such services. Interviews provide data on the challenges faced and assets brought by veterans, from the point of view of administrators. We find that serving veterans is an area of recent and increasing importance to these institutions and that the level of services offered is evolving to include veterans resource centers, training for students and faculty on veterans' issues, and web portals to access veteran-specific information.

Keywords—student veterans; institutional context; university policies

I. INTRODUCTION

As of 2011, nearly a million veterans had used the benefits offered through the Post-9/11 GI bill, and many campuses are seeing significant increases in the numbers of veterans [1], [2]. Military veterans hold tremendous promise for expanding and diversifying the engineering workforce. Yet, little is known regarding the educational pathways and experiences of student veterans in engineering including the institutional factors that shape their experiences.

To better serve student veterans, educational institutions across the country have been charged to “provide meaningful information” to service members, veterans, and their family members to “ensure that educational institutions provide high-quality academic and support services” to active-duty members of the military and student veterans [3]. Institutions have responded to this Executive Order by offering student veteran programs of varying levels of depth and breadth. For example, one report indicates that 62 percent of universities provide programs and services specifically for student

veterans; 71 percent indicated that such programs and services were an integral part of their institution's strategic plan [4].

Through a collective case study across four institutions, University of San Diego (USD), North Carolina State, Purdue, and Clemson, we aim to address gaps in the literature on the experiences and outcomes of student veterans in engineering with a particular focus on the complexities of institutional contexts as they relate to this group. Our overall study seeks to discover why veterans choose to pursue a Bachelor's degree in engineering, how student veterans' military experiences shape their academic experiences, and what are the experiences of student veterans in engineering. This Work in Progress aims to address our fourth key research question, namely how do institutions support veterans in general and in undergraduate engineering education in particular? Later work will include interviews and focus groups with student veterans themselves in engineering to understand how university policies and practices and their military experiences affect their academic experience and success. In its entirety, our study aims to provide actionable information to engineering colleges as they seek to diversify and to service members as they are transitioning to college life.

II. METHODS

A. Data Sources

To better understand the environment and educational context of each institution, we reviewed institutional websites and other materials for information targeted specifically to veterans and conducted semi-structured interviews with key informants who were knowledgeable about policies and services related to veterans. We used a snowball sampling methodology [5, p. 237] and asked each informant for names of others who could provide additional insights. In all cases, we interviewed the VA Certifying Official, a position required by the Veterans Administration for students at an institution to receive benefits. Other interviewees included: administrators

responsible for diversity, engineering advisors, Student Veterans Association (SVA) officers and advisors, admissions officials, counseling center personnel, and veteran services coordinators. In all, we interviewed 23 people – 5 at NC State, 9 at Purdue, 6 at Clemson and 3 at USD. Our interview guide included common information objectives but probes and follow-up questions were tailored to the respondent's position. All interviews, except the first three were recorded and transcribed by a professional transcriptionist; detailed notes were taken at these first interviews. As many of these informants are eager to improve their understanding of the needs of student veterans on their campuses, the research team maintains contact with some of them to remain abreast of relevant changes to the institutional environments and to share best practices from other institutions. Themes were identified by the lead author, with concurrence from her co-authors, from transcript data and informally gathered information using constant comparative analysis [6]. Through member checking, we asked several informants to review and validate our findings.

B. Study Institutions

The four institutions were selected to represent variation in geographic location, proximity to military installations, availability of support services for veterans, enrollment size, school history and mission, and other characteristics. Each of these campuses was identified as a 2014 Military Friendly Campus. A brief description of the institutions is provided below. More detailed information can be found in [7].

Clemson, NC State, and Purdue are land grant institutions, founded in the mid- to late-1800's with agricultural and engineering roots. All three are in the top 25 in undergraduate engineering enrollment and in the top 30 in undergraduate engineering degrees conferred [8] and offer a broad range of fields of study in engineering. Both NC State and Clemson are within two hours' drive of major military installations. Purdue is not but is home to the Military Family Research Institute, described below. In contrast to the much larger land-grant institutions, the University of San Diego (USD) is a Roman Catholic liberal arts institution, founded in 1949. The Shiley-Marcos School of Engineering offers undergraduate degrees in electrical, mechanical, and industrial and systems engineering. Unique to USD is the dual BS/BA degree for all engineering students. San Diego is the home to several major Navy and Marine installations.

In 2014-2015, the total number of veterans using GI Bill benefits at the four institutions was 175 at Clemson, 296 at NC State, 346 at USD, and 379 at Purdue. In Spring 2015, NC State had the most student veterans using the GI Bill in engineering with 56. Each of the other three institutions had fewer than 30. Of note is that veterans make up approximately 5% of the undergraduate engineering students at USD and 1% or less at NC State, Purdue, and Clemson.

III. EMERGENT THEMES

In this early stage of our research, we have identified three themes that shape student veteran experiences on our respective campuses: the presence/absence of key student policies; the availability of student support services; and gaps

in the provision of such services. At each institution, there has been a heightened emphasis placed on improving services for veterans and the policies that provide the framework for these services. We have also identified a few challenges faced and assets brought to campus by student veterans from the perspective of our key informants.

A. Theme 1: Presence/absence of key veteran student policies

1) *Trajectory for change:* All four universities currently participate in the Yellow Ribbon Program, which covers costs of attending the institution beyond what is provided by the GI Bill for post-9/11 veterans and dependents. This program helps veterans afford private colleges such as USD and offsets out-of-state tuition costs at Clemson, NC State, and Purdue. The latter three institutions each provide funding for up to 50 undergraduate veterans per year on a first-come, first-served basis, although more eligible students apply than there is money available; USD does not limit the number of veterans who can receive the benefit as long as they are qualified. Once accepted to the Yellow Ribbon program, students may continue to receive the additional support until either they graduate, their benefits are exhausted, or they are no longer in good academic standing. The amount of support is set by the institution, ranging from \$3,500/year at Clemson to \$8,466/year at USD, with half paid by the VA. Since 2012, GI Bill beneficiaries at NC State have been offered special payment plans, not available to other financial aid recipients, to coincide with their receipt of benefits.

The Veterans Access, Choice, and Accountability Act of 2014 (PL 113-146) requires that as of July 1, 2015, all states provide in-state tuition at public colleges to all veterans using Post-9/11 GI Bill benefits within three years of leaving the service, regardless of their state of residence. The governors of North Carolina and South Carolina signed compliant bills into law in June 2015. Indiana has provided in-state tuition to qualified veteran students at public universities since 2013. While this would appear to effectively eliminate the need for the Yellow Ribbon program at state institutions, there are exceptions in the law that make the program's continuation likely.

Lokken and colleagues have described a military-friendly campus as an institution that strives to identify and remove barriers to the educational goals of veterans and to create smooth transitions between military life and college life [9]. Such campuses also enhance campus awareness of the student veteran population and develop proactive support programs to meet student veterans' needs [10]. USD, NC State, and Purdue are identified as among 1,700 "military friendly" schools in 2015 by Victory Media (<http://www.gijobs.com/schools/>) [11]. USD uses the trademarked "Military Friendly School" seal on their Military and Veteran Students web page to highlight their commitment to their student veterans. Clemson is currently investigating how to regain the military friendly designation that they received in 2014, although informants there emphasized that they are most focused on serving student veterans and that obtaining the military-friendly recognition is a secondary goal.

At the institutional level, each of our land grant institutions is focusing more on student veterans than they have since the

original GI Bill in the 1940's and 1950's. At that time, USD was just beginning so it never had the focus on veterans that it does now. Clemson and Purdue have implemented "Green Zone" training for faculty, staff, and students to help them better understand the challenges faced by veterans and the campus resources available to support them. Clemson has a history as a military institution but a new president has given renewed focus to veterans' issues by elevating the ad hoc Student Veteran Committee to formal advisory committee status. The current president of USD is a military veteran. North Carolina has positioned itself as the "Nation's Most Military Friendly State" [12] and the University of North Carolina System is undertaking system-wide initiatives to be more welcoming of student veterans; these initiatives will then be adopted at NC State. Purdue is the home of the Military Family Research Institute, created in 2000 with funding from the Department of Defense, with a mission to improve the lives of service members and their families through research and outreach [13].

2) *Engineering policies and practices:* Clemson, NC State and USD generally admit veterans to engineering as transfer students. When they seek advice from engineering or the Certifying Official at these institutions, they are advised to take prerequisite math and science courses at a local community college at their own expense, rather than use GI Bill benefits, which are both time and dollar limited. Advisors indicate that taking the courses at a community college, in addition to the cost savings, allows veterans to transition to college and academic expectations more easily.

The land grant institutions require first-time-in-college students in engineering to wait a year before declaring a major to meet prerequisites and explore, through introduction to engineering courses, which engineering discipline, if any, is the best fit. Those entering as transfers, however, like most veterans, are allowed to declare a major immediately upon entry to the school except at Purdue. There, all engineering students are admitted to the First-Year Engineering program and are required to take a series of prerequisites, including a two-semester introductory course on engineering. Typically, students declare a major at the end of the first year. USD engineering students have a common curriculum for the first two years, no matter what major they declare, so they maintain the benefit of exploration and can change majors easily without impacting time to graduation.

B. Theme 2: Availability of Student Support Services

1) *Veterans' resource centers:* During the 2014-15 academic year, Clemson, Purdue, and USD all opened veterans' resource centers. Each aims to provide a centralized place for veterans' needs. At Purdue and USD, this center is a suite located in the student union and is a gathering place for veterans with a lounge, TV, conference room, and other amenities. Their resource centers also host the VA Certifying official(s), Veterans' Student Services Coordinator, and space for the SVA chapter. Clemson University's Student Veteran Resource Center is located in a small room that serves as a lounge and study area in one of the main buildings on campus. The Military Affairs Committee at NC State and the Division of Academic and Student Affairs Strategic Planning Taskforce

both have subcommittees charged with finding a similar space on that campus as it is a recognized need.

2) *SVA chapter:* All four campuses have a local chapter of the Student Veterans' Association, a national association with a mission to "provide military veterans with the resources, support, and advocacy needed to succeed in higher education and following graduation" [14]. Each chapter holds monthly meetings and occasional special events. At NC State, the SVA chapter holds meetings on the engineering campus, in addition to the main campus, to be more inclusive of veteran engineers.

3) *Web pages specific to veterans:* All four institutions have web portals where links to resources of interest to both veterans and prospective students are aggregated. Such a portal, when comprehensive, can give separating service members, and others, one-stop information about campus services targeted to veterans. Students are pointed to information about admissions; the GI Bill and financial aid; campus resources such as the counseling center and disability student services; campus organizations such as the SVA; and external resources such as the nearby VA hospital or local veterans' organizations. Unfortunately, at all four campuses, some information relevant to veterans requires a targeted search to locate. In other words, someone would need to know where the information might be located in order to find it. In addition to a portal for veterans, some departments and services on each campus have added a specific link for veterans to their departments' web pages. Table 1 shows university departments and services where veteran specific information is available either by a link or a web search.

TABLE I. WEBSITE RESOURCES FOR VETERANS (AS OF 4/22/15)

Veterans Specific Links From	Clemson	NC State	Purdue	USD
Admissions	X	X	X	X
Career Services			X	X
Cashier		X		
Counseling Center		X		X
Dean of Students	X			
Engineering				X
Financial Aid			X	X
Housing		X		X
Registrar	X	X	X	X

C. Theme 3: Gaps in Support Services

1) *Data collection:* Since only students who receive GI Bill benefits are required to provide their veteran status, identifying the true number of students and applicants who are veterans is a challenge across institutions. Further, many of those receiving benefits are actually not veterans but are spouses and dependents of veterans or service members. Clemson and NC State have recently added a question about veteran status to their admissions applications; USD and Purdue use The Common Application (www.commonapp.org) which asks about "Armed Services Status" with a drop down list containing: "Currently Serving," "Previously Served," and "Current Dependent."

One issue known to administrators is the reluctance of some veterans to self-identify, particularly veterans who are female, were non-combat, or did not retire [15]. Fernandez [16]

offers several potential explanations: they do not want to be stigmatized by faculty and staff as possibly suffering from PTSD, they want to disengage entirely from the military, and they are resistant to giving out personal information, among other reasons. Students using veterans success centers likewise must self-identify. Because of the lack of centralized collection of veteran status at the university level, information gathered is ad hoc, residing with the certifying official, the SVA chapter, veterans' success centers, and advisors. This makes it more difficult to provide information about services to those veterans who do not self-identify.

2) *Credit for military training.* Admissions officials and engineering departments often do not give credit for training completed while in the military. At USD, department chairs have the authority to extend academic credit for military training as a result of discussions with the Provost's office during a previous NSF grant [17]. Technical training from a Sailor/Marine American Council on Education Registry Transcript (SMART) can be used to satisfy the requirement of up to two introduction to engineering classes. At NC State, the policy is to give credit only for physical education, although the UNC System is studying the transfer of credits issue and developing a system-wide policy to provide additional credit for military training.

3) *Points of contact.* The veterans' resource centers seek to provide a single point of contact for student veterans and their families. However, offices with which veterans interact, such as admissions, registrar, cashier, housing, and others, would also benefit from having individuals within the offices who are knowledgeable about the unique needs of veterans. Where those positions are available, they are highly regarded by the other parts of the campus communities that serve veterans. Although not an official part of the job requirements or duties, several of these offices have had staff who are veterans or advocates who have provided ad hoc support for veterans. Through our interviews, we have found that many of the people who have stepped up to be a point of contact in a particular department or volunteer to serve on military and veterans affairs committee have a personal interest in veterans' issue, often because they are veterans themselves or have a family member who has served.

IV. OBSERVED CHALLENGES FACED BY STUDENT VETERANS

Veterans share many challenges with other non-traditional students due to their age, transfer status, and work-life balance issues related to marriage and children. Through their interactions with the veterans, our informants identified a number of challenges that appear to be unique to them. They observe that it is challenging for students to transition from a highly structured environment in the military to one with far less structure, as found in higher education. Advisors and counselors note the disinclination of student veterans to seek help for academic or personal issues. A percentage of veterans have service-related disabilities, which may or may not be obvious to the casual observer, and may require accommodations such as a particular seat assignment or receiving extra time on tests. Our informants observe that some veterans, however, may be uncomfortable asking for or receiving accommodations despite their need.

V. OBSERVED ASSETS BROUGHT BY STUDENT VETERANS

Informants described strengths that student veterans bring to the university in general, and to their studies in particular. Generally, student veterans have "grit," are adaptable to change, and possess high levels of motivation and maturity enabling success. In addition, veterans are perceived as grateful for the opportunity to be earning their degrees. The diversity and depth of their military experiences enriches classroom experiences and their work ethic and dependability are useful for classroom-based projects that rely on teamwork. Their inclination to support one another is viewed as both positive (student veterans have a built in support network) and negative (relying on one another may preclude them from seeking assistance from non-veterans). Our future work will explore how these and other assets shape student experiences in engineering in particular.

VI. CONCLUSION AND FURTHER RESEARCH

The initial results of our analysis reveal that the four campuses are at different stages in the development of services for student veterans. For example, our study institutions offer varying levels of training to the campus community about veterans issues. Clemson and has offered Green Zone training every semester since Fall 2013 and Purdue offers it to departments on demand and individuals when enough have requested it while NC State is in the process of training the trainers to offer it in the future; USD is investigating the suitability of offering it, in part due to our inquiries. USD offers a legal clinic specifically for veterans while the other institutions do not offer such specifically targeted services. Although there are coordinated efforts at each campus, many student veteran services are offered on an ad hoc basis due to a particular individual's personal motivation as a result of his or her own service or that of family members. These champions are among the advocates for more effective student veteran policies and programs.

In the last few years, there has been an acceleration of efforts to serve student veterans. There is more administrative support for these issues on all four campuses and student veteran centers opened on three of these campuses in 2014-15. This makes our study especially timely as we will be able to investigate how such efforts evolve. This increased interest makes sense given the expected drawdown of the military and the predicted increase in the number of student veterans seeking an education and employment in the private sector.

This study has provided a foundation for our future work that will be from the perspective of veterans themselves. With this groundwork, we will be able both to speak knowledgeably with veterans regarding services on campus as well as determine how well the administrators' perceptions of veteran's service aligns with the experiences of the veterans themselves. Future studies will examine the pace, depth, and breadth of these services and information resources more fully as well as investigate the lived experiences of student veterans. Our goal will be to identify those resources which best meet the needs of student veterans in engineering and create smoother pathways to enrollment and graduation.

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Assessing an Affordable and Portable Laboratory Kit in an Undergraduate Control Systems Course

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Abstract—Lab kits allow students to take home laboratory equipment to complete experiments on their own time. Kits like these can expand access to hands-on experiences for online courses and to budget-strapped campuses. Although students like these kits, no previous studies compared student learning outcomes on assignments using these new kits with previous laboratory equipment. During the 2014-2015 academic year, we conducted a quasi-experiment to compare students' achievement of learning outcomes. Half of the laboratory sections in each semester used the existing equipment, while the other sections used the new kit. The objectives of the laboratory assignments were the same and the instructions were kept as close as possible between the two groups.

I. INTRODUCTION

Laboratory experiences help link theory to practice for undergraduate students [1]. More specifically, [2]–[4] each describe the importance of laboratory experiences in control systems courses, despite challenges such as budget constraints, space limitations, class size, and limited teaching resources [3], [5]–[7]. Providing laboratory experiences to off-campus students is a new consideration with the rising popularity of online courses [2], [8], [9].

A. Background

In a control systems laboratory, students typically learn the following skills: building the system, modeling and analyzing the system, developing a controller to meet performance requirements, simulating the controller and system, observing the physical system, collecting the data, and using the data to improve the system model or control tuning [2], [3], [7]. Although [10] believes the controls laboratory experience should prepare students for a career in control systems, these skills can also benefit students who choose not to pursue such careers. Experiments based on DC motors have been identified to meet these skills for controls laboratory experiences [4], [11]. Not only is it straightforward to control the position a DC motor with a proportional-integral-derivative (PID) control [11], a DC motor setup can be expanded to create more complex setups like the inverted pendulum [4].

Lab kits have become popular as the cost of the required hardware has decreased [12]. The contents of each kit vary based on the learning objectives of the course and can be

assembled by the instructor [5], [12], adapted from an existing kit [13] or purchased as a complete kit such as Lego Mindstorms NXT [14], [15]. With a lab kit, students can take home laboratory equipment and complete experiments on their own time [12], [13].

The literature includes examples of lab kits that are similar in cost but not used in control systems courses. The Arduino prototyping kit described in [12] costs about \$95 and was designed for a multidisciplinary course on perception, light, and semiconductors. The Mobile Studio IOBoard described in [16] has multiple versions ranging in price from \$80–\$130; it is primarily used in undergraduate circuits courses.

Additionally, kits have been designed for control systems courses. Students use the Science and Engineering Active Learning (SEAL) System to develop a cart with an inverted pendulum attachment [5]. The SEAL System kit costs about \$100 plus \$179 for a myDAQ from National Instruments [5], [17]. The MESABox uses an Arduino and costs approximately \$180 [13]. The MESABox kit includes multiple motors and sensors and is based on an off-the-shelf kit from Sparkfun that contains more components than required for the targeted course. The laboratory experiments designed for the MESABox cover a variety of controls topics including using the Arduino programming language and wiring all of the circuits. The DC motor control equipment detailed in [4] includes a motor, gearbox, encoder, and \$80 of hardware components to build a non-portable kit for approximate total of \$400 [4], [18].

End-of-semester satisfaction surveys show these kits have been well received by students [5], [7], [12]. However, these studies do not present data to show whether students achieve the intended learning outcomes with these kits. [4], [13] presented student ratings of their own proficiency on learning outcomes before and after taking the class, but there were no direct measures.

B. Purpose

In this study, we aim to replace the basic functionality of an introductory control systems laboratory with an affordable kit. The target budget for the kit is \$100 because this approximates the cost of other affordable kits and engineering textbooks [12], [16]. Once the kit was built, we sought to

answer the question: Can an affordable kit achieve the same learning outcomes as traditional equipment? To evaluate the effectiveness of the new kit, we conducted a quasi-experiment during the 2014-2015 academic year. This paper presents the initial analysis of the quantitative data collected to compare student learning outcomes between the two groups.

II. METHODS

A. Context of the Study

Control Systems (GE 320) is the first of two required control systems courses for all General Engineering majors at the University of Illinois at Urbana-Champaign. The course topics include Laplace transforms, linear mechanical and electrical system modeling, transfer functions, system stability, and feedback control design to specifications. The prerequisite courses for GE 320 are Introductory Dynamics and Intro Differential Equations. Additionally, GE 320 students must have completed or be concurrently enrolled in Analog Circuits and Systems. Most students take GE 320 course during their junior year or fall semester of their senior year. In the fall of 2014, 59 students enrolled in the lecture and one of six concurrent laboratory sections. In the spring of 2015, 33 students enrolled in the lecture and one of four concurrent laboratory sections. Half of the laboratory sections used the existing equipment (comparison group) and the other sections used the new kit (treatment group). The authors were not involved in teaching the course during the study.

During the 16-week semester, each student participated in six two-hour laboratory sessions, each with a different experiment to complete. The first two experiments introduced the equipment, the next two experiments developed models of the DC motor, and the fifth experiment implemented three different position control algorithms [19]. The last experiment repeats system identification and control design on a new system. Students worked in groups of two (or three if necessary) to complete the experiments. However, they submitted individual answers to pre-lab and post-lab questions as well as two-page laboratory reports.

B. Equipment

The new kit designed for GE 320 consisted of a Raspberry Pi (a single board computer), DC motor, a 3D printed stand, and the associated sensors. It costs about \$130. A photo of the kit appears in Fig. 1. The existing equipment included an analog computer, DC motor, sensors, oscilloscope, function generator, and multimeter, together costing about \$15,000 per station [20]. A photo of the existing equipment appears in Fig. 2.

Even though the kit was designed to be portable, the department purchased six kits for students to use in the laboratory under the same conditions as the existing non-portable equipment used in the course. The objectives of the laboratory experiments were the same and the instructions were kept as close as possible between the two types of equipment.

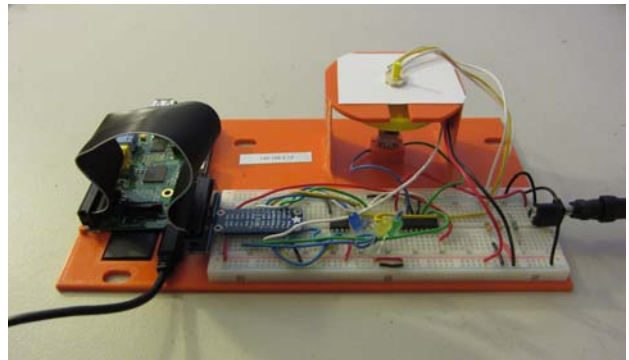


Fig. 1. New Kit

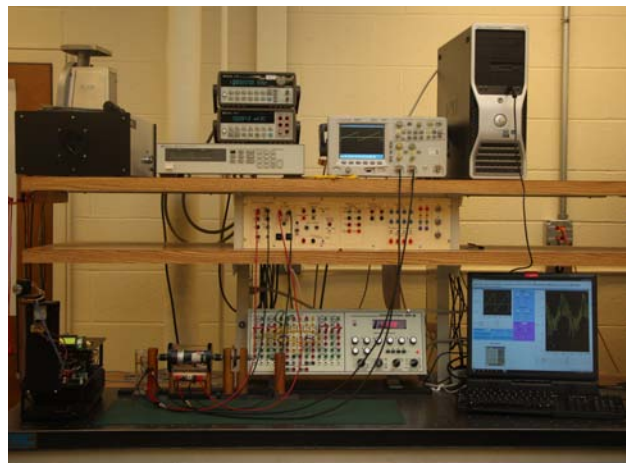


Fig. 2. Existing Equipment

C. Procedure

Quantitative and qualitative data were collected each semester to compare student learning outcomes. The quantitative data included exam scores, laboratory report scores, concept inventory scores, and answers to Likert scale questions on the end-of-semester satisfaction survey. The concept-inventory test is a multiple-choice test constructed by drawing questions from a test that was previously developed to assess students' knowledge about control systems by [21] for mechanical and mechatronics students. Consequently, the original test included questions only about mechanical systems. Students in GE 320 study both mechanical and electrical systems during lecture, but emphasis is placed on electrical systems. We replaced the last question with an equivalent electrical circuit question to ensure a balance between mechanical and electrical systems. A faculty member who has taught GE 320 reviewed the test to ensure the questions were suitable. Student volunteers completed the concept-inventory test and survey on the last day of lecture.

The qualitative data include laboratory observation, student reflections from their individual laboratory reports, and open-ended questions on the satisfaction survey. The analysis of qualitative data is still on going.

TABLE I
FALL 2014 GROUP DEMOGRAPHICS

		Treatment	Comparison
Gender	Male	16	19
	Female	10	8
Class Standing	Junior	13	13
	Senior	12	11
	Other	1	3
Exchange student	No	95%	82%
	Yes	5%	18%
GPA	Average	3.4	3.3

III. PRELIMINARY RESULTS

Table I presents the demographic characteristics of the students in the fall of 2014. Exchange student status and GPA, on a four-point scale, were self-reported. Gender and class standing were calculated from the course roster. Each group has similar demographics and is representative of the overall General Engineering program.

We investigated whether students would achieve the same learning objectives with both types of equipment. In particular, we tested whether the two groups differed in their exam and concept inventory scores.

We started the quantitative analysis of fall semester data by calculating descriptive statistics and plotting the data in histograms. These statistics are presented in Table II. The histograms for each exam are shown in Fig. 3-5 and for the concept inventory in Fig. 6. Then we checked the data for outliers using Grubb's test and normality using the Jarque-Bera test. Exam 1 and the final exam each had one low scoring outlier in the comparison group. Once the outliers were removed, the data from each group and exam were approximately normal.

Finally, we ran a two-sample, two-tailed, t-test for each exam. An $\alpha = 0.05$ was used in each test. Based on this test we do not reject the hypothesis. The Cohen's d effect size and power were also calculated with each test; see Table II. Since the power is very low, additional data will be collected in the spring semester. However, only the concept inventory test will be the same for both semesters.

Even though low scores are expected on concept inventory tests, we checked for other factors that could have influenced the outcome. However, there was no correlation between the time spent taking the concept inventory and the score and very low correlation between the self-reported GPA and the concept inventory score.

IV. CONCLUSIONS AND FUTURE WORK

The initial quantitative analysis of the fall semester data indicates that achievement of the learning outcomes with both types of equipment are the same. However, the power of the tests is low, so more data was collected in the spring semester. Complete analysis of all of the quantitative and qualitative data is still ongoing.

TABLE II
FALL 2014 EXAM AND CONCEPT INVENTORY DESCRIPTIVE STATISTICS

	Treatment			Comparison			Cohen's	
	<i>n</i>	<i>M</i>	<i>SD</i>	<i>n</i>	<i>M</i>	<i>SD</i>	<i>d</i>	Power
Exam 1	24	79.4	14.2	26	82.0	11.6	0.2	0.1
Exam 2	26	83.0	9.4	27	84.3	7.7	0.1	0.1
Final Exam	26	86.1	7.1	25	83.2	7.7	0.4	0.3
CI	16	32.6	11.6	19	35.4	12.0	0.2	0.1

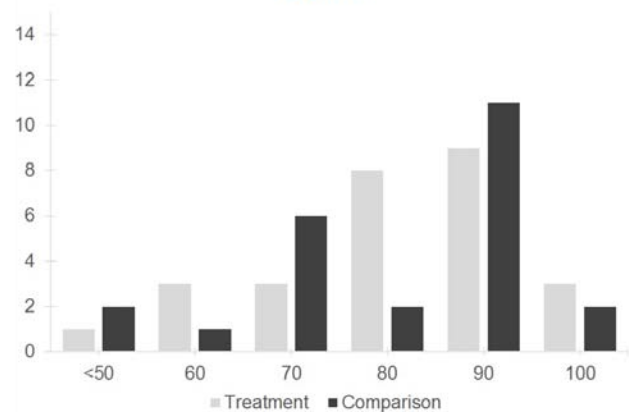


Fig. 3. Exam 1 Results

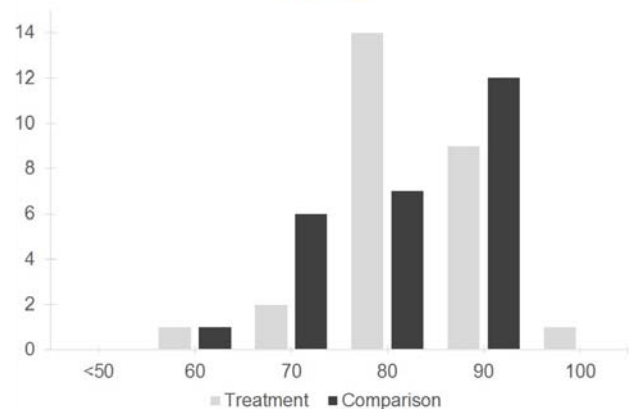


Fig. 4. Exam 2 Results

Future quantitative analysis includes the survey responses and laboratory reports. Select pre-lab and post-lab questions will also be analyzed using a paired t-test. Qualitative data sources will be coded for themes related to the equipment and overall laboratory experience.

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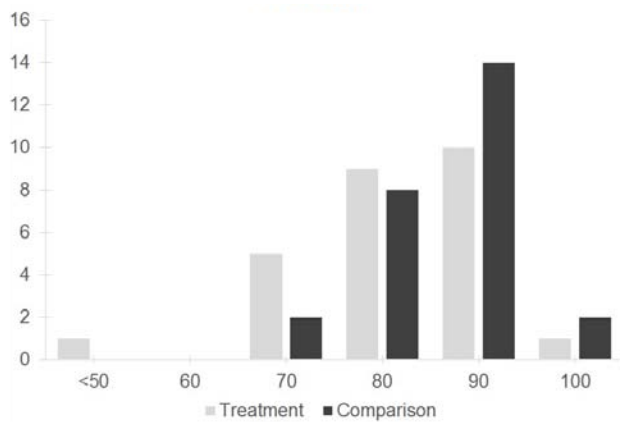


Fig. 5. Final Exam Results

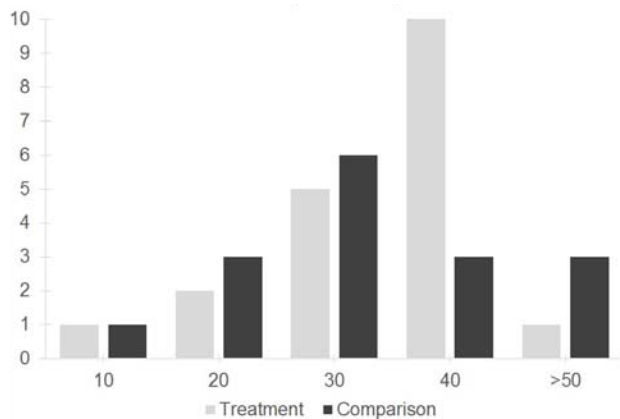


Fig. 6. Concept Inventory Results

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Hands on Project experience in a core class focused on sustainability

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Abstract--This paper seeks to present the findings of an effort to teach sustainability through involving students in hands on projects. The findings have been spread out over three semesters. The course under consideration is part of the core curriculum and is open to students from any major across the university. It is offered by the department of mechanical engineering at a university in the southeast United States. It emphasizes aspects related to global sustainability.

The course focuses on shedding light on sustainability related issues such as environmental pollution, resource utilization, and economics of sustainability. It resorts to innovative design practices as well as novel product ideas as a tool to enhance sustainability. To this end, the course emphasizes hands on learning through design, development and analysis of products from the point of view of sustainability.

Students from all majors across the university typically take this class. They are encouraged to think about a problem critically and approach it from the design perspective in order to try and solve the underlying environmental problem. A physical product prototype is required as part of the final project. In view of the fact that sustainability is comprised of three main pillars namely: environmental, social and economic, students are also required to examine the profitability of their project on a rudimentary level. Students are free to work either individually or as part of a group. Class presentations are due at the end of each semester and are comprised of a design prototype, economic analysis and the environmental relevance of their design solutions. An evaluation rubric is used to grade the final projects in terms of innovativeness, environmental impact and economic justification. To this end, the paper presents examples of a range of student projects.

Keywords-- Sustainability; project; core curriculum; three pillars of sustainability

I. INTRODUCTION

Sustainability related topics are being increasingly taught at many universities across the United States[1], [2], [3]. Phenomena such as global climate change, ever decreasing resources, rocketing oil prices, and food and water shortages are beginning to take on crisis proportions. As a result the topic of sustainability is becoming more commonplace within the public conscience as they realize the gravity of the problem. This is especially true of the younger generation that is arguably more environmentally conscious than their forefathers. Students from all majors are typically interested at least to some degree in sustainable living and enroll

accordingly in classes focused on sustainability. This paper presents the course structure and examples of some hands on projects in a core class focused on this topic.

Sustainability is defined as the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. It deals with improving the quality of human life while living within the carrying constraints of the supporting ecosystems. Said constraints are often biophysical in nature. Any change in an ecosystem can be classified as elastic or plastic. Elastic strain implies the ability of an ecosystem to regain its original properties once the stress has been removed. On the other hand, ecosystems that are subjected to so called plastic strain are often unable to retain their original characteristics and undergo a severe deterioration over time if left unchecked. In principle, there three main pillars of sustainability namely: environmental, social and economic. In order to qualify as a sustainable practice or a sustainable solution to a problem, all three issues need to be addressed simultaneously. For example, a product cannot be termed as being sustainable if it encourages environmental conservation, but ignores the economics and social cost of that conservation. In other words, the question can be asked: conservation, but at what cost (economic and social cost)?

The course being taught at Georgia Southern University addresses this issue by incorporating a final project to be presented at the end of the semester. This practice also ensures that students get involved in the concept of sustainability and focus on actively solving problems through designing products instead of indulging in passive learning (reading material from a textbook and take exams) [4], [5]. It is not sufficient to consume less and to reduce, reuse and recycle. The solution could lie in a different approach to sustainability namely design. Could humankind live sustainably by designing products and processes that are at once greener (environmental pillar), profitable (economic pillar) and socially conscious (social pillar)? Such products and processes will typically tend to use fewer resources and will have the support of the community not because it is the right thing to do, but because it is also the profitable thing to do. To this end, students examine the cost benefit of their product design as well as its profitability.

The following section presents an overview of the course and presents some examples of students' projects from past semesters.

II. COURSE STRUCTURE

TCGT 1530: Global sustainability and Innovation is a core class offered at Georgia Southern University. It is offered

throughout the year and is open to students from all majors across the university. The class usually has about 125-150 students in one section. Students from a variety of majors such as political science, music management, humanities, foreign languages, business and marketing etc. are enrolled in the course. Course content focuses on topics such as definitions of sustainability, environmental conservation, and energy sources (including conventional and non-conventional sources), Water, water pollution and desalination as well as sustainable water management, manufacturing methods, the concept of reverse supply chain, closing the loop through green manufacturing and the economics of sustainability. Students are evaluated on their performance on four exams (including a final exam), an in class group debate (debating the pros and cons of a specific technology for instance) and a final project. Students are free to work in groups or individually on the final project. In terms of topical coverage, the basic information is imparted in addition to quantifiable parameters in terms of pros and cons of different technologies. For instance, the principle of solar power is explained in detail (scientific basis), different types of solar power are explained (such as Concentrated Solar power, photovoltaics and solar paint), as is the deficiency associated with the technology (efficiency of most PV panels is about 20-25% only). Students are then encouraged to apply principles learned in class to real world projects whereby they can seek to further the cause of sustainability. The focus of the class is to solve problems through proactive product design whereby resources can be used repeatedly as long as such use is done on a sustainable basis.

III. FINAL PROJECT

The final project accounts for about 15 % of the final grade. Participation in the final project is mandatory and it encourages students to think creatively about environmental issues. Some students choose to work in groups (no more than 4 students per group), while others prefer to work by themselves. It has been observed that students that work by themselves are often the more creatively inclined and arrive at a more comprehensive solution than students working in groups. One of the main requirements of the final project is that students create a physical working prototype of a product or process that they are trying to improve (even infinitesimal improvements count for credit). Alternatively, said product or process could be a brand new invention that could replace an existing product/process. This prototype is brought to class and presented during the final week of the semester. Accompanying the physical prototype is a presentation of how the product/process contributes to enhanced sustainability: Does it simultaneously achieve conservation, profitability and social following? To this end, an economic analysis of the product is conducted. The cost for building the prototype is computed. The selling price is ascertained. This is generally a function of the maximum price that the market will bear (if there is a market for that product, a survey of a minimum of about 30 customers will reveal the mean selling price along with the standard deviation) and not based on a standard 'mark up' above total cost. Given this background, the profitability of the product can be computed by calculating the profit

margin per unit. The thinking is that if the product and business as a whole is profitable, more people might want to get in on it, thus building a social following. Thus, the practice of sustainability would not necessarily have to depend upon public subsidies, rather it would be self-sustaining.

TCGT 1530 has had the final project component built into it only very recently. The course has been offered in this specific format for the last four semesters. The following paragraphs will present some of the types of students' projects that have been presented in the past.

IV. EXAMPLES OF STUDENT PROJECTS

Final projects span the entire spectrum of creativity and uniqueness. Some projects are inspired whereas a significant number of projects are either 'me too' types of products (products incorporating repetition of existing ideas) or are downright low on the creativity scale. It has been observed that students with a scientific background don't necessarily give rise to creative ideas and vice versa. Knowledge of material learnt in class such as fermentation process, neutralization reaction, functioning of a solar panel etc. is often used in an actual functional design project. It is always stressed that students observe all safety precautions as appropriate in designing and fabricating their products (including use of personal protective equipment as necessary). Students work on their ideas and projects out of class (This is not an in class activity).

Solar powered cell phone charger: An example in this context was a student project from Spring 2014 when a couple of students who were music management majors proposed the idea for a solar powered cell phone charger. The set up consisted of a mini solar panel that was connected to wire and was designed to charge a cell phone purely based on solar power. The process of charging the cell phone was demonstrated in class using a light bulb as a source of light. The fact that a couple of music majors formulated and fabricated a product of this nature is especially noteworthy. In this case, harnessing solar power to generate electricity (used to charge the phone) constitutes the environmental pillar, costing and profitability analysis on a batch scale production constitutes the economic pillar and profitability analysis combined with demonstration of public benefit constitutes the social pillar of sustainability.

Moss based Foot Mat: Another noteworthy project was presented by a Biology student who created a moss based foot mat in Spring 2014. The foot mat was brought to class and presented. Some of the issues in the manufacturing process were discussed. For example, the student's first attempt at trying to make the moss grow successfully was met with failure. She had to make sure that strict guidelines in terms of sunlight, moisture, nutrients etc were followed in order to make a viable product. In this case, using an organic 'green' moss with an intent towards conservation and environment friendly disposal at end of life constitutes the environmental pillar, costing and profitability analysis on a batch scale production constitutes the economic pillar and profitability

analysis combined with demonstration of public benefit constitutes the social pillar of sustainability.

Organic Soap: This is an oft repeated example that is presented in varying forms almost every semester. Students working in groups make soap organically using glycerin and other organic components. This soap is then either cut into bars or poured into molds (such a turtle or a rabbit etc) before solidification. It is claimed that because such a product is free of harmful chemicals, it is helpful to the skin and the overall health of the individual. Fragrance may or may not be added to the soap depending on the inclination of group participants. In this case, using organic ingredients to make the soap and environment friendly manufacturing processes constitutes the environmental pillar, costing and profitability analysis on a batch scale production constitutes the economic pillar and profitability analysis combined with demonstration of public benefit as well as raising public awareness of the benefits of organic soap (to their skin and overall health as opposed to chemicals used in off the shelf soap products) constitutes the social pillar of sustainability.

Organic Cleaner: A student presented this product during Fall 2014. The cleaner was based on vinegar as its main constituent. It was demonstrated that it was able to successfully clean stains from utensils, window panes etc. It was also argued that given the lack of harmful chemicals in the cleaner, it was safe to use and would not lead to the causation of harmful skin infections. In this case, using organic ingredients to make the cleaner (vinegar based) and environment friendly manufacturing processes constitutes the environmental pillar, costing and profitability analysis on a batch scale production constitutes the economic pillar and profitability analysis combined with demonstration of public benefit as well as raising public awareness of the benefits of organic cleaner (to their skin and overall health as opposed to chemicals used in off the shelf cleaning products that could contain potentially harmful carcinogenic compounds) constitutes the social pillar of sustainability.

Paper mache basket: This project was presented by a student working on her own in Fall 2014. This project was more reminiscent of an arts and crafts project, but promoted use of recycled paper. Strips of paper from old magazines were rolled up into circular patterns and glued together into a cohesive basket pattern that was very tough and almost impossible to break. Such a basket could primarily be used for ornamental and decorative purposes. This student was successful in selling the product online. In this case, reusing old paper to make the baskets and environment friendly manufacturing processes constitutes the environmental pillar, costing and profitability analysis on a batch scale production constitutes the economic pillar and profitability analysis combined with demonstration of public benefit and demonstrated practice of recycling constitutes the social pillar of sustainability.

Organic detergent: This project was presented by a group of students in Fall 2014. Using their knowledge of chemistry and chemical formulation, they formulated a detergent that was devoid of harmful chemicals and was thus conducive to

good health from the users' perspective. It was demonstrated that this product was able to remove stains from clothes and yet remain harmless because of its benign composition. In this case, using organic ingredients to make the detergent and environment friendly manufacturing processes constitutes the environmental pillar, costing and profitability analysis on a batch scale production constitutes the economic pillar and profitability analysis combined with demonstration of public benefit as well as raising public awareness of the benefits of organic detergent (to their skin and overall health as opposed to chemicals used in off the shelf detergent products) constitutes the social pillar of sustainability. It is to be noted that the benefits are achieved without compromising functionality

Ethanol: An Information Technology major presented this project during Summer 2014. She used her knowledge of the process of fermentation using yeast to make ethanol from sugar. She also designed an interactive website to help promote and market her product to the community. In this case, using organic ingredients to make the ethanol and environment friendly manufacturing processes constitutes the environmental pillar, costing and profitability analysis on a batch scale production constitutes the economic pillar and profitability analysis combined with demonstration of public benefit constitutes the social pillar of sustainability. This is a special case that demonstrates the fact that learning can be achieved by truly stepping outside of one's comfort zone. As an IT major, this student apparently had no educational background in terms of ethanol production processes. Thus, the fact that she was able to successfully create the product despite this obvious shortcoming is even more commendable. In terms of actually using her IT background, she used it to facilitate outreach and marketing the product by creating her own website.

Coasters made from recycled jeans: This project was presented by a student during Fall 2014. She used the seam from a pair of old jeans to make a coaster for a coffee table (drawing upon the theme of recycling). She was able to advertise this product online and was successfully able to sell it in that forum. In this case, reusing old jeans to make the coasters and environment friendly manufacturing processes constitutes the environmental pillar, costing and profitability analysis on a batch scale production constitutes the economic pillar and profitability analysis combined with demonstration of public benefit and demonstrated practice of recycling constitutes the social pillar of sustainability.

Additionally, there have been numerous other projects worth mentioning such as a portable trash collector made out of recycled materials, displays made out of bottle caps, glasses made out of used bottles etc, which cannot be elaborated in this paper due to space restrictions. It will be realized that the nature of projects is very diverse. The only constraint on the creative thinking process is that the final product should contribute to enhanced sustainability. A rubric is used to assess the quality of the final product and its presentation. It can be argued that the process of innovation and creativity itself is impossible to assess as is the future success of the product under consideration. The author acknowledges both

arguments. The projects are being assessed not with intent to critique the creativity of the participants, but their contribution and level of participation.

Since the hands on project is evolving on an ongoing basis, future emphasis will be an introduction to methods of mass manufacturing, packaging, and a focus on reducing amount of packaging materials used during transportation.

V. ASSESSING THE FINAL PROJECT

Each project is assessed on a scale of 1-5 (1: Poor and 5: Excellent). Each of the sustainability pillars is addressed. A variety of questions is asked and rated on the aforementioned scale. For example, does the product ameliorate an existing situation related to sustainability? If so, how successfully does it accomplish this? Is the product an improvement on an existing product? Does the product minimize use of raw materials on a net basis? Is there a market for the product? How large is said market? How profitable is the product? What is the level of complexity of the process that resulted in manifestation of the product? What was the level of professionalism of the students in terms of their presentation skills? How involved were the students in creating their projects? It was observed that about 60% of the students scored between 3 and 4 on the economic analysis. 20% of the students scored between 4 and 5 on the same analysis. Most students (85%) were professional in terms of final presentation. Very few if any projects were truly unique, but given the fact that this is an introductory course in sustainability being offered to ALL students (irrespective of their major), a very high level of uniqueness is not really expected in terms of final projects.

It has to be borne in mind that the final project is still in its experimental phase in terms of assessment and constraints. This is still a work in process and will continue to evolve over time. The author hopes to be able to present a more comprehensive paper at some point in the future that will offer a more substantial overview of this activity.

VI. CONCLUSION

An overview of course content focused on sustainability and innovation was presented in this paper. A few examples of successful student projects from the past were also presented. The set of constraints imposed upon the projects was discussed as well as the process of assessing the final project. It is hoped that the hands on activity that is designed to get students actively involved in sustainability topics (which is the primary intent of the final project) will achieve its intended goal over time. The author intends to collect sufficient data over at least eight semesters after in order for any discernible trend to merge in terms of student learning. At this stage, the intent is to share the findings in the form of a full paper at this forum.

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Bioinformatics Curriculum Development and Skill Sets for Bioinformaticians

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Abstract— The rapid advancement in biological data acquisition technologies has led to massive biological datasets, which requires the development and application of computational methods to analyze and interpret the information. Bioinformatics is the confluence of biology, computer science, and information technology. The Bioinformatics programs are offered by more than 100 universities in the United States, and much more worldwide. Different degree (including BS, MS, and PhD), and certificate programs in Bioinformatics have been performed. The current bioinformatics programs in the US have been studied, regarding their curriculum, program competencies, sizes of the faculty, and student enrollments. The job market is also explored for bioinformatics professional training and career planning. The bioinformatics skill requirements are analyzed. Systematical analysis is carried out by integrating the core competences and curriculum improvements in bioinformatics. The potential employers for bioinformatics professionals are analyzed according to the properties of the companies, such as the sizes, the focus areas, the locations, the skill requirements, and other information. The results provide guidance for bioinformatics curriculum development, such as the minimized courses to cover the basic required skill sets for a bioinformatics student to be a successful bioinformatician. In addition, the analytical results are applied to the redesign of the curriculum in our bioinformatics program which offers MS, PhD, and PhD Minor. In summary, the systematic study of the existing bioinformatics programs in the US and the current market needs for professionals in bioinformatics provide great insight for education in bioinformatics. It helps the curriculum development and reexamination. It also provides the students with the required knowledge for their future career.

Keywords—*Bioinformatics; Competencies; Skills; Job Markets*

I. INTRODUCTION

The massive biological data, such as data generated from the human genome project and electronic health records, has led to the great need of computational techniques and machine learning over the big data. The field of bioinformatics emerges when computing meets information. Simply speaking, bioinformatics is an interdisciplinary field among biology, computer science, and information technology. Bioinformatics has significantly contributed to the cures for human diseases, improvements of crop quality and production, creation of new technologies, and novel applications to medicine and industries. With the high throughput data generation in

biological science, the necessities for bioinformaticians are on the rise. Hence, it is necessary to train the next generation of bioinformatics professionals with the required skills to prepare them as future successful bioinformaticians.

Bioinformatics programs have been offered at different levels in the US, from BS to MS and to PhD programs. Due to its multidisciplinary nature, it is important that the bioinformatics curriculum will benefit both the computer scientists and the biologists. Different approaches and strategies for bioinformatics education have been proposed [1-3]. Especially, there are great advocate for conveying the computational and information technology skills for biologists to meet the challenges for the big data sciences. The biomedical data analytics, especially for the -omics era, is another challenging area [1, 2]. In addition, the program competencies have been discussed among researchers and educators. For example, some previous work concluded that biology, computer science, statistics, ethics, and core bioinformatics are the five main broad areas of competencies required for bioinformaticians [3].

In this manuscript, the US bioinformatics programs have been investigated and the current job markets for bioinformaticians have been explored. The results provide great help for educational professionals to improve the existing bioinformatics programs based on the specific program requirements and competencies. In addition, the results provide great support for the students to equip themselves with the necessary bioinformatics skills for the bioinformatician job market openings, and help the biology and informatics students to get prepared if they are interested future careers in bioinformatics.

II. US BIOINFORMATICS PROGRAM OVERVIEWS

The various bioinformatics programs have been studied regarding their hosting departments and schools in the United States from two sources. One source is the US bioinformatics education provided by the *Bioinformatics Organization* [4], which lists the bioinformatics programs, arranged for each state and each university. There are total 95 Bioinformatics Programs listed from this web site, including degree programs of BS, MS, and PhD, as well as certificate programs. The other source is Startclass.com [5], which provides detailed comparisons of different bioinformatics degree programs, such

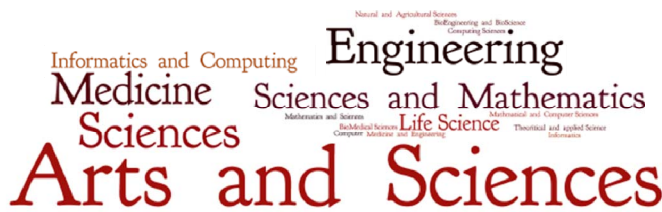


Figure 1. The school names where the Bioinformatics reside.

as the smart rating, acceptance rate, average SAT range, the total number of enrolled students, the number of incoming students, the in-state and out-of-state tuition, and other informatics. For example, the smart rating will combine the information of five attributes: the financial affordability, the career readiness, the admission selectivity, the expert opinion, and the academic excellence. These five attributes again are based on some statistics on ranking from several other sources, such as Forbes, U.S. News, etc.

The following sections introduce the current state of the bioinformatics programs, by combining the information obtained from these two sources, and the program information from the specific program websites.

A. Academic Structures of Bioinformatics Programs

To be noted that the *bioinformatics* programs are also called as *Computational Biology* or *Biomedical Informatics* by some universities.

First, the host departments and schools of the bioinformatics programs are studied. It has been observed that a bioinformatics program can reside in different academic units. Most popularly, the bioinformatics programs are offered by the College of Arts and Sciences (25%), the College of Engineering (17%), the School of Medicine (13%), the School of Sciences (13%), and the School of Sciences and Mathematics (11%). Figure 1 displayed the names of randomly selected 52 schools, based on *Wordle* image [13], where the sizes of the letters in the image are corresponding to the percentages of the school names. For example, College of Art and Sciences is the largest in the figure as it is the most frequent schools who offers bioinformatics programs.

Usually, the bioinformatics program is a program inside a department, commonly inside the Department of Biology, Department of Computer Science, or Department of Engineering. Sometime, bioinformatics may be a direct program under the umbrella of a school, such as the School of Medicine, or School of Informatics. Table 1 lists the popular department names where the bioinformatics program resides.

In addition, bioinformatics can also be an interdisciplinary program through collaborations of several departments. One example is the Computational Biology and Bioinformatics (CBB) program at Yale University. The CBB is an inter-departmental PhD program, with collaboration from departments of biological science, statistics, applied math, etc. In addition, a few bioinformatics programs are joint efforts among multiple universities. For instance, the University of Pittsburgh and Carnegie Mellon University jointly offer a PhD

Table 1. The popular department names offering Bioinformatics programs.

Department Names	Percentage
Biology	10.5%
Biomedical Informatics	10.5%
Computer Science and Engineering	10.5%
Biological Sciences	7.9%
Bioinformatics	5.3%
Bioinformatics and Computational Biology	5.3%
Computer Science	5.3%
BioHealth	2.6%
Bioinformatics and Medical Informatics	2.6%
Biological and Biomedical Sciences	2.6%
Cellular and Molecular Biology	2.6%
Computational Medicine and Bioinformatics	2.6%
Computational Biology	2.6%
Medical Informatics and Clinical Epidemiology	2.6%
System Biology	2.6%

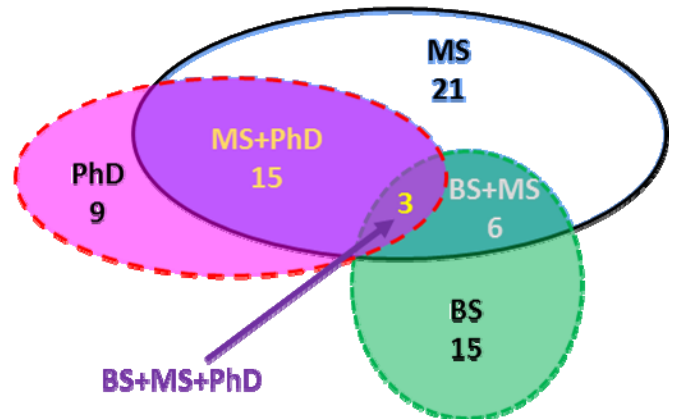


Figure 2. Bioinformatics degree programs distributions.

program in Computational Biology. Some universities don't have a formal bioinformatics program. Instead, Bioinformatics is offered as minor or certificate programs.

Second, the formal degree programs in Bioinformatics include undergraduate and graduate degrees, ranging from BS to MS to PhD. A detailed review of 69 bioinformatics programs, which have the detailed degree information, showed the degree distributions as illustrated in Figure 2. Basically, Graduate degrees are offered by 80% of all the bioinformatics programs. Master programs (MS) in Bioinformatics is the most popular degrees, which is offered by 65% of all the Bioinformatics programs. Of all the bioinformatics programs, 35% and 39% of them offer the BS and PhD programs, respectively. In addition, there is no programs which only offer BS and PhD (without MS) degrees. In fact, most programs offering a PhD degree in Bioinformatics do not offer the BS degree. There are only three Bioinformatics programs offered all the three degrees from the 69 programs.

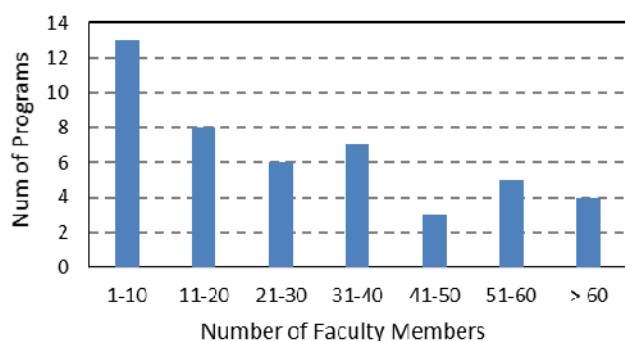


Figure 3. The Bioinformatics program faculty sizes.

Third, the ***bioinformatics program sizes***, such as the numbers of faculty members and the numbers of students, are also studied. Some of the universities do not have the specific faculty information on their program web sites. For the 69 programs with the faculty information listed, the number of faculty in the bioinformatics programs are demonstrated in Figure 2. Most of the programs list all the faculty members together, including the core bioinformatics faculty and the adjunct faculty. Basically, 21 programs (42%) have 20 or less faculty members, with an average of 10 faculty members per programs. There are 13 universities have faculty members between 21 and 40, with an average of 30 faculty members per program.

Most bioinformatics programs do not list their student information on the web site. Only a limited number of programs have their current graduate students listed. Based on the limited information of 20 bioinformatics programs, the average number of MS and PhD students for the bioinformatics programs are 36 students per programs.

B. Curriculum and program competencies

The emerging trend of large scale of biological data has restrained the traditional biologists from utilizing the information and has led to the needs of programming and computer software for data analytics, which led to the 'data-driven science'. At the same time, the Bioinformatics programs have to adapt to meet these new needs. In addition, as an emerging interdisciplinary field, a Bioinformatics program is facing new challenges for curriculum design, course organizations, and training delivery approaches.

The program challenges also affect the trainees ultimately. For example, it is natural for some trainees to wonder if they have been provided or will receive the best and practical training in bioinformatics so that they are career-ready upon completion of their degree programs [6]. The bioinformatics programs are expected to have trainees from different life science and computer science backgrounds, as the bioinformatics is the bridge between life science and computer science [7]. The programs are expected to deliver intensive training in both biology and computing skills, in order to provide the workforce with individuals with an

interdisciplinary set of skills necessary for bioinformatics projects.

Students with strong computer science background are expected to have the capability in creating or modifying bioinformatics software systems and/or applications to address questions in bioinformatics research. Students with life science background are expected to have applied knowledge on how to operate on existing bioinformatics tools and to apply the tools for specific bioinformatics projects. Their strong life science background will facilitate them in the interpretation of the results [8].

In addition, it is necessary to include hands-on training on bioinformatics tools, online data repositories, such as UniProt [9] and GenBank [8], as well as the use of Basic Local Alignment Sequence Tool (BLAST) [7] for identifying sequence similarities in both DNA and protein sequences. It would be better for a single application to integrate multiple bioinformatics applications for training the students in bioinformatics. Such examples include BioManager, which is used in Australia to tutor undergraduate students [7], and the Bioinformatics Training Network [10-12]. Using the BioManager web application teaching tool, the undergraduate students are trained to be familiar with sequence alignment, microarray analysis, protein structure and function prediction, proteomics, motif searching, and many other basic technologies in bioinformatics.

It is a general perspective that the three main areas of bioinformatics are genomics, proteomics, and systems biology [9]. Genomics includes sequencing, assembly, and analysis of DNA. Proteomics specifically deals with the protein structures and functions. Systems biology involves computational data modelling of biological systems which can be molecule, tissues, organs or whole organism.

Existing program courses and curriculum designs are based on these three major areas of bioinformatics. The ***major competencies*** of bioinformatics programs are listed in Figure 4 based on keywords extracted from some bioinformatics web sites. The standing out competencies includes biological database management, genomics, molecular biology, proteomics, statistical methods in bioinformatics, algorithms, bioinformatics programming, systems biology, structural biology, next generation sequencing, data mining, big data analysis, computer modelling, machine learning, and other major skills.

The expected ***program outcomes*** are based on the major competencies and major bioinformatics areas. To be more specific, combining the different bioinformatics programs, upon completion of the graduate degree programs, a student is expected to possess the following bioinformatics capabilities:

- Have a sound knowledge of statistics, computer science, biology, proteomics, and genetics; be able to apply them in their bioinformatics projects;
- be able to search and apply bioinformatics tools from a variety of sources, such as books, journal articles, and online encyclopedias;
- have hands-on experiences and have worked on projects related to different areas of bioinformatics.

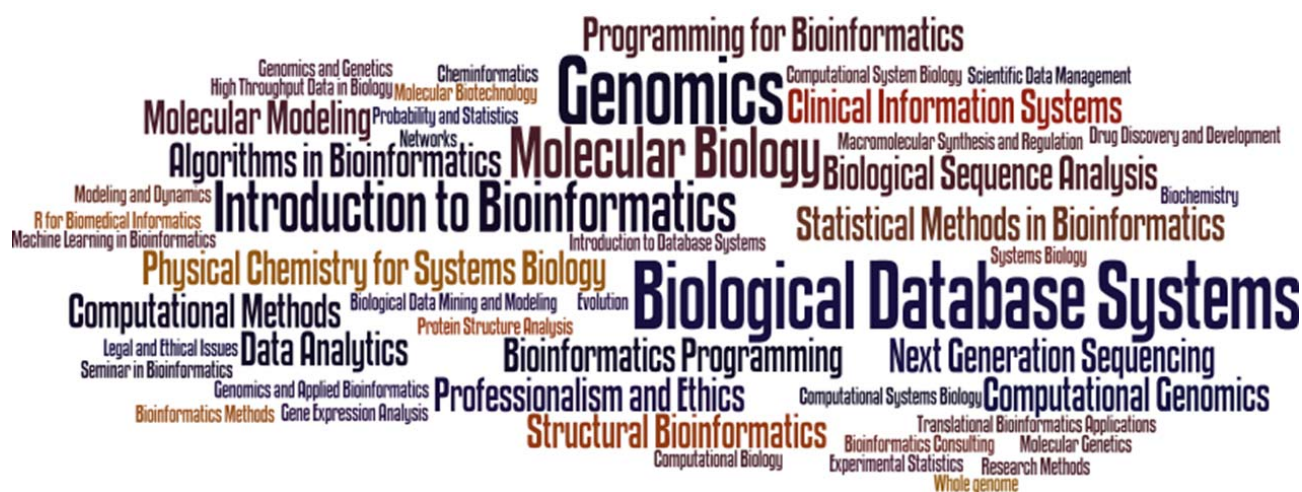


Figure 4. The major competencies of Bioinformatics programs.

- design and conduct biological data management and computational experiments;
- be able to analyze and interpret data based on their biological knowledge;
- apply their knowledge and skills to address some problems in biology oriented research and be able to program to achieve the objectives;
- possess soft skills, such as efficient communication among team members, good presentation skills, excellent written summary, and fluent verbal discussion;
- apply the best practice and follow the ethical guideline in decision making, information sharing, and privacy protections, in a global, economic, environmental, and societal context.

As mentioned before, the major bioinformatics competencies are illustrated in Figure 4, using the *Wordle* images. It can be seen that the Biological Database Systems, Genomics, Molecular Biology, statistical methods in Bioinformatics and others are all part of the expected competencies for the Bioinformatics programs.

III. CAREER FOR BIOINFORMATICS STUDENTS

Detailed examinations on the job market for bioinformaticians in the US have been performed. The summary information below are from two major job postings portal sites: indeed.com and monster.com.

A. Job opportunities and requirements

The job market for bioinformatics students is promising. The bioinformatics graduates can work on various related fields with varying titles. Sample industrial job titles include data scientist, research associate, computational biologist, bioinformatics scientist, bioinformatics scientist, bioinformatics analyst, software engineer, senior software engineer, and others. There are also openings in academia as postdoctoral fellows, research scientist, research professor, and

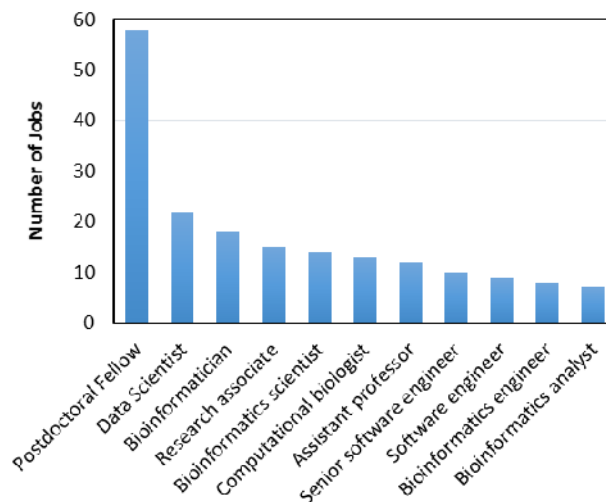


Figure 5. The job postings for different job titles (based on a search of keyword of “Bioinformatics” in April 2015 from Indeed.com).

faculty positions (such as assistant professors for PhD students in Bioinformatics). The top ranked job titles for bioinformatics job openings from Indeed.com are illustrated in Figure 5.

The salary package for bioinformaticians starts from \$40,000+ and goes up to more than \$120,000. With more experience in the field, one can go higher over the salary ladder. Based on more than 4000 job postings in bioinformatics only from Indeed.com, the distributions of job opportunities and the salary ranges are illustrated in Figure 6. Bioinformatics job positions for the salary range between \$40,000 and \$60,000 have the most openings by itself (>1600), which is the entry level jobs for bioinformaticians. The combined job postings for intermediate level in bioinformatics, salary range between \$60,000 and \$80,000, have about 1200 job postings. The more



Figure 7. The required skills for entry level jobs in Bioinformatics.

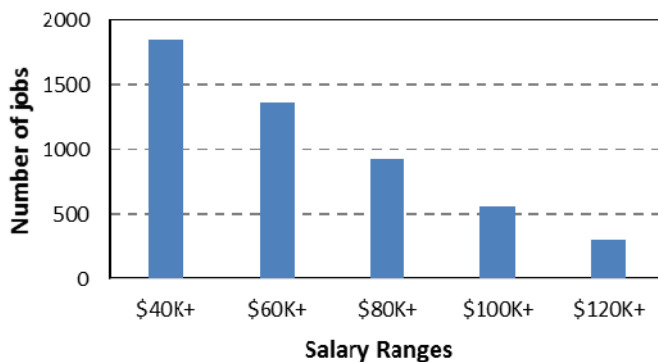


Figure 6. The salary ranges and number of job postings for Bioinformatics professionals.

advanced level jobs for bioinformaticians, with salary range between \$80,000 and \$100,000, have many opening (>700).

The more advanced jobs, such as directors and managers, requires extensive experience in the fields, with salary more than \$100,000. However, the job postings are getting less, with 280 postings in the \$100,000+ category and 120 postings in the \$120,000+ category. Thus, the majority of careers for bioinformatics graduates are in the entry, intermediate, and advanced levels, which are 83% of all the job postings.

Many job postings specifically state that a *graduate degree* in Bioinformatics or related fields are required, although there are opportunities for Bachelor's degree holders. In addition, job seekers with PhD degrees have more openings. A lot of job postings explicitly indicate that PhD degree is preferred over MS and BS degrees.

Regarding the working experiences, a minimum of 3 years working experience on average was required, even for most of the entry level jobs. The required years of experience vary according to the levels of jobs. Usually, a higher paid job required more experience.

B. Skill requirements

Detailed analysis of the skill requirements for different job openings has also been performed. Since the focus on this work is to guide the education program, the skills requirements for the entry level jobs have been summarized below, which are interested in by most bioinformatics degree students. Similar analytical results can be performed on intermediate and advanced jobs.

The required skills for randomly selected 100 entry levels jobs are illustrated in Figure 7 as *Wordle* image [13]. The Figure showed that the most required skills for bioinformatics jobs are programming skills, bioinformatics algorithms, data mining, statistical analysis, database managements, genomics, next generation sequencing, big data analytics, bioinformatics software tools, and others.

More information of the required skills in bioinformatics is summarized below:

- Bioinformatics tools: Samples tools are sequence alignment tools, such as Blast [13-14] or Bowtie [15], the Genome Analysis Toolkit (GATK) [16-17], the Integrative Genomics Viewer (IGV) [18-19], the software system for Next Generation Sequencing, Microarray & qPCR and Data Analysis (Partek), and tools for Ensembl-Havana GENCODE gene set (Ensemble).

Some tools are for database search systems, such as the life science research tool (Entrez), scalable machine learning tools (Mllib), an open source machine learning library for the Python programming language (Scikit-Learn), and a suite of programs for interacting with high-throughput sequencing data (Samtools).

- Statistical software systems: such as SPSS and SAS. In addition, statistical analysis using R or Python is highly demanded.
- Programming skills: It was required for most bioinformatics jobs to be familiar with programming languages. Other than general programing, for

bioinformatics, the most popular programming languages or script languages are R, Perl, Python, Java, and Matlab. At least one of these programming languages will be listed in the job requirements.

- Biology knowledge: Knowledge from molecular biology, cancer biology, and/or modern biology is needed. This is the domain knowledge needed to understand and analyze the data, and interpret the analytical results.
- Genomics and genetics: Genomics and genetics are the core bioinformatics skill sets and are required for almost every bioinformatics job. For example, skills for high throughput sequencing technologies, next generation sequencing, and computational genomics are in high demands.
- Database management: Databases, including traditional relational database systems (e.g., SQL Server or Oracle), NoSQL databases (e.g., MongoDB), big data analytics (e.g., Vertica), and other big data databases (e.g., TCGA) are common required knowledge for potential bioinformatics job seekers. Especially, for big data management or analysis, it is a widely open field and is in great demands.
- Data mining and machine learning: for example, hierarchical clustering and decision trees are common required techniques.

Some additional skills required for the jobs are good communication skills, managerial skills, good team player, ability to multi task, and work independently. These additional skills are the small words in Figure 7.

It can also be observed that there are some overlaps between Figure 4 and Figure 7 (the competencies and the skill requirements). In fact, the more overlap, the better, as it will show that our program competencies meet the job market for bioinformatics.

C. Employers for Bioinformaticians

Based on the job postings, the top 15 companies who have the most job postings in bioinformatics are summarized in Table 2. It can be observed that the leading employer is Leidos, which is a biomedical research Incorporate. It develops and applies advanced technologies for translational research in cancer and AIDS treatments. The second largest company is Illumina, which is a leading developer and manufacturer for next generation life science tools and integrated systems for large-scale biological data analysis. Other tops companies all on biomedical related research and development.

Another way to investigate the bioinformatics job market is the locations of the job postings, which is summarized in Figure 8, for the top 15 locations who have the most job postings. The blue colored areas are on the west coast, mainly in California, which is about 40% for the top 15 locations. The green colored areas are on the east coast in Boston Metropolitan areas, NIH campuses, and New York. The east coast is more than 44% of the top locations. The red colored locations are in the middle areas of the US, which is only 16%, just a little more than Cambridge, MA along. Thus, most of these bioinformatics employers are in the west or east coasts.

Table 2. The top 15 companies who have the most job postings in Bioinformatics. The jobs column lists the number of columns in a random day in April 2015..

Company	Jobs
Leidos	99
Illumina, Inc.	43
Mount Sinai Medical Center	31
The Jackson Laboratory	21
Thermo Fisher Scientific	21
Broad Institute	21
Human Longevity, Inc.	19
Genentech	19
MedImmune	18
Ingenuity Systems	18
Cold Spring Harbor Laboratory	15
QIAGEN	15
New York Genome Center	15
University of Chicago	14
Mayo Clinic	14

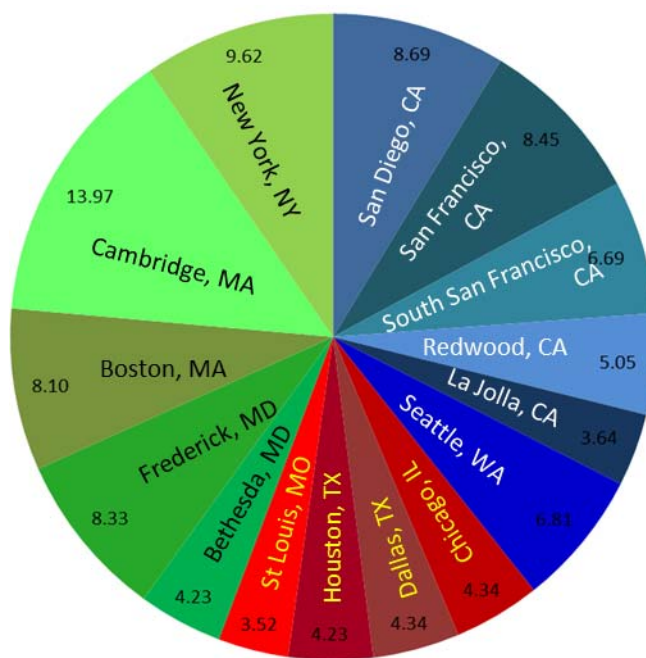


Figure 8. The geographical distribution of the job market in bioinformatics for the top 15 locations.

In addition, if there is a big city with a large medical center, the employment opportunities in bioinformatics will rise, such as in Chicago or Houston. For relative small cities, the job market for bioinformatics is limited. For example, in the city and the metropolitan areas of Indianapolis, IN, there is only 6 openings in bioinformatics, although there is the largest

medical school in the US and a lot of biotechnology companies, besides the giant pharmaceutical company, Lilly, is right next to the city.

IV. APPLICATIONS OF THE INFORMATION OBTAINED

The information learned from this study provides great guidance for the redesign of the curriculum, help for the students to self-evaluated their potential bioinformatics skills, and promotion of hands-on experience for bioinformatics professors, educators, and students.

The bioinformatics program at IUPUI offers both MS and PhD degrees [20-21]. Based on the survey results, the curriculums have been revisited and the competencies have been examined. The information from this project help the bioinformatics programs in the following matters:

- *Eliminate redundant contents:* By examining the program competencies and the individual course outcomes, the redundant contents across courses have been identified and resolved.
- *Develop new course modules:* to cover all the required skills, modular courses of 1 or 2- credits have been designed to cover specifically of one or two required skills. This will guarantee that our students are career ready upon graduation. For example, for the biology oriented students with limited background, the programming courses (R, Python, Matlab, Java) are taught in their first semester entering the programs. This will make sure they are ready to work on bioinformatics projects from the beginning.
- *Reorganize the course offering schedule:* The course offering schedule has been revisited to make sure that the students meet all the prerequisites when they are ready to learn a new skill.

In addition, all the students in our bioinformatics program are provided the opportunities to have hands-on experiences, starting from the beginning of their MS programs. All full-time MS students are provided with partial scholarships and hourly research assistantship. Of course, all the PhD students are fully supported. With acceptance of the scholarships, the students are expected to work on bioinformatics projects upon entering the programs. The student records showed that this is a great way to increase the students' experiences and to improve the portfolios of the students when they are ready for jobs. The employment record shows that our students are more than 95% employed after two months of their graduation.

V. CONCLUSIONS

The bioinformatics education in the United States has been studied and the potential employments of the bioinformatics students has been investigated. The current state of the arts of the bioinformatics programs nationwide has been summarized. The bioinformatics program competencies and the career skill

requirements are described in details. Overall, the bioinformatics is a promising field with high demands, better payments, and interesting projects.

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Students Learn More with Less Text that Covers the Same Core Topics

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Abstract—For textbooks on technical topics, the typical amount of text used is more than what many college students will read. Some teachers observe, and students report, that students commonly skim such text. As such, a writing style that aggressively minimizes text while still teaching the core technical topic may improve student learning; if text is short enough, students may then read and study the text more carefully.

The objective of this study was to compare the effect of text quantity on amount learned.

We created and compared content styles using a lesson that taught Google search techniques. The two main content styles were normal text and minimal text. The normal text style included 6-12 sentences followed by 1-3 examples. The minimal text style included 1-2 sentences followed by 1-3 examples.

We conducted a randomized control study with 168 participants enrolled in a college-level Introduction to Computing course for non-computing majors. Each participant was randomly assigned one lesson style. We provided a pre-lesson and post-lesson quiz, each with ten questions. Additionally, the participants completed background and follow-up surveys. The study was part of a course homework assignment, so self-selection bias was limited. The course is primarily taken by non-majors and covers the basics of Word, Excel, and HTML.

An improvement score is a participant's post-lesson minus pre-lesson quiz scores. The average improvement score for minimal text was 2.4 (6.5 – 4.1), which is higher (p -value < 0.01) than the average improvement score for normal text of 1.1 (5.1 – 4.0).

Thus, teaching the same topic using less text led to more learning. The conclusion is not that materials should be watered down, but rather that great attention should be paid to using minimal text while teaching the same core topics.

Keywords—digital learning; digital education; digital content; lesson assessment; text length, minimal text, college education, college textbooks, STEM.

I. INTRODUCTION

Completing textbook reading assignments improves student learning [4][10], and students are encouraged to complete the readings [3][9][13]; however, 94% of students spend less than two hours per reading assignment [1]. Text length may be a cause. Normal text lengths may use 6 – 12 sentences and 1 – 3

examples to cover a core concept, as shown in Fig. 2(a); whereas, minimal text lengths may use just 1 – 2 sentences and 1 – 3 examples, as shown in Fig. 2(b).

The objective of this study was to compare the effect of normal text and minimal text on the amount learned by students.

II. BACKGROUND

Cognitive load is the amount of mental effort a learner uses during a learning task. Cognitive load theory [8] defines three types of load: intrinsic, extraneous, and germane. Intrinsic load is the load added by the difficulty of the material. For example, adding two small integers has less intrinsic load than dividing two large integers. Extraneous load is the load added by the style of presentation. For example, a description of a square using a drawing has less extraneous load than with verbal descriptions. Germane load is the load added by developing an organized pattern of thought.

Research in instructional design has sought to reduce the learner's extraneous load and increase the germane load [11][12]. This paper focuses on the reduction of extraneous load by reducing the amount of text used to teach a subject.

Text length has been identified as an impactor of reader understanding [5]. Concise text was found to improve usability by 58% [7], where usability is defined by: time to complete a task, errors made during the task, amount remember by user after task, time to recall site's structure, and subjective satisfaction of the user. Longer text has been shown to negatively impact student understanding for secondary language learners [6]. Also, converting written text to spoken text has been shown to reduce extraneous load [2]. However, previous work has not simply measured how much text length impacts the amount a student learns. The problem is especially critical for STEM (science, technology, engineering, math) topics where a solid conceptual understanding of concepts is crucial for a student's continued success in an academic program. We have developed materials using an aggressively minimized-text approach, with anecdotal evidence that the minimal-text approach was well-liked by students and led to improved learning; this paper seeks to provided concrete evidence via a controlled study.

III. PARTICIPANTS

The participants were undergraduate students at the University of California at Riverside enrolled in a basic computing course during the 2013 Fall quarter. The course (CS 8 Introduction to Computing) introduces basic computing applications such as Microsoft Office and web applications, intended for non-computing and non-engineering majors and having no prerequisites. Traditionally, 98% percent of the students are non-computing and non-engineering majors.

307 students participated in the study, of which 164 were randomly assigned to a normal text group and 143 were randomly assigned to a minimal text group. Participants had one week to complete the assignment. Participants from the last three days spent an average of 2 minutes on the lesson, whereas students from the first four days spent an average of 7.5 minutes on the lesson. Thus, students from the last three days were excluded for clearly rushing through without trying and thus improperly skewing results. So, 85 participants from normal text and 83 from minimal text were included in the analysis.

The participants were blind to the conditions and specific purpose of the experiments. The participants were participating as part of their computing applications coursework. The experiments were approved by University of California at Riverside's IRB (Institutional Review Board).

IV. DESIGN

Participants were given one week to complete the assignment by the instructor. Participants who completed the assignment in the last three days were excluded due to apparently rushing the assignment.

The two lesson styles were evaluated for quantity of learning and student engagement. A first measure was the

number of correct answers on the pre-lesson assessment. A second measure was the number of correct answers on the post-lesson assessment. A third measure was the improvement score, which is the second measure minus the first measure. A fourth measure was the length of time spent on the lesson. Fifth through eleventh measures were the follow-up survey questions on how the lesson was used and how useful the lesson was perceived to be.

For each of the third through eleventh measures, we used a Student's T-test to determine whether the lesson styles were significantly different. The T-tests were computed with 2-tails and unequal variances parameters. We applied a Bonferroni correction to account for the multiple tests, so a p-value of $(0.05 / 9) = 0.006$ was needed for statistical significance.

V. MATERIALS

The study was located on a single webpage and included 6 tabs. Only one tab could be viewed at a time, and participants could only progress forward between tabs. At the bottom of each tab was a button to proceed to the next tab. If the button was pressed for the first time but at least one of the input fields was not completed, then the page would generate a pop-up informing the participant that a field was incomplete. Otherwise, the current tab would disappear, and the next tab would appear.

The study page was titled: Digital Education Study. The page included that: "the purpose of this study is to evaluate different ways of presenting educational content." Also, the page included: "Your responses are completely anonymous." The participants were asked to "please refrain from leaving this webpage, using other devices, or asking others for assistance on the content."

In Tab 1, the participant was randomly assigned a unique

Fig. 1. The pre- and post-lesson assessments given to all participants included 10 multiple choice questions.

Num	Question	Your answers			
1	Songs that include the verse: Can't live without you.	<input type="radio"/> Songs can't live without you <input type="radio"/> Songs "can't live without you" <input type="radio"/> Songs "can't" "live" "without" "you" <input type="radio"/> -Songs can't live without you	6	Resumes in the form of a word document.	<input type="radio"/> resume filetype:doc <input type="radio"/> resume: filetype doc <input type="radio"/> resume word document <input type="radio"/> resume.doc
2	Light in the early morning or evening. Note: A popular movie named Twilight exists.	<input type="radio"/> twilight <input type="radio"/> twilight not movie <input type="radio"/> twilight site: not movie <input type="radio"/> twilight -movie	7	Degrees at San Jose State University.	<input type="radio"/> Degrees site:sjsu.edu <input type="radio"/> Degrees "sjsu.edu" <input type="radio"/> Degrees +sjsu.edu <input type="radio"/> Degrees ending:sjsu.edu
3	Job data provided by the government.	<input type="radio"/> Job data site:.gov <input type="radio"/> Job data government <input type="radio"/> "Job data" government <input type="radio"/> Job data "government"	8	Sites that discuss George Bush but not George W. Bush.	<input type="radio"/> "George Bush" "George -W. Bush" <input type="radio"/> "George -W. Bush" <input type="radio"/> "George Bush" -W <input type="radio"/> "George Bush" -"George W. Bush"
4	Research studies on smoking and cancer.	<input type="radio"/> Smoking and cancer <input type="radio"/> Smoking and cancer (on scholar.google.com) <input type="radio"/> Smoking site:scholar <input type="radio"/> "smoking and cancer"	9	PowerPoint documents about the solar system.	<input type="radio"/> solar system <input type="radio"/> solar system ppt <input type="radio"/> solar system filetype:ppt <input type="radio"/> solar system site:.ppt
5	Information on someone named Quincy Magoo.	<input type="radio"/> Magoo, Quincy <input type="radio"/> Name:"Quincy Magoo" <input type="radio"/> "Quincy Magoo" <input type="radio"/> Quincy Magoo filetype:name	10	Research studies on regular, not electronic, cigarettes.	<input type="radio"/> cigarettes <input type="radio"/> cigarettes (searched on scholar.google.com) <input type="radio"/> cigarettes -electronic (searched on scholar.google.com) <input type="radio"/> cigarettes not electronic scholar

Fig. 2. The first digital page of the (a) normal text lesson, and (b) minimal text lesson, representing about one-third of the entire lesson. The same examples were used in each style.

1 Google search tips

Searching the Internet for particular web pages, songs, movies, images, etc., is one of the most common tasks that a person performs on a computer today. Most people just use the basic standard search technique of typing in key words or even a full question, like: What low-cost foods are also healthy? While that technique often works, sometimes people get frustrated that when they just can't find what they are looking for, especially when what they are looking for is very specific. This frustration occurs not only during Internet searches, but also searching for a particular email too, which is very common these. However, there is good news: What many people don't realize is that there are a few search techniques that can really help narrow down those search results, hopefully leading to finding exactly what one is looking for.

Sometimes during a search, you are looking for a very specific combination of words. For example, you might be looking for a specific person who has a name like "Parviz Spaghetti". Consider the following search: Parviz Spaghetti. That search will turn up tens of thousands of pages, mostly about spaghetti, and people named Parviz, and much more. But really you are only interested in seeing pages about the specific person with the name "Parviz Spaghetti", and don't want to have to wade through thousands of pages.

Fortunately there is a solution. One of the simplest and most effective ways of finding something very specific during an Internet search is to use quotes. In a search, **quotes** around words causes the search to search for those words within the quotes, in the exact order that they appear within the quotes, without any other words in the middle. For example, "circle of knowledge" would only find sites with those three words in that order; a site with just "circle of your knowledge" would not match. Quotes are especially useful when searching for a specific phrase, like the famous statement from Albert Einstein about one's "circle of knowledge". Quotes are also very useful when searching for a person's name, using their first and last name.

For example, sites with *knowledge circle*, or *circle of your knowledge*, would NOT match with Einstein "circle of knowledge".

Quotes are useful to find a specific combination of words. But sometimes the problem with search results is that search is returning pages that have nothing to do with the subject one is interested in, but instead just happens to use the same words as the search. For example, suppose you were searching for adventurous things to do in California, like perhaps mountain biking, whitewater rafting, cave exploring, etc. You might type the following keywords in your search: California adventures. But, the results would be entirely dominated by pages relating to the amusement park named: California Adventure, run by the Disney corporation What's needed is a way to *exclude* results that involve Disney, so the pages that really interest you appear.

identifier that was associated with each activity and submitted answer by the participant. The unique identifier was stored in temporary browser cache. Tab 2 was a brief background survey asking in which school or college the student's current or intended major was, in what year in college the student was, and an agreeability statement: "I am very good at performing searches on Google." The agreeability statement had the following choices: Strongly agree, agree, slightly agree, slightly disagree, disagree, and strongly disagree.

Tab 3 was a pre-lesson assessment with 10 multiple choice questions, ordered the same for each participant, and shown in Fig. 1. Each question covered one or two concepts that were also covered in the lesson. At the top of the assessment, the participant was informed that these questions are to assess prior knowledge, so the participant was informed to "give each question your best and move on."

Tab 4 was a lesson on web searching with Google. The lesson was randomly assigned with equal chances to be either the minimal text or normal text style, shown in Fig. 2. Both styles covered the same concepts, including the same 1 – 3 examples per concept. Minimal text had 211 words; normal text had 1,255 words. A timestamp was recorded when the lesson appeared.

Tab 5 was a post-lesson assessment with the same questions as the pre-lesson assessment. A timestamp was submitted when the post-lesson assessment appeared. Tab 6 was a follow-up survey with five agreeability statements about the lesson, two multiple choice questions assessing how the student interacted with the lesson, and an open-ended short answer question about the lesson style. The agreeability

(a) 1 Google search tips

Using **quotes**, as in "circle of knowledge", searches for exactly those words in that order. Quotes are especially useful for a specific phrase or a person's name.

Einstein "circle of knowledge"	Sites with <i>knowledge circle</i> , or <i>circle of your knowledge</i> , would NOT match.
--------------------------------	--

Using a **minus** before a word, as in -Disney, excludes sites that have that word.

California adventures	Results dominated by Disney's amusement park by that name.
California adventures -Disney	Results now mostly outdoor activity sites; no Disney info.

Including **site:** in a search, as in site:.edu, restricts searches to domains with that ending.

does soda cause obesity	Yields news articles, opinion sites, university articles, etc.
does soda cause obesity site:.edu	Yields only pages from from Harvard, Stanford, Princeton, etc.
does soda cause obesity site:harvard.edu	Yields only pages from Harvard.

Including **filetype:** in a search, as in filetype:pdf, limits results to files of that type.

What is dry ice filetype:ppt	Finds PowerPoint files discussing dry ice.
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statements were: "the lesson was sufficient to do well on the post-lesson quiz," "I was engaged with the lesson," "the lesson was the right length," "I liked the writing style," and "I am very good at performing searches on Google." The agreeability statements had the following choices: Strongly agree, agree, slightly agree, slightly disagree, disagree, and strongly disagree.

VI. PROCEDURE

The course instructor assigned the study webpage as homework, in which the participants were given one week to complete the study webpage. The participants chose where and when to complete the study webpage. To maintain anonymity, after completing the study webpage, the participant filled a form to submit his/her student ID number—the student ID number was not associated with the randomly-assigned unique identifier. The instructor accessed the student ID number to award course points.

VII. RESULTS AND DISCUSSION

An improvement score is a participant's post-lesson minus pre-lesson quiz scores. The average improvement score for minimal text was 2.4, which is significantly higher (p-value < 0.001) than the normal text improvement score of 1.1, as shown in TABLE I.

TABLE I. STUDENTS ASSIGNED MINIMAL TEXT IMPROVED SIGNIFICANTLY MORE THAN STUDENTS ASSIGNED NORMAL TEXT.

	Pre-lesson quiz	Post-lesson quiz	Improvement score
Minimal text	4.1	6.5	2.4
Normal text	4.0	5.1	1.1
		p-value	< 0.001

Additionally, participants rated agreeableness of statements on a scale of 0 (strongly disagree) to 6 (strongly agree). Participants rated "The lesson was the right length" for minimal text as 4.8, which is higher (p-value < 0.001) than the normal text score of 3.8, as shown in TABLE II. Also, participants rated "I liked the writing style" for minimal text as 4.3, which is higher (p-value = 0.03) than the normal text as 3.0.

TABLE II. STUDENTS ASSIGNED MINIMAL TEXT WERE SIGNIFICANTLY MORE SATISFIED WITH THE LESSON THAN STUDENTS ASSIGNED NORMAL TEXT.

	Normal text	Minimal text	p-value
Lesson was right length	3.8	4.8	< 0.001
Liked writing style	3.0	4.3	0.03

For the agreeability statement "The lesson was sufficient to do well on the post-lesson quiz", participants assigned minimal text rated 4.6 of 6 and normal text rated 4.5 of 6, which were not significantly different (p-value = 0.67). This suggests that both lessons covered the core topics sufficiently.

For the agreeability statement "I was engaged in the lesson", participants assigned minimal text rated 3.8 of 6 and normal text rated 3.3 of 6, which were almost significantly different (p-value = 0.09). The minimal text was more engaging, but not significantly so.

For the agreeability statement "I am very good at performing searches on Google" in the background survey, participants assigned minimal text rated 2.1 of 6 and normal text rated 2.1 of 6. However, in the follow-up survey with the same question, participants assigned minimal text rated 3.9 of 6 and normal text rated 4.4 of 6, which were almost significantly different (p-value = 0.01). The participant's belief in how much was learned was inverse to the amount actually learned. Perhaps the participants assigned the normal text believed they learned more because more text was presented; however, students actually learned more with the minimal text.

The question "How did you interact with the lesson?" had 5 options ranging from "I read every word in the paragraph text and examples" (rated as 5 of 5) to "I didn't really read the lesson" (rated of 1 of 5). Participants assigned minimal text rated 3.5 on average, which is almost significantly (p-value = 0.008) higher than normal text that rated 3.0.

The question "For reading assignments in your classes, how much of the assigned reading do you typically complete?" had 5 options from "100% of the reading" (rated as 5 of 5) to "0% of the reading" (rated as 0 of 5). Participants assigned minimal text rated 4.0 on average and normal text rated 3.9 (we would not expect a difference among the groups). So, the participants overall say they read about 75% of the assigned reading in their classes.

Participants spent more time with the minimal text (8.4 minutes) than the normal text (7.3 minutes); the difference was not significant (p-value = 0.83). Reading the normal text should have taken *longer* than reading the minimal text, so this indicates that participants may have skimmed over the normal text.

Minimal text naturally leads to a more structured presentation using items like tables or lists. To determine the impact of the tables used in the minimal text, we actually had a third group of students use a hybrid lesson using the normal text but with the examples in table form rather than text. Those students' improvement scores were about midway between the normal text and minimal text groups. We note however that the normal text in typical textbooks usually do not use tables in such an extensive manner due to resulting in unusual-looking content.

VIII. TECHNIQUES TO REDUCE TEXT

Creating minimal-text material requires careful attention to reduce text as much as possible while ensuring coverage of core topics, or as Antoine de Saint-Exupery wrote: "perfection is attained not when there is nothing more to add, but when there is nothing more to remove." Several general techniques were used for the minimal-text used in this study, including 1) concise and clear writing using simple declarative sentences, 2) avoiding or removing text that distracts readers from the core topic, and 3) matching the presentation format to the material presented. We highlight some examples of these techniques to illustrate.

One technique to write clear and concise text is to use simple declarative sentences, consisting of subject, verb, and object, as in "Quotes are especially useful for a specific phrase." This style specifically avoids using superfluous prepositional phrases, such as "when searching" in "Quotes are especially useful when searching for a specific phrase." Such prepositional phrases are only needed when the context is unclear; searching is clearly the context, and the prepositional phrase can be removed here without losing meaning. Additionally, a sentence should start with the real subject to clearly indicate the sentence's main point. Avoid starting sentence with pronouns, as in "It is", as the subject can be ambiguous, which may require some text elsewhere to clarify.

Another technique is to remove text that distracts readers from the core concepts, and focus on presenting core concepts first. While text motivating the need for a topic is important, such text should be kept to a minimum. One common method used to motivate topics is storytelling, often entailing setting up a scenario, defining actors, describing what the actors want to do, and finally introducing a problem they face, all before finally defining the core topic or concepts. Such motivational

examples may require 1-2 paragraphs and half a dozen sentences, as in the first two paragraphs of the normal-text style, shown in Fig. 2. The minimal-text approach instead presents the core topic first, then uses examples to provide the same motivation. With carefully chosen examples, the same motivation can often be conveyed without lengthy text that only serves to motivate. In some case, motivational examples may be needed. Motivational text should focus on providing the minimal text needed before introducing the core concept.

A third technique is identifying presentation formats that are best suited for the topics being presented. The minimal-text style used in Fig. 2(b) uses tables to present example searches with the left column presenting the search and the right column explaining. This presentation format avoids sentence text required to describe or present the example, as in starting a sentence with “For example” or “Consider the following search.” Additionally, as the relation between the left-column example and right-column explanation is clear, the explanations start with “Yields” rather than “This example search yields”; further reducing text.

IX. FUTURE WORK AND LIMITATIONS

This study focused on one particular subject. An intrinsically more challenging subject may benefit more from minimal text, whereas an intrinsically less challenging topic may benefit less. Additionally, this study focused on how text quantity impacted learning. A list of writing rules and guidelines would be helpful for helping authors write clear and minimal text that help students learn more.

A future study might include each participant being shown multiple lessons, such that each lesson has a different lesson style. This may help better understand the students predisposition toward each lesson style.

Future work also includes assessing impacts of text length on multiple other topics, identifying and measuring rules for writing minimal text, and measuring additional learning formats for optimizing learning, such as clear writing, images, animations, learning questions, assessment questions, and interactive tools. Learning questions are another way of reading, wherein the student learns a concept by working through incrementally harder questions that start from a known concept. Assessment questions are designed to test a student’s understanding.

One limitation of this work was that students were awarded course points for simply participating in the lesson and not awarded points for working through the lesson. Also, other than the participation of the lesson, the information in the

lesson was not otherwise a part of the course. So, the incentive for a student to work through a lesson was missing.

X. CONCLUSION

The minimal text lesson had more than double the effectiveness than the normal text. The conclusion is not that materials should be watered down, but rather that great attention should be paid to using minimal text while teaching the same core topics.

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Virtual Laboratory Platform for Computer Science Curricula

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Abstract—Experimenting in computer science course is challenging due to the limitation of site, equipment and special experiment tools. In this paper, based on the analysis of the experiments features of computer science curricula, such as, Principle of Computer Organization, Digital Image Process, Digital Signal Process etc., we design two kinds of virtual lab platforms and develop corresponding virtual lab systems for the courses in computer science curricula. In the first virtual lab, every experiment instrument in real lab is visualized as a Java component. In the other kind of virtual lab, the algorithm students learn in the course is packed as a Web Service component by C, C++ or Java. In both platforms, those components are listed in the system. Students are able to select Java components or Web Service components as the experiment they want to do need and integrate them by building connections between them. Then, the students can set input for the experiment in the input component. After click the button of run, the result will be display for the students in the platform. In the two kinds of virtual lab, students can also write the code in the platform. After it is submitted, those codes will be transferred as a component by the platform and be added in the component list. Then they can use them as the components provide by the platform. So, they can test if the algorithm they write is correct. Both platforms are developed by Java Applet and can be run by a browser. By using our system, students can experiment at any time and any place via the Internet. Teacher is also able to do experiment in the classroom. Based on the platforms, 6 virtual lab systems have been developed and used by more than 5 universities in China. Those virtual lab systems have been received favorably by teachers and students.

Keywords—*Virtual laboratory Platform, computer science curricula, JavaBean component, web services*

I. INTRODUCTION

Experimentation is an important part of the study in computer science curricula, which can give students a way to improve what they learned in the classroom and textbook and improve their ability for coding and understanding of theoretical knowledge. Experimentation is also important for students to get an active, engaging learning experience [1–6].

With the rapid development of Internet, Virtual Lab (VL) has become a new solution for experiment. By using VL, the traditional approach to teaching and experimentation has greatly changed at any educational level. The user can

access virtual lab and perform experiments at anytime and in any places [8].

The paper analysis the feature of experiment of the Computer Science Curricula and divided part of them into two types: complex process and heterogeneous resources, and introduces the design of the virtual lab platform which makes the experiment more convenient and more creative, and introduces the implementation of the key technology of those two type of virtual lab systems according their experiment type. The easy-to-use virtual lab system has been received favorably by students and teachers.

Our contributions in this paper are as follows: we design and develop a virtual lab platform for computer science curricula based on the analysis of the experiment of part of the courses. The platform is easy-to-use for students at any time and in any place. Based on the platform, we design and develop 6 virtual lab systems for courses of computer science curricula according to the type of its experiment.

II. RELATIVE WORK

Virtual lab is a hardware and software operating environment which is used for replacing part of or all of the operating steps for traditional experiment. At present, many scholars have done a lot of research on virtual laboratory. In April 2010, Science introduce an introductory chemistry virtual laboratory, Yaron et al have established a online general chemistry virtual laboratory[9], students can freely choose chemical instruments and reagents chemical experiment in the this laboratory. Bal et al have established a virtual laboratory of a switched reluctance motor which use of LabView as a user interface and invoke Matlab through the Matlab&Simulink[10]. Li et al. have developed a distributed intrusion detection system based on the virtual machine, and analyzed the experimental results of different virtual machine environment[11]. Li et al. have established a physical virtual experiment, which private virtual experiments of electron, optics and pulley [12].

Virtual lab system of computer hardware courses has been improved a lot. Brigham Young University describes a computer organization course on the Web [13]. Students can write and execute assembly language programs on a virtual machine with LogicWorks 3 (Interactive Circuit Design Software), which provides graphical means for user input and

simulation output. They can also design and implement the CPU of the virtual machine via a CAD package. The University of Edinburgh develops HASE system [14]. It is a hierarchical computer architecture design and simulation Environment, encompassing both hardware and software. The virtual laboratory of the University of Calgary [15] comprises two locations: a remotely controlled instrumentation laboratory and a digital design experiments collection where the operation of the basic digital circuits is simulated with html applets. Huang proposed a java-based distance learning environment [16], which is a computer-aided instruction (CAI) system for electronic instruments. Students can learn how to use oscilloscopes, function generators, and logic analyzers.

III. ANALYSIS OF EXPERIMENT OF COMPUTER SCIENCE CURRICULA

The experiment of each curriculum in computer science has its own characteristics. In this paper we analyzed the requirement of experiment of most curriculums and classify them in to two main types: complex process and heterogeneous resources. Its course classification by experiment is shown in Table. 1.

TABLE I. THE COURSE CLASSIFICATION BY EXPERIMENT

Type	Curriculum	Requirements of the Experiment
Complex Process	Theory of Circuit, Analog Circuit, Digital Circuit, Principle of Computer Organization, Computer System Architecture, etc.	Students need to master the principle and performance of experimental devices, and to know the function and the application of experiment components
Heterogeneous Resources	Digital Image Process, Data Structure, Computer Algorithm, Principle of Digital Signal Process, Cryptography	Students need to master the basics theoretical knowledge of the course, deepen understanding of the classical algorithm through practice, and be able to design new algorithms.

Complex Processes: This type is generally present in the experimental of the hardware-related courses. The purpose of these courses is to enable students to master the principles and related hardware performance. The purpose of experiment of these courses is to combine theory and practice, to deepen the understanding of the basis theoretical knowledge through practice, and improve students' ability of design and innovation. In this kind of experiment, students first need to master the principles of hardware components and corresponding performance, then choose the appropriate hardware components to build the structure and set the parameter of the components, and execute the processes and get results. There are many experiment components in the experiment process in this type of experiment. Connection relationship between the experimental components is very complex. There is a complex relationship and a lot of control data path in the experiment. Moreover, the experimental devices in such courses generally are electronic chips which can truly concurrent execute. So, the virtual lab platform should solve the parallel problem of the virtual chips.

Heterogeneous Resources: This type is generally present in the experimental of the algorithm design courses. The purpose of these courses is to enable students to master the basics of relevant theoretical knowledge and apply it. The purpose of experiment of these courses is to practice the theoretical knowledge into practice, to deepen the understanding of the basis theoretical knowledge through practice, and improve the abilities of students. In this kind of experiment, students first need to design or implement an algorithm, then test it and analysis the correctness and performance of the result. The experimental process of this type of courses is generally simple. The sequence of experiment components performed is generally linear. Meanwhile, the experiment component is an implementation of some algorithm. There may be different kind of programming language used for program by the student, such as, Java, C++, even Matlab. So, the virtual lab platform should solve the integration of those heterogeneous components.

The above is the characteristics of two types of courses and it is also the requirement of their experiment. At the same time, the other goal of the platform is to provide a convenient, flexible and easy to use experiment environment for students' experiment. As a new solution for experiments in Computer Science Curricula, the platform must solve those problems in traditional experimentation model. To achieve this goal, we have defined a list of criteria for the platform.

Open and convenient: First, the platform should be able to access by students in 7*24 model, so, when a student has a new idea, he can design and test their idea at any time. Second, the platform should be convenient for the students, thus they don't need to install any software for the experiment.

Innovative: The platform should not just provide a replication experiment model for the students. Students should be able to choose the experiment element and set up the experiment flow according to the needs of their experiment. They also should be able to design their own algorithm and submit the algorithm the platform for testing and analyzing.

Visualized: The platform should provide visual experiment result for students, therefore they can determine the correctness of the experiment flow designed by them.

IV. THE DESIGN OF THE VIRTUAL LAB PLATFORM

A. Architecture of the Platform

The Architecture of the virtual lab platform is shown in Fig.1. The virtual lab platform includes two parts, the server and the client. The client is developed by Java Applet technology, which make the user can use the virtual lab system in any browser with the Java VM through Internet or intranet. Therefore it provides an experiment platform to the user in anytime, at anywhere. It meets the need of open lab which is difficult in real experiment model.

The server includes a database, JavaBean library, Web service component library, collaborative experimental support and user management. The user information, group information and experiment configuration information are stored in the database. The virtual components in the complex process

model experiment are stored in the JavaBean library. The algorithm components developed by Web-service are stored in the web-service library. Collaborative experiment server is used for remote collaborative experiment, for group collaboration experiment management and message forwarding. The user management is used for user rights management, experimental operation and process management.

The client includes design panel of experiment process, analysis and execute of experiment process, and the collaborative experiment client. The user can choose the virtual experiment components and build the experiment process in the design panel. After the experiment process is built, the client will execute the experiment process in the local Java VM.

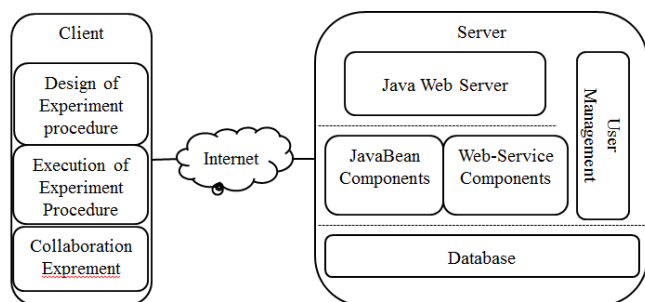


Fig. 1. The architecture of the virtual lab platform

There are some interactions between client and server sides. Firstly, the client tries to connect with web server through browser. After entering the virtual lab, browser will download the Applet pages automatically from the server to the client. Through the Applet, users can choose the experiment component, configure parameters of components, and start to run experiment. Then the client will submit the configuration parameters to the server and request for the Java class files of corresponding components. The server will send these Java class files to the client when it receives the request. Then the codes will be executed on Java Virtual Machine (JVM) at local. At last, the simulation result will be returned to the client.

B. Design Panel of Experiment Flow

The interface of client is shown in Fig.2. It contains three areas: design panel of experiment process, menu and toolbar, virtual experiment component. The menu an toolbar provides the basic operation for users, such as, open, save the file, the start or stop the experiment, rollback and redo of the experiment process, help.

The virtual experiment component contains the list of virtual experiment components in each virtual lab system. All those components are added to the list according to the XML files in the system. When user click one of the components, its information will be displayed blow the list.

The design panel is used for users to build the experiment process. The user clicks the component in the left list and places it in any area of the design panel by clicking the location in the design panel. At the same time, the user can connect the ports of two components to build the experiment process. The virtual experiment components in the design panel can be

moved in the panel by the user. Several connected components can be combined as a new virtual experiment component by the user. The panel is able to be zoomed out and moved by the user. All the operation in building experiment process can be redo or rollback.

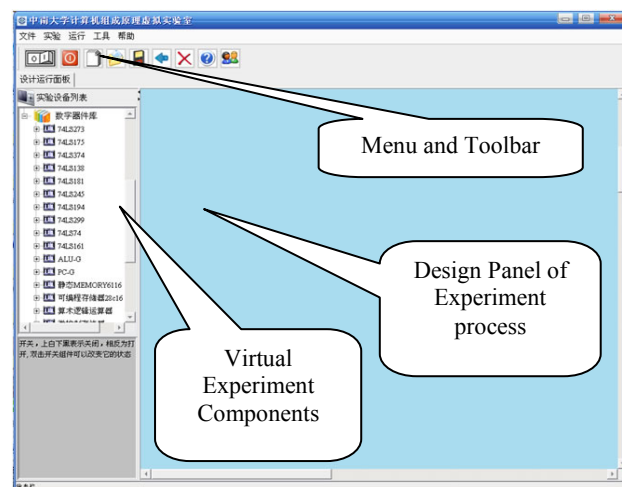


Fig. 2. The interface of client

C. The Virtualization of Hardware Experiment Component

In the complex process type experiment, the hardware experiment component especially the electronic chip is the main resource of the experiment. The variety of those components is huge, and the function of them is complex. At the same time, the connection between them is also very complex. So reusability and extensibility is very important in the virtualization of those components.

The JavaBeans component is a combination of Java technology and component technology, is an integrated assembly model. The JavaBeans is used in this paper to virtualize the hardware experiment component. Each experiment component is packaged as a JavaBeans component, the pin or port of them are packaged as a port. According to the input data, the JavaBean component to perform the appropriate method to simulate the real experiment equipment function to complete the transformation of input data to output data.

The virtualization of hardware experiment component is shown in Fig.3.

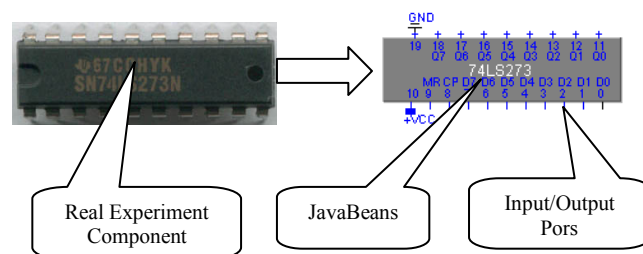


Fig. 3. Virtualization of hardware experiment component

In the platform, the user can also define the virtual experiment component as they need and integrate it into their

experiment process. It is only need the user to program the component in Java language in accordance with the JavaBean standard and the system of rules, not need them to get the source code of the platform.

D. The Virtualization of Algorithm Design Component

In the heterogeneous resources type experiment, the algorithm design experiment component is the main resource of the experiment. In this type of experiment, one algorithm may be implemented by multi programming languages, such as Java, C++, and the third-part software may also be used sometimes. For example, Many algorithms are implemented by C++ and Matlab in the Digital Image Process. Meanwhile, the client of the virtual lab platform is implemented by Java. A method to connect JavaBean component(mainly provide data input and result display) with the component implemented by another programming languages is necessary for this type of virtual lab system.

Web (Web services) is a distributed architecture based on XML and Internet technology. Web services technology provides an integrated and interactive mechanism for distributed applications in heterogeneous, autonomous and loosely coupled. In the paper, all the algorithm components are packaged as a Web Service. Different from JavaBean, all the Web Service component is executed in the server, the client just call the Web service and transfer the result to the next component.

The user-defined Web service can also be integrated in the virtual lab system. There are three ways for user to submit their web service component in the system: 1) the user submits the source code of Java or C++ to the server, the client provide an area for source code submitting. After get the source code, the server will compile it and do the security test. If it is all passed, this web service will be added into the components list in the left side of client interface. 2) The user submit the source code which call the third part software in the server(Matlab is now available), the server do the same work as the previous. 3)The user register a exit web-service into the system.

E. Scheduling of Virtual Experiment Component

A trigger scheduling mechanism based on data-driven to control the executive sequence of components is used in the platform. It improves efficiency and real-time responses of the system. This trigger scheduling mechanism based on data-driven can be described as follows:

Each component is initialized as a thread, and all components communicate with each other by wait-notify mechanism and lock technology. Only if a component receives new data from one of its preceding components and notified by it, it will be driven to execute its function. Otherwise, it is always in waiting state, and will have no chance to run.

The concrete process is as follows: At first, the initial values of all components' pins are null, and the value of "dataflag" is set to 0. When a user starts experiment, dispatch-control module analyzes the experimental flow, then constructs each component as a thread and puts it into a thread group. Except data source components, most components call method

wait() to be in waiting state. When data source component has been allocated by the CPU scheduler, it will call method nextDevice() to obtain the information of relevant succeeding components. If the values of "dataflag" in the succeeding components' input pins are 0, the data source component will get and invoke its functional methods with Java Reflection technology. Then it generates new outputs and sends them to the input pins of the succeeding components. Finally, the data source component notifies its succeeding components and waits for being triggered by user again.

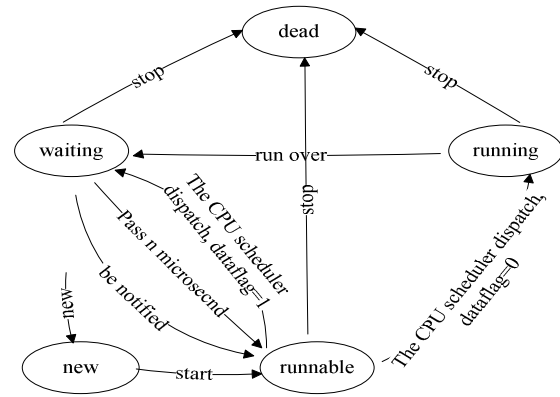


Fig. 4. The state transition diagram

If there is any succeeding component in which the "dataflag" is 1, the data source component randomly waits for a period of time and then check the "dataflag" values again. If all succeeding components are notified, the data source component can adjust itself to a state waiting for running. When it is allocated by the CPU scheduler, it will do the similar operation as the data source component. The difference is that it will be in waiting state again after it notifies its succeeding components. When users click "stop" button in the experiment, the thread group will be stopped, and the experiment will be finished. The state transition diagram is shown in Fig.4.

In order to guarantee successful execution of component, all components must do an atomic operation which can not be interrupted. The atomic operation includes the following operations:

- (1) Execute functional method and send new outputs to the succeeding components.
- (2) Set values of "dataflag" in input pins of the succeeding components and notify them.
- (3) Change the values of its own "dataflag" of input pins.

The virtual lab platform adopts class-lock mechanism to guarantee the execution of atomic operation. The class-lock mechanism represented by synchronized (Class) means that: all threads share only one lock, the component which owns the lock will execute preferentially, and the rest threads should stay in the waiting queue. Only when the atomic operation is over and the lock is released, waiting threads can contend for the lock to execute their function. The process of components scheduling is shown in Fig. 5.

For the special component with bidirectional pins, its pins can be changeable while running. The system defines an attribute variable named “Direction” to represent its running direction. When a component is running, we can get and set “Direction” dynamically by calling methods `getDirection()` and `setDirection()` with Java reflection technology. Then, the component does the corresponding operation according to the current value of the attribute Direction.

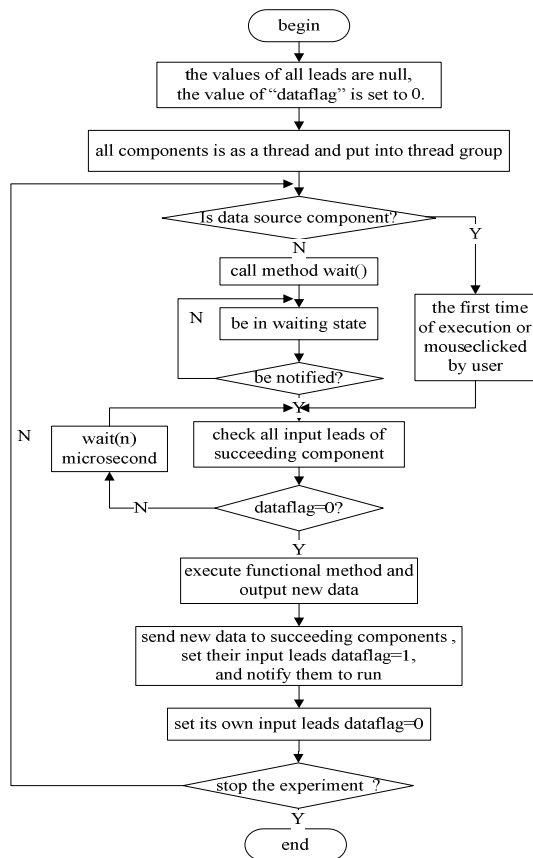


Fig. 5. The flow sheet of components dispatch

V. EXAMPLES OF THE VIRTUAL LAB SYSTEM OF TWO TYPES OF EXPERIMENT

A. The virtual lab of Principle of Computer Organization

The experiment of PCO(Principle of Computer Organization) is a typical complex process type experiment. All the experiment components are electronic chips. The connection of those components is very complex in some experiment of PCO. There is also a loop in the experiment process.

The model computer experiment is the most complex experiment in the PCO. A model computer is a simple but complete CPU mode. It is the best way for students to understand the principle of compute and how chips work collaboratively under the control of the instructions.

A model computer contains micro control chip, timing system, arithmetic logic unit, memory, etc. Some of them are composed by many tiny chips. The connection diagram of a

model computer is shown in Fig.6. The user can select virtual experiment components from the components tree in the left side and place it in the design panel, then connect their ports by connections. The system provides a preset experiment process of model computer. The user can open it from the menu. This procedure contain micro control chip(designed in this system), memory(6116 chip), arithmetic logic unit(2 74LS181 chips) and other chips.

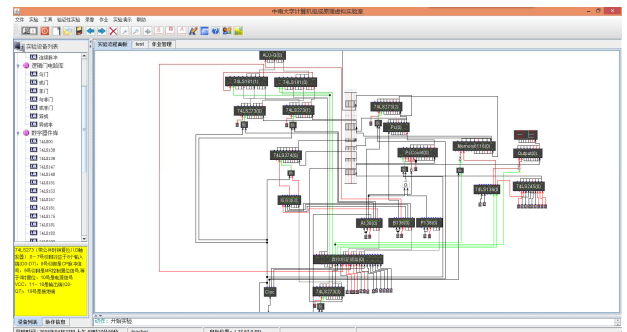


Fig. 6. The experiment flow of model computer

After the experiment is built and the power is turned on, the model computer is ready to run. Then the user can open the model computer debugging windows by the menu, which is shown in Fig.6. In this window, the right side is used for display the sketch map of the model computer, the left side is use for user to input machine code and control the code running.

In this experiment, we use the preset code in the system, which get two input data and plus them. After the preset code is inputted into the system, the user can execute the code one by one on machine code or micro instruction, even on clock. The port and its connection will become red when an available signal is set on it. The state of sketch map and experiment process will change together. The Fig.6 and Fig.7 is the state after a micro instruction of machine code of ‘add’ is executed.

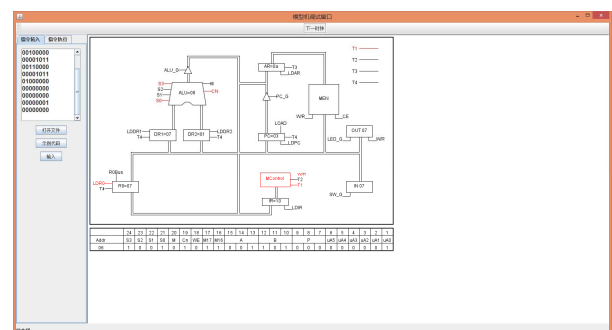


Fig. 7. he interface of model computer debugging

B. The virtual lab of Digital Image Process

The experiment of Digital Image Process is a typical heterogeneous resources type experiment. In this course, the student designs the algorithm of image processing. How to check the validity of the algorithm is difficult in traditional experiment model, because the student need to program the input and output code for the test.

Digital image processing experiments contains many complex and abstract algorithms. MATLAB has a powerful image processing capabilities, and its toolset contains a large number of sophisticated digital image processing functions. OpenCV is also an efficient image processing tool, which implements the general algorithm of digital image processing. In the system, all these heterogeneous components can be packaged as a Web service and integrated into the platform. The platform also supports researchers used their own familiar programming language to develop components and these components are integrated into the platform and compared with the original proven components of the platform.

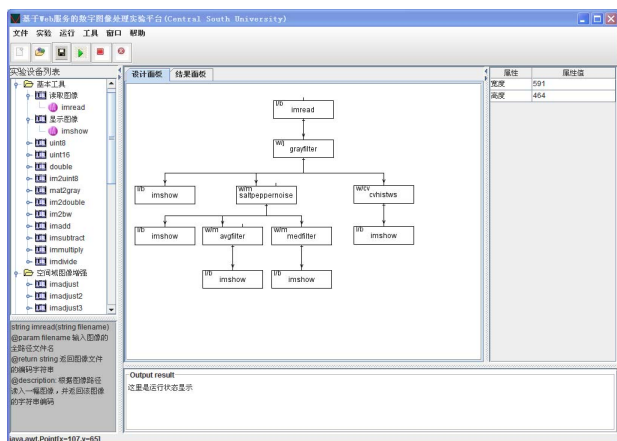


Fig. 8. The expriement flow of image enhancement

There is an experiment of image enhancement point in the design panel shown in Figure 8. In this experiment, the imread component, imshow component are JavaBean components, saltpeppernoise component, avgfilter component and medfilter components are the MATLAB service components, grayfilter component is a Java service components; cvhistws is a OpenCV service component. The result of this experiment is show in Figure 9.

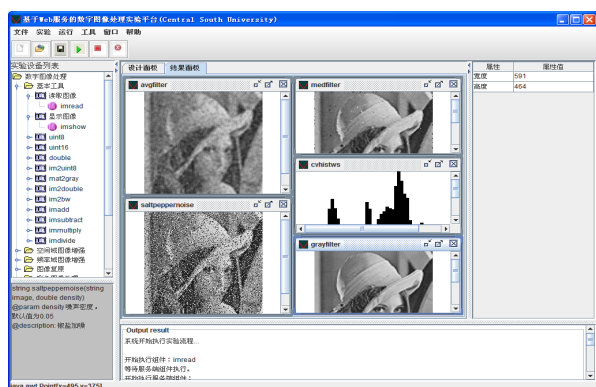


Fig. 9. The result of the virtual experiment

C. Other virtual lab systems

Based on the virtual experiment platform, we have developed Digital Circuit virtual lab system in the complex process type and Operation System, Digital Signal Process and

Cryptography virtual lab systems in the heterogeneous resources type.

VI. THE APPLICATION OF THE VIRTUAL LAB SYSTEMS

All the virtual lab systems of the computer science curricula are used in our university for the students in computer science, information security. And, the virtual lab system of PCO is used in the Beijing Institute of Technology, Guangdong University of Finance and Economics and Hunan Open University. The virtual lab system of Digital Image Process and Operation System are used in the Guangdong University of Finance and Economics.

According to the feedback of those universities, students have responded to the virtual lab platform enthusiastically and favorably, and some of their teachers are also interested in using them in the classroom.

VII. CONCLUSIONS

In summary, we designed and developed a powerful and flexible virtual lab platform and virtual lab systems based on the platform. This virtual lab system has its own virtualization and scheduling mechanism of the virtual experiment components according to whether it belong to a complex process type or a heterogeneous resources type.

Base on the research, we try to design the virtual lab system in HTML5 and cloud computing and other virtual lab system for other specialties.

ACKNOWLEDGMENT

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Cloud-based Teaching in an Engineering-Physics Course

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Abstract— This paper presents a transition from passive, traditional delivery of teaching to an active, “cloud-based” method, in a freshman engineering-physics course. The course is delivered to a traditional on-campus cohort, and also to an off-campus cohort by means of distance education and online learning. Cloud teaching refers to delivering education by means of websites and mobile-technology applications, where constant student attendance at the host campus is not always necessary. This is contrasted with traditional on-campus teaching, which occurs in a classroom. The use of lectures has been reduced while the use of tutorial and lab classes has increased. The new course structure was delivered for the first time in 2014, has run for two semesters, and will continue in 2015. It was found that student performance in the new structure was no worse than that in the older structure. Off-campus students in general welcomed the changes, while on-campus satisfaction did not change from before to after the transition.

Keywords— *Educational technology; Physics education; Cloud learning; Flipping the classroom*

I. INTRODUCTION

Most undergraduate engineering degree programs begin with one or two freshman courses in physics. This sets the educational foundation for studies in specific engineering disciplines. In recent years, research and practical experience have been driving education in engineering from a teacher-centered, passive approach to a student-centered, active approach. In this new model, responsibility for learning, content delivery, and even assessment has increasingly been placed on the student, rather than on the instructor. Thus new innovations in teaching have appeared in the forms of studio classrooms, fewer lectures, more tutorials, workshops and practical activities, the use of videos to deliver content that traditionally was given in lectures, and “flipping the classroom,” where classroom activities focus on problem-solving and applications, and homework involves reading the text and viewing video presentations to absorb concepts and primary course content.

Physics education has come a very long way from the techniques found in the likes of the classic *Feynman Lectures* [1]. It was from an age where teaching occurred in a classroom, often containing several hundred students. Even by the late 1980’s whiteboards were a recent innovation, and not all

classrooms had them. Desktop computers were just becoming common and were still hideously expensive. The best computers found in undergraduate physics laboratories of the day were often nothing more than a Commodore-64, or at best an IBM XT. Programs were written either in BASIC or in FORTRAN. PC’s became widely used in teaching by the mid-1990’s, the same time the use of the Internet was accelerating. About this time calls for “active-learning” in physics appeared [2, 3]. In the late 1990’s and early in the new century the use of computers in education (both physics and engineering) and the Internet to assist communication among students and teachers finally became commonplace, and textbooks that emphasized active learning were published [4]. The same trend happened in Australia [5]. However, at least in America, physics teaching was still largely held in the classroom, and teaching guides, such as that by A.B. Arons [6], assumed that students would still attend class. Experiments in classroom innovations also began about this time, where classes were designed to be collaborative and full of the latest technology. For instance, North Carolina State University reorganized its physics classrooms away from lecture theaters [7], and its experiments in teaching led to the SCALE-UP model of teaching students in studios [8]. In this model, students study the course content at home, generally by reading, and in class they perform group experiments, solve problems, and other activities. The model has been widely adopted in the United States [9] and also in Australia [10]. One criticism of the studio-teaching model is that students are expected to learn the primary concepts on their own by reading the textbook. In this author’s experience, this expectation works in some universities and not in others. Some students need to be taught the basic concepts by a means other than reading, especially students who are more visual learners.

Students themselves are increasingly looking to the Internet for learning resources neither assigned nor provided by their professors. Indeed, on being confronted by a problem, many students now look to Google and YouTube before consulting their textbooks, lecture notes, or other “official” course material. Students are especially looking to videos to learn physics, engineering, and other sciences. Due to growing up with television, movies, videos, and especially now that these are so easily available, younger generations learn visually much more than by reading and careful study. This has led to new education models again. A combination of active learning,

technology advances, Internet communication, and how modern students think has led academics to radically change how they teach. In modern times, this is expressed as “flipping the classroom” [11].

II. FROM FLIPPING THE CLASSROOM TO CLOUD-BASED TEACHING

One may characterize the “traditional” course in physics as containing large class lectures which present concepts and introduce problem solving; smaller tutorials which reinforce problem solving and concepts that are difficult to understand; and lab classes where students confirm key concepts experimentally and gain experience in measurement. Outside of class, on their own or in small study groups, students read and study textbook material and work out problems.

In the “flipped-classroom” model, traditional classroom activities and homework are swapped around [12]. Students learn concepts and the basics of problem solving outside of class. This is accomplished either by studying the text material or by watching videos, or both. Class time is partly spent doing what was formally homework: problem solving and reinforcing concepts. This model also frees up time for lecturers to perform more demonstrations and small interactive experiments, which hopefully makes the learning process more interesting and practical for the students. One of the educational goals is to make classroom learning less passive and more active. Many education researchers have been advocates for active learning in physics for many years. Modern technology, the Internet, and very rapid communication to mobile devices has pushed along a very increased use of video presentations in course material, studio teaching, and other examples of flipping the classroom.

The use of videos in teaching physics has become particularly widespread in recent years, and has come a long way from the classic 1980’s physics video series, *The Mechanical Universe* [13]. The sheer number of video presentations in physics has increased by massive amounts, as has their demand from students. Many universities now routinely video-record their lectures and make the recordings available to students. In Australia, two prominent video-teaching programs are the *PHYSclip* series at the University of New South Wales [14, 15], and *Work-it-Out* at Murdoch University in Western Australia [16]. A simple Google search reveals numerous videos for teaching physics, both on *YouTube* and elsewhere.

Deakin University has extensive experience and expertise in distance education [17], and delivers several undergraduate and postgraduate programs to students who do not attend on-campus classes [18, 19]. This includes a fully accredited major in engineering. Deakin is taking the concept of flipping the classroom one step further by trialing a new teaching model it calls “Cloud teaching” [20]. The name originates from the application of cloud computing to education [21, 22], and refers to delivering educational materials by means of multiple websites and mobile-technology applications, where constant student attendance at the host campus is not necessary. The motivation for this very significant shift in educational pedagogy lies in the fact that students today learn in a different

ways than their parents did, and universities must keep up with social changes in a cost-effective way. In addition to swapping conventional lectures with in-house videos of lectures, Deakin is moving the delivery of educational multi-media onto mobile devices, such as tablets and smart phones, giving students access to educational materials 24 hours a day, anywhere within Australia and overseas. Content itself comes from both the lecturer and also from outside sources, since much is available either freely or under license from other universities and educators. The multi-media material itself is stored “in the Cloud”, rather than only on the university’s web-servers. This is contrasted with traditional on-campus teaching, which occurs face-to-face in a classroom. If they wish, students studying “in the Cloud” can communicate with their lecturers and teachers by means of websites, email, *Skype* and web-conferencing applications such as *Blackboard-Collaborate*. In the context of a freshman-physics course, this paper presents one such transition from passive, traditional delivery of teaching to an active, Cloud-based method.

III. FRESHMAN ENGINEERING PHYSICS AT DEAKIN UNIVERSITY

All first-year engineering students enroll in SEP101, Engineering Physics. For many years the course has been taught in both on-campus and off-campus modes [23]. Currently (2015) the starting enrollment numbers are approximately 120 on-campus and 130 off-campus. The course has five key learning outcomes. On completing the course, students can demonstrate their ability to:

1. Explain basic principles in physical mechanics, fluids, and engineering moments;
2. Apply these principles to natural phenomena;
3. Solve technical problems in basic mechanics;
4. Perform and report on basic physical measurements;
5. Employ experimental methodology.

Running 12 weeks, the course covers kinematics, Newton’s laws, conservation of energy and momentum, rotation, fluid mechanics, oscillations, waves, engineering moments, and moment of inertia. The students also perform six three-hour lab experiments during semester, and write up their experiments in a lab notebook. The reading material is Halliday’s classic book supplemented by readings from a popular statics text. The assessment is 60% final examination, 20% problem-based assignments, and 20% lab reports. Possible final grades are from the Australian system: 80-100% High Distinction (HD), 70-79% Distinction (D), 60-69% Credit (C), 50-59% Pass (P), and below 50% Fail.

Prior to 2014, the course was run in the traditional way for on-campus students and via distance education for the off-campus students [23]. On-campus students attended four hours of lecture and one hour of tutorial each week (five hours class time), and a three-hour lab class every two weeks. Assignments were textbook problems solved on paper and graded by teaching assistants. Lab experiments were written up by hand in class and graded by the lab instructor. Students were expected to study the text material prior to class, and work on solving problems at home.

Off-campus students each received a study pack containing printed study guides written by the lecturer, an overview of the course, and lab manual. Material from the library (books, videos, etc.) was mailed to the students on request. Students mailed their assignment and lab work into the university. Student work was graded by the teaching staff, then mailed back to the student with written comments and corrections. Communication between students and the lecturer was by email, telephone, and fax. Lab classes for off-campus students were conducted on weekends [24]. These students performed all six experiments in a single eight-hour session. Sometimes special arrangements were made for a small number of students who could not attend weekend lab classes. These students were usually given alternative experiments that could be performed at home, including one that students could perform by remote control [25]. For a few semesters, lab classes were “web-cast” to off-campus students by means of video conferencing [26]. Details on how Deakin University School of Engineering has delivered distance education can be found in references [27] and [28]. In more recent years SEP101 has employed university web-sites and learning-management systems to deliver material to the whole cohort, not just off-campus [29]. On-line tutorials based on web-conferencing began in 2009 [30]. Responding to demand from off-campus students, the lecturers began video-recording the lectures in 2012, and providing these recordings to all students.

IV. TRANSITION TO CLOUD-BASED TEACHING

The aim of this work was to shift the on-campus teaching pedagogy from a passive approach to an active approach, essentially “flipping the classroom”, while at the same time maintaining or improving learning outcomes and student satisfaction. The changes were also intended to improve the educational resources available to off-campus students.

Prior to 2013, technological advances in teaching this course proceeded one by one, as new techniques and software applications became available. Most of the advances were applied with off-campus students in mind. On-campus students shared the benefits of these developments because they were made available to everyone. In 2013 the course material was completely redeveloped to follow not only a flipped-classroom model but also a cloud-learning model.

The redevelopments began by dividing up pre-recorded lectures into 10-20 minute segments and arranging them by topics (fig. 1). Each recording shows alternating Power-Point slides and projections from a document camera. Topics, concepts, and key equations are illustrated by Power-Point, and hand-written problems or other illustrations are recorded by the camera. The lecturer’s voice is also recorded throughout. Each video was made available to the students as an .mp3 downloadable audio file, an .mp4 video file, or streamed directly to the students PC, tablet, or mobile device.

Next, a series of detailed video presentations were produced to introduce each of the six lab experiments [31]. All the videos and existing study guides were imbedded into a redesigned course website (fig. 2), driven by the *Desire2Learn* software platform [32]. In this website, for each topic, additional resources were provided such as lecture notes,

video-recorded tutorials (produced in class by means of a tablet-PC [33] and *Camtasia* software) where specific problems were solved, and recordings of the current semester’s lecture classes. The website also had an on-line discussion area where students and lecturers could post messages and replies. On-line tutorials continued, with one evening set aside each week for off-campus students to talk to the teaching staff, ask questions, and work on problems together. The course also employed the *Wiley-Plus* [34] website for the textbook, where students checked their answers to homework problems, obtained formative feedback on their work, and also submitted their two sets of summative assignment problems. Students submitted their lab reports on-line via the course website.

The assessment methodology did not change from 2012 to 2014. All students completed the final exam. Off-campus students attended designated exam centers set up throughout Australia by the university. This new format for the course ran in semester one 2014 (on- and off-campus), summer semester 2014-2015 (off-campus only), and is currently running in semester one 2015 (on- and off-campus).

The on-campus class format was also modified. Lectures were reduced from four to two hours per week. Tutorial classes were increased from one to two hours per week. One tutorial hour was in a classroom, dedicated to answering questions and solving problems. The second was held in the physics teaching laboratory for the students to view demonstrations; perform

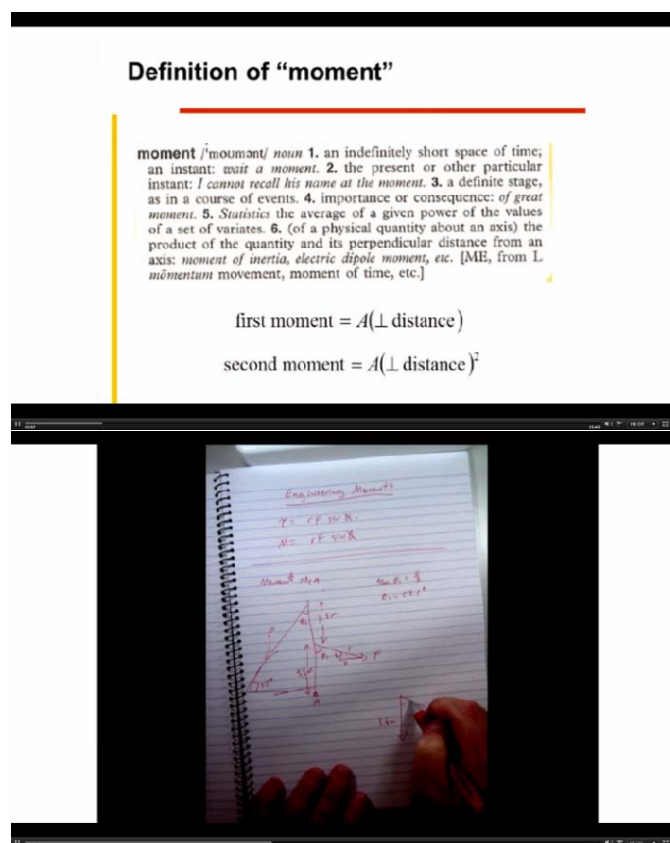


Fig. 1. Example of a lecture recording on engineering moments (top: Power-Point; bottom: document camera)



Fig. 2. Sample section from an on-line study guide

short experiments to illustrate concepts and give the students more experience in handling experimental gear. Each week the lecturer presented an experimental problem for the students to investigate during the hour. Such problems included verifying key physics equations in kinematics, free-fall, Newton's laws, buoyancy, and conservation of mechanical energy. When only one or two sets of apparatus were available, the lecturer and students volunteers performed the experiment in front of everyone.

On-campus lab classes remained unchanged. Off-campus students were required to perform one experiment at home early in semester. The at-home experiments were a choice between a Microsoft-Excel and a basic measurement activity; and oscillations of springs and pendulums. All these activities are easily done on a kitchen table with materials and tools available from a local hardware store. Then they performed the remaining five in the weekend lab session. All students were instructed to view the lecture and lab videos prior to attending the corresponding lecture or lab class.

Average overall grades for on-campus and off-campus were compared over the years 2012-2014. At the end of every semester, students were invited to fill out and submit evaluations of how they perceived the course progressed and helped them to attain the learning outcomes. The University employed a single evaluation system across all courses, posing a series of 10 standard statements concerning quality of course materials, teaching quality, perceived difficulty of the course, and effectiveness of the university library. The results of these surveys are publicly available on the University website [36]. This evaluation system has been successfully tested for statistical validity [37]. Students indicated their agreement with a number of statements by a number on a five-point Lickert scale (1 = strongly disagree, 5 = strongly agree) [38]. Students also had the opportunity to make specific comments. This work focuses on three quality statements:

1. "The course materials in this unit were of high quality."
2. "The on-line teaching and resources in this unit enhanced my learning experience."
3. "This unit was well taught."

V. RESULTS

Table 1 shows the average student grades for the cohorts in years 2012-2014. Summer semester grades are included in the off-campus results. The reported uncertainty on each figure represents half a standard deviation. Interestingly, while on introducing the cloud-learning structure in 2014, the average off-campus grades show no significant change, the on-campus average and median increased by nearly 10%. While the statistical validity of this result is yet to be tested, it suggests that the cloud-learning model was beneficial to on-campus learning.

What did the students think of the changes? Table 2 shows representative student suggestions prior to 2014, before the changes were implemented. Students asked for more interesting lectures, improved organization of the course website, additional instruction on using laboratory data-loggers (PASCO Explorer GLX), and fewer experiments to perform on the one-day weekend sessions.

Figs. 3–5 show the average student responses to the three evaluation statements. Error bars represent the standard deviation of the mean for each datum. While the students expressed general satisfaction with the way the course was delivered each semester (90% of scores are above 3.0), the results are mixed. On-campus satisfaction with the course materials and on-line resources remained steady. Their satisfaction with the teaching quality decreased slightly. The overall trend for off-campus was an increased satisfaction in all three areas. On the quality of the course materials, on-campus students expressed greater satisfaction than off-campus students, and apart from summer offerings, the overall level of satisfaction did not vary much. As for the on-line teaching resources enhancing learning, there are no obvious trends. The overall course satisfaction hovers around 3.5 for 2013-2014. The jump in scores for summer 2014 is encouraging, although only 10 students filled out that survey.

TABLE I. AVERAGE AND MEDIAN GRADES 2012-2014

Year	Number on-campus	Number off-campus	Avg. on-campus grade %	median on-campus	Avg. off-campus grade %	Median off-campus	Avg. grade overall %	Median overall
2012	134	44	61 ± 6	61	62 ± 11	52	61 ± 9	60
2013	138	64	62 ± 7	61	61 ± 11	60	62 ± 8	61
2014	133	65	68 ± 8	68	59 ± 12	61	64 ± 9	67

TABLE II. PRE-2014 STUDENT COMMENTS – WHAT NEEDED IMPROVING

Enrolment	Comment
On-campus	Lectures need to be re-designed.
On-campus	Lecture content. I found them un-engaging.
On-campus	Using the GLX in tutorial/practical. Maybe we should have a lesson in the first week, solely dedicated to the GLX.
Off-campus	Online study materials very messy hard to organize and learn from them.
Off-campus	Practicals for off campus students could be arranged bit differently. Time-wise it was too hard to complete in one day.
Off-campus	There wasn't enough time in the one Saturday practical day to complete all 6 experiments.

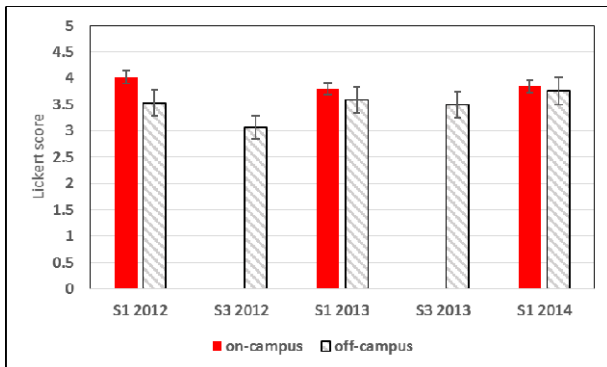


Fig. 3. Student responses to the statement “The course materials in this unit were of high quality.”

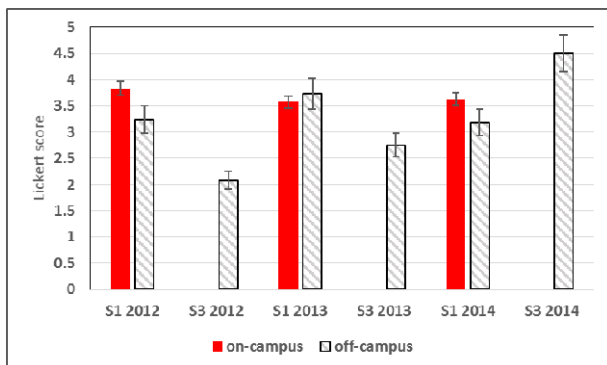


Fig. 4. Student responses to the statement “The on-line teaching and resources in this unit enhanced my learning experience.”

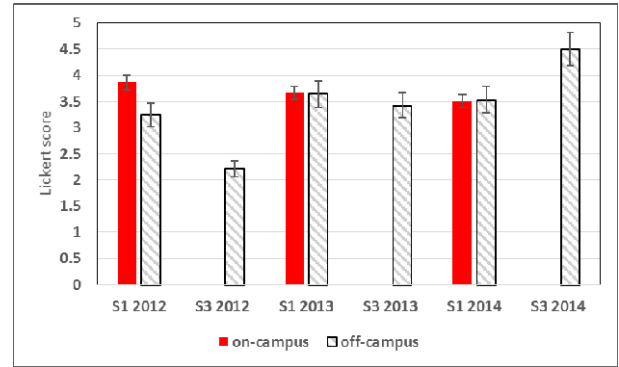


Fig. 5. Student responses to the statement “This unit was well taught.”

Table 3 lists some student commendations on the course changes. On-campus students welcomed the tutorial classes in the lab, where they could engage with real-world physics at a leisurely pace and perform their own investigations. Many students liked the layout of the new course website and the imbedded lecture videos. Suggestions on improvements are given in table 4. Some students found all the information overwhelming, especially when they saw apparent inconsistencies between various elements or changes in English accent or expression. A few students wondered if the videos recorded in the previous year were outdated.

TABLE III. WHAT STUDENTS LIKED ABOUT THE COURSE CHANGES

Enrolment	Comment
On-campus	I enjoyed the one hour labs with Dr Long, they were relaxed and informative.
On-campus	Being able to play with the equipment in the labs during the labs, all the while actually proving the theory.
Off-campus	Each set of week's work is on the cloud.
Off-campus	Firstly, being an (external) student and doing this subject as cross-institutional study, I've been very impressed by the learning resources Deakin provides on the Cloud website. It is very easy to navigate and it is made very clear what to do and how to study the content. Being an online subject, it is not the easiest to learn when there is little interaction with students or teachers, but the videos (lectures etc.) on the website provide good insight to the learning objectives required. The discussion forums are another great idea for student and teacher interaction.
Off-campus	The recorded lectures were for the most part brilliant.
Off-campus	The (online) tutorials are great and there are a lot of online resources available if you apply yourself.

TABLE IV. STUDENTS' SUGGESTED IMPROVEMENTS

Enrolment	Comment
On-campus	(Agreement) between laboratory instructions from videos, lab manuals, instructors' interpretations of the lab requirements was very poor.
On-campus	The online tutorial system's online format was difficult to operate. It has very hard to understand sentences, especially if English is not your first language. Overly mathematical keeps on using very hard to follow English that even Australian students struggle to understand.
Off-campus	Work through the content on the whiteboard (not the document camera).
Off-campus	Organization of the lectures - many lectures had 3 different filenames, or were repeated across different videos, or were recorded a long time ago.
Off-campus	Perhaps the lecture videos could be updated since I've noticed some of them are from 2012 and 2013.

VI. DISCUSSION

The changes experienced by the two student cohorts was more significant for on-campus than off-campus. On-campus students experienced large changes in how classes were run and how they were expected to prepare for those classes. The expected study habits for off-campus students did not change as much, although the use of video was seen as an enhancement of course materials. The differences between on-campus and off-campus results are not surprising. The two cohorts are quite different [39]. On-campus students are largely 17-19 years old, fresh out of high school, and this course is one of the first they experience at university.

Off-campus students tend to be older and professionally more experienced. They have jobs, families, and the pressures that go with them. They study part-time, often work full-time, and in the author's experience, find balancing family, work, and study quite difficult. Some live in very remote parts of Australia [27]. In terms of "customer-service" and value for tuition, they tend to be more demanding than the younger on-campus students. The summer offering of this course adds an additional complexity to the data. Semester three runs over the Christmas and summer holidays. Experience in summer teaching shows that students can easily fall behind in their studies due to the distraction of the holidays. If one considers the evaluation results of semester three in isolation from semester one, an increase in off-campus-student satisfaction from 2012 to 2014 can be seen.

This is only a preliminary study. As further data is obtained from future years, time will tell whether the changes really enhance learning and student satisfaction. In a private discussion with a physics professor from a small mid-western American university, it was noted that when the classroom is flipped, student satisfaction tends to drop sharply, then slowly increase again over some years as the students get used to the new format.

The decision to shift towards flipping the classroom and ultimately cloud learning was made in 2012. After a period of planning and consultation, work on revising the course began

in 2013, and was completed to the present stage in early 2014. It is now in the evaluation and reporting stage. During the planning stage, a "wish-list" of possible video clips to include was drawn up, and the number exceeded 50. With limited time and resources, it was decided to focus on improving how the lab experiments were introduced and a series of high-quality videos introducing each of the lab experiments was the result. Existing video lectures were used in the new on-line study guides.

Offering this course for several years by distance education made this process considerable easier. Most of the educational "infrastructure" was already in place, and the course's delivery to a non-classroom cohort was already established. Thus many elements of the new structure did not have to be produced from scratch.

The next step in this process is four-fold, and will take a few years to complete. First, publicly available physics resources produced elsewhere will be incorporated into the course materials. This will include links to other universities and YouTube, which has a large number of accurate, interesting, and freely-available videos describing all aspects of physics. Conversely, similar videos produced at Deakin will also be made available via YouTube. Secondly, the teaching team will produce its own physics video clips to help keep the course material in a local context. Thirdly, the lecture recordings that found their way into the on-line study guides will be redone to a higher quality. In the meantime the students will be consulted to obtain advice on what resources are the most useful to them. Finally, the data on student outcomes will be more carefully analyzed for statistical significance and student demographics.

VII. CONCLUSION

A freshman engineering physics course was redeveloped to shift the on-campus content from a structure of passive lectures, tutorials, and homework towards a flipped model of more active on-campus teaching, and ultimately to a cloud-teaching model. It was hoped that the changes would enhance learning in the off-campus cohort as well. The use of lectures has been reduced while the use of tutorials and practical lab sessions has increased. The new course structure was delivered for the first time in 2014, has run for two semesters, and will continue in 2015. It was found that student academic performance in the new structure was no worse than that in the older structure. In the case of on-campus students, there was an increase in overall average and median grades. Off-campus grades remained steady. On-campus students showed no significant change in satisfaction from before the changes to after the changes. Off-campus students welcomed the changes. Similar transitions to "cloud teaching" are being implemented in other courses in the university's engineering-degree program.

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An Automation of the Course Design Based on Mathematical Modeling and Genetic Algorithms

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Abstract—This work in progress describes a technique of course design in the form of learning objects (LO) sequences. We defined the distance between LOs (metric of learning objects space based on revised Blooms Taxonomy) and used it to design an objective function. This function is a sum of distances between LOs in the given sequence learning prerequisites of a course and its learning outcomes. In addition, the function contains penalties for the violations of the learning sequence, when, for example, one or more learning prerequisites for the given LO are absent in learning outcomes of previous LOs and course's prerequisites. A genetic algorithm was used to find LOs sequences complied with the given requirements of the course. To provide the series of experiments, this algorithm was realized as a computer-aided application in the development environment Microsoft Visual Studio 12. These series showed that the suggested technique is suitable for automated course design based on big amount LOs. Several suggestions to develop the technique are given at the end of this paper.

Keywords— *Course design; learning prerequisites; learning outcomes; learning object; learning sequence; genetic algorithm*

I. INTRODUCTION AND RELATED WORKS

Contemporary educational society has access to various learning resources and technologies to design and build a course according to given requirements. At the present time, interdisciplinary courses have become very popular because contemporary science and technologies are based on the mixing of two or more fields of knowledge. Thus, teachers are exposed to a wide variety of learning resources and learning objects (LOs) [1] and they have a difficult task in choosing a convenient sequence for the given course design. In addition, students have relevant tasks to choose in order to achieve desired skills [2]. According to this review, there are a number of approaches, including methods using evolutionary algorithms. Paper [3] describes the merging of two ontologies: learning outcomes and Bloom's taxonomy. It shows rules and reasoning mechanisms for identifying the position of learning outcomes relative to each other. Bloom's taxonomy, along with other parameters of an LO's (exercise's) difficulty, is used also in [4] where individual learning paths in programming learning are under consideration. The technique of the construction learning path (or composed curriculum) on the graph of learning objects is presented in [5]–[7]. Their main idea is that there are two phases: first, when we select potential objects to

build the possible learning paths, and second, when we find the best path. The authors of [7] also note that some LOs have learning outcomes not required for the given course.

In this work in progress, we tried to unite some features and advances presented in the abovementioned works to design and create the implementation of the technique to design LO sequences with the use of levels of skills given in the revised Bloom's taxonomy (RBT). The required learning prerequisites (LPs) and learning outcomes (LOCs) should be defined for the LO sequence. In this paper, we consider the following questions:

Q1. How can the distance between one LO, relative to another, in levels of RBT (LO-space metric) be defined?

Q2. How can the objective function to receive the optimal LO sequence for the given LP and LOC be built?

II. THE DISTANCE BETWEEN LEARNING OBJECTS

To evaluate the distance between LOs, we are using levels of the RBT: the "Remembering" relates to the first level, the "Understanding" relates to the second levels, and the "Creating" relates to the sixth level. Suppose we are given a skill, e.g. complex systems simulation, that is one of the learning outcomes of LO #1 and one of the learning prerequisites of LO #2 (LO #2 is the next LO about LO #1). The distance between these LOs in respect to this skill equals zero if the level of the skill in both LOs is the same. If the level of the skill in LO #2 is higher than the level of this skill in LO #1, the distance is defined as follows:

$$Dist_{1,2}^{skill} = \sum_j d_j^{skill}, \quad (1)$$

where:

- the index j is related to intermediate levels between levels of the skill in LO #1 and LO #2, respectively, and the level of LO #2;
- d_j^{skill} is the distance between the skill's level $j - 1$ and j (it can be evaluated by experts).

If the level of the skill in LO #2 is lower than the level of this skill in LO #1, the distance is the negative value received by the formula (1). The negative value of the distance means that LO #1 defines one or more levels of the skill in the LOC which are not required to start learning LO #2.

Suppose we are given several skills with numbers 1, 2, ..., $m_{1,2}$, in both LOs. Let us introduce a weighting factor p_k for the k -th skill (the sum of these factors for $m_{1,2}$ skills is 1). Then we can write the formula for the evaluation of the distance:

$$Dist_{1,2} = \sum_k p_k Dist_{1,2}^k, \quad (2)$$

where k is the index of skill.

Formula (2) assumes that all $Dist_{1,2}^k$ are positive. If one or more $Dist_{1,2}^k$ are negative, we replace them by zero and we can note singly the related indexes k . If the existent skill in the LOC of LO #1 is absent in the LP of LO #2, it means that this skill is not required to start learning LO #2 and the related distance equals zero.¹ If the existent skill in the LP of LO #2 is absent in the LOC of LO #1, it means that LO #1 does not provide a related required skill for LO #2. The distance between these LOs in respect to this skill may be defined by a value, which significantly exceeds the maximum possible distance in a case where these skills exist in both LOs (it is a penalty for a lack of skill in the LOC).

Distances between the given LPs of the course (course under construction) and the LPs of LOs, LOCs of LOs and LOCs of the course may be calculated in a similar way.

Therefore, we defined the LO-space metric (Q1).

Let us show the LO's metric using the following example. Suppose that we have the two following objects:

- LO_1 "Introduction in Gravity Model" with the following learning outcomes: "Gravity model" of "Understanding" level and "Calibration of gravity model" of "Remembering" level;
- LO_2 "Calibration of Double Constrained Gravity Model" with the following learning prerequisites: "Gravity model" of "Analyzing" level and "Calibration of gravity model" of "Analyzing" level.

Let the distance between levels "Understanding" and "Applying" for "Gravity model" be 4 and the distance between levels "Applying" and "Analyzing" be 3. Let the distance between levels "Remembering" and "Understanding" for "Calibration of Gravity Model" be 2, the distance between levels "Understanding" and "Applying" be 3 and the distance between levels "Applying" and "Analyzing" be 5. Define the weight for "Gravity model" as 0,6 and the weight for "Calibration of gravity model" as 0,4. Then, according to the formulas (1) and (2), we have the following distance:

$$Dist_{1,2} = 0,6(4+3) + 0,4(2+3+5) = 4,2 + 4 = 8,2.$$

III. THE OBJECTIVE FUNCTION AND USAGE OF THE GENETIC ALGORITHM

A. The Objective Function

For the evaluation of the objection function, we should have the following data: (1) the list of the skills and their levels of LPs of the course, (2) the lists of skills and their levels in LPs and LOCs of LOs in the sequence, (3) the list of skills and their levels in LOCs of the course. The meaning of the objective function is the sum of the smallest distances between LOs in the sequence, the course's LPs and the course's LOCs. In addition, the objective function may be subjected to the following types of penalties:

- a) penalty for the absence of the required skill before the LO or the course's LOC;
- b) penalty for the negative distance between LOs (or LO) and the course's LPs or LOCs and LO in respect to the given skill, when, for example, the required level of the given skill in the LPs of some LOs is lower than the related skill's level of the course's LP;
- c) penalty for an unnecessary skill, when one or more skills of LOs in the sequence are never used in related LOs and course LOCs.

Thus, we may write the following objective function (Q2):

$$W(LS) = \sum_{j>i} Dist_{i,j} + F_a(LS) + F_b(LS) + F_c(LS) \rightarrow \min \quad (3)$$

where:

- LS is the sequence of learning objects (the controlled factor);
- i and j are indexes of LOs;
- F_a , F_b , and F_c are the penalties of the abovementioned types.

The boundaries are defined from the initial set of learning objects and as an option – the maximum number of LOs in the learning sequence.

Suppose that we have a course's LPs and LOCs, the learning sequence is as shown in Fig. 1. S_k^l is the l -th level of the k -th skill. We can then note that the distance between the first LO and the course's LP in respect to the first skill equals zero. The distance between the third LO and second LO in respect to the fourth skill is a positive value. Since the fifth skill, required for the second LO, is absent in the LOC of the first LO and absent in the course's LP, we have the penalty of type "a." The penalty of type "b" is between the second and the third LOs in respect to the fifth skill. Lastly, the penalty of type "c" can be added for the second skill, which is in the LOC of the second LO.

¹ We may define a penalty instead as zero, if we have an interest in finding the LO that does not provide unnecessary skill(s).

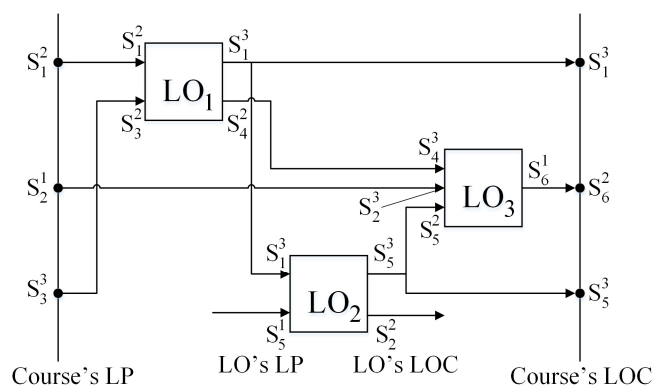


Fig. 1. Example of a course's LP and LOC, and learning sequence with levels of the skills.

B. Genetic Algorithm

To compose the course (learning sequence) with a certain LP and LOC we use a genetic algorithm (GA). We used the initial step of *population initializing* (random generating of sequences, which can contain two or more similar LOs) and standard genetic operators in the iteration loop: *crossover*, *mutation* and *selection*. A *learning sequence* is defined as an *individual* with single chromosome and *LO* – as a *gene*. Formula (3) is used as a fitness function.

Crossover. Each individual is crossed with another random individual by a one-point crossover. The point of crossing is a random point in a shorter individual in a crossing pair. During crossing over, we strive to reduce repeats of LOs in children. In particular, if the LO in the part before the crossing point of the second individual occurs in the part after the crossing point of the first individual, the exchange of related LOs is not proceeded. For example, suppose we defined the following learning sequences: ABC_DEFH and ZEA_JCO (the symbol “_” is the crossing point). We receive the following pair after the crossing over: ZBA_DEFH and ABE_JCO. The received individuals are added to the population. Thereby, we expand our population.

Mutation. In this procedure, we change the order of education elements in a course with a certain probability that is given as a parameter. We do not touch the elite part of the population.

Selection. We use the elitism method for the individuals' selection.

The abovementioned genetic algorithm with fitness function (3) was implemented with the use of language C# in the environment of Microsoft Visual Studio 12. The developed computer-aided program allows us to manage the LOs database and add to an LO's record the description of virtual learning labs (VLL). If a VLL was realized as a cloud service in the CLAVIRE platform [8], the program offers an option to choose a learning model of a VLL's usage for an educational purpose. These models were described in [9].

IV. THE IMPLEMENTATION OF THE TECHNIQUE FOR THE “URBAN TRANSPORTATION SYSTEMS PLANNING” COURSE DESIGN

To check the abovementioned approach we used the learning resources available in the site “Sakshat Virtual Labs.”² On the basis of these resources, we designed the possible scheme of the considered course (Fig. 2). This course considers the following LOs:

1. Volume, Speed and Delay Study at Intersection
2. Regression Analysis
3. Category Analysis
4. Growth Factor Distribution Model
5. Singly Constrained Gravity Model
6. Doubly Constrained Gravity Model
7. Calibration of Singly Constrained Gravity Model
8. Calibration of Doubly Constrained Gravity Model
9. Model Split

The LOs are inserted in six topics: (T1) urban transport simulation, (T2) trip generation, (T3) trip distribution, (T4) model split, (T5) constrained gravity model, and (T6) model calibration. To save space for this paper and make Fig. 2 more vivid, we have hidden the intermediate skills. The following skills are presented in Fig. 2: (S1) apply, create regression, (S2) apply distribution laws, (S3) multinomial logic model, (S4) understand process of mode split, (S5) apply and understand the calibration of Singly Constrained Gravity Model, and (S6) apply and understand the calibration of Doubly Constrained Gravity Model.

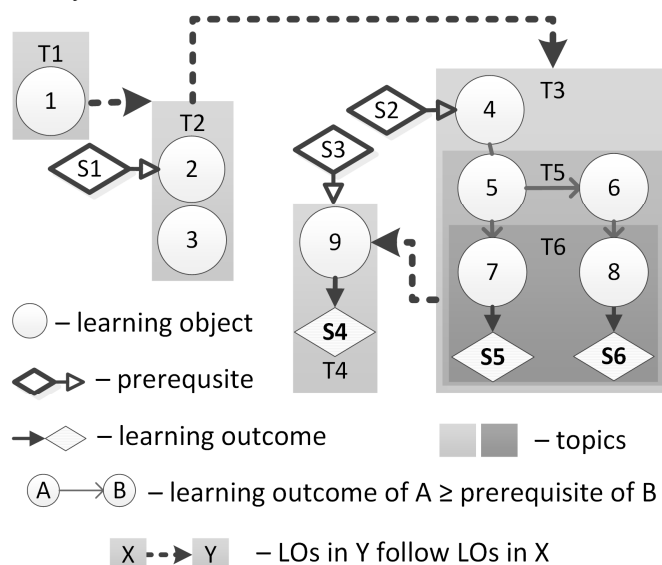


Fig. 2. The possible scheme of the course "Urban Transportation Systems Planning"

² <http://deploy.virtual-labs.ac.in/labs/civil13/>

We held two series experiments with the course's LPs S1–S3. Skill S4, as a course's LOC, was given for the first series, and S6 was given for the second series. The first series showed that to acquire the S4 skill, a student should complete LOs 1, 2 (or/and 3), 4, and 9. The second series gave the sequence: 1, 2 (or/and 3), 5, 6, and 8. The results obtained fit into the designed scheme. Therefore, this experiment confirmed the possibility of a course's design with the use of the offered technique.

V. CONCLUSION AND FUTURE WORKS

In this work in progress, we suggested the technique and related computer-aided software for the course's design in terms of the learning objects' sequence matter with the use of the revised Bloom's taxonomy and a genetic algorithm. The objective function was defined in this work and was used in the genetic algorithm. The experiments showed that the presented technique is suitable for finding a learning path among a few convenient LOs. Its main feature is arranging LOs in accordance with Bloom's taxonomy, thus providing more freedom in constructing a learning path and allowing the connection of objects without direct dependency.

This technique serves as a starting point in our research and will be upgraded through the experience that has been gained by other authors [2]. However, the current weakness is that two problems are solved by one algorithm: selection of relevant objects and their ordering. Also, it does not yet include different criteria of path construction (for example, multidimensional difficulty as in work [3], or type of students' perception) so it can become universal and can be upgraded to the social sequencing method or to the individual sequencing method, or contain both approaches. To analyze the real needs of finding a learning path we designed a full-fledged example in the area of programming and computer graphics using resources such as [10]. In addition, we intend to use the updated technique for design and update courses of our double degree master's programs [11].

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Students of Engineering on Behalf of People with Disabilities: Evaluating the Impact of an Institution's Flagship Project

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Abstract— Service learning is a hands-on pedagogical approach where students participate in activities that are beneficial to society. In engineering, Project-Based Service Learning involves the development of a product for the benefit of an individual or an organization. Being engaged in PBSL provides students with opportunities to design and develop innovative solutions for real clients. Research on the impact of service-learning programs reveals a positive effect on students' understanding of social issues, and improves their communication, teamwork, and cognitive skills. Yet, only a small amount of research has assessed the long-term impact on engineering graduates after several years of integration in industry. This study follows a flagship project that includes several programs involving populations with special needs. The study uses the Grounded Theory Methodology that allows revealing ideas that could not be foreseen. The study's first phase focuses on the perceptions of graduates who participated in a Rehabilitation Biomechanics course that includes development of assistive devices for a disabled people. Analysis of interview protocols reveals their growing awareness of the roles of engineering solutions in assisting people with special needs, the effects on their interests, and the new skills and understandings they take to the workplace.

Keywords— Engineering education, Service Learning, People with disabilities, Assistive devices, Grounded theory

I. INTRODUCTION

Service learning (SL) is a hands-on pedagogical approach where students participate in activities that are beneficial to people and communities, while providing broad learning experiences. SL has been integrated in many academic institutions worldwide in a variety of disciplines including engineering in undergraduate and graduate programs, in both curricular and extra-curricular frameworks.

Project-based service learning (PBSL) in engineering programs includes development of a product for the benefit of an individual or an organization. Being engaged in PBSL provides students with opportunities to design and develop real

and innovative solutions for real clients. PBSL may be part of capstone design courses that involve the construction and testing of prototypes or courses that may be limited to paper design [12][7][13]. Courses are elective or mandatory and deal with various engineering areas [6]. A few examples are EPICS - Engineering Projects in the Community Service in Purdue University [5], the MIT IDEAS Global Challenge [10], SLICE - Service Learning Integrated at a College of Engineering in the University of Massachusetts Lowell [6], and EWB - Engineers Without Borders [<http://www.ewb-international.org/>].

Some of the engineering projects are intended for people with disabilities, and incorporate the design and development of assistive devices for the disabled.

Evaluation research has been conducted to measure the effectiveness of the various programs with regard to their learning outcomes. A meta-analysis of forty courses in the social sciences that include service learning reveals a positive effect on students' understanding of social issues (e.g., attitudes associated with cultural awareness, tolerance of diversity and ethical reasoning skills), personal insights (e.g., perception of leadership ability, determination and persistence), and cognitive development (e.g., problem-solving and critical thinking skills) [14]. Bielefeldt et al. group the potential impacts of PBSL on students into five main categories: student knowledge; student skills; attitudes and identity; recruiting, retention and diversity; and professional performance. The impact on faculty implementing PBSL in their courses has been less researched, but they report it is motivating for them and for the students while requiring requires more time than other pedagogies [1]. Recent research on student perceptions of design projects that involve developing assistive devices for children with disabilities reveals students' satisfaction with regard to the preview of industry, development of teamwork skills, and increased empathy for people with disabilities [13].

Only a small amount of research has been carried out so far in assessing the long-term impact of projects connecting academia and community on engineering graduates. This study follows a flagship project at OBC—a medium-size college of engineering located at the country's periphery—that encompasses several different programs all dealing with

activities of students and faculty for populations with special needs. The study aims to evaluate the impact of the project on graduates' personal and professional life after several years of integration in industry, as well as its influence on other parties involved and the overall effect on the institution.

II. FLAGSHIP PROJECT

The Israeli Council for Higher Education (CHE) seeks to promote proactive involvement of academia in social activities, looking at it as academia's third role beyond research and education. The flagship project at OBC is part of the CHE's initiative to direct the expertise of the academic institution on behalf of the community in which it is located. Those expected to gain are the community, as well as faculty, students, and relevant research areas.

The flagship project's goals are: a. to establish an interdisciplinary academic knowledge center of applied research for the development of engineering solutions for disabled people that is open and accessible to the public, and b. to create an infrastructure of OBC's collaborations with institutions that deal with rehabilitation and employment of people with disabilities.

The main ingredient of this flagship project is the development of unique engineering solutions for people with disabilities. Some are customized solutions for private purposes in accordance with a specific disability, and others are solutions for the workplace (e.g., an electronic waste recycling plant that employs individuals with disabilities) or for public spaces (e.g., playgrounds adapted for children with disabilities). The activities are conducted as part of academic courses, capstone projects, or internships, and at the college's entrepreneurship center. The flagship project also includes volunteer activities of students in social organizations and general studies, research related to people with disabilities and involving faculty and students, and a web site that aims to share the public's accumulated knowledge in these areas.

III. METHODOLOGY

The study is qualitative and follows a constructivist-interpretive Grounded Theory (GT) methodology of a systematic generation of theory from data [8][12][4]. Data comprise interviews, texts, observations, videos, and other sources. The main characteristics of the GT methodology are initial coding of meaningful units and categorization of data—identifying main themes that emerge and labeling them; concurrent collection and analysis of data; writing memos—recording researchers' thoughts during the study; constant comparative analysis and use of inductive logic and abstraction so theory is gradually constructed from data; theoretical sensitivity—researchers' awareness of their own perspectives and professional knowledge; and selecting a core category that encapsulates all the others and integrating relevant existing theories until finally accomplishing a comprehensive explanation of the phenomena, which is the generated theory [3][11].

The study was planned as longitudinal research and incorporates an assessment of several programs within the

flagship project, separately for each program. It concludes with integration and meta-analysis of the accumulated findings.

Research tools include questionnaires and interviews with students, lecturers, and stakeholders from outside the institution. Other information is collected from students' reflection reports, clients' satisfaction regarding the products developed by the students, therapists in the rehabilitation institutions regarding their interaction with the students, documentation of activities such as videos, and academic and other publications of researchers involved in the flagship project.

The study's first phase focuses on the perceptions of graduates who participated in a Rehabilitation Biomechanics course three or four years ago. This elective course has been taught for several years. It is a semester-long course (13-14 weeks) where students develop small-scale projects intended for the disabled community involving real clients (students in school or people from a rehabilitation center). There is direct interaction of the students with disabled people who are involved to some extent in the design process of the device. They define their needs, take part in choosing a solution from amongst several options/concepts, receive the product directly from the developers, and submit a client evaluation of the designed product after a period of four to five weeks of use. Students may also connect with the clients' families if needed. Prior to this course the students must complete a mandatory conceptual design course, and it precedes the capstone project course.

IV. INTERVIEWS WITH GRADUATES

Graduates of the Rehabilitation Biomechanics course have been interviewed. The participants are asked to tell their stories about their experiences regarding the devices they developed for disabled people, without interruption or guidance to focus on certain aspects. This approach allows revealing ideas that could not be foreseen. Later during the interview the list of questions is examined so aspects of interest that were not mentioned by the participant are raised by the researchers.

Each interview starts with collecting details of the year of graduation, field of expertise, current employment, previous jobs, and current role in the workplace. The opening question is: Tell us about the projects you have carried out during your studies at OBC that involved people with disabilities. What did you derive from this course? Other questions asked—if not answered spontaneously by the participants—are: What did you learn from the project about the needs of people with disabilities in the engineering context and in general? Did the project have an impact on your professional or personal life in any way? Describe the interaction between the disabled customer and yourself, and to what extent was s/he involved in the design process? To what extents do engineering professionals have an obligation towards people with disabilities? To what extent are you interested in engineering development for the population of people with disabilities? Following are profiles of the graduates and their projects.

[ET] Project: Designed and fabricated 1) a folding sunshade for an electrical wheelchair, 2) a workstation for the cognitive

impaired in an electronic waste recycling factory. **Employed** as a department director on the production-line in a company that manufactures and markets an extensive range of stainless steel fittings and flow products.

[EG] Project: Designed and fabricated a sliding device enabling the client to bridge a 20 cm gap between the chair and the floor. The device assists the client during transition to and from the chair, obviating the need to lift the client during transition. **Employed previously** as a development engineer for design of medical fittings at medical company. Currently employed at OBC as a project advisor for rehabilitation projects at a local hospital, while trying to fulfil the requirements for medical school.

[VO] Project: Designed a device for carrying a backpack on a posterior posture walker. **Employed** as a development engineer at a company that engages in the design, development, and manufacture of degreasers and washing machines.

[KA] Project: Designed and fabricated a foldable wheelchair insert for a CP client that fits into the luggage compartment of a cab, allowing the client to travel using a manual wheelchair with an orthopedic insert, which can be dismantled or reassembled within two minutes. **Employed** as a project manager at a water systems company.

[MA] Project: Designed and fabricated a device enabling a pelagic client to insert his sleeping bag into its sack. **Employed** as a project manager at an international hi-tech company engaged in a wide range of defense projects.

VI. ANALYSIS AND PRELIMINARY RESULTS

Five of the interviews' recordings have been transcribed and coded according to the GT guidelines so far. The following section describes several themes that emerged.

A. Attitudes toward Developing Engineering Solutions for People with Disabilities

The participants described the conflict between the sense of duty and responsibility they feel for the disabled, and the lack of economic viability of products tailored to a specific client. Although there are off-the-shelf products for people with disabilities, the types of disabilities are very varied, and often require adjustments and individually customized solutions. **[ET]** *"This entire population has not received enough real answers, and no one has delved into its needs. These people have only the basics and they have to make do with them. It is sad to see. There is much to do in this area."* **[KA]** *"There is a huge hole regarding the issue of aids for the disabled."*

There is a growing sense of missed opportunity. The engineers recognize that developing a customized product is often not difficult: **[ET]** *"A job that may take me two to three weeks can mean the world for such children."* **[VO]** *"If, as a mechanical engineer, I could provide this type of help I would be very happy."*

One student, who has more entrepreneurial experience than the others, offered to solve the conflict in a way that has commercial potential. Problems of customers with different

disabilities could be solved with a generic solution according to principles of universal/inclusive design [9]. **[MA]** *"I can create something that requires very expensive production technology. There is no chance of implementing it for this niche market. Instead, I can adjust something that exists, solve such problems in many different ways, and turn the total of all these solutions into something more generic, and on that basis make the necessary adjustments for a particular client."*

Students also referred to the importance of exposure and experience when developing accessories for the benefit of the disabled as part of the academic framework. **[ET]** *"At what stage in life do we have an opportunity to do this? Not when you're married with kids, you start work... whereas when you are a student you have time available to do it ... it seems to me to be the right time, and the college is the incubator."*

Beyond feelings of personal commitment, the respondents expressed a sense of collective commitment, of corporate responsibility. **[ET]** *"I think that the company or organization that employs such people has to take it upon itself."*

Their experiences stimulated business and entrepreneurial thinking: **[ET]** *"There is currently no such thing in the market. We wanted to develop it into something that is more entrepreneurial, I think it can also be successful."* **[EG]** *"This is something that goes through my head every day since this course. I've already done countless checks to address these sectors... Everyone will benefit from this, both emotionally and materially ... there is no such thing today."* **[VO]** *"I can see the business potential of companies who address the areas of biomechanical rehabilitation."*

B. Interaction with Disabled People and Changes in Attitude

Interacting directly and personally with a disabled person, whether adult or child, led to an overwhelming change in perceptions of this population, especially in terms of interpersonal communication. The first meetings were accompanied by fear and embarrassment, but they were quickly replaced by rapport and cooperation, thereby removing communication and "otherness" barriers. **[EG]** *"At first I tried to talk at his level ... I realized very quickly that I need to talk to him normally and directly. Maybe he won't give you feedback, but he understands everything. And that's something that made me completely alter my communication with people like that. Since then, every time we meet, I speak perfectly normally."* **[VO]** *"At first I did not know how to behave, but after a very short time I understood that I should ignore the differences between us. Ultimately these children are very happy and active... You can't even call them disabled ... They're just different. I really liked working with them."* **[MA]** *"...It can also be very painful in terms of appearance. It requires understanding and acceptance. I come from wanting to really help, not simply to finish my project."*

The interaction included home visits, the involvement of the clients in defining their needs, the selection of a solution from a number of concepts, and finally, the delivery of the final product to the clients and the use of the product. This all led to feelings of joy and satisfaction on both sides. **[ET]** *"It was heartwarming to see that she really wanted us to help her. She would hug us when we came and went, the father too. What*

chance is there that someone who is almost an engineer would think about them and give them an answer to something like that ...?"

C. Effects on Personal and Career Development

Exposing students to the needs of people with disabilities echoes their current employment and their thoughts concerning future development, whether regarding further studies in the field, contributing to the community, developing aids for the disabled, or going into business in the field.

AG specialized in biomechanics and the internship included planning and development of medical devices. *"Within a very short time I knew I was going to make a change in my life ... and I'm trying to be accepted to medical studies... One day I came to the hospital independently, as a volunteer. I went into a daycare center for cerebral palsy children and asked if I can maybe start a project. ...one of the things I do [at OBC] is to mentor students in the development of projects for the hospital ..."* [VO] *"Today I am considering a master's degree in biomechanics rehabilitation."* [ET] *"This exposure opened my mind to more directions ... it helped me understand the need to focus more on these populations."* [KA] *"It contributes to you as a future engineer, in dealing with a real problem that requires an answer when you have limited time, and at the same time create interactions with suppliers and customers."*

It is apparent that the points that were chosen and perceptions reflected in their statements relate to the current occupation of each person. For example, AT has started a new role as head of department for the production of stainless steel parts. He tries to instill changes in the work environment of the employees in his department to positively affect output. *"Someone who has gone through this experience as a student and then works, will surely want to promote it. They took me in as the engineer in a management role... The first thing I looked at in the department was how the employee feels. So I ordered floor mats for them, adding marks of where to put everything on the table ... It opened my eyes and now I look at things differently. It is difficult to implement but when the worker produces another fifty or sixty parts because he has these mats, others will see it and eventually there will be change."*

MA is in the role of a project manager and responsible for receiving and absorbing new engineers. He refers to the impact of his experiences in college on his perspectives. He assumes that product design is a platform for training students to deal with a real customer. The student is required to understand the problem presented by the client and formulate a strategy for the development of a solution, thus gaining engineering experience during studies. He talks at length about his interviews of candidates, some of whom are still students, and what he looks for: *"Today in job interviews you ask what project you are working on, and what you have done. A person who comes in with a project, which at the end of the process results in a product, has something to talk about in a job interview. At first you have to know the requirements of the customer or how the customer will use the product, to understand that you have to match the customer's requirements to the engineering capabilities, we need not only a product solution, but a solution designed properly that is fun and comfortable to use ..."*

VII. DISCUSSION AND FURTHER RESEARCH PLANS

A main mission of engineering is to design and develop solutions to problems for the wellness of human beings. This study seeks a deeper insight into the impact of students' involvement in projects for people with disabilities in their personal and professional lives, and on the way they perceive the role of engineering in society several years after graduation; accordingly, a qualitative research approach was chosen. The flagship project involves a major investment, as do other learning service programs around the world, and knowing more about their outcomes is highly important. Research findings may help promote the project at OBC as well as in other institutions and communities.

An outcome from the interviews is that PBSL experience in rehabilitation biomechanics has contributed to the development of students' personal and professional skills: (a) One of the most important skills for an engineer dealing with design is the interpersonal communication with the client. Precise collaboration over the nature of the needs of the disabled is challenging because of the difficulties in communication, so the ability to remove the barriers is of utmost importance to get to the root of the problems to be solved. This skill may contribute positively also to working with clients from different disciplines and cultures. (b) Students have encountered other fields of expertise and development circles that hands-on projects in a real setting allow. Protocols analysis shows that this awareness of specific needs can transfer to the "normal setting" of a workplace, exemplified by one of the graduates, a department manager at present, who implemented changes in the working conditions of his department workers to improve the efficiency of their work, having in mind a similar experience he had in his learning service. (c) The direct interaction with disabled customers in their natural surroundings has had an immense effect on the students. The interrelation changed the way they view people with disabilities today.

Experience in the full process of product development may assist students in succeeding in job interviews; it also has an effect on their interests and future study aspirations. One participant has applied to medical school and another plans a second degree in rehabilitation biomechanics. The achievement of designing and manufacturing an assistive device according to specific needs, coupled with helping disabled people gain more independence, yielded strong emotions of satisfaction and meaningfulness.

Those interviewed so far were the first to respond to our invitation to join the study and may have special characteristics (such as more enthusiasm towards these projects). Therefore we will continue interviewing other graduates. In addition, we plan to interview students who participated in other SL courses, lecturers involved in the project, and other stakeholders.

The themes raised by the participants illustrate the potential of PBSL programs involving interaction with disabled people to achieve learning outcomes such as understanding of professional responsibility and understanding the impact of engineering solutions in a global and societal context (ABET). Consequently, the experience seems to contribute to the development of their professional identity as engineers.

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Enhancing the Educational Experience for Deaf and Hard of Hearing Students in Software Engineering

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Abstract—Software engineering is largely a communication-driven, team-oriented discipline. There are numerous hurdles for ensuring proper communication and interaction between all project stakeholders, including physical, technological, and cultural barriers. These obstructions not only affect software engineering in industry, but in academia as well. One possible issue that is often overlooked in software engineering education is how to best educate Deaf and hard-of-hearing (Deaf/HoH) students, and how to fully engage them in the classroom.

In this paper, we present our experiences in teaching software engineering to Deaf/HoH students. In the classroom, these students work very closely in activities and on project teams with their hearing peers. We also present recommendations for creating a more robust software engineering educational experience for not only Deaf/HoH students, but for hearing students as well.

We encourage instructors not only in software engineering programs, but in other computing disciplines to consider our recommendations and observations in order to enhance the educational experience for all students in the classroom, whether Deaf/HoH or hearing.

I. INTRODUCTION

Efficient and effective communication is an integral part of most software projects. This includes proper communication between all stakeholders of the project — customers, management, users, and developers. Communication is also very important in the educational process, between instructors and students, and between student peers. This is often made more difficult with the different communication abilities of students and instructors.

A recent study by Gallaudet University reported that between 9 and 22 people out of every 1,000 in the United States have a severe hearing impairment [3]. Even with the availability and effectiveness of sign language interpreters to assist student and faculty communication, the educational experience is typically significantly hindered for both Deaf/HoH students and their hearing classmates. Studies have found that Deaf/HoH students were only comprehending 50-80% of interpreted or assisted lectures, in comparison to 84-95% from their hearing peers [14], [15]. Universities across the United States face considerable challenges in educating students with disabilities in computing fields [8]. Students with disabilities are much less likely to pursue careers in computer science and engineering, and the dropout rate for these students is high [6], [16], [4].

The Software Engineering Department at the Rochester Institute of Technology (RIT) is the first and largest undergraduate program of its kind in the United States [13]. RIT is also home to the National Technical Institute for the Deaf (NTID), with a goal of providing technical and professional education to Deaf/HoH students, with over 1,500 Deaf/HoH student enrollees [17]. Even though NTID is a separate college from the rest of the university, its students often attend classes with hearing students. Interpreters and other necessary resources are made available to all students on an on-demand basis. They are available for classroom lectures and activities, team project time outside of class, or whenever else they are requested by the student. NTID is a two-year college, so many of its students will transition to one of the many other colleges at RIT (including Software Engineering). Additionally, not all Deaf/HoH students at RIT begin their college career in NTID.

Software engineering is a team and communication-driven discipline [18]. At the Software Engineering department at RIT, our courses typically include a team project component. These teams may be comprised of both hearing and Deaf/HoH students. Other than the additional resources such as interpreters provided by the university, Deaf/HoH students are treated just like any other students in the program. While we have achieved a considerable amount of success educating students with hearing loss in our software engineering program, we have also faced significant hurdles. Despite the best efforts of the interpreters, Deaf/HoH students are prone to losing a large amount of both verbal and nonverbal communication through an interpreter. Group discussions and multiple conversations are largely impossible for interpreters to fully communicate to the Deaf/HoH students [2].

This work is not only aimed at helping Deaf/HoH students and faculty, but their hearing counterparts as well. In both academia and in industry, students are very likely to work with differently abled coworkers, bosses, and customers, which may include visual or other physical impairments, including hearing. Students need to learn to effectively and efficiently work with a diverse set of people. Not doing so will not only limit their effectiveness in the workplace, but also limit the people they are able to work with.

In the following paper, we discuss some of our experiences and future work in creating the most robust educational experience as possible for our Deaf/HoH students in the software engineering educational process along with observations and recommendations from a Speech Language Pathologist (SLP). We propose the following work in the hope that it may assist

instructors and students at other institutions. The specific goals of this work are to:

- Share our experiences in instructing Deaf/HoH students in the field of software engineering.
- Create a *Best Practices* guide for instructors.
- Discuss common mistakes in educating Deaf/HoH students.
- Discuss improvements to be made, both at our institution and others.
- Lay the groundwork for future work in this area.

The remainder of this paper is organized as follows: Section II describes our experiences and lessons learning with instructing Deaf/HoH students. Section III provides recommendations for students and instructors when interacting with Deaf/HoH students. Section IV provides a list of related works. Section V addresses limitations and future research to be conducted, and Section VI summarizes the findings of this work.

II. OUR EXPERIENCES

In order to understand the perspectives of faculty and hearing and Deaf/HoH students, we asked each group to fill out an anonymous survey based upon their experiences. For both the hearing and Deaf/HoH student participants, we sought a wide and diverse range of students. The students ranged from freshmen to seniors, and some had profound hearing loss while others were able to hear through the use of hearing aids or cochlear implants [23].

In the following section, we will discuss some of the student and instructor feedback we received.

A. Student Deaf/HoH Feedback

We first asked Deaf/HoH about some of their biggest communication challenges in their courses. Some responses were:

“It’s hard for all of us as a whole including hearing [people]. We may have an increase in difficulty in communicating with our professors because some of them speak at the speed of light, while others have heavy accents.”

“The biggest challenge I had during class was trying to figure out the instructions given to me from the professor.”

The Deaf/HoH students provided very mixed reviews regarding their software engineering experiences. While several students provided very positive experiences, others expressed concerns and displeasure over their experiences. Very early in the team-based project component of many courses, many Deaf/HoH students felt unwelcome by their hearing teammates. They immediately felt like others in their team largely viewed them and their disability as a burden and many hearing students wished to avoid being on teams with them. Deaf/HoH students felt that their teammates did not know how to deal with them, and were largely ignorant of how to communicate, interact, or even act around them.

While even a small level of ignorance is not desired, it is expected. What is the significant amount of reported ignorance at an institute such as RIT, where a significant portion of the student body is Deaf/HoH. This problem is likely much more profound at other institutes without so many Deaf/HoH people in the student body.

One of the recommendations that Deaf/HoH students had for helping to limit this ignorance by having the two groups of students perform team-building exercises, getting to know one another before the start of the group activity. One student stated:

“Generally, we [Deaf/HoH students] just need exposure. Both sides need to be willing to communicate. And sometimes, a student just isn’t a good student, which reflects badly on one side. Feeling a connection (for example, becoming friends) is really helpful. Get to know the other person. Do team-building exercises.”

Deaf/HoH students also stated that they have had good experiences when they’ve advocated for themselves, and been proactive in the work being done with their team. Some of the student quotes include:

“I would recommend that they advocate for themselves as much as possible so as to ensure that they are included as much as possible in the team’s work.”

“I would say participate and communicate a lot. Take a leadership role! This is actually no different than a non-deaf person, but when there’s a mixture of hearing and deaf students, communication is even more important. A mixture multiplies communication problems, so it’s super-important to communicate well. Taking a leadership role means not just sitting there and expecting others to do the work. This is very hard in a classroom environment, unfortunately, but it needs to be done.”

Many students also said that they preferred to use the note-taking service, as it helped them very much with reviewing the course material after lecture or lab hours. (Note-taking is a service provided by NTID in which a hearing student takes detailed notes, combining slides and spoken content.)

“Notetaking helped a large amount! It was very nice and convenient to be able to go back and look at the material on my own time.”

“I use the notes from the note-taker to review for quizzes and tests. Since I started doing that, I feel like I’m more able to contribute to the class or group.”

While RIT has a large and excellent group of interpreters which is readily and freely available to students upon request, there were still some issues. Many students described difficulties with attaining an interpreter for team meetings since they had to request one in advance. This posed a problem for shorter, ad-hoc team meetings, or ones scheduled with little notice. Some students also described issues with the lack of technical background most of the interpreters had.

They were often unable to understand computing acronyms and terminology, leading to a large amount of communication loss in translation. While this is an issue which can certainly be examined, we sympathize with the interpreters because it is not reasonable to expect them to be an expert in such a wide-range of difficult, technical areas. Many Deaf/HoH students also stated that they did not utilize interpreting services made available by the University since they did not feel like they needed this assistance. Much of this feedback is surprising, especially considering RIT has one of the largest, if not the largest, set of interpreters available at any institution in North America. This leads us to believe that similar problems not only exist at other institutions, but may be even more profound.

TABLE I: Example Questions: Deaf/HoH Students

Question	Responses
How was your overall experience with the other members of group projects?	Poor: 13%, Neutral: 34%, Good: 53%
During class time, do you feel that you are "in the loop" regarding the coursework?	Yes: 80%, Sometimes: 13%, No: 7%
During class time, do you feel that you are at the same level as your peers?	Yes: 60%, Sometimes: 13%, No: 27%
When working in a group, do you feel confident communicating with hearing team members?	Always: 40%, Sometimes: 53%, Rarely: 7%

Most Deaf/HoH students indicated that they wanted to interact more with their team, but were unable to do so. Their team would often relegate the Deaf/HoH students to non-leadership roles so they would not have to interact with the team as much. In other situations, the communication lost through the use of an interpreter hindered their ability to interact more in team meetings. One reasonably simple recommendation is to have only one person on the team speaking at a given time, which would allow the single interpreter to not be overwhelmed with the virtually unachievable task of trying to relate several conversations at once. One student stated:

"Communication was the main issue for me because everyone was talking at once and I was completely lost."

Communication in the classroom and in smaller groups is paramount to the success of all students, especially those who are Deaf/HoH. Good communication comes from focus. Many of the Deaf/HoH students said that the learning material was rushed and unclear, which led to issues understanding the material and subsequently diminished their credibility during smaller ad-hoc group meetings. Students reported that the instructors would typically speak and perform an in-class demo at the same time. When the Deaf/HoH students tried to follow along with the demo, they cannot see the interpreter and the monitor, whiteboard, or projection screen at the same time.

Another issue that many Deaf/HoH students discussed was lag time: the time that it takes for the interpreter to hear what another student, group, or the professor is saying and interpret it into sign language for the Deaf/HoH student to see. Even though the interpreters do their best, there is usually around a 2-3 second delay between what is said and what is signed. Regardless of this, Deaf/HoH students still were able to understand the information that was signed to them. Many of the Deaf/HoH students said that they thought the interpreters did a great job overall:

"Yes, an interpreter was there to interpret in the classroom and made the communication go smoothly."

B. Hearing Student Feedback

Creating a cohesive learning environment is important for both hearing and Deaf/HoH students. We created an anonymous survey asking hearing students about their experiences with working on a team comprised of both hearing and deaf/hard of hearing students and asked them to rate their experience as *below average*, *average*, or *above average*. Table II illustrates that an overwhelmingly large portion (75%) of hearing students rated their experiences as being below average. Based on the feedback attached to the survey, a large portion of negative feelings are due to extra time required to complete tasks due to the communication barrier. Most hearing students felt that properly run team meetings and better overall communication practices could have alleviated most of the issues.

TABLE II: Example Questions: Hearing Students

Question	Responses
How would you rate your experience with teams comprised of both hearing and Deaf/HoH students?	Below Average: 75%, Average: 13%, Above Average: 13%
Have you found that the services offered, such as an interpreter or notetaker, has been adequate to address your team needs?	Yes: 33%, Somewhat: 67%, No: 0%
Did you typically have an interpreter at your meetings?	Yes: 25%, No: 75%

Many hearing students feel that the Deaf/HoH student does not advocate for themselves in the group and therefore the other members of the group are lost on how to interact with the them. One student said:

"My teammates and I ended up picking up the work the hard-of-hearing teammate would have completed because we did not want to fall behind on the project."

Many hearing students also expressed issues in bringing the Deaf/HoH students up to speed whenever they met in a group. Most of these meetings were ad-hoc and therefore had to rely on other means to communicate since interpreters were not always available. When interpreters were requested for these meetings, many of the hearing students felt that they did very well in conveying the information to the Deaf/HoH students. Additionally, many of them felt like they did not do enough to accommodate the Deaf/HoH student and welcome them in their group. It was also mentioned that the flow of communication was significantly easier to facilitate if one of the members in the group knew sign language.

"It's nice to have an interpreter, but it's not always possible. I am not an interpreting major but I have been forced to do some amateur interpreting out of necessity."

When group members communicated electronically with Google Docs or another form, documentation for their projects went much more smoothly.

"Documentation [went much better] because almost all conversations were recorded electronically."

Due to the risk of miscommunication and the effort required to include the Deaf/HoH person, it was easier to simply exclude them from the project by assigning them a less strenuous workload.

“This [text-based communication] made it very difficult to explain assignments and the work we needed done - the [Deaf/HoH] student ended up doing almost no work on the project.”

Hearing students had their own struggles with incorporating the Deaf/HoH student in their work and their group. Having interpreters was a great help, but unfortunately the option was not always available. While none of the survey respondents questioned the quality of the interpreters, many felt that the lack of interpreters hurt their interactions. In many cases, the Deaf/HoH student felt that they did not need one and could communicate well enough without them, and thus did not request an interpreter for either their in class work, or their project work outside of class. Several hearing students stated that the lack of an interpreter really hurt their team communication. Other hearing students echoed the thoughts of the Deaf/HoH students in that communication was made more difficult since the interpreters did not understand, and therefore were not able to effectively interpret, a wide range of technical terms. One student stated:

“Even though they tried their best, interpreters were unable to understand (and therefore) communicate many of the technical terms and ideas. Interpreters were not present for many of the meetings due to a variety of reasons. Maybe the deaf student did not request them or were not available due to ad-hoc meetings.”

Some hearing students acknowledged problems with how they treated a Deaf/HoH teammate. From the beginning of a team-based project, many hearing students felt that they did not do enough to welcome or gain understanding with the Deaf/HoH student who was working on their team. Even though this meant more actual assigned work for the hearing teammates, many felt that it was easier to simply ignore the Deaf/HoH students in their group and not make them as much of a part of the team as their hearing counterparts. Even though they could see that many of the Deaf/HoH students were trying to become more involved with team activities, many hearing students stated that they did not have the patience to work with or understand Deaf/HoH students and would not properly involve them with their team.

“The increased difficulty in communication made it difficult to explain and assign work — almost to the point where it was easier to just assign to someone else and not include the deaf student.”

“There is a language barrier which prevents smooth in-person communication between team members. Deaf tend to be left out of conversations and ad-hoc decision making. The technology for smooth communication and interpreters are available ad-hoc and require extra planning. Typing is inefficient.”

Many hearing students also felt that Deaf/HoH students have learned to work autonomously from the rest of their team. Software engineering is largely a team-based exercise, which relies upon strong team cohesion to deliver a high quality product on time and on budget. Software engineers working away from the rest of their team goes against much of how we actually want to teach the students to create software using the proper engineering mindset.

Regardless of whether Deaf/HoH members are part of the team itself, team-related issues that need to be addressed during the course of a project still arise, ranging from the technical to personal and interpersonal issues. Learning how to properly address these situations is an important part of the learning process. Far too often, however, students would fail to address various issues with their Deaf/HoH teammates largely due to the communication barriers. As an example, many did not wish to involve a 3rd-party interpreter in possibly confrontational issues.

Even with a significant amount of communication and cultural differences to overcome, hearing students generally had a very positive experience when working with Deaf/HoH students. Many took the time to understand Deaf culture and learn American Sign Language (ASL) to varying degrees. Most hearing students acknowledged that Deaf/HoH students thought just like everyone else and, just like hearing teammates, some were good teammates and worked hard, while others did not try to contribute much to the team. Many students enjoyed the experience of working with a more diverse set of teammates.

“I enjoyed it because it brought in a new perspective for the team to work with. As a result, we were able to deliver high end products that met a larger scope of users.”

“...it [working on a team with Deaf/HoH students] was a good experience that opens your eyes to how different people can be.”

This diversity had other positive effects for the team as well. One student stated that the extra documentation and extra focus on communication had a positive effect on their final product:

“What went well is that they[Deaf/HoH] are just as capable as anyone else, and the fact that we are going at a slower pace allows for an actual full thought process to occur instead of trying to blaze through half-thought-out options.”

C. Faculty Feedback

We surveyed 7 Software Engineering faculty members about their experiences with having Deaf/HoH students in their class projects. A wide range of instructors responded to our questionnaire — from brand new faculty to 30-year tenured faculty. In general, most instructors did not notice many significant abnormalities or problems with Deaf/HoH students in comparison to ones who were hearing. One common observation was that documenting classroom materials was a significant help in keeping everyone up to date.

TABLE III: Example Questions: Faculty

Question	Responses
Do you feel like you were adequately prepared to have a deaf/hard of hearing student in your class?	Yes: 33%, Somewhat: 50%, No: 17%
Do you feel like there were provided sufficient resources to address the needs of the student, both in and outside of the classroom?	Yes: 83%, Sometimes: 17%, No: 0%
As an instructor, have you used any resources offered for the support of deaf/hard of hearing students?	Yes: 17%, No: 83%

Most of the feedback regarding the interpreters was very positive, with some instructors feeling that they were doing an excellent job with terminology, while others saying there were understandable difficulties. A common theme was that it was important to get the Deaf/HoH students involved in team-based projects and help to motivate their participation in groups. One example statement:

“Be sure to include the students in group activities, etc. Sometimes it can be hard to distinguish between barriers or issues caused by the disability and individual personality traits of the student.”

Many faculty said that having a Deaf/HoH student in their classroom really made them rethink their method of communicating their curriculum to the class. Many of them took the feedback they received from the Deaf students to heart and improved their own methods of teaching:

“Have the same expectations of Deaf/HoH students as you would anyone else. If extra time is needed on tests, follow that procedure (or any other accommodations listed). CC [closed caption] any video used. Don’t speak to the board while lecturing, your other students will appreciate that too.”

Additionally, many of the RIT/NTID interpreters faced struggles within their own field. Three interpreters that were interviewed claimed that many of the instructors here at RIT do not fully understand how to teach Deaf/HoH students. This may stem from lack of experience or training, but this is something they say the majority of interpreters have noticed. It was suggested that a workshop for instructors and faculty would help immensely. They were informed that RIT did, in fact, provide workshops, but that workshops were not mandatory.

One other issue that was brought up was that in New York state, there is no certificate requirement for interpreting education. RIT does have RID (Registry of Interpreters for the Deaf) certified interpreters, but not all interpreters have this certification. There are different levels of certification: community interpreting is the most basic; medical and educational interpreting require a much higher level of certification. Some suggested that RIT could pay for the newer interpreter’s certification tracks, which would lead to an increase in the quality of interpreters overall. RIT currently does not pay for certification fees, and this led to a lack of motivation to take the certification exams. This, combined with the fact that certification is not a job requirement has made certification a lower priority to many interpreters. Recently at RIT, the Promotion Career Ladder Committee (PCLC) was established, chartered with helping interpreters to pursue higher levels in their career and driving participation in their career. An

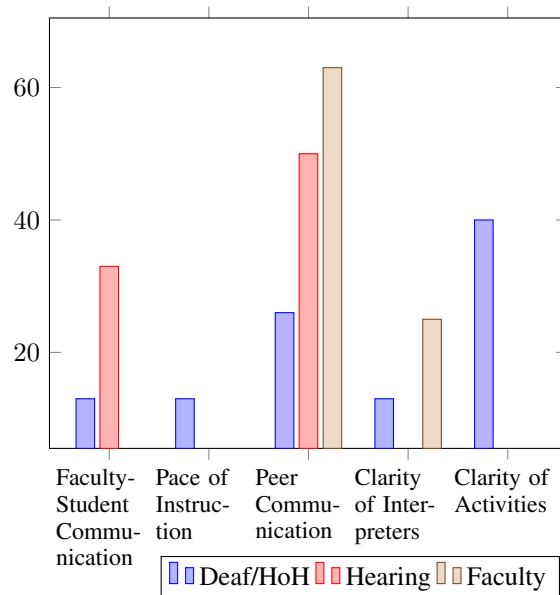


Fig. 1: Primary Challenges for Each Group (%)

increase in number of certified interpreters could improve the clarity of technical information interpreted for the Deaf/HoH student.

D. Analysis

Most faculty felt that the resources available to them for communicating their material to Deaf/HoH students was adequate enough for the Deaf/HoH students to succeed in and pass the course. Interestingly, most Deaf/HoH students reported that they felt the teacher’s materials were unclear and very vague, some feeling that the information itself was vague and therefore was interpreted as vague. This can amount to a large roadblock in the success of these students in the academic learning environment.

III. RECOMMENDATIONS

With an eye on the primary challenges shared by each party, shown in Figure 1, this section includes recommendations for each person or interaction: Instructors, Deaf/HoH Interaction, Classroom Lectures, Group Work, Deaf/HoH Students, and for all students based on our research. Many of these recommendations were derived from our own observations, best practices from previous publications, and recommendations from a Speech Language Pathologist.

A. For Instructors

Working with a Deaf/HoH student is a new experience for many instructors. Teachers in the elementary and secondary levels have training on how to differentiate lessons and teach to a more diverse group of young people yet most still require support from specialized teachers or Teachers of the Deaf (TOD) to understand how to best educate Deaf/HoH students. At the university level, instructors are not typically versed in teaching philosophies and differentiation strategies, and do not have the strict support services from a TOD received by their elementary and secondary counterparts. Due to this,

instructors entering a university where they may have students who are Deaf/HoH and are of mixed backgrounds, learning styles, and/or abilities may feel unprepared for differentiating their instruction style. They may also be unaware that small accommodations in the classroom can make for a much different communication and learning environment.

In this section we will discuss some measures instructors can take to communicate and teach more effectively to any class, but specifically classes of both hearing and Deaf/HoH students. A goal of this work is to assist instructors in the computing field in becoming more knowledgeable and understanding in ways they can help enhance the educational experience for students who are Deaf/HoH in their courses. Some general recommendations for interactions with Deaf/HoH individuals are:

General Interactions with Deaf/HoH individuals

- When speaking with a Deaf/HoH individual, look at and speak to the individual not toward the interpreter. Speak clearly and naturally.
- Keep sightlines open and clear from obstruction — seeing the speaker's face is important for speechreading (lipreading) and nonverbal communication such as facial expressions.
- Clarify/repeat messages and/or give examples. Allow for repetition of information, do not say “never mind” if the information was missed.
- Deaf/HoH students may use different modes of communication: American Sign Language (ASL), Signed Exact English (SEE), Pidgin Signed English (PSE), Cued Speech, speechreading, and spoken/written English or other languages.
- Deaf/HoH students may have access to auditory information via a hearing aid, cochlear implant and/or FM system. Each student will be different in their ability to utilize the auditory and spoken avenue for communication.
- Familiarize yourself with Student Access & Support Services and Disability Services available on campus (C-print, interpreting, note-taking, tutoring).
- Students who are Deaf/HoH and also have an additional disability or blindness are known as “Deaf Plus” or “Deafblind” respectively. Numerous supporting resources may be found on the web.^{1 2 3}

Classroom Lectures

Dual or multi-directional attention is a huge barrier in a classroom for Deaf/HoH students. Dual attention refers to the consideration needed to attend to two stimuli simultaneously. Hearing people often do this with little effort (you may listen to a teacher while taking notes or looking at a handout). “In contrast to hearing students who use dual channels — auditory and visual — for the input of classroom information, Deaf/HoH students tend to rely primarily on a single channel

— the visual channel.” [22]. A classroom is full of auditory and visual channels that a Deaf/HoH learner must process through a mostly visual sense. (i.e. watch an interpreter, see information on the board, take notes, and look at handouts or a computer screen). For those with auditory access, they must also try to process the spoken message from the professor and filter out extraneous conversations and noises. All of this can be overwhelming when trying to focus on multiple channels simultaneously. This often results in the Deaf/HoH student missing information in one of these areas. The following are recommendations for ensuring quality classroom lectures:

- Talk with the Deaf/HoH student(s) about their communication preferences and needs.
- Determine which services (if any) they will be using throughout the course (C-print, note-taking, interpreting, etc).
- Allow them preferential seating.
- Allow for all information to be accessed visually, (put everything up on the board, access slides on course website, etc.)
- Face the class when speaking. Speak first, then write on the board, try not to speak while facing away from the class or writing information that the student will need to see at the same time.
- Account for interpreter lag time. Although most skilled interpreters are extremely fast and efficient at relaying information, there will always be a bit of a lag time when interpreting. Time delay can affect turn taking and make it difficult to stay current in the conversation [21]. Consider the situation where an instructor may call on a hearing student to answer a posed question before the interpreter has even finished signing the original question [12].
- Ask students to raise their hand and say who they are before speaking — this is helpful for the student and/or interpreter to be able to indicate who is speaking and where the speaker is.
- Provide notes and new vocabulary in advance. Pre-teach technical vocabulary if possible. Discuss vocabulary terms with interpreter (or student) prior to the lecture to ensure that the terms will be explained clearly.
- Document the goings-on of the class and publish on a class website.
- Design lesson plans in an organized, sequential manner.
- Using a chat program or message board for discussions outside of class can help with communication process. Examples include Google Docs, Gchat, question forums, or online resources provided by your school.
- If a student uses an amplification device:
 - Cut down on extraneous noise (limit side conversations, limit shuffling of chairs, close doors/windows, etc.).

¹<http://www.rit.edu/ntid/deafplus/about-website>

²<http://www.rit.edu/ntid/support-services>

³<http://www.rit.edu/studentaffairs/disabilityservices/info.php>

- Consider students seating arrangements and allow for preferential seating.
- Consider the acoustics of the classroom (tile flooring, humming computers, outdoor noises, sound reverberation, etc.) [1].

Groups

Group work can be one of the biggest challenges in a software engineering courses. Working in a mixed hearing and Deaf/HoH group makes communication more challenging. Faculty need to take the lead by setting up clear guidelines and make comments on interaction with clear reinforcement. One option is to create a point system for group involvement where bonus points are assigned based on collaborative accomplishments. If using this option, when group work is occurring in the classroom, wander around and assign extra points to those teams that are working collaboratively. Establish roles, responsibilities, and expectations in group interactions. Encourage interaction amongst all group members.

Research shows that although giving communication strategies (turn taking, eye contact, facing toward communication partner, etc.) is important and useful for group work, it doesn't seem to be as powerful as using an overriding open/transparent way of communicating through technology. (i.e. g-chat, white board, Google Docs, question forums, etc.) [12]. The use of a chat program can help with communication by allowing each student the time to process the information and clearly communicate responses while working collaboratively. The level of complexity of communication goes up when everyone is involved and able to fully participate [12].

Based upon some of the responses from our surveys, some recommendations are:

- Encourage Deaf/HoH students to take leadership roles within the group.
- Get to know your group mates — lead team-building exercises to encourage communication.
- Maintain the same group for the semester — once students set up working relationships with their group and develop communication strategies that work for them, encourage them to use the developed relationships to their advantage.
- Deaf/HoH students should advocate for themselves as much as possible.

B. For Deaf or Hard of Hearing Students

We next provide recommendations for Deaf/HoH students to ensure that they receive the best possible learning experience. To advocate for themselves, Deaf/HoH students may:

- Determine which access and support services will be most useful for you to utilize. Use them to support your work in lecture and group work.
- Notify the professor of any and all services you are using and how they can support these services to the best of their abilities.
- Inform the interpreter if you do not understand their signing, a term presented, or parts of the material.

- Go to office hours, email, or communicate electronically with your instructors to discuss any questions or concerns you may have.
- Explore other avenues of support for your communication needs within a group when an interpreter is unavailable to you. Consider researching which technological supports will work best for you, such as web-based chat programs or document programs (g-chat, Google Docs), text-to-voice/voice-to-text mobile or computer app options (C-Print, Dragon), and Video Remote Interpreting (VRI).
- Develop communication rules or “Communication Courtesy” within a group. Examples could be:
 - Acknowledging the speaker
 - One person speaks at a time
 - Raise hand to take a turn
 - Limit interjections and distractions
 - Utilize a note-taker in the group and share all notes
 - Consider the environment, lines of sight, lighting, and acoustics

C. For All Students

It is important for all students in a group to feel that each group member is equally contributing. Each group member wants to feel valued and should be equally relied upon for work. Regardless of hearing status, if a member of a group is viewed as apart from the rest, excluded, not “pulling their weight”, or not willing to collaborate or compromise, it will change the dynamics of the group and could result in a lower quality end product. All students need to learn how to work effectively in groups and develop strategies to ensure all group members fully participate and the work is completed to the standard of all group members. Learning how to properly address group situations and to work collaboratively is an integral part of the university learning experience.

D. General Recommendations

Based on the information collected from our surveys and research, we believe that further research and information is needed to determine the extent to which the following recommendations can be achieved:

- Instructors at universities with high concentrations of Deaf/HoH students should be required to take a workshop or course designed to introduce them to teaching Deaf/HoH students, give overview of support services available to students, and how to adjust the classroom environment to best support these students.
- Technology-based departments should work more closely with the interpreters and the interpreting department to support terminology development for courses that contain jargon central to the subject.
- Find better more user-friendly strategies for students in mixed hearing status groups, with the goal of allowing them to communicate freely and effectively.

IV. RELATED WORK

This paper represents the first known work on students with hearing loss and software engineering education. However, there are numerous previous papers that discuss Deaf/HoH education in computing. Ross [19] described several methods of teaching programming to deaf students, one of which was through the use of a dynamic library of programming language examples. Other problematic areas for deaf students have also been conveyed, including difficulties with professional note-takers and interpreters due to their lack of a computer science background, resulting in a significant loss of information.

Cavender *et al.* [8] described a 9-week summer program for students with hearing loss. This program is designed to provide a catalyst for the academic careers for Deaf/HoH students. This is largely accomplished through the use of tutors and mentors for these students, some of the lessons included the need to inform instructors on how to more properly educate Deaf/HoH students and the need to recruit tutors and mentors who are themselves differently abled so they may better relate to the students. One surprising finding is the communication variations which exist in the Deaf/HoH community along with the diversity of accommodation needs. Not all Deaf/HoH students possess the same sign language communication skills, nor do they necessarily have the same preference in sign languages. Students may communicate using American Sign Language (ASL), Signed Exact English (SEE), or “Simultaneous Communication” (Simcomm).

Burgstahler *et al.* [6] discussed several ways of increasing the participation of students with various disabilities in computing fields. Included in these was the collaboration and knowledge sharing of disability service programs across the United States where strategies for recruiting and retaining disabled students in computing fields is discussed. This work also stated that disabled students were underrepresented in computing and that increasing the participation of disabled students would require a collaborative effort from students, educators, and employers.

In order to assist educating Deaf/HoH students in computing disciplines, several papers have been written. Kheir and Way [10] discussed using real-time speech transcription in order to assist the inclusion of Deaf/HoH students in computer science courses. An affordable solution was described which greatly assisted HoH students in these computer science courses. Li and Xu [11] studied an inquiry-based teaching model for Deaf/HoH students. Inquiry-based teaching models are very student-oriented and allow students to investigate real-world computing problems under the direction of the course instructor. This research found that such a model would be beneficial for Deaf/HoH students.

Bueno *et al.* [4] described several methods of assisting instructors in adapting e-learning content. The primary contribution of this work was a tool which processes lecture text for Deaf/HoH students. This tool highlights words or expressions which are difficult to understand for Deaf/HoH students and links them to external visual resources. A visual resource is used because numerous studies have found that Deaf/HoH students who predominately communicate via sign language process images more efficiently than words [20]. This paper also discussed some of the manners in which Deaf/HoH

students learned differently compared to hearing students. One example is the observation that Deaf/HoH students learn at their own pace which is very distinct from the pace of their hearing classmates [5].

V. LIMITATIONS & FUTURE WORK

While we have addressed a significant amount of issues for Deaf/HoH education, there is still a substantial amount of research to be done. While software engineering programs are rapidly growing from their beginnings in 1996 [13], they still represent a minority of computing education fields worldwide. We believe, however, that a substantial portion of our lessons learned and recommendations will be applicable to not only other computing fields, but to a vast array of other programs as well. We surveyed a relatively large number of hearing and Deaf/HoH students and faculty, but this obviously represents only a very minor subset of these respective groups at only a single institution.

The use of technology and computing to support communication for Deaf/HoH individuals is an expanding field with innumerable other areas of research ranging from allowing hearing and Deaf/HoH to communicate using a Kinect [9], all the way to creating mobile devices which can assist Deaf/HoH individuals with medical responders [7]. We understand that the use and development of new technologies and communication techniques will not replace the need for skilled interpreters who relay information clearly and effectively or improved methodologies and understanding by instructors and students. Deaf/HoH individuals are not members of a homogeneous group and each will have their own preferred method of communication. In the case of our students, some prefer to use interpreters over technologically-based communication, but education for all students is a case-by-case basis, regardless of hearing status, and there is no “one size fits all” approach.

VI. CONCLUSION

Deaf/HoH students are typically underrepresented and encounter significant hurdles in computing curriculums in higher education. In the Software Engineering department at RIT, we have a higher number of Deaf/HoH students than the typical university due to the presence of NTID on campus. While there are numerous challenges yet to be overcome, we hope that instructors and students will benefit from our work at other institutions. Additionally, we encourage further research and knowledge sharing in improvements to Deaf/HoH education, not only in software engineering, but in computing as a whole.

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Getting the Attention of Underrepresented Minority Community College Students to Consider Engineering as a Career

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Abstract – In order to have more students in engineering and computer science, we need more students interested in these fields. Many community college (CC) students believe that engineering is boring and has little to do with their lives, but also admit that they know very little about engineering. Our research question is: How can we best get the attention of CC students in order for them to get engineering and computer science on their radar screen to consider as a career? In particular, we are asking if a different approach is needed for underrepresented minority students than majority students. A survey was given to 72 students (21 minority) students at one non-metropolitan CC and 159 (112 minority) students at another. In this paper, we will compare the beliefs about engineering and computer science by ethnicity within each college and across the two CCs. Results show that a higher percentage of non-minority students at the first school are interested in engineering and computer science as a career (63%) than minority students (52%) and at the second school, a higher percentage of minority students (45%) than non-minority students (35%) are interested in engineering or computer science, even if about 20% of each group admit that they really don't understand what engineering is all about. The minority students appear to be more interested in working with robotics and are more likely to believe that engineering and computer science have nothing to do with their life than do non-minority students.

Index Terms – Undergraduate engineering and computer science students, Underrepresented Minorities, Recruitment

I. INTRODUCTION

Community college (CC) students are a prime source for increasing the number of engineers and computer scientists in the United States. Forty-six percent of all U.S. undergraduates are enrolled in a CC, as well as 41% of first-time freshmen, 61% of Native Americans, 57% of Hispanics, and 52% of Blacks. In addition, 57% of all CC students are women. [1] The majority of CC students do not earn a certificate, an Associate Degree, or go on to a four year school. However, “72% of community college students who transfer with an associate degree complete a bachelor’s degree within six

years. (Only) 56% of CC students who transfer without an associate degree complete a bachelor’s degree within six years.” [2] The success rate of transfer students depends on the type of institution to which they transfer. “Only students who transferred to a four-year public institution had a higher eight-year completion rate than their peers who began at a four-year public institution (74 percent and 63 percent, respectively).” [2] Based on our experience, there are many more CC students who, with the proper encouragement and support, would go on to earn a Bachelor’s degree, even in engineering and computer science. Henceforth in this paper the term “ENGR” shall include engineering and computer science.

For over ten years we have been talking to CC students about ENGR. This work was partly funded by NSF grants, most recently an S-STEM (#1060226) and STEP (#0856834). A crucial, first step to having more students interested in these fields. Students in non-metropolitan CCs may have very little knowledge of ENGR and have seen very few, if any, role models in ENGR. For seven years we have been talking ENGR with mathematics and science students in rural CCs. In each case we were the first engineering professors to visit their campus to talk about these majors. For these students it was not a matter of “changing the conversation,” it was a matter of starting a conversation. [3]

Many CC students believe that ENGR is boring and has little to do with their lives, but also admit that they know very little about ENGR. These students may also hold several myths about ENGR which they use to conclude that ENGR is not for them. Our research question is: How can we best get the attention of CC students, especially underrepresented minority students, in order for them to get ENGR on their career radar screen?

II. BACKGROUND

We have worked with upper division ENGR students for 13 years. During these years we have had many conversations with these students about their reasons for choosing and staying in ENGR. In addition, we have researched and surveyed ENGR students over these years. In Fall 2012, we administered a survey we designed for CC students in classes

at our five partner CCs in order to answer the question: “What about ENGR attracts or does not attract you?” [3] After asking for demographic data, and verbally telling the students that we considered computer science to be a part of engineering, we asked the question: “Is engineering your career choice?” If the answer to this question was “Yes,” the student was directed to check all of the factors that were true for them as to why engineering was their choice. If the student answered, “No,” they were directed to a separate list of items where they were asked to check all the factors that were true for them as to why engineering was not their choice. For either list, the student was asked to rank their top three as 1= most important, 2=2nd most important, and 3=3rd most important. [4]

The survey was given to students in math and science classes with the permission of the instructor. We administered the survey before we began our dialogue so as not to influence the answers. The survey was taken by 338 students, 118 females and 220 males. Of these respondents, 189 said YES to engineering and 149 said NO to engineering. For students who said YES to engineering and based on their top 3 reasons, the top six reasons were: money, like math/science, exciting, many job opportunities, challenging, and want to make a difference. Money was clearly the main reason that students said there were interested in engineering. The 50 females who said YES to engineering had a similar top six (with a different order of ranking) as the 139 males who said YES with the following exception that “Want to help people” was ranked 6th and “Many job opportunities” was ranked 7th. The males who said YES to engineering included “Like to solve problems” in their top 6, and not “Want to make a difference,” which was ranked 8th. [4]

In analyzing the top 3 reasons that students were not interested in engineering, we found that the top reasons were: does not sound interesting to me, not good enough at math, think engineering is simply too hard, do not like math, not aware of many engineering job opportunities, and I want to work outside, not in an office. “Do not like physics” was the 7th highest rank reason. This information informs topics that are good to discuss with students who do not know much about engineering. [4]

The three most significant differences ($p < .025$) between females and males in their reasons for saying YES to engineering is that men valued many job opportunities, rewarding, and like to solve problems more highly than did females. Males were more concerned about job security than females and females were more likely to give challenging as a reason to say YES to engineering ($p < .10$). Trends ($p < .16$) were seen in that females were more likely to like math/science, to want to help people, and to consider job flexibility a factor. [4]

For the students who said NO to engineering, the largest difference ($p < .025$) between females and males was that females were less aware of many engineering job

opportunities. At the $p < .10$ level, females were more likely to say that engineering did not sound interesting to them and were less likely to say that they did not like to study. At the trend level, females were more likely than males to say that they were not good enough at math, engineering is simply too hard, that engineering would be boring, and that they did not like computers. [4]

The items from aforementioned survey were used to develop a new survey. A major difference in this survey is the students were asked for their degree of belief of a statement and not just if they believed it or not. The 22 items were listed in random order, but basically came from four categories: interest, lack of information, misperceptions, and inadequate information. This survey was given to students at two non-metropolitan CCs, which included a few high school students co-enrolled at the CCs. The total number of students was 64. [5] The mathematics level of the students was from pre-calculus to differential equations.

From the combined responses, the statements with the most positive responses were: I want to use my career to make a difference, ENGR jobs have a lot of flexibility and variety, I want to use my career to help people, ENGRs work outside as well as in offices, ENGR has many job opportunities, I could use ENGR to help my community, and the US needs more ENGRs to stay competitive. [5]

Only 25 of 63 students (student totals vary by how many answered each question) agreed or strongly agreed with the statement “I understand what an ENGR does.” Items showing the most lack of understanding were: An ENGR must be a “brain,” An ENGR major must love math, ENGRs have low unemployment rates, and ENGRs have the highest starting salaries with a Bachelor’s degree. These items are commonly misunderstood and need to be clarified for students. [5]

Of the 63 students who responded to the statement, “I’m interested in Engineering or Computer Science as a degree,” 26 (41.3%) strongly agreed or agreed with the statement, 12 (19.0%) were neutral, and 25 (39.7%) either disagreed or strongly disagreed with the statement. Additional analysis showed that students who are interested in ENGR generally understand what an ENGR does and students, who do not understand what an ENGR does, are not that interested in ENGR. [5]

III. LITERATURE REVIEW

In spite of the need for ENGRs in the U.S. and the many attractive attributes of the profession, few students are choosing ENGR as a career. Only 11% of freshmen students are studying engineering and only 3% are studying computer science. [6]. We have already mentioned that CCs are a great source for more ENGRs, and since CCs have a higher percentage of underrepresented students than universities, there is the potential for more diversity in ENGR through

recruitment at the CCs. We also know that many of the students at CCs have not yet decided on their major. Through our own research, we have discovered that 30% of the ENGR students in our program only decided on ENGR while they were at the CC. [7] This fact gave us the incentive to spend time travelling to CCs to talk to students about ENGR to make sure that ENGR was one of the careers that they considered.

The U.S. Education Department reports that only 60% of students entering four year institutions earn a Bachelor's degree in six years, and only 31 percent of public community college students go on to complete either an associate or a bachelor's degree in six years. [8] We believe that if we can help students find an interest in ENGR that students will be more likely to enter and to be retained in these fields.

Although there has been increased attention paid to CCs by the National Science Foundation and other funding agencies, the CC is still a largely untapped resource for interesting more students to major in ENGR. For several years there has been an emphasis on changing the message about engineering. A Committee on Public Understanding of Engineering Messages, "Changing the Conversation" was published in 2008. [3] The primary idea to come out of this study was that engineering needed to be presented in more positive ways, in ways that emphasized the areas that females, minority students, and males wanted to have in a career. As we shall see in this paper, many students still have little or no idea of what engineers or computer scientists do. With this lack of knowledge about the careers, it is very difficult for students to decide they want to pursue this career.

Other research has focused on what community colleges can do to better prepare their students for transfer to a four-year, comprehensive research university. [9] Zhang and Ozuna adopted Rendon's [10] validation theory to explore the students' experience in the CC and concluded that CC faculty were the most important support for participants' interpersonal validation experiences. In order for this to work for recruitment into ENGR, this means that the CC students need to be exposed to ENGR either through their CC faculty, guest speakers, or ENGR student role models, as well as informed advisors.

IV. THE SURVEY/METHODOLOGY

Grounded theory has been used for the development of a survey with CC students about their thoughts on engineering and computer science as their career. Our grounded theory is very closely connected to Social Cognitive Career Theory [11] with career choice factors as follows:

- Environmental variables as financial resources and access to role models and social supports;
- Cognitive person variables such as outcome expectations, self-efficacy, and goals;

- Other person factors such as gender and ethnicity.

Students were first asked if they were interested in ENGR and why. From these answers a survey with 22 items was constructed. Sixty-four students at two non-metropolitan CCs were asked to rank their belief in each statement on a Likert scale.

In Fall 14, a similar survey was given to 71 and 159 students at two non-metropolitan CCs and their beliefs about ENGR were analyzed by gender. In this paper, we will analyze their beliefs about ENGR by ethnicity and compare the results. See Table I for the statements by category.

<i>Interest:</i>
1. I am interested in Engineering or CS as a career
2. Engineering and CS do not interest me
3. Working with robotics would be interesting
<i>Lack of Information</i>
4. I do not really understand what engineering and CS are about
5. I understand what an engineer or computer scientist does in their career
<i>Misperception</i>
6. An engineer or CS major must be a "brain"
7. Engineering and CS are too difficult for me
8. Engineering and CS majors require too much work for me
9. An engineer or CS major must love math
10. I don't like Physics and therefore do not want to be an engineer or CS major
11. Engineering and CS majors are not well suited for women
12. Engineering and CS have nothing to do with my life
13. Engineers work outside as well as in offices
14. I want to use my career to help people
15. I think I could use engineering and CS to help people
16. I want to use my career to make a difference
<i>Inadequate Information</i>
17. Engineering and CS have many job opportunities
18. The US needs more engineers and CS majors to stay competitive internationally
19. Engineering and CS have the highest starting salaries after a Bachelor's degree
20. Engineering and CS have low unemployment rates
21. Engineering and CS jobs have a lot of flexibility and variety

Table I. The 21 Statements in the Engineering Interest Survey.

The survey used in this study is similar to the survey described in the Background section. The previous survey results were based on 64 students and we wanted a larger sample. Also, we

changed this new survey to only have 21 statements instead of 22 by eliminating the statement “Engineering and CS sound interesting.” We believe that the statement “I’m interested in Engineering or Computer Science as a career” is a more accurate statement, as well as being more inclusive. We still include the statement “Engineering and CS do not interest me” as a check for validity.

The statements were listed at random in the surveys. The students were asked to judge each statement according to a Likert scale from 5 to 1: Agree Strongly, Agree, Neutral, Disagree, Disagree Strongly. The number of participants in this study are shown in Table II. The totals vary since not all students identified their gender, ethnicity, and ENGR interest.

CC	Female	Male	Under represented Minority	Non Minor ity	Total
A	40	31	21 (29.2%)	51	72
B	70	89	112 (70.4%)	40	159
Tot.	110	120	129	91	231
%	47.8%	52.2%	56.8%	41.4%	

Table II. Gender and Ethnicity Breakdown of Students Taking Survey in CC A and CC B.

From Table II we note that the underrepresented minorities (African American, Hispanic/Latino, and Native American) are 29.2% at CC A and 70.4% at CC B. We can also see a good representation of females in the survey.

V. ANALYSIS OF SURVEY

In order to better understand the students who took this survey let us consider Tables III and IV.

In Table III we see the breakdown for the percentage of students at CC A, who declared they were interested in engineer or not, further broken down by minority and gender status. At CC A we see that 40% of the students who took the survey were interested in ENGR. Of the 20 underrepresented minority students who declared their ethnicity, 7 (33.3%) were interested in ENGR. The percentage of females interested in ENGR at CC A is 23.1% (9/39) and the percentage of males interested is 61.3% (19/31). These are encouraging percentages.

In Table IV, we see that 34.6% of the students at CC B who took the survey are interested in ENGR (a somewhat lower percentage than CC A). Of the 109 underrepresented students, 36 (33.0%) were interested in ENGR. This percentage is the same as that at CC A. The percentage of females interested in ENGR at CC B is 12.9% (9/70) and the percentage of males interested in ENGR is 51.7% (46/89). The percentage of females is quite a bit lower than for CC A (although their numbers are small) and the percentage of males interested in

ENGR at CC B is somewhat lower than at CC A. This percentage of males is still very encouraging (61.3% and 51.7%).

CC A: Count of Engineering/Non-Engineering			
	Female	Male	Total
Engineering	9 (23.1%)	19 (61.3%)	28 (40%)
African American	1	0	1
Asian	1	4	5
Caucasian	5	11	16
Hispanic	2	4	6
Non-Engineering	30 (76.9%)	12 (38.7%)	42 (60%)
African American	0	1	1
Asian	4	0	4
Caucasian	17	6	23
Hispanic	8	2	10
Native American	1	1	2
No Response	0	2	2
Grand Total	39 (55.7%)	31 (44.3%)	70 (100%)

Table III. Distribution of Students by Gender, Ethnicity, and If They Are Interested in ENGR Career or Not at CC A.

CC B: Count of Engineering/Non-Engineering			
	Female	Male	Total
Engineering	9 (12.9%)	46 (51.7%)	55 (34.6%)
Asian	1	1	2
African American	0	1	1
Caucasian	3	10	13
Hispanic/Caucasian	0	1	1
Hispanic/Latino	5	27	32
Native American	0	2	2
No Response	0	4	4
Non-Engineering	61 (87.1%)	43 (48.3%)	104 (65.4%)
Asian	5	0	5
African American	1	4	5
Caucasian	14	6	20
Hispanic/Latino	36	27	63
Native American	3	2	5
Other	1	2	3
No Response	1	2	3
Grand Total	70	89	159

Table IV. Distribution of Students by Gender, Ethnicity, and If They Are Interested in ENGR or Not at CC B.

In a previous presentation, we explored the survey results from a gender point of view. [12] At CC A, we discovered that although the females agreed with males on some issues,

they disagreed with them on many others. The females and males agreed (no statistical difference) that they wanted to use their career to make a difference and wanted to use their career to help people, indicating that these are good messages for both females and males. Not enough females or males understood what ENGRs do (50% and 65%, respectively). Less than half believed that ENGRs command the highest salary with a Bachelor's degree (42.5% for females and 48% for males). There was a statistical difference between the beliefs of females and males (with females having a lower percentage) on: ENGRs have many job opportunities, ENGRs have a low unemployment rate, the U.S. needs more ENGRs, and working with robotics is interesting. Females were also less likely to believe that an ENGR could help their community. The females and males agreed that an ENGR must be a "brain," must love math, and ENGR requires too much work. Ten percent of the females said that ENGR had nothing to do with their life. The females and males disagreed with the statements, "I am interested in ENGR as a career" and "ENGR jobs have flexibility and variety," with the females having a lower percentage of belief. On two categories the females had a higher percentage than the males: "I don't like physics, therefore I don't want to be an ENGR" and "ENGR is too difficult for me."

When we looked at CC B, contrary to CC A, the females and males only disagreed statistically in their beliefs on ONE item: "I am interested in an ENGR career," (females: 21.4% and males: 61.8%). At the same time there were many differences among the females at CC B if we compared them by whether they were interested in an ENGR career or not. Also, there were many differences in beliefs by ethnicity at the second CC. A conclusion from these studies is that it is not enough to look at one CC, even a non-metropolitan one, and assume that all non-metropolitan CCs are alike. In addition, these CCs are both classified as HSIs.

In this paper we wish to explore the results from an underrepresented minority view. First we will compare the responses of the minority students with those of the non-minority students. In Table V we have ranked the questions in order of the percentage of students in the minority category who strongly agreed or agreed with the statement.

In this survey, the biggest difference between the minority and the non-minority group of students was that 100% of the minority students agreed that there were many job opportunities in engineering and CS, while only 84.3% of the non-minority students thought so ($p=.002$). The next highest statistically significant difference was that 71.4% of the minority students and only 37.3% of the non-minority students thought that the highest salaries for baccalaureate graduates was in ENGR ($p=.004$). Falling close behind in significance ($p=.005$) is that 90.5% of minority students believed that ENGRs work outside as well as inside. Another very significant difference ($p=.020$) between the groups is that 76.2% of the minority students agreed that an engineer or CS

major must love math, while only 49% of the non-minority students did. This last result seems contrary to common logic.

CC A: Statement about (Engineering and CS) =ENGR	% Agree Min	% Agree Non Min	p-value
Have many job opportunities	100	84.3	.002 ***
Want career make difference	95.2	90.2	.419
Want career to help people	95.2	86.3	.181 *
Work outside/inside	90.5	64.7	.005 ***
US needs more ENGR	90.5	74.5	.071 **
Must love math	76.2	49.0	.020 ***
Highest starting salary at BS	71.4	37.3	.004 ***
Must be a "brain"	66.7	58.8	.526
Jobs have flexibility/variety	61.9	51.0	.390
Work with robots interesting	61.9	70.6	.483
Help people in community	61.9	62.7	.947
Interested in ENGR career	52.4	62.7	.419
Understand their career	47.6	58.8	.385
Low unemployment rates	47.6	39.2	.514
Don't like physics	28.6	17.6	.330
Do not understand ENGR	25.0	23.5	.980
Too difficult for me	25.0	19.6	.629
Do not interest me	23.8	25.5	.880
Require too much work	14.3	15.7	.87.9
Not well suited for women	00.0	2.00	.313
Nothing to do with my life	00.0	7.80	.037 **

Table V. Comparison of Percentages of Students at CC A Who Agreed with Each Statement by Minority Status
***= $p<.025$, **= $p<.10$, *= $p<.182$

Two items were judged somewhat differently statistically by the two groups. "Engineering and CS have nothing to do with my life" was believed by 7.8% of the non-minority students, while none of the minority students believed it ($p=.037$). While 90.5% of the minority students believe that the U.S. needs more ENGRs to maintain an international competitive edge, only 74.5 % of the non-minority students did ($p=.071$). The fact that there is a base near the school may help to account for the fact that over 75% of each group believed the statement.

For the statement, "I want to use my career to help people," although not statistically significant ($p=.181$), this p-value is low enough to note this as a trend. It may be that minority students are more likely to believe this (95.2%) than non-minority students (86.3%). The fact that both groups had a quite high percentage, shows that it is a good to point out to

students that there are many areas of ENGR that directly help people. Obvious examples of this are biomedical, civil, chemical, and industrial engineering.

Now let us consider the same survey results for CC B. In Table VI we see these results.

CC B: Statements about (Engineering and CS) =ENGR	% Agree Min	% Agree Non Min	p- value
Use career to make a difference	88.9	82.5	.342
Use my career to help people	82.1	80.0	.777
Many job opportunities	72.2	75.0	.731
ENGR work outside/inside	68.2	62.5	.519
US needs more ENGR	66.4	57.5	.328
Work with robots interesting	64.8	45.0	.030 ***
Must love math	63.6	45.0	.042 **
Must be a "brain"	56.5	35.9	.023 ***
Help people in community	54.2	52.5	.854
Jobs have flexibility/variety	51.4	42.5	.333
Interested in ENGR career	45.9	35.0	.223
Understand their career	45.8	35.0	.228
Highest salary after Bachelor's	39.3	25.0	.087 **
Lowest unemployment rates	29.0	35.9	.434
ENGR do not interest me	27.4	32.5	.549
Don't understand ENGR	23.4	22.5	.911
Require too much work for me	22.4	07.5	.010 ***
Too difficult for me	18.9	10.3	.163 *
Do not like physics	16.7	22.5	.438
Nothing to do with my life	09.3	17.5	.213
Not well suited for women	06.5	00.0	.006 ***

Table VI. Comparison of Percentages of Students at CC B Who Agreed With Each Statement by Minority Status

***= $p < .025$, **= $p < .10$, *= $p < .182$

The biggest discrepancies between the beliefs of the minority and non-minority students at school B were, in order, on the statements that ENGR is not well suited for women ($p=.006$), ENGR requires too much work ($p=.010$), and an ENGR must be a "brain" ($p=.023$). Interestingly, no non-minority students agreed with the statement about women not fitting well in ENGR, but 7 of 107 minority student thought so. This is a topic that needs to be discussed, especially with minority students. There was a statistical difference of $p=.010$ between minority (22.4%) and non-minority (07.5%) students that being an ENGR takes too much work. Again, more minority students (56.5%) than non-minority students (35.9%) percentage-wise believed that a person needed to be a "brain"

in order to be an ENGR. All three of these statements are beliefs that could hold some minority students from choosing engineering. These results support the general research that shows that females and underrepresented minority students tend to have a lower self-confidence.

Two other differences between the minority and non-minority students show up in this survey that could tend to make minority students overlook ENGR. A high percentage (63.6%) of the minority students agreed that an ENGR major must love math, while only 45% of the non-minority students believed so ($p=.042$). Although not statistically significant, a trend was evident with the statement "Engineering and CS are too difficult for me." Among minority students, 18.9% agreed with this statement, while only 10.3% of the non-minority students did so ($p=.163$).

Two additional differences between the minority and non-minority groups were in the favor of minority students considering ENGR. More minority students (39.3%) than non-minority students (25%) believed in the statement on high starting salaries for engineers ($p=.087$). More minority students (64.8%) than non-minority students (45%) agreed that it would be interesting to work with robotics ($p=.03$).

We need to point out that we do not get the same results from the two schools regarding minority and non-minority beliefs. It is important to understand that the populations of CC students at a particular school may have its own personality and that the same message about ENGR may not be apropos for all schools.

Regarding the high starting salaries that ENGRs earn, for school A, 71.4% of the minority students and only 37.3% of the non-minority students ($p=.004$) believed the statement. For school B, again the minority students believed the statement (39.3%) more than the non-minority students (25.0%) at $p=.087$. It is interesting to note, the higher percentage of minority students at school A, who believed the statement than at school B. Since more of the minority students believed that ENGRs make very good salaries, this should be a positive factor for more underrepresented minorities entering ENGR.

The other common statement that "ENGRs need to love math," was believed by 76.2% of the minority students at school A and by only 49% of the non-minority students ($p=.02$). At school B, 63.6% of the minority students agreed with the statement, while only 45% of the non-minority students did ($p=.042$). The percentages were higher at both schools for minority students. The results of the agreement with this statement could account in part why there are not more underrepresented minority students in ENGR.

We were also interested in the strength of the interest in ENGR as a career by percentage of students, minority or non-

minority, and female or male. In Table VI we summarize these statistics.

"I am interested in Engineering or CS as a career"				
	Minority	Non-Minority	Female	Male
CC A				
Agree	11 (52.4%)	32 (62.7%)	17 (42.5%)	26 (83.9%)
Neutral	4 (19.0%)	6 (11.8%)	6 (15%)	3 (9.7%)
CC B				
Agree	50 (44.6%)	14 (35%)	14 (20%)	55 (61.8%)
Neutral	20 (17.6%)	7 (17.5%)	12 (17.1%)	16 (18.0%)

Table VI. Number of Students Who Agreed or Were Neutral on the Statement: "I Am Interested in ENGR as a Career" by Ethnicity, Gender, and Community College

In Table VI, we also included the numbers of students who believed that they were neutral on the statement. The neutral beliefs may have been because the students are still undecided on their major or do not know much yet about ENGR. As long as the student did not disagree with this statement, there is a possibility that they may still become interested in ENGR.

We see from Table VI that at College A, a higher percentage of non-minority students are interested in ENGR, while at College B, the percentage is higher with minority students. At both schools there is a much higher percentage of males interested than females, although the ratio is about 1/3 as many females at one school and about 1/2 at the other school. The percentage of neutral students is surprisingly quite consistent across all categories. It is unknown why the percentage of students interested in ENGR is so much higher in school A. It could be a bias of the type of classes that we visited at each school since the selection of classes is somewhat random, depending on which classes are available at the time of the visit and which instructors give us permission to speak with their classes.

VI. CONCLUSIONS AND FUTURE WORK

A primary conclusion of this study is that the beliefs of students about ENGR vary by school and ethnicity, as well as gender. Practitioners who speak with CC students would do well to try to understand the students at any particular school in order to better focus their message in trying to get students to put ENGR on their radar as a possible career.

It is clear from this survey again, that certain myths are still alive and well and that several attractive aspects of ENGR careers are not well known by CC students.

These surveys give us a good picture of many beliefs that students have about ENGR, but we do not know (for lack of longitudinal studies

) how effective our presentations are, even though we try to address the myths, misperceptions, and lack of information to the students with whom we dialogue. Future work should include securing evaluations from the students after our presentation to see if we are eliminating any of these myths and misunderstandings and to determine which parts of our message are the most effective.

Future work includes comparing the CC student views with high school students to see if our message needs to be different for high school students. We also want to do additional analysis with respect to gender and ethnicity, as well as to analyze the difference in beliefs between students who are interested, neutral, or not interested in ENGR. We encourage others who are speaking in CCs and high schools to better understand the population of students to whom they are speaker in order to make their presentations have more impact by speaking to students about areas in which they little information or have misinformation, as well as those areas in which they are most interested.

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Effect of Assertion Headings and Expandable Examples in an Online Engineering Textbook

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Abstract—Many engineering courses are transitioning from traditional paper textbooks to online and multimedia instructional modules to present content to students outside of class time. As the use of these online resources expands, research about the effective use and production of these resources should grow in tandem. We study the effect of three different educational interventions: expandable worked examples, assertion headings, and hand-drawn figures on students' learning and affective responses in online instructional texts for an introductory electrical engineering course. Although measures of students' performance on technical content showed few significant changes, affective measures of student course satisfaction with the materials had improved.

I. INTRODUCTION

Textbooks form the backbone of nearly every college course [1]. They are considered an “indispensable resource” by many professors [2]. Novice teachers and those teaching outside their expertise depend on textbooks to an even greater extent [3]. Teachers use textbooks to supplement material covered in class or to provide more information on topics that could not be covered fully in class. Today teachers are pushing basic knowledge acquisition toward out-of-class activities (“flipping the classroom”) in order to open up more class time for high-impact instruction [4]. As students are expected to learn more outside of class, the role of textbooks in explaining material has risen in importance. In this context more than ever, teachers need high-quality textbooks that have been proven to be effective learning aids [4].

Current evidence suggests that textbooks are failing their goal of supporting student learning. Most students do not read their textbooks to understand the topic, but rather to reduce anxiety about upcoming exams [2], [5]. Fewer than half of students use their textbooks even once a week [4], [5], [6], [7], [8], [9]. This low usage is partially explained by student perceptions of textbooks. Students must *perceive* a textbook as useful for the textbook to be an effective learning tool [10], [11]. Students do not believe reading the textbook produces a tangible improvement in exam performance [6], [8].

Student perceptions are not entirely to blame for low textbook usage, however. The structure of textbooks also plays a role. College seniors can locate relevant textbook content independently [8], but younger students must be told *exactly* what to study [7], [5]. Since students do not know what material in the textbook is relevant to their exams [9], they favor their instructors' lecture notes over textbooks. Textbooks

must clearly signal the boundaries between essential and non-essential information; otherwise students will waste precious study time focusing on unnecessary information, or they may give up on the textbook as a study resource altogether [5]. If educators want students to read textbooks, they must maximize students' ability to learn while engaged with the texts [12].

Increased demand for effective textbooks requires greater knowledge of what makes textbooks a useful tool for promoting student learning [4], [2]. Both private corporations [13], [14] and universities [15] are expanding their exploration of electronic textbooks to reduce costs and increase availability for students. This expanding development of electronic textbooks provides an exciting chance to change students' perception and use of textbooks for the better. Students who encounter new electronic formats with animations, interactive elements, and dynamic content might find that textbooks are still ineffective at helping them study, or they might find that textbooks are evolving into more effective learning tools and will begin to use textbooks more often. Increased textbook usage by students will liberate teachers from spending class time on basic material and allow them to deepen student learning in the classroom.

To explore how to create effective online engineering textbooks, we studied how different textbook authoring styles affected student performance and satisfaction in a first-year engineering course: Introduction to Electronics (ECE 110). Specifically, we studied the effect of assertion headings [16] and expandable worked examples [17] on student performance and satisfaction. We present some background on these interventions before describing the research study, its results, and its implications for instructional practice.

II. BACKGROUND

Research on the use of textbooks has uncovered some features that students report as being useful for learning [1]. Students consistently rate worked examples [1], [7], [2] as the most useful elements in college science, technology, engineering, or mathematics (STEM) textbooks. A **worked example** shows all the solution steps needed to reach the final answer to a problem and sometimes includes the reasoning behind taking those solution steps. See Table I for a typical worked example. Worked examples are a common instructional tool to teach problem solving skills in structured domains such as engineering and physics [18]. More so than their

classmates, struggling students depend on worked examples to help them learn [19], [18]. Additionally, most students rely almost completely on worked examples and chapter reviews without reading the chapter text at all [2].

TABLE I. WORKED EXAMPLE FROM ALGEBRA.

$5 = 3x - 1$	Solve for x .
$5 + 1 = 3x - 1 + 1$	Add 1 to both sides to eliminate the -1. Attack the object furthest from x .
$6 = 3x$	Add numbers and cancel.
$6/3 = 3x/3$	Since x is multiplied by 3, we divide both sides by 3 to isolate x .
$2 = x$	Do the arithmetic, x is isolated!

Unfortunately for the instructors and authors designing worked examples, the effectiveness of worked examples depends on their specific structural features [20]. Text and images must be properly integrated [21], [18], [22] for worked examples to be most effective. Many worked examples in textbooks lack detail [19], [10] or strategic information [23], [24], [25], [26]. The presence of additional problem-solving explanations can sometimes even hamper learning [27]. Some researchers believe there is no possible algorithm to consistently design effective worked examples [10]. Though much research has been done on worked examples [18], little is focused specifically on college-level STEM textbooks.

Development of worked examples is further complicated by the **expertise reversal effect** [28], [21], [29], [30]. Expertise reversal occurs when an educational intervention is effective for low-skill learners, but is less effective for high-skill learners (or vice versa) [31], [32], [33], [34]. To understand expertise reversal, consider the analogy of adding training wheels to a bicycle. Adding training wheels onto the bicycle of a child first learning to ride would greatly assist the child in becoming a proficient rider, but adding training wheels to the bicycle of a Tour de France cyclist would be a debilitating burden on their performance. Likewise, pedagogical techniques that help some students can be ineffective or even detrimental for experienced students. Skilled readers can waste precious cognitive resources on information they already understand [24], [22]. This expenditure of cognitive energy reduces the potential for learning new material.

The expertise reversal effect presents educators with a problem: how can teachers design worked examples to help both novice and experienced students? One potential solution to this problem is the use of **interactive worked examples** [17] with *optional* extra detail. An interactive worked example allows the reader to display or hide extra explanations, allowing experienced readers to bypass redundant material (a contributing factor to expertise reversal). Expandable examples are a promising way to mitigate the expertise reversal effect, but there is little research on developing interactive worked examples for electronic STEM textbooks.

Chapter reviews and summaries are the second-most used textbook element by students [1]. Students frequently fail to understand how the text material fits together. Students frequently cannot discern the overall takeaway message of the text. This failure in comprehension is exacerbated when the text fails to provide **global coherence**. A passage of text has

global coherence when a reader can relate each statement in the text back to the main topic of the passage and comprehend the overarching message of the chapter or section. A lack of global coherence often reduces reader comprehension and understanding of the reading material [32], [35].

One way to increase global coherence in textbooks is to improve an important part of textbooks that students already use: section headings [1]. Headings, end-of-chapter summaries and in-chapter reviews can moderate learning and comprehension through global coherence [32], [35]. Possible methods to improve the global coherence of section headings in textbooks can be found in research on effective science presentations and proofs. Rather than using a short topic-subtopic slide title during PowerPoint presentations like “Diode Current Flow,” a presenter can use a complete sentence assertion title such as “Diodes allow current to flow in only one direction” to improve coherence and learning during presentations [16]. The assertion title provides global coherence by summarizing the content presented on the slide. Similarly, comprehension of mathematical proofs can be improved when the principle of the proof is asserted before the proof itself [36]. Assertion headings appear in some successful STEM textbooks [37], [38], but there is no research on their effectiveness.

This study examined whether two features of an online engineering textbook would improve or impede a student’s ability to understand and learn material from the textbook. We conducted a concurrent mixed-methods study to investigate two research questions regarding assertion headings and interactive worked examples.

Research Question 1: Do expandable worked examples improve academic performance and course satisfaction compared to static examples and mitigate the expertise reversal effect observed in static worked examples?

Research Question 2: Do assertion section headings improve academic performance and course satisfaction in an online engineering text compared to topic-subtopic headings?

While we explored the first two questions, feedback from student volunteers about hand-drawn figures raised a third research question. We used a sequential mixed-methods study to explore the third research question:

Research Question 3: Can hand-drawn diagrams increase student satisfaction more than computer-generated diagrams?

III. METHODS

This study examined a first-year course, Introduction to Electronics (ECE 110). ECE 110 is a required course for Electrical Engineering and Computer Engineering majors at a large, public research university in the American Midwest. ECE 110 was selected for our study because the course instruction team was already dissatisfied with the available textbook options for the ECE 110 curriculum. The ECE 110 instructors planned to write their own instructional text before researchers of this study became involved. These procedures were approved by our university’s Institutional Review Board (Protocol #14927) overseeing human subjects research.

During the semester our study took place, 445 students enrolled in ECE 110. In this class, 74% of students were freshmen, 19% were sophomores, and 7% were upperclassmen. For

gender demographics, 85% of students were male and 15% of students were female. For race and ethnicity demographics, 37% of domestic students were Asian, 58% were white, 7% were Latino, and 3% were any other race (students could select more than one race, some are double counted). Additionally, 31% of students were international students.

To explore the effect of assertion headings and expandable worked examples in an engineering instructional text, the researchers and ECE 110 instruction team collaboratively created online text resources for ECE 110. The ECE 110 course website included course notes and worked examples, which together played the role of a textbook for ECE 110.

Each chapter of course notes covered two 50-minute lectures of material and contained text, figures, headings, a table of contents, and an end of chapter summary, much like a typical textbook. Unlike a typical textbook, the course notes included assertion headings (see Figure 1). The text was formal but friendly in tone. Each chapter contained numerous internal links to other parts of the text and external links to other websites. The figures were hand-drawn in full color.

Each chapter of the course notes was accompanied by interactive expandable worked examples. Similar to the examples in a standard textbook, the expandable worked examples included a problem statement, full-color computer-generated figures, equations, and explanations of the steps to solve the problem. However, unlike a standard textbook, the expandable worked examples could expand to show small sub-steps and manipulations that would consume too much space in a traditional paper textbook or would be superfluous for more experienced learners. Only problem steps that a student would be expected to show on an exam (expert-level work) were visible by default. Additional explanatory problem steps were hidden by default to avoid distracting the students who did not need more information, but these details could be displayed by clicking a button. All the expandable worked examples were written in an informal tone and explained both the steps taken to solve the problem and the rationale for taking each step. See Figure 2 for a sample of expandable worked example content.

QUANTIZATION Quantizing samples to levels and then to sequences of bits leads to quantization error.

A sequence of samples like $v[n]$ in Fig. 5 is not a digital signal because the sample values can potentially take on a continuous range of values. In order to complete analog to digital conversion, each sample value is mapped to a discrete level (represented by a sequence of bits) in a process called quantization. In a B -bit quantizer, each quantization level is represented with B bits, so that the number of levels equals 2^B .

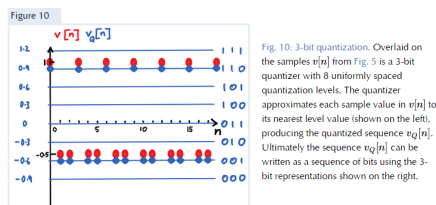


Fig. 1. Sample of the course notes. The topic-subtopic heading is “Quantization.” The assertion heading is “Quantizing samples to levels and then to a sequence of bits leads to quantization error.”

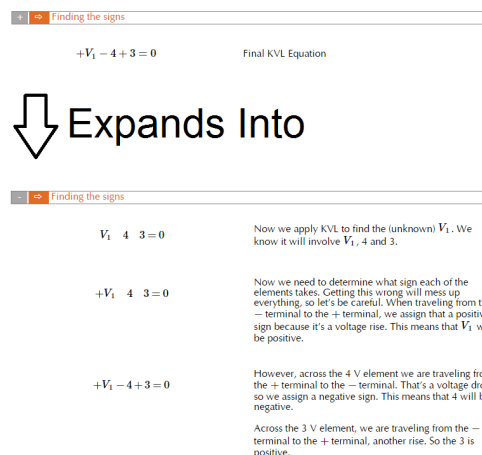


Fig. 2. Before-and-after picture of part of expandable worked example. Clicking the ‘+’ button expands the sub-steps in a particular problem step. Simple operations like sign conventions in the right column can impede a first-time learner.

Worked examples were displayed in a two-column format because the ECE 110 instruction team preferred that format and it was easy to produce examples that way. However, displaying information in two columns can impede learning because the reader must integrate multiple sources of information that are spatially separated into a single mental construct. This phenomenon is referred to as the split-attention effect [22]. To minimize potential problems from the split-attention effect, the left column (which contained figures and equations) was designed so that it could be followed independently of the right column (which contained explanations).

During the summer before the main study, we conducted a small pilot study to test the course notes and expandable worked examples with undergraduate volunteers. The initial pilot study produced an unexpected finding. Students spontaneously voiced strong opinions about the hand-drawn diagrams in the course notes. Students claimed that the hand-drawn figures were more believable and more attractive than the computer-generated figures in the worked examples. To explore this unexpected finding, we added our third research question: “Can hand-drawn diagrams increase student course satisfaction compared to computer-generated diagrams?” See Figure 3 for an example of the difference between hand-drawn and computer-generated figures in our study.

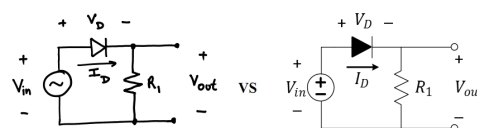


Fig. 3. Comparison of the same diagram drawn by hand (left) and typeset by computer (right).

We selected two chapters of course content for examination during the study: *Diodes* and *Sampling*. We selected these chapters because of their timing in the course. Each topic was covered in lecture just after an exam. The ECE 110 instruction team felt that holding our study shortly before an upcoming exam would be unfair to the students and would reduce response rate because students would prepare for exams rather than participate in the study.

We constructed two versions of each worked example from the *Diodes* and *Sampling* chapters. The experimental version included the expansion feature, whereas the control version did not. The control version worked examples had the same level of detail as a typical textbook worked example.

We constructed two versions of both the *Diodes* and *Sampling* chapters of the course notes. The control version of the course notes contained only ordinary topic-subtopic (noun phrase) headings, whereas the experimental text also included assertion (complete sentence) headings (see Figure 1). The control version of the course notes contained topic-subtopic phrases in the table of contents, whereas the experimental course notes contained assertions in the table of contents. In both versions of the text, the assertion statements were listed at the end of each chapter as a chapter summary. Chapter summaries are considered good practice for textbook authoring [1], so we included them to avoid bias against the control text. Both versions of the course notes contained identical text and figures; only the table of contents and section headings varied.

We partitioned students into three stratified random groups with equal numbers of freshmen and females. In each chapter, the control group (group TS) received course notes with topic-subtopic headings and low detail, non-expandable worked examples. The first treatment group (group AH) received course notes with assertion headings and expandable worked examples. The second treatment group (Group EO) received no course notes and only expandable worked examples to see if text passages would be ignored [39], [2]. Each group received one variant of the content in the *Diodes* activity, and a different variant during the *Sampling* activity (see Table II). This alternating treatment reduces the risk of bias against one text variant because of non-identical groups of students.

TABLE II. THE COURSE MATERIALS AVAILABLE TO EACH GROUP OF STUDENTS ON EACH TOPIC.

	Group 1	Group 2	Group 3	Response rate
<i>Diodes</i>	- Topic-subtopic headings in course notes - 2 Low-detail examples (N=57)	- Assertion headings in course notes - 2 Expandable examples (N=73)	- No course notes - 2 Expandable examples (N=74)	204/444 (46%)
<i>Sampling</i>	- Assertion headings - 5 Expandable examples (N=46)	- No course notes - 5 Expandable examples (N=51)	- Topic-subtopic headings - 5 Low detail examples (N=46)	143/444 (32%)

One week before *Diodes* was covered in lecture, we released the experimental versions of the *Diodes* course notes and worked examples to all ECE 110 students via email. Each student was linked to one variant of the course notes and worked examples (Table II). All students were also linked

to the same online technical content quiz over the material covered in the *Diodes* chapter and an attitudinal survey about the electronic course materials (See Table III). The students had until the day before *Diodes* was covered in lecture to complete the quiz and survey outside of class time. This timing eliminated the effect of the lecture itself on students' quiz performance. One month after the *Diodes* activity, a second activity was released covering the *Sampling* content, which followed the same format.

Students could take as much time as they wanted to complete the activity (course notes, worked examples, quiz, and survey). Due to the experiment design we could not measure the time it took students to complete each activity, but students in the pilot study took under an hour to complete similar activities. Unlike other studies of reading comprehension [32], students could read each activity's course notes and examples while completing the activity's quiz, much like natural studying. For fairness, all versions of the instruction materials were released after that activity's quiz was due. Participation in the study was optional but participation could be credited toward a portion of students' class participation grade in ECE 110, worth 1% of their final course grade. In the *Diodes* activity, 45% of ECE 110 students chose to participate, and in the *Sampling* activity only 32% of students participated.

To explore the satisfaction dimensions of our research question about expandable examples, we included two Likert scale items in both activities and asked a free response question during the *Sampling* activity. To explore the satisfaction dimensions of our research question about assertion headings, we asked one Likert scale question both activities and asked a free response question in the *Sampling* activity. To explore our research question about hand-drawn figures, we asked one free response question in the *Diodes* activity (see Table III). The responses to this free response question (see Table IV) informed the construction of quantitative Likert scale questions included in the *Sampling* activity (see Table XII).

TABLE III. SUMMARY OF ACTIVITIES FOR EACH CHAPTER.

<i>Diodes</i> Activity	<i>Sampling</i> Activity
- 6 conceptual questions - 2 quantitative questions	- 2 conceptual questions - 5 quantitative questions
- What do you think of the complete sentence headings? - Rate the usefulness of the expandable worked examples. - Did you find the expandable features of the examples useful? - Do you prefer hand-drawn or computer-generated diagrams?	- What did you think of the complete sentence section headings in the Sampling chapter? - Rate the usefulness of the expandable worked examples for the Sampling topic. Did they help you learn? - Did you find the expandable features of the examples useful? - 9 questions on aspects of hand-drawn figures, influenced by the free response questions in the <i>Diodes</i> activity
Why do you prefer hand-drawn or computer-generated diagrams? (160 responses)	- Why did you find the complete sentence titles helpful or unhelpful? (48 responses) - Why did you find the expandable feature helpful or unhelpful? (48 responses)

Three coders analyzed the responses to the free response questions in the *Sampling* activity. Given the small dataset, the author established an initial codebook independently. A second coder applied the codebook to the data. Disagreements were used to refine and finalize the codes and their definitions. To test the trustworthiness of the coding scheme, a third coder coded each response independently before comparing notes

with the author. These final comparisons were used to calculate an inter-rater agreement of 75%.

Responses to the free response question “Why do you prefer hand-drawn or computer-generated figures?” from the *Diodes* activity were coded by two researchers. Because we could find no prior research documenting students’ preferences, we began coding without an a priori coding scheme. A codebook was developed through an iterative process before codes were finalized. In the first phase of analysis, two researchers cooperatively established an initial codebook for 30 of the 160 responses. Using the preliminary codebook in the second phase, both researchers independently coded 50 of the remaining responses, and used disagreements to refine the codebook. In the third phase, each researcher coded the remaining 80 responses independently and any disagreement was counted against the validity of the coding scheme. Disagreements were resolved through discussion. We obtained an inter-rater reliability of 95% for the final 80 codes. These codes inspired a group of Likert scale questions in the survey in the *Sampling* activity (see Table III).

We analyzed the nine code-inspired Likert scale survey items from the *Sampling* activity by grouping them into three categories: one for items about neatness and readability, one for items about affective responses, and one for items about credibility. For each pair of survey items, we computed a linear correlation coefficient. For groups of survey items that had at least moderate correlation coefficients ($r > 0.5$) for each pairing, those survey items were combined into a composite score. No survey items fit into more than one group. We did not conduct an exploratory factor analysis of the data. These composite scores were reduced to a four-point scale of 0-3 (see Tables X and XI). Survey items that did not correlate well with any other survey items were discarded, since we could not establish validity for those items.

Since the first exam preceded the study, we used students’ scores on the first exam of the semester to estimate baseline ability and preparedness for each treatment group. We used scores on the *Diodes* and *Sampling* quizzes to measure differences in performance between treatment groups.

According to the Shapiro-Wilk test, quiz and exam scores were not normally distributed. We used the Kruskal-Wallis test rather than Analysis of Variance (ANOVA) to analyze quiz scores and exam scores because ANOVA is sensitive to deviations from normality at small sample sizes. We chose a α value of $\alpha = 0.01$ for the quantitative analysis of quiz scores and exam scores because we were equally concerned with false positive and false negative errors. We measured effect size with Cohen’s d since we did not observe large differences in variance of quiz scores or exam scores between groups.

IV. RESULTS

We used students’ scores on Exam 1 to measure differences in ability between treatment groups. We found no statistically significant differences in students’ preparation during the *Diodes* and *Sampling* activities (Table V).

We used students’ scores on the quizzes to measure treatment effects between groups. Only one statistically significant difference was found: The students given topic-subtopic course

TABLE IV. CODES FOR RESPONSES TO “WHY DO YOU PREFER HAND-DRAWN OR COMPUTER-GENERATED FIGURES?”

Hand - Inviting	Students have a positive affective response
Hand - Relatable	Hand-drawn figures are more similar to what students produce
Hand - Clean and Clear	Hand-drawn is easier to read
Don't Care - Clean and Clear	No preference as long as it is clean and clear to read
Don't Care - Equally effective	No preference as long as both can be understood
Don't Care - Indifferent	No preference
Computer - Relatable	Computer-drawn figures are similar to what the students must produce
Computer - Clean and Clear	Computer-drawn is easier to read

notes and traditional examples scored higher than the students given the assertion headings notes and expandable examples on the *Sampling* quiz.

TABLE V. PAIRWISE COMPARISONS OF QUIZ AND EXAM SCORES FOR EACH GROUP DURING THE *Diodes* AND *Sampling* ACTIVITIES. THE LETTERS INDICATE THE GROUP THAT PERFORMED BETTER. STATISTICALLY SIGNIFICANT RESULTS ARE BOLDED. T

Group Comparison	Exam Effect Size d	Quiz Effect Size d
<i>Diodes</i>		
TS vs AH	0.38 AH	0.12 TS
AH vs EO	0.11 AH	0.29 EO
EO vs TS	0.27 TS	0.17 EO
<i>Sampling</i>		
AH vs EO	0.19 EO	0.27 EO
EO vs TS	0.13 TS	0.45 TS
TS vs AH	0.32 TS	0.72 TS

Students responded positively to the expandable worked examples with more than 80% of students responding favorably (see Table VI). The response to the expansion feature itself was even more positive, with 40% of students choosing the most positive response.

TABLE VI. STUDENT RESPONSES TO LIKERT SCALE QUESTIONS REGARDING THE EXPANDABLE WORKED EXAMPLES.

Question	Bad	Poor	Good	Great	Mean (0-3 scale)	Response Rate
Rate the overall usefulness of the worked examples (<i>Diodes</i>)	4 (2%)	32 (16%)	119 (60%)	46 (22%)	2.03	45%
Rate the overall usefulness of the worked examples (<i>Sampling</i>)	3 (2%)	17 (14%)	78 (66%)	21 (18%)	1.98	27%
Did you find the expandable feature of the examples useful? (<i>Diodes</i>)	3 (2%)	17 (9%)	89 (50%)	71 (40%)	2.27	40%
Did you find the expandable feature of the examples useful? (<i>Sampling</i>)	3 (3%)	3 (3%)	53 (50%)	46 (44%)	2.35	24%

Analyzing student responses to the free response question

“Why did you find the expandable feature helpful or unhelpful?” yielded a codebook of seven codes. A list of those codes and their definitions is shown in Table VII.

TABLE VII. BRIEF CODEBOOK FOR “WHY DID YOU FIND THE EXPANDABLE FEATURE HELPFUL OR UNHELPFUL?”

Code	N	Code Description	Exemplar
Organized	7	Student finds the expandable examples cleaner	<i>“Doesn’t take too much space if you don’t need to see the work. Explanations are helpful.”</i>
Work By Myself	10	Encourages student to try the problem before looking at solution	<i>“The expandable feature allowed me to either work out the problem on my own or click for help if I needed it.”</i>
Detail	13	Likes the level of detail they can get with the expansion feature	<i>“Sometimes I’m confused with some very basic stuff, and when it happens, these things help me.”</i>
Skip What I Know	4	Student doesn’t have to look at information they already know	<i>“Yes it is helpful because we can open the parts we want to read and close the parts we already know.”</i>
Disorganized	3	Hard to follow, disorganized	<i>“It was unhelpful because it disturbed the flow of ideas from section to section.”</i>
Autoshow	8	Wishes the problem was fully expanded	<i>“This is just an extra step. I find it much better if the author just left the equation on the page instead of hiding it first.”</i>
Helpful	10	Misc. positive responses	<i>“They are great! allow for good interaction”</i>

The “Detail” code was applied to statements that revealed students’ appreciation for the level of detail they could get with the expansion feature. The presence of the “Detail” code indicated that some students benefited from the large number of sub-steps shown in the expandable examples. Many students struggle with only a single sub-step [19], and can be without recourse if that sub-step is not shown in a worked example.

The “Skip what I Know” code was applied to statements where the student mentioned the ability to skip or ignore the collapsed portions of the example easily. The presence of this code indicated that some students liked being able to easily ignore superfluous information. The presence of this code was expected from the worked examples literature [18].

Together the “Skip what I Know” and “Detail” codes capture the potential mitigation of expertise reversal, supporting our hypothesis for Research Question 1. Two exemplar quotations reveal the differences in how students reacted to the expandable examples based on their level of expertise. When asked why they found the expandable examples helpful, one student responded, *“Yes, it is helpful because we can open the parts we want to read and close the parts we already know.”* This more advanced student did not want to be distracted by superfluous information and uses the expansion feature to avoid superfluous information. In contrast, a less advanced student responded to the same question with, *“Sometimes I’m confused with some very basic stuff, and when it happens, these things help me.”* Without the ability to view sub-steps, students might end up missing a basic concept or forgetting a trivial manipulation [19], and they may be unable to find this information in other places.

The “Work by Myself” responses indicate that breaking up the example into phases (and hiding the details) may promote healthier study habits. These responses were unexpected because we had not found prior evidence from the literature suggesting this result. Some students slowed down and attempted problems on their own rather than copying the solution steps. When asked why he or she found the expandable examples helpful, one student responded, *“You are given a hint in the right direction of how to solve the problem, but are not just given the answer straight away. This discourages me from just looking at the answer without really giving the problem a shot.”* With the inclusion of multiple sub-steps, students can open them individually, and try to solve the next part of the problem before viewing the solution.

The affective response to the assertion headings was both strong and positive (see Table VIII). Most students (more than 85%) rated the assertion headings as more useful than ordinary topic-subtopic headings.

TABLE VIII. RESULTS FOR THE FREE RESPONSE QUESTION “WHAT DO YOU THINK OF THE COMPLETE SENTENCE HEADINGS?”

Question	Bad	Poor	Good	Great	Mean (0-3 scale)	Response Rate
What do you think of the complete sentence headings? (Diodes)	2 (1%)	12 (7%)	73 (40%)	94 (52%)	2.4	40%
What do you think of the complete sentence headings? (Sampling)	4 (4%)	11 (10%)	41 (38%)	51 (48%)	2.3	24%

TABLE IX. CODES FOR FREE RESPONSE QUESTION “WHY DID YOU FIND THE COMPLETE SENTENCE TITLES HELPFUL OR UNHELPFUL?”

Code	N	Code Description	Exemplar
Summary	15	Headings provide takeaway main points after reading	<i>“Rather than simply mentioning the general ideas covered in the section, the complete sentence titles also gave insight into what exactly we should take away from each section.”</i>
Prepare	10	Headings help the student know what to pay attention to.	<i>“It was a good indication of the main idea that I needed to get out of the notes.”</i>
Navigation	2	Heading help student find the information	<i>“If I want to know how to compute a certain thing or want to understand a certain topic, I can scan the titles.”</i>
Problem Solving	2	Heading help the student solve problems	<i>“They are applicable and can help me solve problems!”</i>
Content	6	Headings provide extra information	<i>“The complete sentence titles give more information about the subject at hand.”</i>
Unhelpful Length	5	Sentence headings are too long	<i>“It was too much to read.”</i>

The “Summary” and “Prepare” responses to the free response question “Why did you find the complete sentence titles helpful or unhelpful?” indicated that the assertion headings gave students a take-away main point. Students (especially novices) are not yet skilled at discerning what information is vital and what information is tangential, and the assertion headings helped students identify key information. Students

expressed two subtly different views on this aspect. Some students used the headings as a way to verify they had read correctly *after* reading (Summary), others used the headings as guideposts to inform them what they should look for in the text *before* reading (Prepare). These data support our hypothesis for Research Question 2: The assertion headings successfully increased global coherence in the course notes. The “Summary” and “Prepare” responses to the free response question “Why did you find the complete sentence titles helpful or unhelpful?” indicated that the assertion headings gave students a take-away main point. Students (especially novices) are not yet skilled at discerning what information is vital and what information is tangential, and the assertion headings helped students identify key information. Students expressed two subtly different views on this aspect. Some students used the headings as a way to verify they had read correctly *after* reading (Summary), others used the headings as guideposts to inform them what they should look for in the text *before* reading (Prepare). These data support our hypothesis for Research Question 2: The assertion headings successfully increased global coherence in the course notes.

Based on the free response question “Why do you prefer hand-drawn or computer-generated figures?” we created three hypotheses and survey items in the *Sampling* activity to address each one. First, we hypothesized that students prefer hand-drawn figures for affective reasons, such as a perception of caring from the instructor (items 16, 17, 22). Secondly, we hypothesized that students prefer computer-generated figures for reasons of legibility (items 19, 21, 23 and 24). Last, we hypothesized that hand-drawn figures may raise trust concerns for students (items 18 and 20).

The code-inspired Likert scale items from the *Sampling* activity yielded more precise information about some of the themes discovered during the free response question “Why do you prefer hand-drawn or computer-generated figures?” We combined items involving legibility (see Table X) into a composite index of 3 items, and also combined items about emotional response (see Table XI) into a composite index of 4 items. The items are shown with the student response that inspired the creation of that survey item in Table XII.

TABLE X. THE LEGIBILITY COMPOSITE INDEX OF THE SURVEY ITEMS 19, 20 AND 24 FROM THE *Sampling* ACTIVITY.

Strongly Prefers computer-generated	Slightly Prefers computer-generated	Slightly Prefers Hand-drawn	Strongly Prefers Hand-drawn	Overall (0-3 scale)
14 (15%)	44 (47%)	32 (35%)	3 (3%)	1.25

TABLE XI. THE EMOTIONAL COMPOSITE INDEX OF SURVEY ITEMS 16, 17, 20 AND 22 FROM THE *Sampling* ACTIVITY

Strongly Prefers computer-generated	Slightly Prefers computer-generated	Slightly Prefers Hand-drawn	Strongly Prefers Hand-drawn	Overall (0-3 scale)
8 (9%)	15 (16%)	58 (62%)	12 (13%)	2.2

The emotional composite index was composed of four survey items and examined the emotional response to hand-drawn figures (see Table XI). Responses indicate that students feel more confident with, more cared for by, and more invited

TABLE XII. THE LIKERT SCALE ITEMS FROM THE *Sampling* ACTIVITY.

#	Survey Item	Inspiring Response	Code
17	Hand-drawn figures help me learn how to draw those figures better for myself	<i>“Easy to compare to my diagram”</i>	Hand-Relatable
16	Hand-drawn figures make me feel like the instructors care more about my learning	<i>“Feels as if the person cared for the education.[sic]”</i>	Hand-Inviting
22	Hand-drawn figures are more inviting and less intimidating	<i>“The hand drawn ones just seem friendlier and more welcoming”</i>	Hand-Inviting
20	Hand-drawn figures are more credible	<i>“Hand-drawn perceived as more accurate”</i>	Pilot Study
24	I am more likely to pay attention to a computer-generated figure than a neat, legible hand-drawn figure	<i>“I don’t really know, I find that I’m less likely to glaze over them though”</i>	Hand-Inviting
21	Computer-generated figures are easier to interpret	<i>“Easier to read”</i> (occurred verbatim 4 times in the sample)	Computer-Clean and Clear
19	Computer-generated figures are easier to read	<i>“Easier to read”</i>	Computer-Clean and Clear
18	Computer-generated figures are less likely to have errors	<i>“Hand-drawn perceived as more accurate”</i>	Pilot Study
23	Neat, legible hand-drawn figures are less cluttered than computer-generated diagrams	<i>“The symbols on computer are more spaced out and clutter up the diagram”</i>	Hand-Clean and Clear

by hand-drawn figures. The index favored hand-drawn figures by about 3:1. From these results alone, we cannot determine whether the positive emotional responses will lead to increased textbook use or increased performance on exams. Research shows a relationship between a student’s perception that their professor cares about them personally and higher motivation to engage in the course [11]. We were particularly encouraged by one response from a student who responded that the hand-drawn figures made them feel that the professor cared about their education (see Table XII).

The legibility composite index was composed of three survey items and examined the value of neatness and readability in figures (see Table X). Responses favor computer-generated figures over hand-drawn figures by about 2:1. Some students may have been comparing computer-generated figures in ECE 110 to all the hand-drawn figures they had seen in previous classes, and some may have been comparing them to only the hand-drawn figures from the ECE 110 course notes. Negative experiences with sloppily drawn figures in previous classes may have amplified the response to these survey items.

V. DISCUSSION

The quantitative results do not show much statistical significance, but the free response answers are over 90% in favor of expandable examples. Based on the coding results, students value the expandable examples for the reasons we hypothesized they would, choosing to use or ignore the expansion sections depending on their own preparedness for the particular problem at hand. Responses to “Why did you find

the expandable feature helpful or unhelpful?” like this one “*Yes it is helpful because we can open the parts we want to read and close the parts we already know*” support our hypothesis for Research Question 2. Novice students could access the detail they needed to solve the problem, but advanced students could skip the details they already knew. With no prompting, students recognized this purpose of the expandable examples.

Surprisingly, the expansion steps acted as a speed bump for students; they attempted the problem, instead of copying the solution. Students know they need to solve problems independently in order to succeed, but often succumb to the temptation of copying solutions [40]. With expandable examples students can more easily resist the urge to use the entire solution, but if they get stuck, they have the option to view the key part of the solution. Expandable worked solutions could bring extra value to online solution manuals, encouraging students to work through the solutions rather than look for quick answers.

Since students prefer to read summaries of chapters over the whole body of the text [1], [2], it is important that educators developing textbooks consider the amount of time it takes students to study when creating and evaluating the usefulness of pedagogical materials [12]. Students are concerned with whether a particular passage helps them solve the problem at hand and do not want to waste time reading unnecessary information in the text. By scanning the headings for relevance to their current task rather than reading the whole section, students can spend less time looking through irrelevant materials. In this small study, the assertion headings did not have any significant effect on quiz performance, but the free-response questions indicate that the assertion headings helped students focus on the important parts of the material while they were reading the text. Given the small amount of extra writing involved, assertion headings may be a quick and easy way to add value to textbooks and increase their use.

Unfortunately, the possible effect that assertion headings have on the author of the textbook while writing could not be studied. Because the author of the course notes wrote them with the assertion format in mind, we suspect having assertions in mind influenced his style of writing. We suspect that conforming to the assertion form constrains the writing of the text, forcing the author to maintain global coherence for each passage. Many textbook chapters have crowded sections with too many ideas jockeying for prominence and meandering passages with no main thesis. The author of the course notes casually reported that writing with the assertion format in mind caused him to focus his writing. Additional research is needed to investigate this idea.

The majority of students agreed that hand-drawn figures allow them to be more confident in their own ability to draw similar figures from the material. This theme came as a surprise to us. It appears that a sort of vicarious self-efficacy [11] effect may be generated by the hand-drawn figures. Though a computer-generated figure and a hand-drawn diagram represent the same circuit, students feel a hand-drawn figure is easier to replicate and compare to their own work. Since students do most, if not all, drawings of circuits on paper in introductory courses like ECE 110, hand-drawn diagrams in the course notes or textbook may affect the quality of student drawings or the ability of students to turn computer-generated images into their own drawings without having seen someone else do it

first. A future study could investigate the effect of hand-drawn figures on the quality of circuit sketches produced by students.

Students’ responses to “Hand-drawn figures make me feel like the instructors care more about my learning” were encouraging. To succeed, students need to feel that their instructors care about them [11]. Perhaps students inferred their instructors cared more because students know that neatly drawn figures take time to make and believe that only a caring instructor would spend the time to make a nice figure. Another possible explanation is that simply knowing someone personally created the figure may affect students emotionally. Drawing figures *neatly* entails an extra time cost to authors compared to computer generation, and also imposes consistency problems on larger works with multiple authors. Our results do not suggest changing all textbook figures to hand-drawn ones. However, figures students are expected to replicate might be more effective if they are hand-drawn in the textbook.

A. Limitations

We had no control for time-on-task in any of the experiments, given the natural studying design of the study. Furthermore, the short (1 hour) time of exposure to the content was not long enough for students to deeply learn the material. The demographic makeup of students participating in the two activities may have shifted. Some students may have ignored the assertion headings, or members of the control group may have found the end of chapter assertions equally helpful. Prior experience with the technical content topics was not controlled for, nor did we perform any rigorous pretest/posttest comparison. The implicit difference in difficulty of the content between the *Diodes* and *Sampling* topics may also muddy results. Similar to McNamara’s study [32], it is possible that some students actually performed better when exposed to less coherent materials. It is possible than even a small difference in initial preparation by the Assertion Headings group could have had a large impact on performance in the much more difficult *Sampling* activity. The affective responses may be skewed positive due to the Hawthorne effect [41], person-positivity bias [42], and acquiescence response bias [43]; the highly positive ratings of the new course materials must be interpreted with caution.

VI. CONCLUSIONS

The textbook innovations explored in this study had a marked affective impact on students. The effect on students’ feelings toward the instructor, self efficacy, and self-regulation indicate these techniques are worthy of further investigation (given the low additional cost of implementation over traditional textbook writing). Due to several confounding factors and the exploratory nature of the experiments, no firm conclusions can be drawn on the influence of these textbook writing styles on student performance or willingness to read their textbook more. However, the survey responses are encouraging.

The changing nature of textbooks with technological innovations provides an unprecedented opportunity to change the perception of textbooks and increase their use. To help textbooks evolve from costly and unhelpful materials to exciting and valuable resources, additional research on textbook construction is warranted.

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STEM Summer Camp Follow Up Study

Effects on Students' SAT Scores and Postsecondary Matriculation

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Abstract— Postsecondary matriculation is important for a young person's future financial and social positioning. Matriculation can be attendance at a four-year institution, two-year program, or a trade school of some kind. Scores on standardized tests such as the SAT are often components of a student's application to attend a postsecondary education institution. This is a follow up study to one in which students ($n=35$) from the same school attended a STEM summer camp. The STEM camp lasted 13 days and engaged students in project based learning activities 8 hours per day. Students attended classes on robotics, bridge building, solar power, and other challenging, informal learning activities. The results of that study found statistically significant gains for both reading and writing, although not for math. This study followed up with 27 of those students by obtaining their SAT scores and matriculation to postsecondary education data. Correlations between SAT and matriculation, confidence intervals for SAT results, and effect sizes are given. Further research recommendations are discussed.

Keywords—STEM, SAT, matriculation, informal learning, project based learning

I. INTRODUCTION

The Aggie STEM summer camp combined two key elements to bring about student success: an informal learning environment and project-based learning. Students can learn in many different ways and the traditional school setting gave only one platform for teaching and learning. Informal learning environments offered students experiences outside of the typical classroom walls and enabled them to engage with content in a new and exciting way. These informal settings could take place in many forms, such as after school programs, museum trips, and summer camps. Project-based learning, a method of instruction that was hands on and practical, enabled students to put their knowledge to work. Collaborating to achieve a common goal, students could strengthen their understanding by applying their content knowledge to real world problems. The Aggie STEM summer camp offered opportunities for students to engage in project-based learning activities and to enhance their knowledge of the STEM disciplines. A national emphasis on science, technology, engineering, and mathematics (STEM) and increasing college attendance have made endeavors such as the Aggie STEM summer camp a growing interest to researchers, politicians, and parents. Therefore, researchers followed the academic progress of students who had attended the Aggie STEM summer camp and investigated how they performed on national standardized tests and their eventual matriculation to postsecondary study.

A. STEM

In recent years, interest has grown concerning the learning and teaching of STEM disciplines in the United States. This growth resulted from the performance of students in the United States compared to that of their international peers on math and science exams and the lack of students graduating with STEM degrees to fill the growing number of STEM jobs in the United States. These two areas were critical in insuring that the United States maintains a position of leadership on the international stage.

The Programme for International Student Assessment (PISA) was an international study in which a test evaluating student proficiency in mathematics, science, and reading was administered. These students were 15-year olds, and the sample was representative of each nation's student population. The PISA test was first administered in 2000 and has been repeated every three years since that time. Results of the 2012 administration listed the United States as 27th in mathematics and 20th in science when compared to other Organisation for Economic Co-operation and Development (OECD) member countries [1]. While the actual scores of students from the United States have not statistically significantly changed from the 2009 test, the United States' ranking has changed. This indicated that students from other nations were outperforming students from the United States. Such a downward trend in the rankings was startling, especially for a nation that was seen as the technology and innovation leader of the world [2; 3; 4]. These students who were performing below their international peers were the future workforce and leaders of tomorrow.

The workforce being produced in the United States was also an area of growing concern. The number of researchers in science and engineering fields was increasing at a higher rate outside of the United States in countries such as South Korea and China [5]. This increased number of researchers dedicated to the creation and growth of new knowledge in STEM fields could be perceived as a challenge to the United States' leadership in these areas. On the other end of the job market spectrum, positions that may not be seen as STEM jobs still require proficiency in problem-solving, basic STEM knowledge, and technical expertise [6; 5]. Having a population of workers that lacks proficiency in STEM disciplines and the associated problem solving skills in an ever increasingly interconnected and technological economy could threaten the productivity of the United States. In response, President Obama launched the Educate to Innovate campaign with the purpose of raising student understanding, interest, and attainment in STEM areas [7]. This project and others were crafted in an attempt to bring the United States to the forefront in mathematics and science achievement and to meet the domestic labor force needs of an innovative economy.

This need for more students to be proficient in the STEM disciplines and a more STEM competent general public catalyzed the development of the Aggie STEM summer camp, an informal learning environment in which students engaged in STEM related tasks through project-based learning (PBL). Informal learning settings and PBL were cornerstones in the creation of the Aggie STEM summer camp because they have

been shown to engage, motivate, and inspire students in a multitude of ways.

B. Informal Learning

Informal learning has been defined in many different ways. The definition applied in this paper emphasized learning that occurred outside the school setting, was voluntary in nature, and was developed separately from the school curriculum [8]. Informal learning programs originally developed out of concerns for improving school achievement, youth safety, and exposure to enrichment opportunities in the arts and sciences [9]. Activities that were classified as occurring in an informal setting could range from watching television or shopping in a mall to playing on a sports team or going to museums [10; 11]. The home was an important informal learning environment where parents could play an impactful role in the development of a child's numeracy and literacy skills [12]. More structured informal learning environments consisted of museums, zoos, afterschool youth programs, clubs, and science media designed for learning [13]. Reports have shown that these structured informal learning environments play an important role in students learning science [14; 11; 15; 16]. Increasing the content knowledge of students by utilizing informal learning environments could be critical in addressing the issues of innovation and a STEM proficient workforce. Beyond learning content in informal learning environments there were affective benefits as well.

The benefits of structured informal learning environments were more than cognitive. Field trips to science centers could generate in students enthusiasm and wonder that would not normally develop in the traditional classroom setting [17; 18]. Research has shown that motivation, attitude, and academic engagement play key roles in mathematics and science achievement [19; 20]. These experiences may also create an interest in the STEM disciplines, which had an impact on students deciding to pursue STEM as a career later in life [21]. Real world applications that were meaningful to students raised their interest in STEM [22], and these additional programs encouraged students to consider college majors in a STEM field [23]. The STEM subjects were traditionally male dominated, but these informal learning environments gave girls an opportunity to learn in these fields in a non-competitive setting [18]. Increasing student interest in and motivation to pursue STEM through informal learning opportunities could help address the issues of international competition and an under skilled domestic workforce.

The combination of informal learning and STEM has been the focus of research and financial investment. The National Science Foundation, through its Science Learning + program, will provide up to \$14.4 million in grant funding for researchers to investigate best practices in informal learning with a specific focus on STEM learning for students of all backgrounds [24]. Reference [25], in its report of recommendations to the president, suggested that students be involved in out-of-school STEM learning activities including after school programs, STEM contests, and summer programs. The Aggie STEM summer camp fit these recommendations and sought to motivate young people to pursue STEM fields.

C. Project Based Learning

The method of instruction prevalent at the Aggie STEM summer camp was project-based learning (PBL). PBL was described as students working to solve real world, difficult problems through an inquiry process that required gathering information, collaborating with peers, developing a plan, and presenting a unique solution [26; 27; 28]. This active learning engaged students in problem solving that was substantially different from the traditional classroom and emphasized the use of knowledge in a context. Therefore, while rote knowledge may not be enhanced by PBL, evidence has shown that PBL enhanced the application knowledge of students [29]. This application of knowledge translated into students being able to use their formally taught knowledge in meaningful ways, thus helping them make the connection between the classroom and real life.

Benefits to using PBL, much like the benefits of engaging in informal learning, were both cognitive and affective. PBL was found to be beneficial in increasing young children's knowledge and made learning enjoyable and meaningful [30]. Middle school students who learned in a classroom that effectively implemented PBL learning strategies appeared to be more engaged and more motivated in the classroom than students in a classroom that used traditional lecture methods [31; 32]. At High Tech Middle, where students were admitted based on a lottery system and where PBL was an integral part of the learning experience, students performed at a high level on standardized tests, and 99% of graduates went to college after high school [33]. In the high school science classroom, the use of PBL was shown to prepare students to be more successful than similar non-PBL instructed peers [34]. Implementation of PBL over a three-year period in one high school resulted in higher student motivation, greater self-image, and an increase in the total number of students meeting college entrance requirements [35]. Real world applications that required students to combine knowledge that they acquired from the classroom in order to address problems could help students to see themselves as the problem solvers of the future. PBL was used widely in engineering courses on the college level because of its similarity to actual engineering work that involved the application of an interdisciplinary set of knowledge to complete a project that could possibly take a long period of time to finish [36]. While PBL and informal learning may improve students' readiness for college, some young people may be asking the question: Is it still worth going to college?

D. College Enrollment

As the cost of college attendance has increased in recent years, many were left asking if it was profitable to go to college. Research has shown that earning a college degree compared to only a high school diploma or less still has great economic benefits and even more so now than at any other time in the modern era [37]. Even with debt and missing out on potential earnings during college, average students could recover the cost of attending college by the age of 40, meaning that all earnings after that point were returns on their investment in a college degree [38]. Students who earned a college degree had a median income 50% higher than the

median income of their peers who only had a high school diploma [39]. During times of recession, those without a college degree were more likely to lose their jobs than those with a college degree [40]. Earning a college degree increases earning power and could help with job security, even in an unstable economy. Having the opportunity to go to college could be a challenge, with many admissions committees looking at a long list of criteria for admittance. However, one trait of many that universities had in common was an interest in performance on the Scholastic Achievement Test (SAT).

One item used by many colleges in admissions decisions was scores on the SAT. This test, taken by many high school juniors and seniors, was comprised of critical reading, writing, and mathematics sections and was accepted as a component of admissions decisions by almost every college and university [41]. Each section of the SAT had a maximum point value of 800 points. SAT test scores and high school grades have been shown to be predictors of college success, making achievement on this exam even more critical [42; 43]. Recognizing the importance of doing well on these exams, students have turned to many informal learning sources to improve their performance. Millions of dollars have been spent sending students to learning centers, taking test preparation courses, and purchasing test prep manuals to reinforce knowledge assessed on the exam and gain test taking skills that may give students an advantage on test day [44]. Informal learning opportunities have been shown to be a means of increasing student success; however, this investment at its extreme has been criticized as overly pressuring students to attain an unrealistic expectation [45]. The investment and importance placed on the SAT put achievement on the exam in the national spotlight. Due to the SAT being so widely used and accepted as a metric of student ability, results on the exam by graduating seniors could be used to identify achievement gaps that exist in the United States. These gaps limit the potential of some groups of students to attain college admissions and the associated benefits of a college degree.

Differences in performance on the SAT existed based on gender and ethnicity [46]. Since 1972 a performance gap has existed between males and females on the SAT. The average scores for college bound seniors in both the critical reading and mathematics sections have been in favor of males. This gap was smallest for critical reading, with gender differences each year ranging from 2 to 13 points. For mathematics, the gap was consistently larger, ranging from 31 to 46 points. The combined scores of both test sections yielded an average gap of 44 points in favor of males from the years 1972 to 2014. When investigated by ethnicity for graduating high school seniors in the year 2014, the average SAT combined critical reading and mathematics scores for Asians was 1121, Blacks was 850, Hispanics was 910, and Whites was 1053. Average scores by ethnicity and gender indicate gaps in achievement and may contribute to the explanation as to why there exists an underrepresentation of minority groups and women in STEM fields. Gender gaps within these ethnic groups were evident and were generally consistent with the overall gender gap. These differences in achievement beckon researchers and educational innovators to come up with new solutions to address inequities.

The Aggie STEM summer camp was developed to increase students' content knowledge and to instill in them a desire to pursue a STEM field and college in general. The informal learning environment complemented the students' school learning by enabling them to engage in the same subjects but in a different context. Through the implementation of PBL and by being located on a college campus, the Aggie STEM summer camp sought to increase student interest and motivation to pursue STEM fields and to create an environment in which students could see themselves as future undergraduates.

II. METHODOLOGY

During the summer of 2010, The Aggie STEM Center provided a two-week long STEM residential summer camp for underrepresented secondary students from one urban inner city academy in Texas. These students ($n = 35$) participated in an intensive STEM focused curriculum for 13 days. Sessions included real world science and mathematics applications through project-based learning (PBL) activities, robotics, university engineering and science lab tours, radio and television communication, museum tours, and SAT preparation. For example, one of the STEM projects students were given was to design and build a popsicle stick bridge that could hold as much weight as possible. Students engaged in the engineering design process and were required to plan and develop designs for their bridges prior to construction. On the final day, these bridges were tested and the one with the highest load capacity won. The SAT preparation sessions were held daily focusing on mathematics, reading, and writing for a minimum of one hour. Emphasis was placed on these three content areas plus general test taking strategies. These sessions supplemented advanced mathematics, science, and engineering instruction that students received during the remaining 7 hours of the camp day. The content of the PBL activities was not directly aligned with specific SAT type questions, although students did have to utilize some knowledge that can be tested on the PSAT and SAT to complete the projects. Students took PSAT tests at the beginning and at the end of the camp.

After the camp was over, Aggie STEM maintained contact with the students informally through its website and social media. School visits and supplemental instruction were conducted three times during the school year until all students had graduated in 2014. This study demonstrated the learning successes that can be achieved through STEM project based learning during a summer camp and with periodic follow-up and interaction via social media at a major Texas university with underrepresented high school students.

The final SAT scale score used for college admittance was available. Due to the longitudinal nature of this study, eight students relocated and were lost to the study leaving a reasonable study sample that still reflected the original group ($N=27$). The final sample consisted of 10 females and 17 males. There were two Asian, 11 Black, 11 Hispanic, and three White students in the final sample. Data analyses consisted of recommended methods [47; 48; 49; 50]. The recommendation for data analysis was to report findings in a way that promotes meta-analytic thinking so that conclusions can be drawn across studies [51; 52]. Therefore, in addition to disaggregated means, standard deviations, and correlational analyses, non-sample

size dependent estimates of importance were used. Data were analyzed using 95% confidence intervals and Cohen's d effect size estimates. Data confirmation follow-up was scheduled for the semester following post secondary matriculation.

III. RESULTS

When examining overall longitudinal performance, students matriculated at a much higher rate than that of the school overall: 52% as compared to 28%. Pearson r correlations were calculated between PSAT and SAT scores. The PSAT scores were derived from the post test scores taken during the summer camp. Results showed that PSAT scores were nearly perfectly correlated with SAT scores (Reading PSAT with Reading SAT, $r = 0.999$, Math PSAT with Math SAT, $r = 0.999$, Writing PSAT with Writing SAT, $r = 1.000$). The correlations were not unexpected because the PSAT and SAT tests were shown to be strongly correlated [53; 54; 55]. The overall matriculation rate of 52% included four students for whom matriculation information was not available but who remained in the total. This method ensures a conservative estimate. Matriculation data came directly from students, whereas the school provided SAT scores. The most common issue in failing to obtain matriculation information was wrong or changed telephone numbers and/or closed or incorrect e-mail addresses. Of the sample, 48% had not committed to a post secondary institution with 62% having decided to pursue or having a full-time job, of which 15% chose to enlist in the U.S. armed forces. Point-biserial correlation coefficients were calculated between SAT results and matriculation. The point-biserial correlation coefficient was algebraically equivalent to Pearson r , however point-biserial characterized the relationship between an intervally scaled variable, in this case score results on the SAT, and a dichotomous variable, in this case matriculation [56]. The correlations between scores and matriculation were: 0.408 with Reading SAT, 0.542 with Math SAT, and 0.338 with Writing SAT scores. The correlations between matriculation and Reading SAT scores and matriculation and Math SAT scores were statistically significant at the 0.05 level. It was possible that while Writing was perfectly correlated between PSAT and SAT it was not as important to matriculation. Perhaps post secondary institutions place a greater emphasis on Mathematics and Reading scores in admission decisions. Students would benefit from knowing that added emphasis on reading and mathematics could result in more favorable college admission results.

A planned follow-up during the summer resulted in fewer than 30% successful contacts so no further data were gathered to determine first semester success or changes in matriculation. There was both a practical and statistically significant difference in scores when comparing students who had matriculated ($M=1070$, $SD=104.73$) and who had not matriculated ($M=932$, $SD=82.78$) (see Figure 1). The Cohen's d was 1.45 favoring those who had matriculated. While one would expect the group who matriculated to have scored higher, the effect size was impressively large being nearly 1.5 standard deviations different. To examine the potential for matriculation more closely, the mean scores for males, 1028.82 ($SD= 96.43$), and females, 961 ($SD= 96.43$), indicated that there was no statistically significant difference (See Figure 2),

but the Cohen’s d (0.596) indicated the results were practically significant.

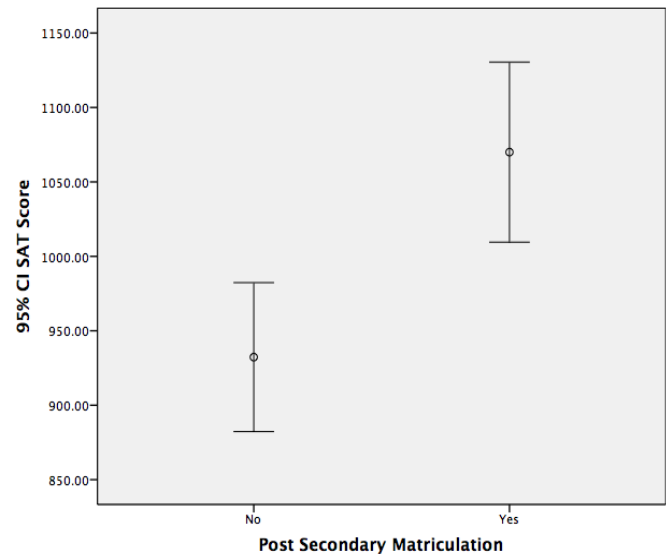


Figure 1. Post secondary matriculation by SAT scores.

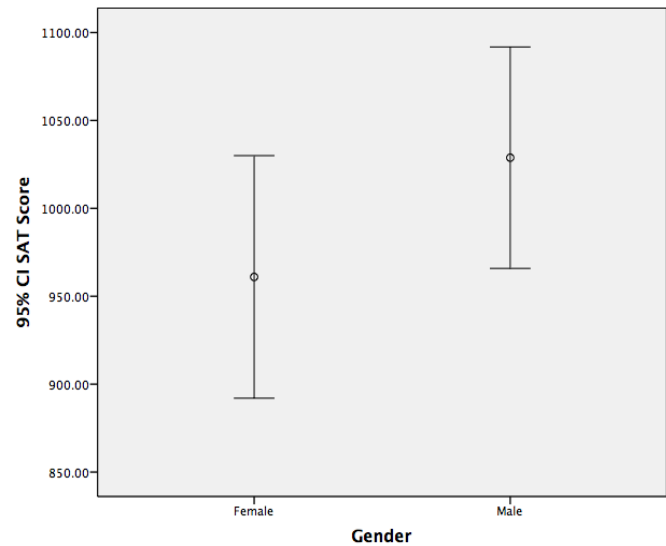


Figure 2. Gender by SAT scores.

When considering male and female performance for students who matriculated into a post secondary program, the scores were not statistically significantly different ($M_f=1001.67$, $SD=105.60$; $M_m=1121.25$, $SD=71.40$) (See Figure 3). However, the mean difference was 119.58 points, which accounted for a Cohen’s d effect of 1.37 that was large. Males exhibited a practically important gain over female scores.

The sample was ethnically diverse but the sub-groups were small. When considering the group as a whole there were

neither statistically nor practically significant differences by ethnicity on obtained SAT scores (see Figure 4).

When considering only those who matriculated into a post secondary program, the means were slightly higher than for the whole group but only marginally. Only one Asian student matriculated so a point on the graph represents that estimate. While that number was larger than for the group it was hard to draw conclusions about a single case. There were no practically or statistically significant differences (see Figure 5).

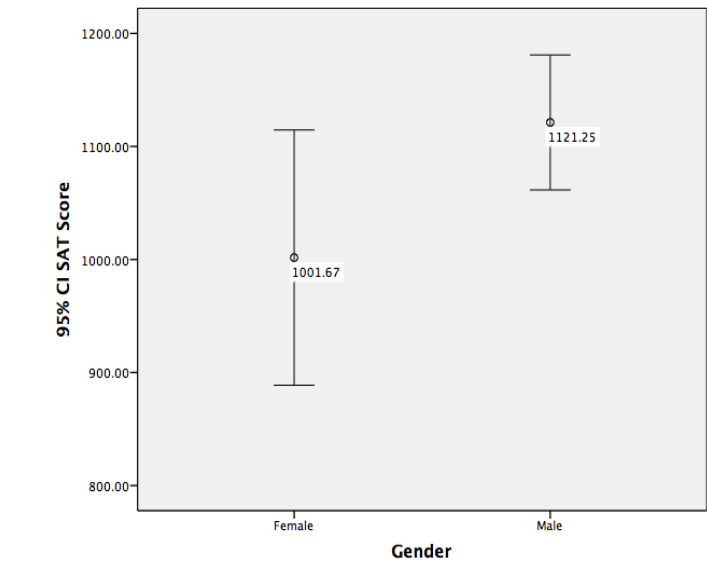


Figure 3. Gender by SAT scores for post secondary matriculation.

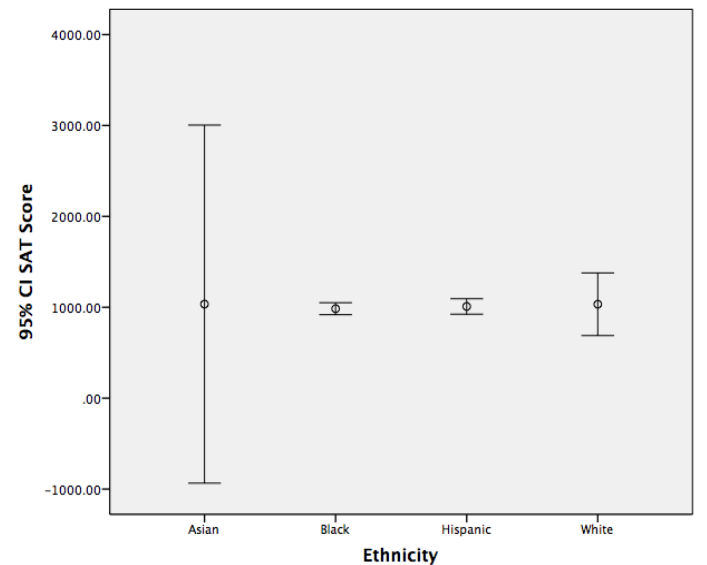


Figure 4. Ethnicity by SAT score.

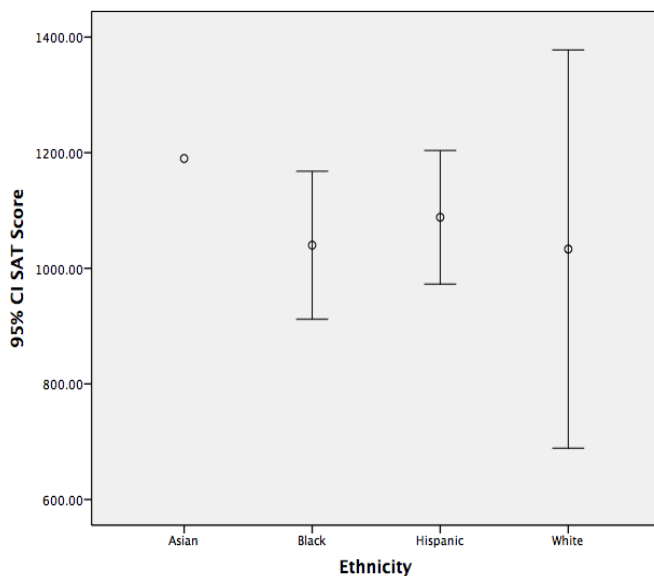


Figure 5. Ethnicity by SAT score for post secondary matriculation.

IV. DISCUSSION

The United States has been the technology and innovation leader of the world. That mantle, however, is in danger of leaving the United States as other countries are taking steps to improve the mathematics and science knowledge of their students. The Aggie STEM camp was designed to help meet the challenge of growing a generation of young people interested in and motivated to pursue a postsecondary education with a STEM major specifically in mind.

The informal learning environment that a camp such as the Aggie STEM camp provides is an ideal setting for engaging students in new and exciting ways. This opportunity to learn outside of the traditional classroom creates an environment for mutual attainment regardless of gender and apart from the pressures of standardized testing. PBL compliments this environment well by giving students hands on learning opportunities. This strengthens their ability to apply classroom knowledge in real life situations or with tasks that resemble what they will be doing in future careers.

Another emphasis of the camp was to give students a college like experience. With students residing on campus for the duration of the camp and experiencing some aspects of the college life, they were able to see how it will differ from their high school experience. Such exposure to a college campus would hopefully motivate students to take steps that will help them matriculate later in life. SAT preparation can make a difference in student performance on the SAT and thus make an impact on whether or not they are accepted to a university. This study followed students who experienced the Aggie STEM summer camp into postsecondary matriculation.

The students who came to the Aggie STEM summer camp were successful in several ways. They matriculated to postsecondary schooling at a higher rate than the average of students at their school. This informal learning experience on a

college campus may have contributed to students seeing themselves as future college students and may have instilled in them a sense of belonging on a college campus. Students were also successful in their performance on the SAT. Gender gaps did exist for the data collected from these students; however, the gaps that traditionally exist for ethnicities were not prevalent. These results show that while the Aggie STEM camp experience, and possibly other informal learning environments, may not be able to completely eradicate performance inequities, the camp experience could be a means of minimizing these gaps.

SAT score results were correlated with matriculation to a postsecondary institution. These results showed that a relationship between performance on the SAT and decisions to matriculate existed, especially for mathematics and reading. The SAT is often used in college admissions decisions, so a higher performance on these tests would make a student more appealing to a university or other institution's admissions board.

The Aggie STEM summer camp has been further developed since the time of the initial data collection. New projects have been created to increasingly engage students in activities that are interesting and that utilize classroom knowledge in new, applicable ways. The camp itself has grown in attendance so that now multiple camps are necessary to accommodate all of the students that are interested in attending. As the camp continues to grow and impact the lives of students, further research can be conducted.

Further research needs to be conducted on informal learning environments, project-based learning, and STEM education. One limitation of this study was the small sample size. Future research on informal learning, PBL, and STEM education could benefit from using a larger sample size. Research investigating the potential of informal learning environments to reduce achievement inequities found by ethnicity and gender could indicate how best to support and encourage the involvement of underrepresented groups in colleges and careers. Informal learning environments that encourage collaboration in a non-competitive environment may help to address these issues. Research can be done with longitudinal tracking of students through postsecondary matriculation. The current study attempted to longitudinally track students through their first year of matriculation but was unsuccessful in doing so. Such a long-term study would yield greater insight into the possible far reaching implications informal learning and PBL have on students. More research on the use of PBL and the teaching method's impact on student motivation and interest may help to clarify PBL's strengths. Studies that use a pre/post test evaluation of student interest and motivation with a PBL teaching intervention may yield such results. Finally, STEM education is a national issue that many are attempting to address. In order to insure the continued prosperity of the United States, developments in understanding how students best learn STEM and what can be done to interest more students in the STEM disciplines are critical.

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Nanotechnology STEM Program via Research Experience for High School Teachers

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Abstract— In this work, we report the outcomes from the IUPUI STEM outreach program “STEMCorp” that inspires high school students to pursue STEM majors. The STEMCorp program was modeled after the Multidisciplinary Undergraduate Research Initiative (MURI) at IUPUI. MURI research program introduces undergraduate students from at least two different departments with mentors from different disciplines to address research issues that may compose both engineering and sciences. The STEMCorp program brings undergraduate students to work with faculty and high school teachers to create a positive impact in enriching the high school students by introducing them to engineering and science with emphasis on nanotechnology for future careers. The program describes the collaborative activities between faculty, undergraduate students and high school STEM teachers in the creation of project-based, student-centered learning modules in the field of nanotechnology. The paper details the activities of the STEMCorp participants including their experiences in developing working partnerships and creating and implementing learning modules in the designated high school courses. The success of the program is assessed by the measurable outcomes of high school students’ research projects. Specifically, two different learning modules are presented, including the processes used in the development of these modules and their outcomes. The collaborative research

discussions between the faculty, undergraduate students, and high school teachers are detailed, covering research methodologies, hypothesis, and expected outcomes.

Index Terms—STEM, nanotechnology, research experience for teachers, high school students, projects, collaboration

I. INTRODUCTION

MURI is a research program that was established at IUPUI more than 10 years ago. It was created to encourage multidisciplinary projects from across schools [1, 2]. Projects offered by mentors from different disciplines have led to unique research experiences for undergraduate students. More than 40 students are funded every semester from this program. The projects are analogous to industrial models where different engineers and scientists work together on a multidisciplinary project. One example of such a collaborative project is a battery system, where electrical engineers contribute to the electrical and mathematical models while mechanical engineers contribute to the thermal science issues within the system. Chemical engineers, however, are also experts in the electrochemical process of the system. Control engineering and computer engineering may add to the optimization and safety of the devices. Likewise, in many medical research projects, students from biology, bioengineering, computer engineering, image processing, among many others, may contribute to such multidisciplinary research. These programs operate with the same ideology; using information and skillsets from various disciplines to achieve a common goal. This approach can provide more rounded and comprehensive solutions to modern day problems.

It has been widely acknowledged that there is a need to improve students’ STEM skills and increase diversity in STEM fields at all levels of education [3-6]. A necessary step in addressing this need is drawing students to STEM disciplines at an early age thereby assuring that they have developed necessary skill sets for college degrees in STEM fields. For this, based on the MURI model, a pilot project,

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“STEMCorp,” was designed to form collaboration among high school teachers from urban schools, IUPUI students who have been successful in STEM fields, and IUPUI faculty who have demonstrated interest in improving STEM education. The project also builds on IUPUI’s existing strengths in nanotechnology outreach and education through the Integrated Nanosystems Development Institute (INDI) [7]. INDI provides a good infrastructure for student-mentor interactions, which was utilized because nanotechnology has proven to be a STEM subject attractive to high school students. More specifically, the project builds on the success of the already established INDI nanotechnology camps for high school teachers and students that were established four years ago [8]. The need for a better means of transferring the content and the skills from these camps into classrooms has been identified by high school teachers who have taken part in assessments at the end of the camp sessions. The STEMCorp collaborative research team addresses these concerns as research questions and provides solutions that relate to this gap in transference.

The STEMCorp program is developed and administered in collaboration between the following three IUPUI campus units:

The Center for Research and Learning (CRL) [9]

This center is associated with the Office of the Vice Chancellor for Research. CRL is dedicated to serving students through a series of undergraduate research programs overseen by CRL program leaders. These programs offer students the opportunity to carry out innovative research, scholarship, and creative activity with faculty mentors through internally and externally funded programs. CRL programs expose and engage students in research experiences, providing effective pathways for lifelong active learning, scholarship, and professional development. The vision of CRL is to create and sustain world class programs in inquiry-based student learning through innovative multidisciplinary collaboration and effective mentoring, and promote lifelong active learning and professional development.

A. The STEM Education Research Institute (SERI) [10]

SERI is dedicated to education research in STEM fields, combining knowledge of teaching and learning with deep knowledge of discipline-specific science content. Based on this, the institute is dedicated to the development and dissemination of STEM education programs in collaboration with external partners. The vision of SERI is to be a nationally and internationally recognized center of excellence for STEM education research, contributing to the advancement of STEM education in Indiana and the nation.

B. The Integrated Nanosystems Development Institute (INDI)

INDI is a research center comprised of faculty from the Schools of Science, Engineering and Technology, and Medicine. The given faculty have expertise in a wide range of

fields, including chemistry, physics, biology, material science, electrical and computer engineering, mechanical engineering, orthopedics, pathology and laboratory medicine. The vision of INDI is to be a resource for the realization of nanotechnology-based miniaturized systems that contribute to the economic growth and social advancement of Indiana and the nation and benefit humanity as a whole.

II. STEMCORP

For STEMCorp, the project was divided into four distinct phases.

A. Phase I

Three high school science teachers from the Indianapolis area were recruited, three IUPUI faculty in STEM disciplines were identified (one from science, one from engineering, and one from education), and six undergraduate students (STEMCorp scholars) in STEM fields were recruited who served as the research scholars in the summer and as high school teaching assistants and peer mentors in the academic year.

B. Phase II

The STEMCorp scholars participated in three weeks of INDI’s nanotechnology camp activities, including the sessions for high school students and high school teachers. In addition, the scholars participated in the CRL’s summer undergraduate research program and attended a series of research and professional development workshops designed to enhance their research skills. The STEMCorp Scholars also obtained documentation required to engage in human subject research and to work with minors. At the end of Phase II, the team delivered the following:

- 1) *Initial needs assessment data*
- 2) *A set of activities that can be used in high school classrooms to further nanotechnology-related skills*
- 3) *Guidelines for the facilitation of these activities*
- 4) *A prototype for a mobile kit that contains the materials needed to implement these activities*
- 5) *A set of online resources (web quests, videos, interactive games, etc. that can be used to further enhance students’ skills)*
- 6) *A schedule for piloting the activities in the classrooms during the following academic year.*

C. Phase III

The research team implemented the activities with the high school students. The high school teachers took the lead and IUPUI STEMCorp scholars assisted the teachers. The Program Coordinator, IUPUI faculty, and the high school teachers all served as mentors for the IUPUI STEMCorp scholars.

D. Phase IV

Finally, in Phase IV, the STEMCorp team will reassemble to assess outcomes and write a final report on the results. Deliverables for this phase of the project will be

- 1) research abstracts, posters, and papers from the STEMCorp student scholars
- 2) final reports from the IUPUI faculty mentors, high school teachers, and the program coordinator
- 3) needs assessment data and program evaluation outcomes gathered by the two SPEA students
- 4) presentation of results at one conference at a minimum
- 5) development of options for sustaining the STEMCorp program

Both formative and summative assessment methods are being employed including surveys, interviews, focus groups, and analysis of research products (teaching modules). The inputs from these assessment methods will be used to reflect and to enhance the program. In continuation of Phase IV, participants will review and evaluate their individual experiences of their first summer and academic year participation in the program, as part of their work. Reporting of the student experiences will take place through participation in the CRL's summer poster symposium, the IUPUI Research Day symposium, and/or the Indiana University Undergraduate Research Conference. Phase IV will also include collaborative work by the "community of practice" with the product of a summary "white paper" reviewing outcomes of the assessments and evaluations. In addition, the white paper will identify the elements associated with successful completion of STEM coursework and make recommendations for sustaining the program.

III. OUTCOMES

A. Short-term Outcomes

- 1) Indicators identified for competence in nanotechnology-related knowledge and skills mapped to high school standards.
- 2) Collaboration among faculty from IUPUI Schools of Science, Engineering & Technology, and Education; high school science teachers interested in integrating nanotechnology-related content and skills into their high school curricula; and IUPUI STEM majors interested in research and nanotechnology.
- 3) Increased knowledge and skills related to nanotechnology among IUPUI faculty, high school teachers, IUPUI STEM majors, and the approximately 200 high school students from schools represented by teachers in the program.
- 4) Increased research, mentoring, and professional development skills for IUPUI STEM majors.
- 5) Materials and resources related to nanotechnology skills identified and links placed on INDA and SERI websites for use by other community schools.
- 6) Hands-on mobile nanotechnology teaching kits developed for use by CRL scholars and high school teachers in the field.

B. Long-term Outcomes

- 1) Changes to high school curricula to integrate nanotechnology knowledge and skills.

- 2) Increased number of participating high school students selecting STEM majors in college (especially those related to nanotechnology).
- 3) Increased number of participating high school students selecting IUPUI as their college of choice.
- 1) Increased number of CRL scholars going on to graduate school in STEM-related fields (especially those related to nanotechnology).

IV. RESULTS AND DISCUSSIONS

Two teaching modules have been developed under STEMCorp so far.

A. Example Project 1

Project 1 was conducted by high school students at local career and technical center. The students involved were high school juniors or seniors in their third-year of the Project Lead the Way Biomedical Science curriculum. In the first semester, students designed a lab to compare the antimicrobial effects of silver nanoparticles, silver ions, and traditional antibiotics on the growth of multi-drug resistant bacteria. Most students compared the zone of inhibition created by the different potential antibiotics. Students wrote lab reports describing their findings.

In the second semester, student groups researched ways to use nanotechnology for the early detection of cancer and presented their findings. Students created 3-D models demonstrating how the device works, image 1.



Image 1: 3-D models of lab on a chip and nose sensor constructed by students at McKenzie Career Center using simple school supplies.

Students were given a pre-test and post-test (N=76). To measure the change in their knowledge of nanotechnology, nanotechnology devices and their usage in cancer detections. The questions include:

1. Which of the following is/ are nanoscale objects?
 - a) An antibody.
 - b) A hydrogen atom
 - c) A strand of DNA.
 - d) A cancer cell
2. Elaborate on the nanotechnology processes for detecting cancer?
3. Much research is devoted to developing better methods for diagnosing cancer. Describe TWO of the problems or limitations of the current cancer diagnostic methods/ tools.

4. List TWO types of nanotechnologies or nanomaterials used in the detection of cancer.

5. Explain how ONE developing nanotechnology for cancer detection works.

- Include as many details of the process as you are able.
- Be sure to discuss why this is a NANO-technology.
- What is NANO about it?

6. Describe ONE advantage that nanotechnology devices/materials have over our traditional methods of diagnosing cancer.

These questions were assigned point values. The first two questions were worth one point each, questions three through six required detailed description and thus were assigned multiple points.

For the pre-test, the majority of students from the class responded “I don’t know” to the above set of questions. After the activity, they were given a post-test which was identical to the pre-test. The questions were designed to test their knowledge of nanotechnology processes, current research in cancer diagnosis using nanotechnology and advantages in nanotechnology devices that may have over traditional methods of cancer diagnosis.

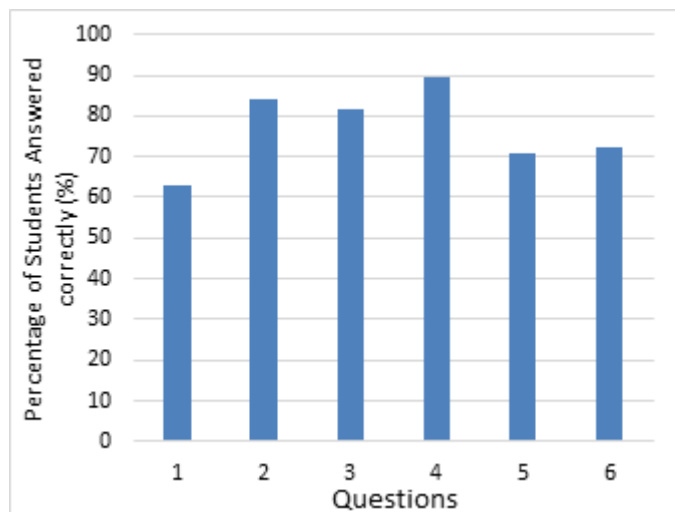


Figure-3: Shows the percentage of students that answered correctly. 68-out-of-76 students, 89.5%, provided two nanotechnologies or nano-materials that are used in cancer detection.

Scores from all 76 students were averaged to 86%. Students scored high on questions relating to cancer detection (Figure-3) However, students struggled with identifying the three nano-scale objects, and only 48 students answered it correctly.

Overall, student response was highly positive and their feedback with the module was encouraging.

B. Example Project 2

This project is a two week long Project Based Learning Unit (PBLU) that focuses on creating a model of a renewable energy source that is best suited to produce energy at the local Charlestown state park. Students picked their own groups based on group roles, collaborated in their group, fulfilled their specific group roles, and presented to a professional audience as a cohesive group.

The four group roles were Project Coordinator, Scientist, Engineer, and Nanotechnology Specialist. The Project Coordinator updated the teacher, twice a week, on how the group was doing, helped other students with their tasks, and was responsible for any work of absent students. The Scientist collected data for a renewable energy source assessment, created arguments for the best type of renewable energy source based on data, and did research on renewable energy sources to pick the best possible one. The Engineer used a 3D printer to create a working model of a renewable energy source and did research on renewable energy source structures. Finally, the Nanotechnology specialist explained how nanotechnology is used in this field, turned in a presentation on how nanotechnology can affect renewable energy technology, and researched renewable energy sources.

Each member also presented their group’s final product. Some interesting points of the project are: 1) students collected real world data on light intensity, water speed, wind speed, and biomass at Charlestown State Park. From this, the students decided on the best renewable energy source (solar, hydroelectric, wind energy, or biomass) based on the collected data; 2) students created a dye-sensitized solar cell; 3) students created a 3D working model of energy technology using a 3D printer. All of the groups operated by using one or more of the following: 1) identification of specific relevant group roles decided on by group members, 2) creation of a group contract to make group norms and ways to deal with in-group problems; 3) presentation to professionals in the field during a gallery walk, and 4) reflections on project outcomes and group and individual performances. This last piece is especially important because it builds metacognitive skills the students will need to self-evaluate.

This project was developed to help students realize the importance of renewable energy sources, introduce them to nanotechnology, demonstrate how nanotechnology is used in many renewable energy sources, express how nanotechnology is becoming more relevant in modern science, technology, and medicine, and expose them to how collaborative projects are conceived, implemented, and given exposure in the real world. The goal was to build the necessary skills among students to teach self-reflection, constructive feedback norms, presentation skills, constructive problem solving skills, and to give the students a better grasp on how scientific inquiry is implemented in the real world.

Participating students (N=39) were given a pre- and post-assessment that consisted of multiple choice questions to gauge the student’s basic understanding of general

nanotechnology and renewable energy concepts; fill in the blank questions to test a student's understanding of the integration of nanoscale processes in renewable energy sources; and open ended questions to gauge a student's understanding of what nanotechnology actually is. Between taking the pre-assessment and post-assessment, students created dye-sensitized solar cells and were taught on how nanotechnology plays a role in solar cells. The students were also given a basic introduction to what nanotechnology is and other applications of how nanotechnology is used in modern technology.

The students showed a 49.7% increase in individual score on the post-assessment when compared to the pre-assessment. Students showed a 28.4% increase in their general nanotechnology and renewable energy understanding and a 73.2% increase in their understanding of lab-specific questions. Open ended questions from the pre-assessment showed that the students did not have a good understanding of nanotechnology. The post-assessment indicated that the students gained a basic understanding of nanotechnology and would still like to learn more about nanotechnology and how it can be integrated into modern technology. From the assessment, the students showed a base understanding of the integration of nanotechnology in solar cells, however many students were interested in learning other applications. From this, it can be inferred that by providing an introduction of nanotechnology to high school students their interest will increase and they will possibly do further research. To help facilitate this, students can be provided with other examples of nanotechnology integration and given sources for independent research.

V. CONCLUSION

The two projects conducted at high schools covering healthcare and renewable energy projects indicate the success of the STEMCorp activities. These two projects served as a pilot study where the STEMCorp, faculty, high school teachers, and undergraduate students have all participated in the initiation of these projects. These projects showed success, however, some aspects of each project would have helped them develop much quicker. Early coordination between the advisors, students, and teachers would have led to quicker success of this program. Nonetheless, once there was proper coordination, there was a great impact among the students. By sending a student from STEMCorp to the high schools, students showed more interest in learning about nanotechnology and other STEM related subjects. The collaborative work between the various units from INDI, STEMCorp, SERI, CRL, and University faculty have led to the success of this program. The outcomes of these activities have enhanced the students' understanding of nanotechnology. By introducing students to the research in nanotechnology, they are aware of modern applications of nanotechnology in energy and medicine and hence, understand possible careers in nanoscience.

VI. ACKNOWLEDGEMENT

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L.E.A.P.: Localized Energy Awareness Program through Collaborative K-University STEM Projects

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Abstract—As the world’s energy usage continues to rise while the natural energy sources continue to dwindle, it is becoming more important that the general public’s awareness of energy is increased. The National Academy of Engineering, NAE, has deemed this issue so important that five out of the fourteen Engineering Grand Challenges deal with energy. Raising awareness with children about energy consumption and generation issues will help create a sense of familiarity and potentially, a desire to follow career paths that deal with solving these future energy challenges. Introductory energy modules are being taught in K-12 classrooms in California, New Jersey, and Pennsylvania with support from the National Science Foundation, NSF, GK-12 Ph.D. Candidate Fellows of Drexel University and the Dragon’s Teach Program, which stems from the UTeach Program in the country.

A Localized Energy Awareness Program, LEAP, has been formed through a K-University STEM collaborative project. Curriculum is being taken from the university level and broken down to each K-12 level to give insight into the topic of energy. In the new Next Generation Science Standards, NGSS, for science and engineering practices there are eight practices that should be taught at each level of K-12. Through these practices and the NAE Grand Challenges, energy awareness modules have been developed to bring into K-12 and Drexel University freshman engineering classrooms. The modules focus on the current energy usage situation, current active methods of energy harvesting including renewable and non-renewable energy sources, and modeling (drawing, building and computing depending on age group) new solutions and awareness for the energy crisis.

Surveys are being used to gauge the effectiveness of our activities with the students, teachers, and participating undergraduate and graduate students. This is a work in progress and results of the surveys and work are still being processed.

Index Terms—K-12 STEM Education, Energy Awareness, NGSS, Energy Education.

I. INTRODUCTION

The world’s energy usage continues to rise while the natural energy sources continue to dwindle. It is becoming more important to increase the general public’s awareness of energy consumption and usage, especially with children. The National Academy of Engineering, NAE, has deemed this issue so important that five out of the fourteen Engineering Grand Challenges deal with energy[1]. The most important age group to raise awareness with is the one that is accessible through school and is going to take over the world and all of the problems it faces. Raising awareness with children

about challenges involving energy will help create a sense of familiarity and potentially, a desire to follow career paths that deal with solving these future energy challenges. This is seen in many studies of energy awareness that have been conducted over the years [2], [3], [4], [5].

This module focuses on STEM (Science, Technology, Engineering and Mathematics) education in K-12 and first year university. A Localized Energy Awareness Program, LEAP, has been formed through a collaborative STEM project. University-level material and has been broken down to each grade level to provide insight into the topic of energy. This has been done previously in the authors work [6], [7]. In each grade level, discussions ranging from “What is energy?” to “How can renewable energy be used more?” are brought into the classroom as students learn new material and model their inputs, ideas and solutions through drawing, building physical models, and using virtual reality software. Overtime, students will work off of each previous grade level’s work to further build on and improve upon already thought-out plans.

In the new Next Generation Science Standards, NGSS, for science and engineering practices, Appendix F, there are eight practices that should be taught at each level of K-12 [8]. The main NGSS practices shown in these modules are the following: (1) Asking questions and defining problems, (2) Developing and using models, (3) Planning and carrying out investigations, (5) Using mathematics and computational thinking, (6) Instructing explanations and designing solutions, and (8) Obtaining, evaluating and communication information. Through these standards and the NAE Grand Challenges, energy awareness modules have been developed. The modules focus on the current energy usage situation, current active methods of energy harvesting including renewable and non-renewable energy sources, and modeling (drawing, building and computing depending on age group) new solutions and awareness for the energy crisis. This project has been grouped in the age levels that the NGSS provides their standards: K-2, 3-5, 6-8, and 9-12.

II. METHOD

This project is broken down into many areas of study and age levels. The common goal is to raise awareness around en-

ergy and the energy crisis that is occurring in the world. With awareness comes the need to solve the problem at hand. The first and most known method of accomplishing this is through alternative energy sources or renewable energy sources. This is the focus matter of this module from kindergarten all the way through first year university students. They are learning about what energy is, why it is so important to our day to day lives and how it effects their local environments, i.e. classroom and homes.

This brings the problem at hand into their focus and center and makes it easier to grasp because it is relatable. From here the students then start to develop methods on how to make their local environments more efficient through the alternative energy solutions they have learned about through assorted activities depending upon grade level. This has also been seen to work in a Taiwanese project where the students in primary and secondary schools have implemented alternative energy methods directly to engage with the students [9].

This project starts before the material reaches the students. It begins with the teachers. The perspectives of the educators is the starting point because their views are what will be passed down to the students and carried on throughout the classroom long after the module has been ran. The teachers that are and have agreed to run the modules within their classrooms took an energy awareness survey. This survey was based on the DeWaters' Energy Literacy Survey that focuses on knowledge, attitude, and behavior [5], [10]. This provided a great comparison of energy values across the United States. The survey included states of New York, New Jersey, Pennsylvania, Washington D.C., Florida, and California with a nice split of 54% and 46% east coast and west coast, respectively, comparison.

A. Pedagogy

This project is has formed a collaboration group of Drexel University's National Science Foundation, NSF, GK-12, Department of Education, DOE, Graduate Assistance in Areas of National Need, GAANN, and UTeach programs [11], [12]. These groups were selected due to their involvement with the local inner city Philadelphia schools. This collaboration has now outreached to high schools, middle schools and elementary schools all over the United States and in many different subject matters including mathematics, core sciences, language arts, social studies, and art. Outreach is still looking to incorporate Texas and South Dakota in addition to the states listed above.

All modules are set up to use two or three days of 40 - 60 minute class periods depending on grade level. Each grade level section is broken down with curriculum content appropriate for that learning and age level. The teachers involved with the project work with the collaboration to adapt each module content to the appropriate level of the classroom with the common goals of the project intact. The Dragon's Teach program is one way these modules will be implemented into the different classrooms from 3 - 8 grade levels along with the NSF GK-12 program within the 9-12 grade levels.

The modules are primarily taught by the teachers with the assistance of an engineering Ph.D. Candidate. This is to assure that the teachers are learning the material and are able to run the module by themselves as the project moves forward in coming years.

B. Content of Grade Levels K-2

At the beginning, the focus is on learning about energy and evaluating where the students are by creating a large K-W-L chart. The class holds a discussion about what they know about energy, what it is and where it comes from. Their answers go in the "K"now column of the KWL chart. Then ask them what they would like to learn about energy. These questions go into the "W"ant column of the chart [13]. Following these discussions, interactive activities allow the students to visually see energy in a physical way are completed. One example is the jumping jacks exercise where the students do jumping jacks until they become tired and an explanation of "running out of energy" is done. Afterwards the KWL chart becomes completed with filling in the last column, "L"earned. The students then make sun mobiles to show how much energy the sun provides us and how much the sun is used in and effects our local surrounds.

The main focus of the second day is now to get the students to creatively start thinking about the how they can use the sun as alternative energy to improve their current surroundings, their classroom. At this level, the students will create models via drawings of their classrooms. They need to come up with one thing they would change in their classroom to use alternative energy. Before this can begin, a class discussion on what uses energy in the classroom is done. This allows the students to recognize what around them uses energy and how much energy each item uses. In groups of two or three the students can then create their own ideas. The groups allow them to bounce ideas off of each other and learn how to work in groups to solve problems. After drawing their ideas, the students will present their invention or adaptation that uses alternative energy. This is part the eight NGSS for science and engineering practice: (8) obtaining, evaluating, and communicating information [8].

C. Content of Grade Levels 3-5

For the first day again, the focus is on learning about energy and evaluating where the students are at by creating a KWL chart for the discussion. Renewable energy coloring books have been created based on the California Energy Commissions Energy Quest [14]. These teach the students about six different types of renewable energy: solar, wind, hydro/ocean wave, geothermal, biomass, and biofuel. At the end of each coloring book the students are given a page to create their own invention using the type of renewable energy that is in the booklet. There are four coloring books in total. This can be done in groups, pairs or individually based on the teachers desecration of their students.

For the second day, the focus moves to their current environment, their classroom. In groups of 2 or 3 the students

discuss and create a list about what in their classroom uses energy. From this they draw their most energy-efficient classroom within the poster paper provided to them. They should draw ideas from what they've learned about energy and the renewable alternatives available, as well as their lists of items that use energy in their classroom. To conclude the project, each group presents their energy-efficient classroom with an explanation of their design.

D. Content of Grade Levels 6-8

The first day of this level is still dedicated to understanding what the students already know and what they want to learn about energy. This will be done through classroom games such as Family Feud, The Price is Right, and Jeopardy, which have all been adopted and placed in classroom settings previously [15], [16]. The energy material here have been adapted to these formats and provided to the teachers with making sure that the highest priority is raising awareness about the energy crisis and renewable energy sources. The students are then shown the K-5 energy efficient ideas and solutions.

This will leads to the students choosing an idea they want improve upon. Next, the students will start modeling their ideal through sketching. Once their ideas are presented and discussed with their teachers, another step in the NGSS (6), they are given building materials (paper, cardboard, markers, crayons, glue, tape, poster board, etc.) to actually develop and build a prototype of their energy-efficient classroom [8]. Finalizing their prototype, the students present their models to the classroom with a small write up of their understanding of how their improved invention will make their classroom more energy efficient.

E. Content of Grade Levels 9-12

The high school level will stay in common practice of dedicating the first day in the classroom to an introduction of energy awareness. This is done through an interactive lecture with the students that has been provided to the teachers. The high school students will now improve upon the 6-8th grade level's ideas and models. The students will be choosing which model they would like to improve upon. This time the students will not only be expanding upon their classrooms, but the school as a whole. They have the option of their high school or the elementary/middle school that the idea originated from. From here, the students have the choice to develop a working-physical model or a virtual-reality model. The virtual reality require computers and software. Therefore this can only be done where the appropriate funding is available. The working physical models use electronic and mechanical structures. Students may use solar cells, build windmills, build generators, hydro dams, etc. This is researched and developed entirely by the student.

With the curriculum and length of this project, the classrooms should be high school science and/or engineering classes. Currently, more than 10 high school science classrooms are in collaboration with the project through the NSF GK-12 Program. Finally, the students present their work to the

class and principal of the school of choice as a way to make it more energy efficient and create an actual impact in the local environment.

F. Content of University

The university level is almost identical to the 9th-12th grade curriculum. The important thing here is that it is for a freshman design engineering class. The students have the engineering physical and virtual reality model requirements to fulfill. At the end the students have to present their work to either the school district that they have done the work for or a company that may be willing to invest or donate to create their project.

As seen in this section, the grade levels each differ, but the goal is to have each grade level build off of the previous grade level's work and ideas. This is important within the NGSS. This is a long term project that will be implemented with many school systems across the U.S. It doesn't take a large amount of class time, but brings excitement and knowledge around the topic of energy. This is important with the energy crisis in the world. As seen in American Association for the Advancement of Science, AAAS, Project 2061 Atlas of Science Literacy, students need and education on energy and the influence it holds in their daily life styles [5].

III. PRELIMINARY RESULTS

Preliminary results have been taken from the teachers working with the project in the states of C.A., N.J., N.Y., D.C., and F.L. through an energy awareness survey based on Dewaters' Energy Literacy Survey using the survey tool Qualtrics. [10]. Although all participants remained anonymous to obtain unbiased and truthful data some profile statistics was taken. The age group was between 20 to 61 years with 71% under 30 years of age. The participant pool consists of 29% male and 71% female and teach a wide range of topics and grade levels. This is a comparison study between the teachers and their knowledge of energy awareness across the country. Cross tabulations were ran between west coast and east coast K-12 and university teachers. They were surveyed based on the three areas of energy awareness: knowledge, attitude, and behavior. The results varied in each category, especially in comparison of location within the United States.

TABLE I
ENERGY AWARENESS

	East	West
Knowledge	56.8%	60.1%
Attitude	72.1%	83.4%
Behavior	48.2%	65.0%

The results seen in Table 1 show positive attitudes for the east and west cost. However, the level of knowledge and behavior drop. When determining the level of knowledge the teachers themselves had, they were surveyed on basic questions of renewable energy and energy usage/waste. None of the teachers could name six main renewable energy sources. However, 69% could name solar and wind. One teacher

actually named natural gas as a renewable energy and 23% couldn't name even one renewable energy source.

When it came to energy awareness education 92% of the teachers stated that they either "strongly agree" or "agree" that energy education should be a part of every school's curriculum. However, only 31% have taught energy awareness in any manner in their classrooms. None of the teachers have used the NGSS in their classrooms nor are they familiar with the NGSS. Only 50% have even heard of the NGSS with 79% being mathematic or science educators.

Overall, California was more motivated and aware of the conservation of energy and ways to save energy. They put their motivation into action and try to save energy at most times. However, in understanding where energy is mostly wasted in an average American home: heating and cooling of a home, less than 50% of Californians were aware that heating and cooling the house is the most wasteful. The eastern states actually were more aware of this. This is most likely due to the fact that all four seasons are witnessed on the east coast, where as California barely uses the heating and cooling tools of a home.

IV. DISCUSSION AND FUTURE WORK

The results of this work allude to the conclusion that energy awareness is necessary in K-12 and university education. Therefore an innovative practice and collaboration has been developed and put into action to accomplish this. Through the development of modules for each grade level in energy awareness the students learn what energy is, how it is used, what is renewable vs. nonrenewable, and what they can do to improve energy efficiency in their local environments. These modules are formed through energy awareness curriculum, the NAE Grand Challenges and the NGSS for engineering and science.

The preliminary results show that the education of energy needs to start with the teachers. By educating the teachers on the subject matter they will be better equip to teach the generation of students that will need to solve the energy crisis. When asked if just taking the survey has made them more aware of their energy usage, the teachers replied with a positive 86%. Therefore, just introducing the topic to teachers had an impact and continuing with the project will create a larger impact with them and by extension, their students.

The STEM energy awareness project is already in motion in California, Pennsylvania, and New Jersey and is expected to run full circle within the next school year. Florida, Washington D.C. and New York are expected to start running the modules in the fall. Contact has also been made with South Dakota and Texas school systems as well. Feedback and data will come through surveys and project results as the modules continue to run in the different classroom levels. The future goal is to see change within the schools associated with the project on becoming more energy efficient and the students seeing the STEM fields applied in a positive way.

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Using common elements to explain electromagnetism to children: Remote Laboratory of Electromagnetic Crane

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Abstract— It is important to bring engineering to young people, and it is better to do so at an early age. In this case, the goal is to show children aged 10-15 years how electromagnetism works, and how we can find it in common tools that surround us. To do so, we are developing a remote laboratory that will be used in the sessions of science and technology in a school. Concept of electromagnetic crane has been chosen because a crane is a common tool. It is an object used in construction and in factories. Using electromagnet power to move metal objects is also a common concept that children can understand. Using these tools as an example, we seek to bring science to everyday life and promote the interests of children and young people in engineering and technology. The aim is to encourage them to seek education in engineering programs in the future, and teach them to understand and appreciate how important technology is.

Initially, the laboratory will move left and right in a circumference of 350 degrees and permit up and down different preselected masses. Also, students can increase or decrease the voltage of the electromagnet to raise masses. The entire system will be accessible remotely by the student who will be able to move the crane, activate or deactivate the electromagnet, and lift or take down the masses.

At the same time, the user interface displays the image of the laboratory and a graph showing the relationship between the power and its capacity to lift the mass every time the student applies voltage to the solenoid. All of this will allow us to see the effect that the applied voltage has over lifting the mass.

This work in progress is associated with different learning environments to adjust the experience at different ages which range between 10 and 15 years.

The students will interact with the remote laboratory from their homes, but also, the laboratory can be used in the classroom taking advantage of the data displayed through the user interface. Another objective is to show how engineering and science allow us to control remote objects and measure their effects through technology. Planting in students the seed of curiosity may be a good way to arouse the interest of future engineers.

Keywords—remote laboratories; technology; children; schools; crane; electromagnetism

I. INTRODUCTION

A good way to bring technology to children is through practice. After the line started within the Go-Lab project, UNED in collaboration with Karbo School developed a remote laboratory whose purpose is to be explaining how electromagnetism works.

As it explained in this work, we consulted teachers who teach children between the ages of 10 and 15 years old and with their suggestions we developed an ILS (Inquiry Learning Space) named "The power of electromagnetism", [1]. This ILS, combined with the laboratory, could help explain concepts such as magnet, electricity, electromagnetism, mass, weight, etc., in classroom.

An ILS is a web content framework that uses text, multimedia, links, etc. to create a learning environment using a website. The ILS contents a learning path that uses different phases to bring the content of a subject easily to the student. This path contents an Orientation, Conceptualization, Investigation, Conclusion and Discussion phases. The remote laboratory is content into the Investigation phase.

On the same way it was developed a simple, graphical user interface for the cited laboratory. The user interface shows what is happening all time on the laboratory, and it helps to explain on a visual way the above concepts.

As a result, it has developed the "Electromagnetic Crane Laboratory", [2]. This whole process, objectives and outcomes are explained in this paper.

II. A PRACTICAL, USEFUL AND REMOTE TOOL

When we develop a remote lab, we consider different factors that would help to deliver a session in classroom, but it also help the students to learn by themselves in practice the subject learned in theory. Definitely, we look for that this tool will be:

- Practice: it is essential that the student and the teacher have a real (not virtual) tool that allows them to demonstrate how the laws of physics work (in this case the electronics and magnetism) in a simple way, but reflecting all the potential and importance these laws have.

- Useful: it must be possible that this tool can be use in classroom by the teacher, but also directly accessible by students from home. This facilitates the students' ability to review the classroom session at any time the student wishes, and even facilitates further learning from home.
- Remote: this feature transforms the laboratory to a teaching tool that goes beyond the physical barrier of the classroom itself and the school building. Furthermore, the laboratory being available on Internet giving students and teachers access from home, which improves accessibility for students with physical barriers (disabled) or who, because of time, cannot access to the classroom in person.

Another interesting aspect of having a remote laboratory is being able to transfer the lessons to other environments. A teacher can travel to a remote village, a garden, or a museum with a laptop and there, conduct sessions using the remote laboratory. To do this, he/she only need an Internet access.

Classroom is no longer limited by the physical building where sessions are taught. With this tool, we can expand the environments, opportunities, and options for session learning.

Likewise, the teacher can prepare their sessions at home, using the remote laboratory without having to travel to the location of the laboratory. This allows him/her to save time and reduce travel costs as sessions can be prepared in advance and find and correct session errors. Also, teacher can test the practical exercises of the session previously presents them to the classroom. Since the remote laboratory is a tool, a teacher can use it to prepare and integrate their sessions, [3], [4]. The use of robotic or mechanical laboratories is a good method to bring closer the students to science and engineering, [5], [6].

III. USING FAMILIAR ELEMENTS BY THE STUDENT

It is needed to provide an easy user interface of the laboratory (Figure 1), but is also essential that the student is comfortable with that laboratory. To do this, there is nothing better than using everyday items that students can understand quickly.

In this case, we chose different elements that anyone can see daily in a city:

- Crane: in any city it is common to find cranes for construction. The element itself has been in use in one form or another for centuries and is an easily recognizable icon for any child. Also its use and operation is simple and straightforward: a rotational movement from right to left 360°, which in this case has been limited by certain physical bumpers (in this case 180°), and a limited upward and downward movement along the floor and the top of the crane.
- Polystyrene balls with tacks: play the role of a subject of study since the aim of the experiment is to deduct; using the tools and information given to it; the mass of each one. Each of these balls has a different amount of metal tacks whose work is twofold: firstly, be used to fix with security to the electromagnet, and secondly, to make these balls vary in grams (mass).
- Electromagnet: the key of this laboratory, which can be operated with different intensity by the student or teacher to raise a polystyrene ball and to deduce its mass.

Common and understandable elements for students of cited ages, but as well they are low in cost. If for any reason, parts need to be replaced, this can be done economically. So it is possible to increase the life of the laboratory and thus its profitability.

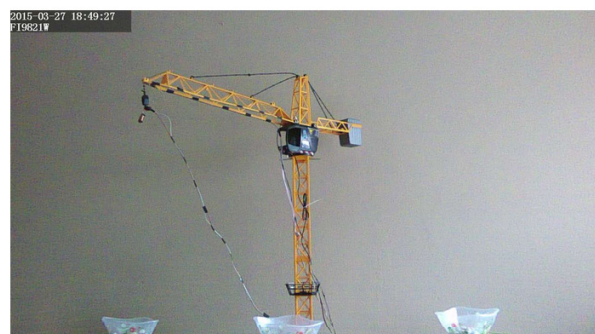
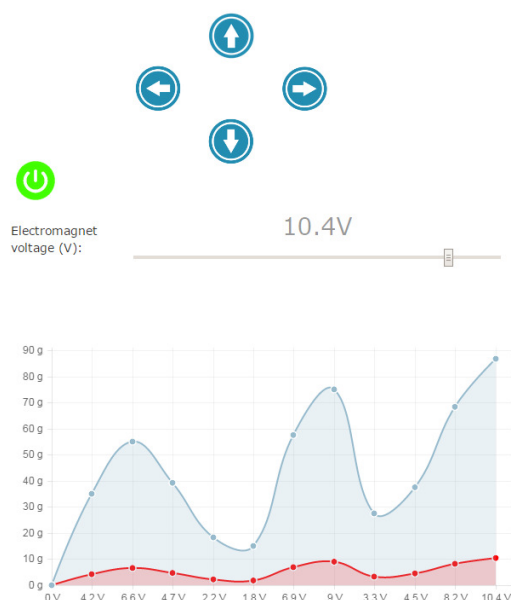


Figure 1. User interface of Electromagnetic Crane Laboratory.

As a result, the presentation of laboratory to the students is simplified, and the learning time to use it, is reduced. That, accompanied by a visual user interface with graphic elements indicating the degrees of movement or the voltage value, and a graph that can dynamically calculate the relationship between the applied voltage and the maximum lift mass, allows students to take the laboratory control almost from the start.

The development of theoretical formulation that confirms the usefulness of this laboratory is explained below.

The magnetic field energy per unit volume is:

$$w = \frac{1}{2} \mathbf{B} \cdot \mathbf{H} = \frac{1}{2} \mathbf{B} \cdot \mathbf{B} / \mu_0 = B^2 / 2\mu_0$$

$$[w] = \text{Joules/m}^3 = \text{Pascales}$$

Energy per unit volume of magnetic field is a pressure and can be interpreted as a magnetic pressure.

The magnetic force on a ferromagnetic material can then be calculated by multiplying by the area:

$$F = (B^2 \cdot A) / (2 \cdot \mu_0)$$

* B is the magnetic field (measured in Teslas)

* F is the magnetic field strength (in Newtons)

* A is the area of the pole faces (in m²)

* μ_0 is the permeability of free space ($4\pi \cdot 10^{-7} \cdot \mu_0 = \text{H/m}$)

As the magnetic field B will be produced by an electrical current I through a coil with N turns, we can write the field B as:

$$B = \mu \cdot N \cdot I / L$$

* N is the number of turns of the conductor

* I is the current in Amperes == V / R (electromagnet circuit)

* L is the length of the magnetic circuit

Substituting the force is:

$$F = (\mu \cdot N^2 \cdot I^2 \cdot A) / (2 \cdot L^2)$$

$$F = (\mu \cdot N^2 \cdot (V/R)^2 \cdot A) / (2 \cdot L^2)$$

Since each μ , N, R, A and L are constant then

$$F = K \cdot V^2, \text{ where } K = (\mu \cdot N^2 \cdot A) / (2 \cdot R^2 \cdot L^2)$$

$$[K] = N/V^2$$

Since $F = m \cdot g$, then

$$m = K \cdot V^2 / g = K' \cdot V^2$$

Thus we can calculate K' in a practical way by taking a series of samples and adjusting by a quadratic regression to a parabolic function

The chart reflects the above relationship and allows modifying the voltage dynamically inferring the mass of the ball by simply reading their approximate value in grams before they fall off the electromagnet.

Furthermore, intuitive elements have been searched for the user interface with the aim of increasing the ease of use by the student or teacher and looking for to simplify its usefulness. The elements used are:

- Buttons with their respective arrows, indicating the direction of movement. Clicking on them you can move the crane from right to left or up and down the electromagnet.
- Button to activate or deactivate the electromagnet. On that way user can turn on or turn off the voltage applied to the electromagnet immediately and directly.
- Slider to increase or decrease the power of the voltage applied to the electromagnet.
- Graph that indicates dynamically the relationship between the voltages applied to the electromagnet and mass to rise it at a given moment.
- Indicators that represent the final position of the crane and the voltage being applied to the electromagnet and to help user to see the motion and voltage limitations in each case.
- A webcam that allows students follow in real time the evolution of the whole laboratory all time. Both the crane itself and the process to follow to catch and release the test balls. It allows students deduce the mass of the ball by increasing or decreasing the voltage applied to the electromagnet.

All these elements facilitate interaction, reduce learning time to use laboratory and allow practical use of it without tutoring or monitoring.

At the same time, the development of the laboratory ensures the security and integrity of the internal software and hardware mechanisms that prevent the crane for a exceeding of a 180 degrees rotation, or a maximum application of more than 12 volts.

IV. USING REUSABLE ELEMENTS BY THE TEACHER

Another important element to consider is the use of reusable elements for sessions taught by the teacher.

For this, the laboratory should be configured as a tool in the teaching process. Laboratory was configured as an independent element but can be integrated into an existing learning environment.

In this case, within the theory explained in classroom sessions, the teacher can use the lab as a "test bench", where, without risk to himself/herself or his/her students, he/she can prove the theory previously taught.

In order to a remote lab will be a tool and not a problem for the teacher, it must meet certain characteristics:

- Easy learning: laboratory should be as easy to use as possible. The teacher should not have to spend much time learning to use it, because otherwise, he/she will not use it as a tool because the loss of time will not make it a practical tool.
- Neutral: laboratory must be neutral. That means that its design must be easily adaptable to different learning sessions or different ages. Thus, the laboratory can be integrated much better in any educational itinerary.
- Operative: laboratory should be used to check items already seen in theory. The interface, through the use of graphics, images, or mere observation, should address particular theoretical problems in an easy and reliable manner.

All these factors should help the teacher consider the laboratory as a useful tool, and feel free to use it when the occasion demands.

There is an important difference between a virtual laboratory and a remote laboratory. A remote laboratory lets use a real hardware, software and architecture. The user can manage and control robotic equipment (crane in this case) on your own in real time, and can see and test real behavior using a webcam.

The sessions were designed, by the teachers, fitting the age of the students. As an example can be cited that in early stages the theoretical content was focused on the physical concepts as mass or weight, but in older stages the crane was used to explain more difficult issues as parabolic movement among others.

Crane acts as an important factor to keep the attention and motivation of the students in sessions, but it is a useful tool for the teacher because can use it in real time any moment during the session to explain or complement theoretical concepts.

Both in early and older stages of age the crane has been a focus for several questions out of the mere subject, for example the students want to know how is possible to control the crane remotely and how works Internet of Things devices and architectures to let use the crane through Internet a browser and smartphones or PCs. All of this increases the learning experience of the students and teachers, and shows new

possibilities to get the attention of the student during the sessions.

V. CONCLUSIONS

Simplicity of use of this laboratory allows students and teachers to start using it from the beginning, both in person and remotely. Currently, the laboratory and ILS associated with it are hosted in the Go-Lab project repository allowing direct access from several schools in different parts of the world in real time.

This research decides to use the power of Internet of Things devices and architectures to bring new educational tools. Usually the Internet of Things point of view is more focused on the domestic, wearables, automotive or ludic uses, but as we have demonstrated on this research it is possible to move it to education and learning tools.

This flexibility of use and the ability to use the lab remotely are providing an educational value outside the classroom that makes it attractive for both teachers and students.

From a teacher's perspective, with the ability to integrate it into their sessions and adapt it to their specific needs, it becomes a tool to prepare his/her classes.

From the point of view of the students, the possibility of use it in the classroom and remotely allows them to review the sessions in the comfort of home if needed and as often as desired.

At the same time, the daily nature of the materials used for the development of the laboratory allows the teacher to justify new topics for discussion at his/her sessions, e.g. construction, physics, gravity, parabolic motion, etc.

From the beginning, teachers' suggestions and recommendations have been taken into account in order to enhance the usefulness of the laboratory.

The good reception of this laboratory has led to further discussions with Karbo School to continue developing new remote laboratories within the educational environment of primary and secondary levels.

UNED has been developing several projects in this direction and intend to continue on that line to strengthen engineering and technology among young people, and provide teachers with new tools to increasingly bring the experience to their students.

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An Agile Learning Design Method for Open Educational Resources

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Abstract—Open Educational Resources (OERs) have provided new perspectives for the construction, access and sharing of knowledge. While OERs can bring benefits to, and impact on education, there are still challenges to their widespread production and use. One of the challenges faced by developers (including educators and practitioners) of OERs has been how to produce quality and relevant learning materials, capable of being reused and adapted in different learning situations. In our work we propose and define an agile learning design method to support the design and creation of OERs. It is based on agile practices from software engineering and on practices of learning design from the OULDI project at the UK Open University. We illustrate our ideas with an experiment that validates the proposed method through its application in the design and creation of an OER in the software testing domain. The results obtained so far have shown that the method is feasible and effective for the design and creation of OERs.

Keywords—open educational resources; learning design; agile practices

I. INTRODUCTION

Open Educational Resources (OERs) have provided effective mechanisms for open and flexible education, expanding access to knowledge with reduced costs and enhancing cooperation and collaboration. They promote and support innovative practices in teaching and learning. OERs can be characterized as teaching, learning and research materials in the public domain or released under an intellectual property license allowing their free use or re-purposing by others¹. They include full courses, course materials, lecture notes, modules, textbooks, streaming videos, images, software and any other tools, materials or techniques used to support the construction and access to knowledge.

Although the creation and adoption of OERs have been gaining support and incentives from institutions and researchers across the globe, the full potential of OERs has not yet been reached [14]. One of the difficulties faced by educators and practitioners is to understand the implicit design behind OERs to know how to reuse them in their own teaching contexts [17]. Making the design more explicit helps to capture its key aspects, as well as the learning objectives, the activities

and outcomes associated with the learning materials, supporting both teachers and learners [20].

Instructional Design (ID) is an approach for designing learning instructions. It is defined as a systematic application of scientific principles about “how people learn” to develop instruction [13,21]. The term “instructional” means anything that is done purposely to help and facilitate learning [22].

With the advent of Web 2.0, new approaches for designing learning materials have been proposed. Learning Design (LD) has emerged within this context, bringing a broader perspective to teaching and learning and helping with the definition, creation, and sharing of effective pedagogical designs of learning materials [12,17]. LD consists of a set of activities supporting the understanding, description and sharing of pedagogical design practices. Research on LD has increased in the last few years primarily due to a gap between the potential and actual use of technology to support teaching and learning [12]. However, initiatives to foster the design and creation of quality OERs with reduced time and costs are still incipient.

The need for systematic and flexible approaches to the design and creation of OERs is highlighted by several authors [2,24,25]. This paper offers a contribution to address this need, by proposing a method for the development of OERs that learns from practices in other disciplines, namely the practice of agile methods in software development.

Agile methods gained prominence in software development, to address problems of long delivery times, and of software that has not fulfilled its promises or solved what was required. They promote simplicity and flexibility to deliver products and services that are relevant and add value to the market in due time. One of the characteristics of agile methods is that they are “people-centered”, encouraging and prioritizing effective collaboration and involvement of users in the development to deliver software more quickly and efficiently [4].

The concerns and characteristics of agile methods resonate with the needs identified in the development of OERs, as previously mentioned. The collaboration and involvement of users (educators, learners) is also appealing in the context of the development of OERs [8,10].

In our work we propose and define an agile LD method to support the design and creation of OERs based on agile

¹ hewlett.org [last accessed on 03-2015]

practices from software engineering [1,7,26] and on practices of LD that originate in the Open University Learning Design Initiative (OULDI) project proposed by the UK Open University [12]. The OULDI was funded by JISC, a public body that supports and champions the use of digital technologies in education and research across the UK. Our proposal builds on a preliminary version firstly introduced by Arimoto and Barbosa [3]. We validate our method with an experiment involving the design and creation of OERs to teach software testing, a topic within software engineering education.

This paper is organized as follows. In section II we discuss related work; in section III we describe the main characteristics of the agile LD method for OERs; section IV reports on an experiment to validate the method by designing and creating an OER within a software testing domain; concluding remarks and further work are presented in section V.

II. RELATED WORK

Instructional Design (ID) has a long trajectory as an approach for designing learning instructions in a systematic way. "It is the process of deciding what methods of instruction are best for bringing about desired changes in student knowledge and skills for a specific course content and specific student population" [13,23]. Learning Design (LD) has emerged more recently over the last decade, primarily in Europe and Australia. "It has developed as a means of helping teachers make informed choices in terms of creating pedagogically effective learning interventions that make effective use of technologies" [18,12].

LD and ID are closely aligned but have distinct focuses. As argued by Conole [13], ID focuses on designing the instructions to meet learning needs for a specific audience and setting, while LD takes a much broader perspective and regards design as a dynamic process, which is ongoing and inclusive, considering all stakeholders involved in the teaching and learning.

The OULDI was initiated in 2007 to derive a more "practice-focused approach for LD" [11]. It defined a method, tools and a notation to represent LD including: (1) different types of design representations to help guide design decision-making process; (2) digital tools to help visualize and represent designs; and (3) mechanisms to encourage the sharing and discussion of learning teaching ideas, including face-to-face events [12].

Design representations in the OULDI include [11]:

1. *Macro-level* (the course map view): an overview of main components of the course to enable educators and practitioners to think about the design of a course using 4 dimensions: content and experience, guide and support, communication and collaboration, and reflection and demonstration.
2. *Meso-level* (the learning outcomes view): a notational vision showing how learning activities and assessment tasks are linked with learning outcomes of the course.
3. *Micro-level* (the task swimlane view): a map of tasks that the learners undertake to the learning materials and tools they use during the activities in the course.

4. *Pedagogy Profile*: types of activities in which learners participate during the course or sequence of learning events. These are categorized as assimilative, information handling, communication, productive, experimental, adaptive and evaluation.
5. *Course Dimensions*: details on the nature of the course, a refinement of the course map view.

As highlighted by Avraamidou and Economou [5], levels 1 up to 5 of the OULDI cannot be seen as separate parts. LD often requires refinement and improvement. This implies that the design process should allow moving back and forwards through the levels according to the needs. Although the OULDI approach intends to make the design more explicit, it does not specify the steps and guidelines for a LD process.

There are other initiatives using LD. Learning Activities Management Systems (LAMS) [15] is a platform that offers automated support for LD. This platform is used to design learning activity sequences, describing the whole teaching process including learning contents, learning activities, and assessment. The Learning Design Support Environment (LDSE) [19] is another initiative in this direction. Both LAMS and LDSE have in common more self-contained and complex environments than the OULDI, which difficult their use. The demand for the creation of learning materials as OERs within the expected cost and schedule, together with the lack of time [27] to produce these materials, also highlight the need for more agility in the LD process.

In the context of LD, there is a lack of initiatives that explore the use of agile methods; this is not the case with ID. Bahl [6] proposed an approach for ID based on ADDIE [28], and Scrum [26]. ADDIE is a generic model for ID used for the development of instructional materials and training; whilst Scrum is a well-known agile method used for the management and planning of software (and non-software) projects. The approach proposed by Bahl defines a linear and iterative cycle:

1. *Initiation and planning* of the overall project, including project definition, pedagogical needs, objectives, stakeholder's identification and high level budget and timelines.
2. *High level analysis* of functionalities needs to prepare a high level project plan.
3. *Iterative design & development* of functionalities reviewed by experts at the end of each iteration.
4. *Feature integration* of functionalities implemented throughout the cycles.
5. *Solution roll out* culminating with the closure of the project.

Willeke [29] discusses the use of Scrum in ID in an online educational course at Ohio Christian University with the following quantitative improvements:

- *Satisfaction*: positive feedback on the Scrum process, contributing to a better quality course.
- *Time saving*: the time invested reduced over 30%, and the time for total development dropped 40%.
- *Internal communication*: the interaction and communication within the team involved in the process increased, allowing problems to be solved quicker.

Despite this success, Willeke [29] mentions the need of a cultural change for the adoption of an agile approach in the educational environment. These initiatives also fall short of the application of some agile practices such as the active participation of users (e.g., potential learners), throughout the development. Our proposed method combines a wider range of agile practices with LD; in particular, it gives emphasis to the collaboration and active participation of users to ensure the quality and relevance of the produced learning material.

III. AN AGILE LEARNING DESIGN METHOD FOR OPEN EDUCATIONAL RESOURCES

We propose an agile LD method for OERs based on a combination of agile software design practices and OULDI practices. This method allows designs to be modified, repurposed and evolved according to the needs of users emerging during development. Pedagogical design practices are embedded in the development of OERs improving quality and facilitating reuse and adaptation. It also accommodates change and improvement, minimizing cost and impact.

The agile practices, in Table I, are combined with LD, assisting and guiding the design and creation of OERs:

- Users (educators² and potential learners) actively participate throughout the development, either in person or via collaborative technologies (wikis, microblogging, social networking and messaging systems). They assist in the identification and establishment of learning objectives, activities and pathways, content and assessment.
- Collaborative development is promoted by the constant interaction and communication amongst all involved. Several activities are carried out in group brainstorming and workshop sessions, either face-to-face or by synchronous communications tools (text mode or videoconference). This helps to reduce time and effort and enables effective design of OERs.
- Architecture/Design envisioning is used early in LD activities to sketch a design (initial architecture and resources) to obtain an overview of the OER, and help educators and potential learners to think about the key elements.
- Iterative modelling/design produces sketches of OER's modules that are revised in each iteration; they represent the learning activities, and connections to learning outcomes, content, the tools and assessment.
- Design storming is used for the flow of activities and the strategies for the development of the OER. It triggers refining and decomposition of activities into individual activities and tasks, helping educators and potential learners to reflect upon an aspect of design.
- Refactoring improves the learning structure and content without changing the learning outcomes. It is performed whenever an opportunity for change and/or improvement is identified.
- Evaluation is carried out early and continuously throughout the development, especially at the end of

each iteration. With the design of small modules of the OER, educators have the opportunity to check whether the modules designed are in agreement with those planned. It is possible to identify new designs, modifications or inclusion of new activities and content, and improvements in relatively short periods of time, minimizing the cost of change.

TABLE I. AGILE DESIGN PRACTICES

Practices	Description
Active users participation	Users are involved in the development process, helping to identify and solve problems and mistakes and providing rapid feedback to the team
Collaborative development	All team members constantly interact and communicate throughout the development process, promoting a collaborative and productive environment
Architecture/Design envisioning	Initial software architecture and requirements are designed at the beginning of a project to identify and think through critical issues
Iterative modeling/design	Software functionalities are designed at the beginning of an iteration to identify team's strategy for that iteration
Model/Design storming	Software functionalities are designed on a just-in-time (JIT) basis to reflect on specific aspects of team's solution
Refactoring	Small changes are performed to improve part of a solution without changing its semantic meaning
Early and continuous Evaluation	Testing and validation activities are conducted at the beginning of the project and extend throughout the development process

Our agile LD method is structured in four steps or macro-activities (Establish the initial architecture, Plan and create the structure, Refine the structure/create the content and Evaluate), as shown in Fig. 1.

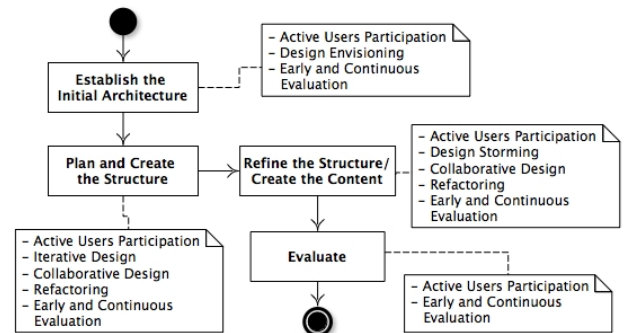


Fig. 1. Agile LD method for OERs: an overview

A. Establish the initial architecture

This step defines an initial architecture for the OER (Design envisioning) based on the Course Map View from OULDI. At the beginning of development, all users including educators and potential learners come together by a brainstorming session (face-to-face or by synchronous communications tools – videoconference) to identify and think about critical issues and the main elements of the intended learning. The initial architecture of the OER is sketched without too much detail (“just barely good enough”), as the design should be constantly evolving throughout the iterations.

Educators start by drafting the learning objectives and the context or domain of the OER. Irwin DeVries [16] highlights that many OERs do not have basic elements of LD such as learning objectives. This makes it hard to assess the OER in terms of its overall purpose, and the pedagogical alignment of learning materials, activities and assessment. He also argues that learning objectives are essential elements for reuse; they

² By using the term “educators” we also include practitioners, teachers, lectures and tutors.

help identify if an OER has the level of coverage and depth appropriate to be used in a different context.

Educators specify the context or domain in which the OER will be applied. For instance, whether the OER will be a key part of a course in the curriculum, a complementary part of a course, or a short specialization course. They also need to include cultural and languages issues in the OER's context.

Pre-requirements and specific knowledge needed to use the OER are defined. The estimated time (duration) for the application/use of OER in a particular course or training is also specified. For instance, a short course or class may require only a few hours while a full course (such as a complete software engineering course) may require weeks or months.

Educators identify the primary content of the OER. There is no need to identify all content a priori; further content can be added or changed throughout development. In order to identify content, the following issues should be considered:

- the way in which the OER will be delivered to learners, i.e., face-to-face, online or both;
- the way in which learners will be supported, i.e., face-to-face, online or both; and,
- the kind of activities learners will need to perform.

Typical examples of content include: lessons, lab activities, study guides, examples, readings, support materials, case studies, pilot projects, surveys, systematic reviews, and experiments/controlled experiments.

Educators need also to define learning assessment activities to help teachers gather evidence from learners to adjust and improve their teaching strategies. In the same way, learners can improve their learning strategies according to these activities. Learning assessment activities are defined considering:

- whether the assessment activities will be online, paper based or both; and,
- whether the assessment strategies will be diagnostic, formative, summative or all of them.

Typical examples of learning assessment activities include: in-text questions, self-assessment questions, brief in-class assessments, oral presentations, team projects, papers, essays, and exams (written or oral).

Educators also need to think about the way in which learners will interact and collaborate with educators and colleagues when using the OER within a course, and consider:

- whether learners will communicate and collaborate with their colleagues online, face-to-face or both;
- whether learners will communicate and collaborate with educators online, face-to-face or both; and,
- whether learners will perform their activities individually, peer-work or work in a group.

Typical examples of means of communication and collaboration include: synchronous and asynchronous tools (such as instant messaging system, forum and email), and face-to-face tools (such as workshops, brainstorming sessions, work in groups, peer-to peer works and seminar).

At the end of this step, all those involved in the design and creation of the OER (including educators, designers, media

creators³ and potential learners) need to agree on the initial architecture of OER and approve it.

B. Plan and create the structure

This step plans and creates a learning structure for the OER in the current iteration, representing the connections between the main elements for learning to achieve an effective learning pathway. The design is created "just enough for now, since we can always come back later" (Iterative Design)[1]. It prioritizes the most relevant aspects to be addressed by the OER. Other aspects considered less important are discussed later.

Initially, educators together with the designers, media creators and potential learners plan and agree the releases to be delivered in a short period of time, usually ranging from a week to month (depending on the complexity and size of OERs). In terms of OERs, a release corresponds to modules or small sets of modules (or components, topics) considered "ready" to be used by potential learners. A release is composed by learning activities, contents, assessments, roles and tools needed to meet the learning objectives of the OER.

The modules of the OER are designed in a few short iterations, each lasting hours, days or a few weeks. Short iterations promote visibility for the OER; an opportunity for users to perceive how the design and creation of the OER is progressing during the development.

Educators prioritize small modules or parts of the OER to be designed and created in the current iteration based on the initial architecture of the OER established in step A. They introduce these modules to designers and media creators, indicating what should be done with each one.

Educators along with designers and media creators come together in a brainstorming session to discuss the design of the OER to obtain a structured process for the learning. Based on the initial architecture of the OER, they establish the activities that learners will perform (learning activities) to achieve the desired learning results. This helps them reflect on the flow of the activities of the OER and the strategies for its development.

The learning activities are linked with the intended learning outcomes, content, tools and assessment activities. A sketch of this mapping is created based on the meso-level (learning outcomes view) from OULDI. The structure of the OER is reviewed and approved by educators and potential learners, serving as input for the next step.

C. Refine the structure /create the content

In this step the learning structure of the OER is refined and related content is created. Designers and media creators come together to discuss how to design effective learning materials with embedded pedagogical design practices. The active participation of all users (mainly the educators and potential learners) is essential.

Designers together with educators refine and decompose the OER activities in simpler activities and atomic tasks, helping them to reflect upon one aspect of the design solution

³ We refer to media creators the responsible for editing and updating all contents and media associated to the OER.

and how they can transform it for a more effective OER. This refinement is based on the micro-level (task swimlane view) from OULDI.

Learning content and the required media are developed: text documents, html pages, wikis, multimedia files (such as podcast, streaming videos and animations), images, open textbooks, and lecture notes. These materials can be developed from “scratch” or reusing third-part material. Educators and media creators should search for suitable materials that could be reused and adapted to meet the learning objectives.

When third-part material is used to compose a new OER there is a need to check and assess whether: (1) the file format is modifiable and suitable to the desired needs, (2) the licensing policies are explicitly defined, allowing reuse and modification, (3) the contents are from reliable sources (institutions engaged with education, renowned authors, etc.), (4) the content fit the didactic and pedagogical objectives, among others.

Licensing policies to share the OER must be established. An OER must be shared through an open license with little or no restriction on its (re)use and adaptation. The licensing policies for an OER need to consider: (1) the authorship and intellectual property rights of third-part materials (when used), (2) how the OER will be available (non-commercial allowed or not), and (3) the appropriate license according to items 1 and 2.

Primary metadata for the OER are identified and gathered. Metadata describe relevant characteristics of the OER, facilitating its reuse and recovery by search engines. When an OER has integrated metadata, any user can easily find it.

Media creators and users (educators/potential learners) work in constant collaboration. New solutions and improvements could be highlighted through feedback provided by interactions and cooperation with users. Media creators constantly refactor their solution aiming to simplify and enhance it.

The structure of the OER, activities and content are regularly reviewed throughout the development to detect mistakes and other problems which may affect the quality of OER. Media creators must update the work to reflect the necessary corrections and changes.

D. Evaluate

This step evaluates and approves the work and artifacts delivered in each iteration which compose a release. Educators and potential learners are involved in verifying whether the learning pathways associated with the content contribute to the learning. They also analyze whether the type of content and activities, learning assessment, and tools are appropriate to the purpose of the OER, e.g., aligned with the learning outcomes.

Peer review should evaluate the design quality, and academic staff and domain experts should also evaluate it.

Also, designers and media creators need to think about the strategy adopted during iteration, focusing on how they can improve their work. They should identify “what worked well” and “what did not work well” during the iteration. They also discuss “what needs to change and improve” in the next iteration. Lessons learned and feedback from the evaluation are

gathered and will be used for improving the following iterations, contributing to the continuous improvement process.

Early and continuous evaluation of the design process helps clarify the problems and solutions and identify the needs for corrections and improvements. The OER modules, or part of them, can be reviewed by educators and potential learners throughout the process, and any change can be made at any stage of the development. This is one way to ensure the design quality and therefore the OER as a whole.

Once the OER module (release) has been approved by the educators, it can be used in a teaching environment. Its use by a group of learners is critical to identify weaknesses and propose improvements. Educators should provide the support needed by learners in their activities and monitor their progress. Data about the learners experience should also be collected and analyzed to improve the quality of the OER.

Effective access to the OER release should be through platforms or repositories and institutional or stand-alone websites. Media creators need to check whether the OER is made available together with associated metadata, according to packaging standards, and appropriate license.

IV. APPLYING THE AGILE LEARNING DESIGN METHOD

An experiment was conducted within the software testing domain in order to evaluate the applicability and effectiveness of the Agile LD method by comparing it with an AD-HOC approach. With an AD-HOC approach the development is informal with no defined process to guide the development.

We chose to perform an experiment to allow a more rigid control on the environment, and a more rigorous manipulation of the phenomenon we study. An experiment can generate more concise results based on quantitative analysis, providing evidence of the validity of our proposal to create OERs. It can also allow the generalization of the results within a population, and the replication of the experiment.

In the experiment we refer to our proposal as AM-OER (Agile Method for the Development of Open Educational Resources). The research questions for the experiment were:

- How effective is the AM-OER in the creation of OERs compared to AD-HOC approach?
- How efficient is the AM-OER in the creation of OERs compared to AD-HOC approach?
- How much better are the results obtained by AM-OER compared to AD-HOC approach?

The subjects of the experiment were 8 participants including graduate students (MSc and PhD), educators and researchers in Computer Science from the Institute of Mathematics and Computer Sciences (ICMC) at University of São Paulo (USP).

The participants were divided into two balanced groups with the same number of participants. We also tried to create homogeneous groups according to the level of knowledge of each participant, especially in relation to the development of learning materials and software testing.

Both groups created the same module of an OER, representing a full class (3 hours of duration) within the

software testing domain, focusing on Functional (Black-box) Testing and its criteria, including Equivalence Partitioning Testing and Boundary Values Analysis. Each group had 4 hours and 30 minutes to finish the work.

Before the developmental activities of the experiment, the participants took part in a training, lasting 2 hours and 30 minutes. The training covered topics related to OERs and software testing, especially regarding to the specification of the OER module to be created within this domain. Furthermore, the group of participants that used the AM-OER was also trained into the main aspects of the method. The materials used in the training were also made available to the participants. During the experiment, the groups could not communicate each other.

We consider some factors that may affect and impact the analysis and interpretation of the results from the experiment. The main threats to validity of the experiment:

- *Internal validity*: the AM-OER method cannot provide well-defined steps to guide the development of OERs, requiring appropriate training.
- *Extern validity*: the number of subjects is relatively small and may not adequately reveal the applicability and effectiveness of the AM-OER in the development of OERs. The level of experience of subjects can also influence in the validation. Furthermore, the experiment must be performed in laboratories adequately furnished with computer and internet access.
- *Construct validity*: the responsible for the experiment must be careful with the treatment of variables in order to meet the objectives predefined.

A. General Overview of the OER Module

The group using the AM-OER created the module following the agile design practices for OERs discussed in Section III.

The learning objectives established for the module were:

- Students will summarize the fundamentals of Functional Testing.
- Students will argue and defend the two major Functional Testing Criteria: Partitioning Functional Testing and Boundary Values Analysis.
- Students will be able to apply the Partitioning Functional Testing and Boundary Values Analysis.

The module is in the context of a software testing course. The target audience includes undergraduate students in Computer Science and other related areas. It can also include students interested in learning about Functional Testing. As prerequisites and experience, the students must have basic skills on fundamentals of programming and software testing.

The content required for the module include guidelines, lessons, examples, supporting materials and specification and the implementation of a selected program (Calendar program named Cal). Assessment activities include essays, self-assessment questions and reports. The means of communication and collaboration include chat, forum, peer-to-peer work and discussion in group.

A sketch of the learning structure of the module is shown in Fig. 2. According to the figure, a student enrolled in a software testing course can take as *activity Design and execute test cases using Functional Testing Criteria*. A learning outcome could be that the learner has acquired practical knowledge on the subject (*Demonstrate ability to apply Functional Testing Criteria*) according to evaluations conducted throughout the course (*Report on Design and Execution of Test Cases*).

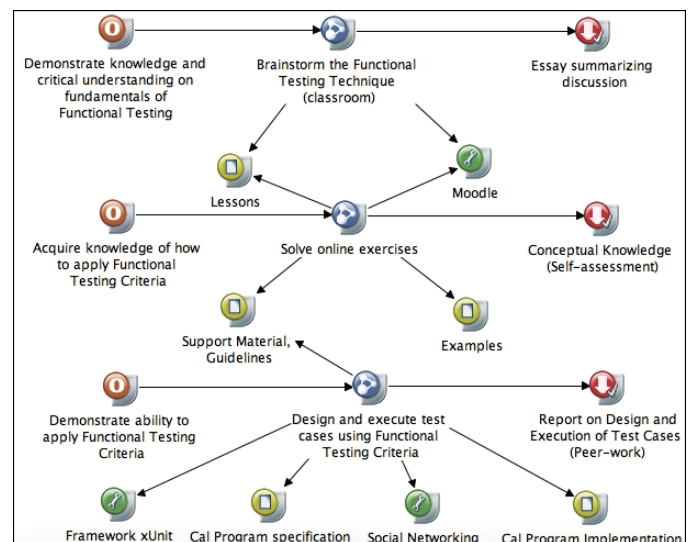


Fig. 2. Learning structure of the module

Figure 3 shows a sketch of a refinement of the structure of the module above for the activity *Design and execute test cases using Functional Testing Criteria*. It contains atomic tasks associated with their content and respective assessment activity.

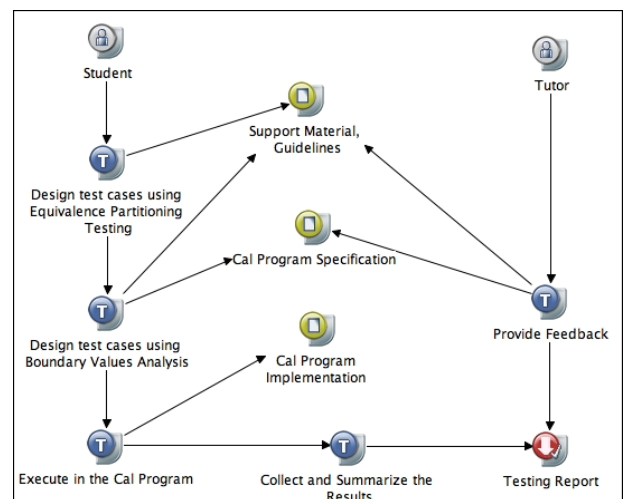


Fig. 3. Refinement of the learning structure

The Functional Testing module is composed by html pages, text documents, lecture notes, images and video. Fig. 4 shows one of the proposed activities to assess students.

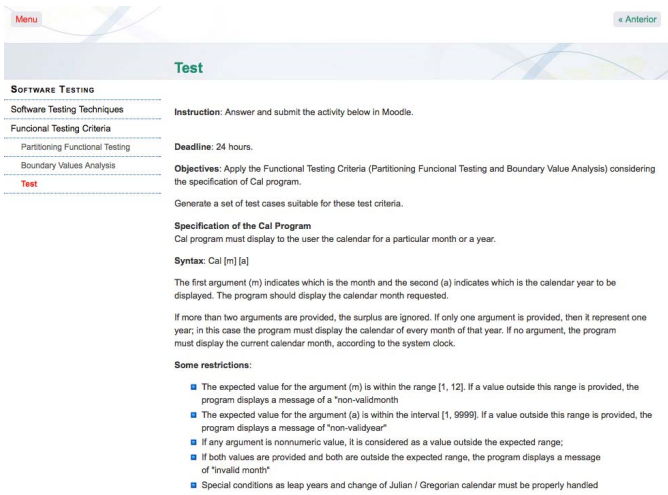


Fig. 4. OER on software testing

B. Comparing Effectiveness

Effectiveness measures the capacity of each approach in the development of the planned OER. It is related to the OER module “planned” to be developed and to the OER module “developed”.

Figure 5 shows the results obtained by each approach, displayed by box-plots representing the sample data in three quartiles. The first quartile or lower quartile (Q1) corresponds to the value related to a quarter of data. The second quartile (Q2) corresponds to the value representing the median of the sample data, whilst the third quartile or upper quartile (Q3) corresponds to the value representing three quarters of the sample data. The box-plots also show the minimum and maximum values of the sample. As can be observed, the minimum and maximum values of box-plots range from 50 to 100%. In the sample of AM-OER, most of the percentage of results achieved is between 80 and 100%.

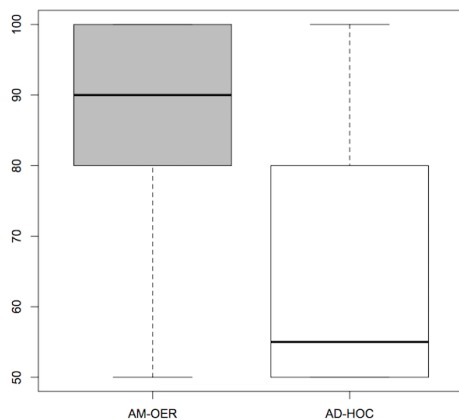


Fig. 5. Results obtained by each approach

The metric to calculate effectiveness was: $\sum(x_i / y_i) * 100$, $i = 1..n$, where x_i is the average percentage of requirements fulfilled by each approach whilst y is the requirement planned to be fulfilled.

According to the results it seems AM-OER presents better level of effectiveness, achieving 86,2% against 65% of AD-HOC approach.

In order to statistically infer that the effectiveness of AM-OER is greater than the effectiveness of AD-HOC approach we test the hypotheses established for it. Both samples associated to effectiveness are presented as percentage. In this case, test for proportion is indicated.

The hypotheses related to effectiveness are:

- *Null hypothesis* (hypothesis we want to reject): the effectiveness of AM-OER is similar to the effectiveness of AD-HOC approach, $H_0: \mu_{AM-OER1} = \mu_{AD-HOC1}$.
- *Alternative hypothesis*: the effectiveness of the AM-OER is higher than the effectiveness of AD-HOC, $H_1: \mu_{AM-OER1} > \mu_{AD-HOC1}$.

In the experiment we adopt the usual practice of admitting a low value or level of significance for both errors: $\alpha = 0,5$.

To test both samples for equality proportions we use the function `prop.test()` from R software, a free software environment supporting statistical computing and graphics. The obtained result was $p\text{-value} = 0.004$. There is a statistical significance when the p -value is lower than the level of significance used in the experiment. Therefore we reject the null hypothesis $H_0: \mu_{AM-OER1} = \mu_{AD-HOC1}$ and accept the alternative hypothesis $H_1: \mu_{AM-OER1} > \mu_{AD-HOC1}$.

C. Comparing Efficiency

Efficiency measures the effort required by each group of participants to develop the planned OER. It is related to the OER module developed by each group of participants and the time (in hours) spent to develop it. The metric to obtain the efficiency was: $\sum(x_i / y_i)$, $i = 1..n$, where x_i is the average percentage of requirements fulfilled by groups on each approach whilst y is the time (in hours) spent by them.

Table II shows the results of efficiency obtained for each approach. It is noteworthy that the higher value obtained, the greater the efficiency. It seems that AM-OER presents better level of efficiency, 0.86 against 0.73 of AD-HOC approach.

TABLE II. EFFICIENCY OF EACH APPROACH

Approach	Time (in Hours)	Requirements Fulfilled	Efficiency
AM-OER	4.5 / 4.5 (100%)	86.2%	0.86
AD-HOC	4 / 4.5 (89%)	65%	0.73

In order to statistically infer that the efficiency of AM-OER is greater than the efficiency of AD-HOC there is a need to test the hypotheses established for efficiency:

- *Null hypothesis* (hypothesis we want to reject): the efficiency of AM-OER is similar to the efficiency of AD-HOC approach, $H_0: \mu_{AM-OER2} = \mu_{AD-HOC2}$.
- *Alternative hypothesis*: the efficiency of AM-OER is higher than the efficiency of AD-HOC, $H_1: \mu_{AM-OER2} > \mu_{AD-HOC2}$.

The result was $p\text{-value} = 6.174e-11$. Thus, we reject the null hypothesis $H_0: \mu_{AM-OER2} = \mu_{AD-HOC2}$ and accept the alternative hypothesis $H_1: \mu_{AM-OER2} > \mu_{AD-HOC2}$.

D. Comparing Quality Results

The quality of the results is measured by a specialist according to the percentage of compliance to quality attributes / desirable characteristics of an OER derived from the definition and main characteristics of an OER.

In Fig. 6, box-plots were created to show the percentage obtained by each approach regarding the quality of the results. The box-plot of AM-OER shows the results are closer to 80% and 100%, ranging from 50% (minimum value) to 100%. On the other hand, the box-plot of AD-HOC shows a higher variation, ranging from 0% to 100%. Discrepant values within of set of values are considered outliers (0%).

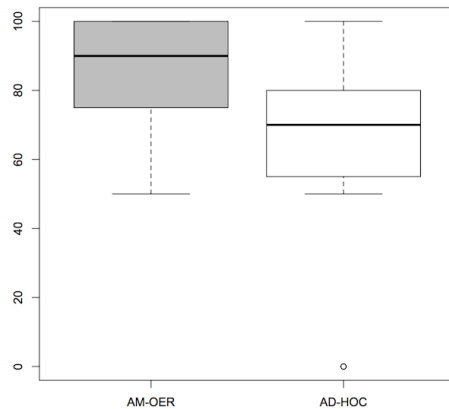


Fig. 6. Quality of the results of each approach

In order to statistically infer that the quality of the results of AM-OER is greater than the quality of the results of AD-HOC there is a need to test the following hypotheses:

- *Null hypothesis* (hypothesis we want to reject): the quality of the results of AM-OER is similar to the quality of the results of AD-HOC approach, $H_0: \mu_{AM-OER3} = \mu_{AD-HOC3}$.
- *Alternative hypothesis*: the quality of the results of AM-OER is higher than the quality of the results of AD-HOC approach, $H_1: \mu_{AM-OER3} > \mu_{AD-HOC3}$.

The result was $p\text{-value} = 3.419e-05$. In this case, there is an evidence to reject the null hypothesis $H_0: \mu_{AM-OER3} = \mu_{AD-HOC3}$ and accept the alternative hypothesis $H_1: \mu_{AM-OER3} > \mu_{AD-HOC3}$.

E. Qualitative Analysis

To explore the applicability of the AM-OER in the development of OERs we also investigate a set of research questions covering three perspectives: appropriateness/usefulness, ease of use and satisfaction. The answers for the research questions were provided according to the following scale: (a) 1 – Strongly disagree, (b) 2 – Partially disagree, (c) 3 – Indifferent, (d) 4 – Partially agree and (e) 5 – Strongly agree.

Figure 7 summarizes the results of all questions covering appropriateness / usefulness, ease of use and satisfaction by box-plots. According to the results, the majority of answers ranging between “4 - Partially agree” and “5 - Strongly agree”. The results show a tendency of the acceptance of the AM-OER in the development of OERs. However, other assessments must be conducted in order to provide more consistent results.

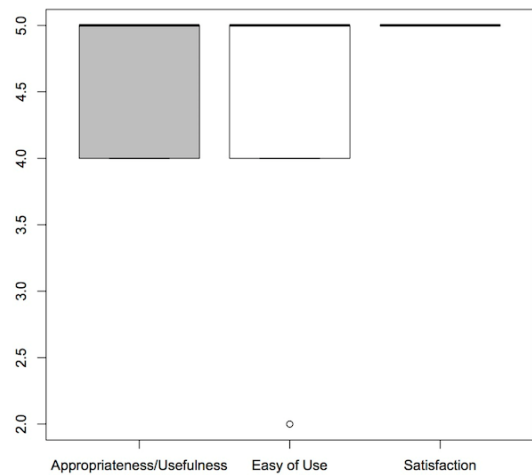


Fig. 7. Qualitative analysis

Participants also provided suggestions for changes and improvements to the AM-OER. The data collected during this analysis will be used later to refine the AM-OER.

This study shows that agile design practices together with LD practices are feasible to design and create OERs.

II. CONCLUSIONS AND FURTHER WORK

In this paper we proposed and applied an agile LD method to support the design and creation of OERs. Our main goal is to provide an explicit and flexible agile LD method that considers not only LD as a dynamic process but also allows for the design to evolve incrementally, and be modified, repurposed and enhanced as needed. We defined the agile LD method to facilitate the reuse and adaptation of OERs and to contribute to their quality by embedding pedagogical design practices. The method provides a more collaborative approach to the development of OERs, prioritizing the participation of users throughout the process to meet their real needs. This can reduce the development time and effort, promoting an effective production process for a sustainable supply of OERs.

The method has been initially evaluated through an experiment. Considering the quantitative analysis, the results obtained so far have shown that the method is effective and efficient to the development of OERs. In terms of its applicability, the preliminary results indicate that the method is useful and easy to use, especially for non-experts in the development of OERs.

Regarding the limitations of the experiment conducted, we highlight: the number of participants was small, what may affect the representativeness of the sample of population, and the time allocated to the experiment was not sufficient, but we were constrained by the unavailability of participants.

We intend to refine and evolve our proposal based on the results of the experiment and on the feedback from participants. For further validation, we plan to replicate the experiment on a larger number of subjects. Also, other experiments will be planned and developed within different knowledge domains. The OERs created by using our proposal should also be evaluated in terms of their effectiveness in student's learning.

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Student-Perceived Effectiveness of Online Content Delivery Modes

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Abstract—This Work In Progress focuses on student perceptions of the effectiveness of three content delivery modes; a) traditional, residential in-class b) class capture for asynchronous online delivery, and c) modularized targeted content videos for online and blended or flipped classroom mode.

Despite the growth of MOOCs and the concomitant shift from long lecture videos to learning modules, many online courses still rely on a class capture method. A recent study on video use by students in online courses recommends the use of short videos, six to nine minutes in length, based on student viewing habits. [1] The student behavior was inferred from click-stream data captured within the LMS but there was no direct interaction with students to gauge impressions of the content delivery or impact on learning. To improve both the residential and online experience requires a deeper understanding of those features which promote learning in each approach. Some of this understanding can be gleaned from traditional academic course evaluations, but student perceptions yield an additional level of understanding.

For this study we analyzed data from multiple offerings of a 7-week graduate level numerical analysis course; Application of Finite Element Analysis. Over three years this course was offered residentially and online using multiple delivery modes. We categorize the delivery modes as Traditional, Class-Capture, and Modularized/Blended. Each student studied the material using one delivery mode and was then asked to review the material using another delivery mode. The students were asked to evaluate the perceived learning attained based on their original content delivery mode and the alternate mode. The feedback from this analysis, combined with traditional course evaluations will be used to develop a more comprehensive and objective survey to be used in the next round of courses.

I. INTRODUCTION

Increased focus on Massively Open Online Courses (MOOC)s has raised awareness of online learning and sparked significant debates about the value of online learning and its place in the academic landscape. Despite the debates, it is clear that graduate engineering programs must support both full and part time students. While full time students have the flexibility to attend lecture courses on a university schedule, most part time students are full time practicing engineers who need to take courses at a time and place that fits into an industrial work week. Traditionally this meant online courses where the in class lectures of a residential course were recorded and posted for remote students to watch offline. These courses are generally asynchronous with support via email, discussion boards and occasional video conferencing.

Concurrently, the use of technology to build online courses has lead to an increase in flipped or blended learning modalities at the university level. Here we define a Flipped or Blended modality as a learning modality that requires the student to independently work through content and course material prior to a face-to-face class meeting. Using this definition we see that "Flipped Classrooms" are not novel, as any liberal arts seminar course requiring reading prior to a discussion section or engineering course requiring laboratory preparation prior to a laboratory can be considered blended or flipped. We choose this definition for the simple reason that engineering education must be a combination of theory and practice and we aim to increase the amount of time devoted to building solutions such as devices, systems or software. Furthermore, as content has moved online in the form of documents, ebooks, websites and YouTube videos, what the engineering professor offers a student is the example of an expert's approach to design, analysis and trouble-shooting. For students, a blended learning environment offers the opportunity for the novice to observe the way an expert approaches application of the theory to the design, development, testing and modification cycle to create a solution.

Despite increased use of video and screen capture presentations in both online and blended course instruction, there is little research regarding the relative effectiveness of these delivery mechanisms. Several studies aimed at capturing student perceptions of the flipped classroom pedagogy [2], [3] focused on student acceptance of the new pedagogy. While the outcomes were positive and qualitative evidence suggests that students create deeper understanding using the flipped classroom this does not address the effectiveness of the delivery mechanisms. Older studies, such as [4] compared fully online to blended learning, asking students to connect the format to their level of learning, while [5] considered the components and interface design required for effective e-learning. These studies parallel the comparison of traditional classrooms to the flipped pedagogy, providing important insights into student preferences but don't directly address the effectiveness of the delivery. The aim of this study is to uncover a set of questions and metrics that can be used to capture the benefits and limitations of various delivery modes.

II. METHODOLOGY

The course used for the study was a graduate level Mechanical Engineering course in the application of the Finite Element Method. The students ranged from upper level undergraduates pursuing a BS/MS program to second year graduate students. The course included the theoretical and practical development of numerical simulations of physical phenomena using the Finite Element Analysis. As with any numerical technique, the practical aspect of Finite Element Analysis required developing software solutions for each assignment. While some engineering disciplines have extensive undergraduate experience with software development, in general this is not true of mechanical engineers. On average the students were familiar with using third party software but had little programming experience and no software development background.

Over the past three years the course has been offered for residential and remote students using multiple delivery formats. The residential section was offered once using traditional lecture and twice using a blended format. During the same time, the online section was offered four times, twice using class capture and twice using modular videos targeted for each topic covered in the course. The modularized videos are part of a course redesign using the edX pedagogy. [6] In this design, each section of a traditional lecture course is broken into individual concepts that must be mastered by the student. The decomposition yields a concept map where each concept is equivalent to a unit within the edX course pedagogy. When using the edX approach to building a course, concepts are delivered using video, written text and simulations. Interspersed between the concept units are assessment units; questions, problems and discussion topics meant to review and consolidate the learner's understanding of the concept. At the time of the last Finite Element Analysis offering we did not have an open edX instance running for students, so we incorporated the philosophy into each of the targeted videos, notes and questions and supplied them through our Blackboard platform.

For this study, the Class-Capture mode relied on lecture capture, wherein each two-hour, in-class lecture was captured and posted for asynchronous viewing. Our second method for content delivery examined the modularized, targeted topic videos described above. The modularized presentations spanned the same course content as presented in the in-class and lecture-capture sections. A third content delivery mode flipped an in-class course offering by delivering the modularized content online prior to class meetings, using the same targeted topic videos. Within the formal class time, students worked on homework and group endeavors, but did not receive formal lectures. We categorize the delivery modes as Class-Capture, Modularized, and Blended, respectively.

Our initial appraisal of delivery styles is based on standard course evaluations used at our institution. The questions closely resemble those in [4]. The Institute's standard course evaluation includes twenty-six questions primarily focused on evaluating the instructor's teaching ability. All questions are to

be answered relative to other courses taken at the institution and are scored on a five point scale where 1 is "much less" and 5 is "much more". We selected the four survey questions that emphasized student perceptions of learning and effort, namely

- The amount I learned from the course (relative to other courses) was
- The intellectual challenge presented by the course (relative to other courses) was
- The amount of reading, homework and other assigned work (relative to other courses) was
- The amount of effort I put into this course (relative to other courses) was

The responses to the course evaluation questions provide some insight into the student perceptions of the overall course relative to other courses at the same institution. To develop a better understanding of the relative merit of class capture and modular, single concept videos, we asked the summer 2015 online section the following questions:

- does the shorter single concept video v the class capture video help you learn?
- what is the added benefit of the single concept video?
- what are the drawbacks of the single concept video?
- some videos are still 20 mins long, would it be better to break these up?

This unscientific survey produced anecdotal information that helped us frame our most recent experiment.

Based on the answers to the evaluations and the anecdotes from the summer online section, we selected a topic common to the course that had been taught in multiple modes. To capture student perceptions of the content presentation modes, we asked students to review the material using a delivery option different from that used in the course they had completed. We selected a specific topic, Numerical Quadrature, for the content delivery comparisons. The Class-Capture mode covered this topic in a two-hour lecture. The Modularized delivery mode used three 10-minute objective-specific videos. Each video included two self-check assessment sections to verify student understanding of the concepts presented in the video. The Blended delivery used the same three objective-specific videos, but replaced the self-check assessments with an in-class group project with Instructor support as needed.

The study participants are students who successfully completed the course within one of three delivery modes. The students were asked to evaluate the perceived learning attained based on their original content delivery mode and the alternate mode by answering the following questions.

- What was your level of understanding the theory?
 - based on your original class delivery mode
 - based on the alternate delivery mode
- How confident are you to be able to use this material in a future application?
 - based on your original class delivery mode
 - based on the alternate delivery mode
- How do you rate the ease of information retrieval at some later point in time?

- based on your original class delivery mode
- based on the alternate delivery mode
- What modifications would aid your learning having experienced at least two class delivery modes?

We acknowledge the inherent bias that will exist when a student is asked to review previously presented material via a new delivery mode. However that bias exists in all situations. Those students that initially received a modularized delivery mode will receive the lecture-capture style and vice versa. The bias associated with going from mode A to mode B will be consistent with (and hence negate) that of going from mode B to mode A.

These responses, in combination with the evaluations and summer student survey will be used to gauge the effectiveness of different online delivery modes. The last question is an open-ended question which will guide future studies delineating the differences between class delivery modes in terms of student learning and effectiveness.

III. PRELIMINARY RESULTS AND DISCUSSION

A. Course Evaluations

Table I presents the results from the current course evaluations as gathered for all courses at our institution. The table is presented for three course delivery modes: a) Traditional, residential in-class delivery; b) Lecture capture purely online; and c) Blended/Modularized Online.

TABLE I
INSTITUTION COURSE EVALUATIONS

Question	Traditional In Class $N = 33$ \bar{x}, σ	Lecture Capture Online $N = 17$ \bar{x}, σ	Blended/ Modularized $N = 16$ \bar{x}, σ	Significant Difference at 95% Level
1	4.73, 0.45	3.59, 1.3	4.5, 0.76	Yes
2	4.72, 0.46	4.41, 1.1	4.64, 0.63	No
3	4.33, 0.78	3.82, 0.88	4.07, 0.83	No
4	4.67, 0.54	4.41, 0.80	4.38, 0.77	No

The blended/modularized online mode had two subgroups - those that did the blended or flipped classroom and those that did the modularized online course redesign following the edX pedagogy. However, there was no statistical difference between these two delivery modes and their results were merged in column 4. There was no statistical difference between the Blended/Modularized delivery mode vs the Traditional In-Class mode, columns 2 and 4. However, there was a statistical difference at the 95% confidence level between the Traditional In-Class Mode and the Lecture-Capture Mode (columns 2 vs 3) for question 1 as delineated in the last column (column 5).

Question 1 asked the student how much they had learned relative to other courses. The student responses strongly indicate that they learned the least when the class delivery mode was lecture capture. The intellectual challenge, amount of reading and amount of effort between the delivery modes was not significantly different, questions 2 thru 4, respectively.

B. Summer Student Survey

In the summer of 2014, a 7 week online section was taught using the edX style modular approach. During the third week of the term, at roughly the half way mark, an informal survey was sent to the students, using the questions previously itemized in the Methodology Section. The number of responses was small and are included here as anecdotal information that helped inform the next phase of our study. The overwhelming response was that the shorter modular videos lead to greater understanding because

- it was easier to focus on the single topic and be confident that they understood the concepts
- the topic and concepts weren't lost in a lot of other information
- it was easier to rewind and review the shorter video.

While all of these comments suggest more effective learning using shorter videos, the last comment is particularly significant. Students stated that they were more likely to review a short one or two concept video when they got stuck or confused particularly while attempting to apply the concepts to the development of scientific software.

C. Ongoing experiment

The evaluation questions described in the Methodology were sent to previous students coupled with a link to the material presented through an alternate delivery mode. These responses will be tabulated and added to our existing results by the end of this summer.

IV. CONCLUSION AND FUTURE WORK

We delivered three variants of a graduate level Finite Element Analysis course to residential and online students. The variants included traditional lecture and lecture capture, targeted concept videos for online sections, and a blended (or flipped) section using targeted concept videos for the content delivery and pre-class preparation. Based on course evaluations and a brief survey of online students, we created a set of questions to ascertain student perceptions of delivery mode effectiveness. Using these questions, we surveyed students to gain insight into the effectiveness of delivery strategies. To accomplish this, students who has successfully completed the course in one of these modes were asked to review the Numerical Quadrature module delivered in a mode different from their initial introduction.

This Work In Progress analysis provides another step toward understanding how to create and deliver online content effectively, whether for online or blended courses. To improve the quality of both online and blended learning, we need to determine what questions, learning management system analytics and assessments best highlight the adjustments needed to strengthen learning and understanding.

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Topic Based Segmentation of Classroom Videos

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Abstract—Video of classroom lectures is a valuable and increasingly popular learning resource. A major weakness of the video format is the inability to quickly access the content of interest. The goal of this work is to automatically partition a lecture video into topical segments which are then presented to the user in a customized video player. The approach taken in this work is to identify topics based on text similarities across the video. The paper investigates the use of *screen text* extracted by Optical Character Recognition tools, as well as the *speech text* extracted by Automatic Speech Recognition tools. An automatic text-based segmentation algorithm is developed to identify topic changes and evaluated on a set of twenty-five lecture videos. The key conclusions are as follows. Screen text is a better guide to discovering topic changes than speech text, the effectiveness of speech text can be improved significantly with the correction of speech text, and combining screen text and accurate speech text can improve accuracy. Results are presented from surveys showing a high level of satisfaction among student users of automatically segmented videos. The paper also discusses the limits of automatic segmentation and the reasons why it is far from perfect.

I. INTRODUCTION

Video is gaining popularity as a learning resource. Video recordings of classroom lectures are often made available as additional material for a conventional course, as the core of a distance/hybrid learning course, or posted publicly for community learning. Lecture videos are posted on a large scale on portals such as MIT OpenCourseware and Apple's iTunes University. In recent years MOOCs (Massive Open Online Courses) driven by video and other features have emerged as a potential disruptive technology for the delivery of education. There is a substantial body of research that has established that video is a versatile learning resource that is considered valuable by students and instructors [1], [4], [15], [17], [18]. The lecture videos that capture the overall classroom interaction provide an experience that mirrors the actual class to the students who are not able to attend. However, video is also commonly employed by students to access specific information, not just to replace missed lectures. In particular, review of the class content, e.g., for quizzes and exams, is an important use of video. Efficient retrieval of the appropriate information in a long lecture video is a major challenge with the video format. Therefore, dividing videos into topical segments is important for the advancement of video as a learning tool.

The research presented in this paper is in the context of the ICS (Indexed, Captioned, Searchable) Videos project at the University of Houston[18], [22]. The goal of the project is

to ease navigation of lecture videos, making them a companion resource for learning, similar to a textbook. A video lecture is automatically partitioned into segments based on image and text analysis. We refer to this process as *indexing* or *segmentation*.¹ Video is searchable for keywords and concepts. Captions are developed for videos with speech recognition and crowdsourcing by students. All videos for an entire course (or department) are treated as a single “videobook” stream with global indexing and search capability. Several thousand students were surveyed and hundreds of students participated in focus groups during the project. Conclusions from this project relevant to the research presented in this paper are i) videos are a very valuable learning resource and ii) indexing enhances the value of videos significantly [3], [22].

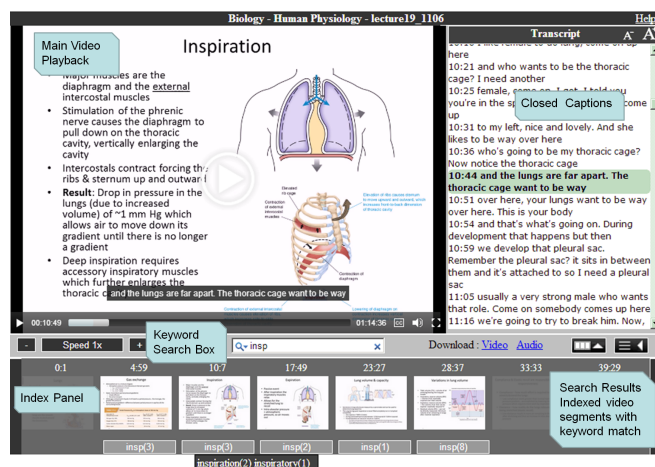


Fig. 1. ICS Video player with index points, search box, captions and transcript

The ICS Video player that encapsulates indexing, search, and captioning is illustrated in Figure 1. An index panel is situated on the bottom of the player; each index point represents a new topic in the form of a screen-shot of the video at that point of time. Users can navigate different topical segments of the video by clicking these index points. A search box is located below the main video playback for searching inside the video. Keyword search across videos is also supported. Captions are displayed as an overlay at the bottom of the main video playback window, in addition to a separate transcript window on the right side.

The goal of the research presented in this paper is to automatically partition a lecture video into topical segments, which can then be presented to the users as visual index points. However, automatically segmenting a video lecture by topic or

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¹In this work, the terms *indexing* and *segmentation* are used interchangeably.

subtopic is a very challenging problem as the precise meaning of a topic is subjective. The approach taken in this work to identify topics is based on text similarities across the video. A segmentation algorithm based on *cosine similarity*, a common metric to measure the similarity between two blocks of text, was employed. For topic-based segmentation, two approaches were investigated based on *screen text* or *speech text*. Screen text is the text that appears on the video frames, which typically corresponds to the viewgraphs used in teaching a class, but can also be from other sources such as web pages. Screen text is extracted with the help of optical character recognition (OCR) technology [20]. Speech text is the text corresponding to the audio in a lecture video, which includes everything spoken by the instructor as well as the interaction with students. Speech text is gathered by using an Automatic Speech Recognition (ASR) system. For selected videos, automatically generated speech text was corrected manually to remove errors in speech recognition.

Evaluation was done on a set of twenty-five lecture videos from courses in Computer Science and Biology and Biochemistry. The ground truth was established by asking the lecture instructor or another topic expert to manually identify topic transitions in the video. The segmentation obtained with screen text, speech text, corrected speech text, and combinations of these were evaluated for accuracy against the instructor generated ground truth. The inherent inaccuracy of human segmentation was also measured by asking multiple subject experts to segment the same videos by topic. The results show the accuracy of different approaches to segmentation as well as the limitations of the text based automatic segmentation process. The main reasons for errors in automatic segmentation are also presented based on a manual analysis of some of the videos employed for evaluation.

This paper is organized as follows. Section II discusses prior work related to segmentation of lecture videos. Section III discusses the extraction of screen text and speech text. Section IV presents the text based automatic indexing algorithm. Section V discusses the evaluation methodology and presents the results of indexing algorithm employing screen text and speech text. Section VI presents the results of evaluation of indexing by student users based on survey results. Section VII discusses the reasons for indexing errors with slide text and speech text. Section VIII contains conclusions.

II. RELATED WORK

In general, video segmentation or indexing requires the detection of key frames or labels that indicate a change of content in a video [6], [8], [11], [14]. A multitude of methods have been developed that use low-level image properties, such as color and texture, to group contiguous video frames and provide reasonable automation while lacking the ability to provide topical segmentation [2], [7], [12], [16]. The work presented in this paper focuses on classroom lecture videos or screencasts. We employ similar techniques as a preprocessing step for detecting the slides in lecture videos.

Topic based segmentation of lecture videos requires processing the screen text extracted by OCR, and/or speech text extracted by ASR. Various methods have been developed that use both OCR and ASR data for content-based video retrieval,

semantic multimedia retrieval, and meta-data generation [10], [13], [25]. Extraction of segments and keywords from both OCR and ASR methods and ranking the keywords is discussed in [25]. Comparing the speech text segments for similarity to determine the topic boundaries is studied in [10] employing a dictionary-based approach that compares selected features among segments. However, human supervision is required for customizing the dictionary for a particular subject area. The indexing in our work is different as the video indexing method is unsupervised and fully automated.

In summary, the main directions of related research are indexing of movie videos, segmentation based on visual properties, and extraction and analysis of OCR and ASR keywords. These are complementary to the work presented in this paper. The main subject of this paper is how speech and text compare as the input for segmentation of videos, if they can be used together, and the reasons why these approaches often fail.

III. EXTRACTING TEXT FROM VIDEOS

The main research objective of this paper is segmentation of video lectures based on textual content of the lectures. Here we discuss how different types of text are extracted from a video.

A. Screen Text

Screen text is obtained by applying Optical Character Recognition (OCR) tools to video frames. Typically this text corresponds to viewgraphs employed during the lecture but can also include other content such as web sites or files displayed during a lecture. One of the premises of this research is that an analysis of screen text can provide guidance on topic transitions in a video lecture.

After a comprehensive analysis of available OCR tools, we opted to use the MODI (Microsoft Office Document Imaging) tool set. We found that OCR tools generally have limited effectiveness at recognizing text in the presence of 1) certain text and background color and shade combinations, 2) text mingled with colorful shapes, and 3) small and exotic fonts. To increase the detection efficiency of text on video frames, we used simple image processing techniques for image enhancement (IE) prior to the application of OCR tools. IE operations employed include segmentation of text, enlargement with interpolation, and color inversion. The process of obtaining screen text from videos employed in this research is detailed in [23]. Typically an accuracy of well over 90% is obtained with this enhanced OCR extraction framework. Hence this work does not consider manual correction of OCR errors.

B. Speech Text

Spoken text is simply the text corresponding to the audio in a recorded lecture. It primarily consists of the lecture from the instructor but may also include student interaction. Speech text can provide important information that determines topic changes in a video.

Various ASR(Automatic Speech Recognition) tools are commercially available and we experimented with *Dragon Naturally Speaking*, *Windows Speech Recognition*, and *YouTube*. In the end, YouTube was employed based on an

analysis discussed in [5]. The accuracy of speech recognition varies widely based on the instructor and lecture content. The average accuracy in our experiments was only around 68%.

C. Hybrid Text

Hybrid text is simply the union of screen text and speech text. In order to utilize the strengths and topic-related keywords from both speech and screen text, we employed a hybrid text type for video indexing purposes. It should be noticed that the volume of speech text typically far exceeds the volume of screen text.

D. Corrected Speech Text

All ASR tools generate significant errors when employed on the speech component of classroom videos. There are various reasons for errors, such as a heavy accent, technical vocabulary, poor recording, and the colloquial nature of a classroom lecture. The speech text was corrected manually using a crowdsourced caption editor [5] in order to evaluate the impact of ASR errors on topic based video segmentation. The average speech text accuracy on selected videos was improved from 68% to 99% with this correction process.²

IV. TEXT-BASED INDEXING

Indexing is the task of dividing a lecture video into segments that contain different topics. A video is composed of a sequence of thousands of images (or frames). In order to process video data efficiently, a video segmentation technique should detect scene changes and find the unique images. Therefore, video segmentation task involves two steps as depicted in Figure 2. First step is preprocessing to identify all transition points, i.e., places where the image on the video changes significantly. Subsequently, a subset of these transition points are selected as index points representing topic change based on text analysis. The assumption is that topic transitions happen at transition points which typically represent slide changes in a lecture.

A. Preprocessing: Identifying Transition Points

Identification of transition points is based on a comparison of successive frames in the video. Frames are commonly recorded in 24-bit RGB representation; color value for each pixel is encoded in 24 bits where three 8-bit unsigned integers (0 through 255) represent the intensities of red, green, and blue. Corresponding pixels in successive frames are considered different if they differ by a minimum RGB threshold when the RGB values of the pixels are compared. The threshold value is chosen empirically after evaluation of a large number of diverse lectures. Details of the process of identification of transition points is discussed in [23].

²About 1% of the words were not correctly identified by students making the corrections manually. The ground truth is the instructor's version of the transcript.

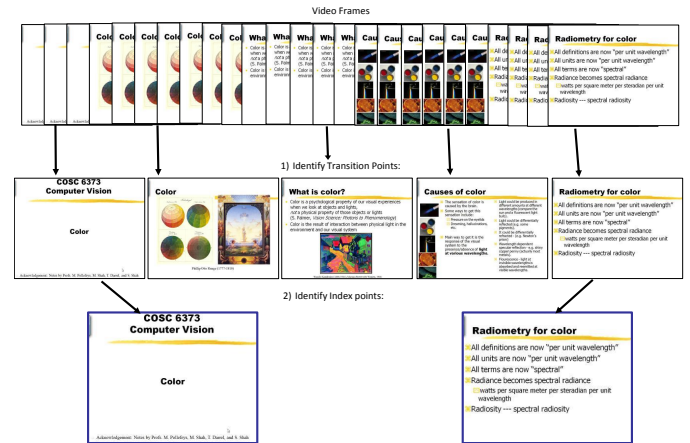


Fig. 2. Indexing framework steps: 1) Transition points (unique video frames) detected by RGB Color difference. 2) Index points representing different topics are selected among the transition points.

B. Text Similarity Metric: Cosine Similarity

The core idea of text based segmentation is that different topics are represented by different groups of words. Comparing the frequencies of different words in blocks of text establishes how similar they are in content and topic. Intuitively, a video splits into different topical segments at the point where the mix of words being used in video frames changes significantly. And this change can be detected by a comparison of the similarity of two text blocks. While many different text similarity metrics have been discussed in literature, we used *cosine similarity*, a well known and proven metric in information retrieval and text mining [9], [19]. It is a measure of similarity between two vectors, calculated by the dot product of the vectors divided by the product of their norms as shown by the formula below. The vectors A and B correspond to the frequency of words in the context of text based segmentation.

$$\cos(\theta) = \frac{A \cdot B}{\|A\| \cdot \|B\|} = \frac{\sum_{i=1}^n A_i \cdot B_i}{\sqrt{\sum_{i=1}^n A_i^2} \cdot \sqrt{\sum_{i=1}^n B_i^2}}$$

An example of text similarity calculation is depicted in Figure 3. Three frames and their word frequency vectors are listed. The cosine similarity between the vectors representing adjacent frames is computed as follows.

$$\begin{aligned} \text{cosine_similarity}(Frame_1, Frame_2) &= 0.57 \\ \text{cosine_similarity}(Frame_2, Frame_3) &= 0.19 \end{aligned}$$

This matches the intuitive judgment that $Frame_1$ and $Frame_2$ are more similar to each other than $Frame_2$ and $Frame_3$. The implication is that any topic change inside this sequence should start with $Frame_3$. Cosine similarity measure is normalized with respect to document length as it compares the relative frequency of common words.

C. Text-based Indexing Algorithm

The main purpose of the indexing algorithms is to partition a lecture video so that each segment represents a topic. Before the indexing phase, the lecture video is divided into transition segments. [21], [24]. The segmentation algorithm repeatedly




	Frame1	Frame2	Frame3
			
	Birds fly. Birds chase fish.	Cats chase birds. Cats eat fish.	Trees are green. Birds visit trees.
	Frame1	Frame2	Frame3
birds	2	1	1
cats	0	2	0
chase	1	1	0
fish	1	1	0
fly	1	0	0
green	0	0	1
trees	0	0	1
visit	0	0	1

Fig. 3. A sequence of frames and their frequency of word vectors is computed to determine similarity text similarity

merges the smallest segment in the video to the segment on the right or left, based on cosine similarity with a group of segments on the left, and a group of segments on the right, respectively, as illustrated in Figure 4. An empirically selected value of *Grouping Duration (480 seconds)* determines the number segments on the left and right that are included for text comparison. The algorithm is explained as follows.

Data: A list of transition points ;
Required number of index points (N);
Grouping duration in seconds;
Result: N index points that are a subset of given transition points;
repeat
 Select transition segment with smallest duration;
 if the similarity is more towards right group **then**
 merge right;
 else
 merge left
 end
until Number of transition points == Required number of index points;
Algorithm 1: Text-based indexing algorithm

A pictorial example of the algorithm is provided in Figure 4. In this example, the similarity of the smallest segment K is compared with the left as well as the right group and merged with the most suitable neighbor depending on the similarity value.

We have employed a simple indexing algorithm that assumes a fixed number of index points. A detailed comparison of different algorithms is included in [21]. However, the goal of this paper is to compare speech text and screen text as the input for indexing, and we believe this algorithm is adequate for this purpose.

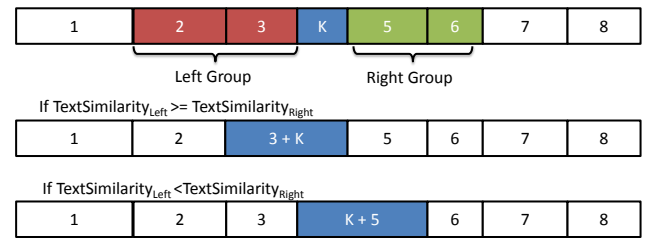


Fig. 4. Text based indexing algorithm: Shortest segment compared to left and right group of neighbor segments and merged based on similarity

V. EVALUATION

The objective of evaluation is to measure the accuracy of segmentation based on screen text and speech text.

A. Evaluation Framework

A suite of 25 video lectures listed in Table I was selected for evaluation. The subject areas were Computer Science and Biology and Biochemistry. The sources of the video were lectures recorded at the University of Houston and the Coursera website. The textual content of the videos was obtained by using OCR methods and YouTube as discussed in Section III. For a subset of the videos, the text obtained from YouTube was manually corrected for ASR errors for evaluation.

TABLE I. LIST OF SOURCE OF COURSES USED FOR EVALUATION

Source	Major	Course Name	Lecture Count
UH	Computer Science	Introduction to Computing	4
UH	Computer Science	Computer Organization and Programming	5
UH	Computer Science	Digital Image Processing	2
UH	Computer Science	Computer Architecture	2
UH	Biology	Human Physiology	3
Coursera	Computer Science	Compilers	3
Coursera	Computer Science	Cryptography	2
Coursera	Computer Science	Machine Learning	2
Coursera	Computer Science	Probabilistic Graphical Models	2
Total			25

A major difficulty in evaluating an automatic segmentation algorithm is that the ground truth, i.e., the optimal set of index points, is often not obvious even to the instructor of a course. It is very challenging to decide if a transition point is the start of a subtopic or not. The creator of each lecture video (normally the instructor teaching the course) was asked to rate every transition point on its appropriateness to be an index point based on the extent to which it represented a change in the topic. The following scale was used for ranking:

- Definitely Index Point (+2)
- Probably Index Point (+1)
- Probably Not Index Point (-1)
- Definitely Not Index Point (-2)

However, the output of the segmentation algorithms is binary, i.e., each transition point is determined to be an index point (1) or not an index point (-1). The quality of the set of index points identified by an automatic indexing algorithm is determined as follows. Suppose the ground truth for a transition point is “Definitely Index Point”. Then if the algorithm correctly identifies it as an index point, +2 is scored, while if it is incorrectly identified as not an index point, then -2 is scored. Now suppose the ground truth for a transition point is “Probably Index Point”. Then if the algorithm correctly identifies it as an index point, +1 is scored, while if it is incorrectly identified as not an index point, then -1 is scored. Similarly, +2 or -2 is scored for segments rated as “Definitely Not Index Point” and +1 or -1 for segments rated as “Probably Not Index Point”. The scoring mechanism is illustrated in Figure 5. The sum of all individual scores is added to determine the raw indexing score for a video that we label as the Video Indexing Score (VIS).

Suppose the video lecture contains n transition points. Each transition points will have a ground truth score and an algorithm score. If G_i and A_i are the ground truth score and the algorithm score, respectively, of transition point i then the overall Video Indexing Score is represented as:

$$VIS = \sum_{i=1}^n (G_i * A_i)$$

		Ground Truth			
		Definitely Not IP	Probably Not IP	Probably IP	Definitely IP
		-2	-1	+1	+2
Algorithm Output	-1 (Not IP)	(+2)	(+1)	(-1)	(-2)
	+1 (IP)	(-2)	(-1)	(+1)	(+2)

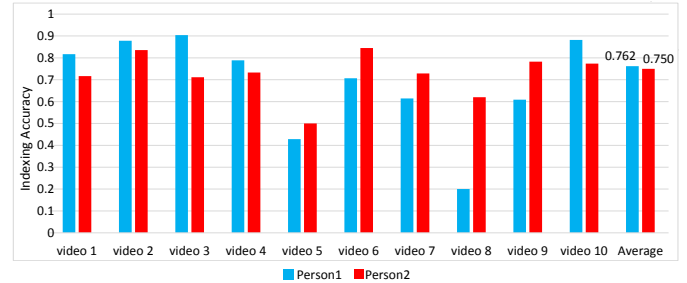
Fig. 5. Video indexing scoring for different ground truth values and algorithm results

Finally the accuracy score of an algorithm for a video is computed as a percentage of the theoretical maximum VIS score for the video corresponding to theoretically optimal indexing. It should be noted that this metric is designed for comparing algorithms but not necessarily an indicator of absolute accuracy; the accuracy score drops in a non-linear fashion with errors in indexing, and can theoretically be negative.

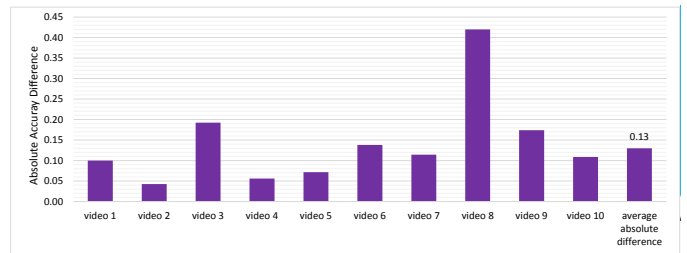
B. Human Accuracy

The ground truth employed for evaluating indexing algorithms is the information on index points provided by the instructor. However, it is important to note that experts familiar with the subject matter are likely to come up with different ground truths. In order to validate this, an experiment was conducted where two subject matter experts were asked to index a set of videos and the results were compared against the ground truth provided by the instructor. The results are tabulated in Figure 6. Figure 6 (a) shows that the two experts

have different accuracy on different videos, although their average accuracies are very close; 0.750 vs 0.762. Figure 6 (b) shows that the the difference in accuracy between the two experts varies between 4% (video 2) and 42% (video 8) with an absolute average difference of 13%. The implication is that further enhancements could improve the performance of video indexing algorithms, but it may be impossible to achieve perfect accuracy because of the uncertain nature of the ground truth. In the results of this paper, we also plot *human relative indexing accuracy* which is the accuracy achieved by an algorithm as compared to the average accuracy of our human experts.



(a) Indexing accuracy of human experts



(b) Absolute difference in accuracy of human experts

Fig. 6. Evaluation of indexing by human experts

C. Results

The text based indexing algorithm was employed to segment a suite of twenty five videos with screen text, speech text, and hybrid text; the latter simply being the union of screen text and speech text. The accuracy was measured in relation to the ground truth. Additionally, the relative accuracy as compared to human indexing was also computed based on the discussion earlier in this section, and is represented as *Human Relative Indexing Accuracy*. The premise is that an algorithm can at best achieve human accuracy. The results are presented in Figure 7.

We observe that the accuracy of segmentation with screen text is somewhat higher than that with speech text, while the accuracy of segmentation with hybrid text is in between the two. The accuracy varies in the range between 82.8% and 86.3% as compared to human accuracy. However, screen text is not the best choice for every video; 19 videos showed better segmentation with screen text while 6 videos showed better segmentation with speech text. We speculate that the reason for overall higher accuracy of screen text is that speech text has errors and screen text is sparse but is still likely to contain the keywords that define topic transition. The hybrid approach did not improve over the screen text, possibly because it is

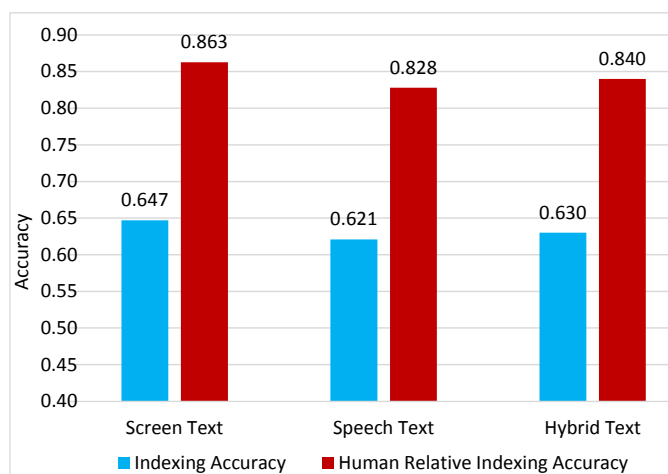


Fig. 7. Automatic indexing accuracy for screen text, speech text and hybrid text

dominated by speech text as the sheer volume of speech text far exceeds screen text. Perhaps better ways of combining speech text and screen text can lead to results superior than what can be achieved individually.

Speech text is automatically generated from lecture audio by YouTube. It typically had many errors because of the weakness of automatic speech recognition. Further, the quality of speech text varied significantly among videos. Figure 8 plots the accuracy of automatic indexing for different ASR error rates. It is clear that the accuracy of speech recognition is an important factor in automatic indexing.

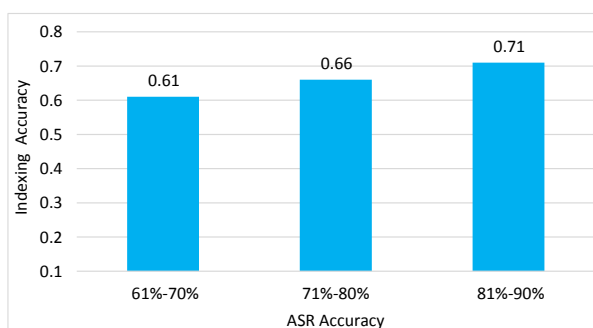


Fig. 8. Average indexing accuracy in relation to accuracy of automatic speech recognition

Additional experiments were conducted to determine any relationship between the human judged quality of speech text and the corresponding accuracy of automatic indexing. A scale from zero to five was developed to rate the quality of speech text:

- 5- Excellent
- 4- Very Good
- 3- Good
- 2- Average
- 1- Poor
- 0- No Text

Each video lecture was heard for 10-15 minutes by one of the authors in order to assign a quality rating to the speech text. No videos were rated 0 or 5 in this process. Subsequently the segmentation accuracy was measured for each group separately for analysis. The results are presented in Figure 9. The figure again shows a positive correlation between the quality of speech text and the quality of indexing.

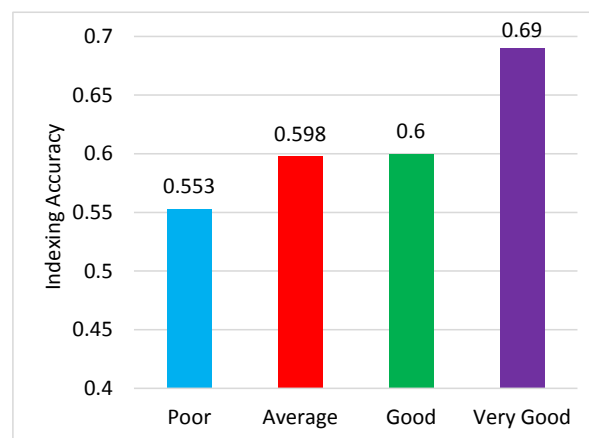


Fig. 9. Average indexing accuracy in relation to human judged quality of automatic speech recognition

To further explore the relationship between the speech recognition quality and indexing effectiveness, we performed an evaluation using manually corrected speech text. Speech text from 11 of the videos was manually corrected with the help of the ICS captioning tool. The accuracy of segmentation with speech text, corrected speech text, and screen text for these 11 videos is displayed individually in Figure 10 and summarized in Figure 11. Corrected speech text leads to significantly better segmentation accuracy as compared to (uncorrected) speech text and performs better than screen text.

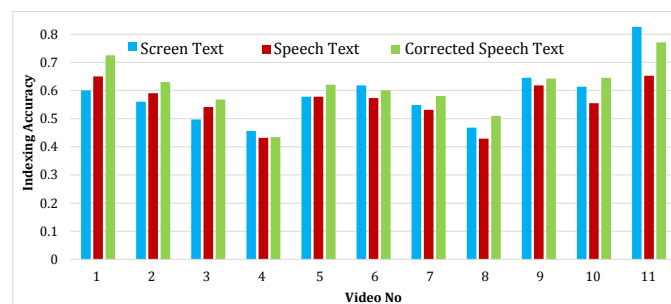


Fig. 10. Indexing accuracy with corrected speech text for selected lecture videos

In summary, the screen text received from OCR tools was better for segmenting lecture videos than speech text generated by ASR tools. However, the quality of speech text is important for accuracy and corrected (and hence virtually error free) speech text is better than screen text for segmentation. Simple hybrid text obtained by combining speech text and screen text did not perform any better than screen text alone. Experiments were not performed for corrected screen text because the automatically derived screen text was fairly accurate; usually over 90%. However, this will be a subject for future work.

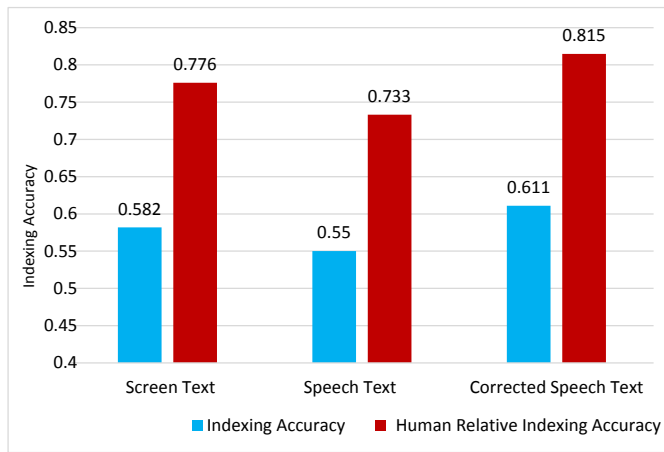


Fig. 11. Average indexing accuracy with screen text, speech text and corrected speech text for selected videos

VI. SURVEY RESULTS

Indexed Captioned Searchable (ICS) Video usage is assessed to develop an understanding of the overall perceived value of the video lectures as well as the value of video indexing. Surveys were administered over 5 years in more than 10 semesters [3]. Figures 12 and 13 show the response of approximately 120 students from Spring 2013 and Fall 2013 semester to a forced-answer question about the usefulness and value of the indexing. Figure 12 shows that well over 90% of respondents agreed, that the video indexing was helpful, that the placement of index points in the video timeline was appropriate for the lectures, that the layouts of the index images made the index feature easy to use, and that the index points separated a lecture into logical segments. In this figure “Disagree strongly”, “Disagree” and “Disagree slightly” is merged to “Disagree***” due to the low number of responses.

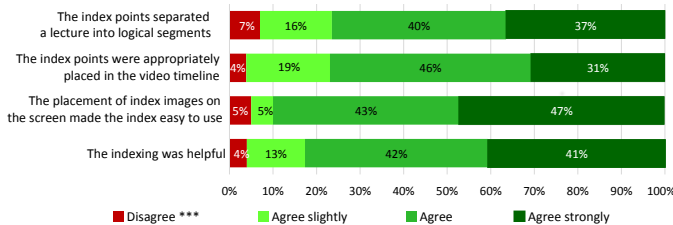


Fig. 12. Quality of video indexing

Responses to additional questions on the value of indexing are presented in Figure 13. Students are strongly supportive of the statements that the index feature functioned well, that the index points provided enough information to identify video segments of interest, and that the index made it easy to navigate the video. The statement that index points represented the start of a new subtopic had somewhat weaker support than the other assertions. It is important to note that even imperfect indexing is perceived as very valuable by the students.

In open-ended comments, students reported several benefits from using the index including (a) saving time, for example one student wrote, “I did not have to wade through the rest of the lecture just to answer one question”; (b) skipping through material the student was familiar with to get to the

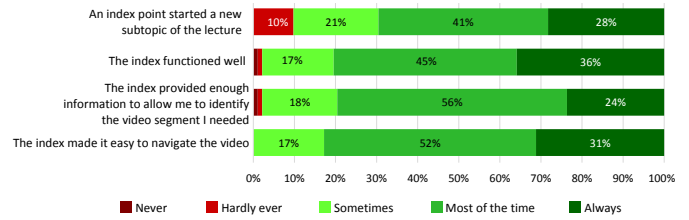


Fig. 13. Value of video indexing

challenging sections; and (c) returning to a section of the lecture if an interruption occurred. For example, one student wrote, “Sometimes I would have to pause the lecture to take care of other responsibilities that I had to attend to, and when I was ready to come back to the lecture I’d pick up exactly where I was at. It was great!”. Another student said, “The indexing feature, in my opinion, is one of the best parts regarding this video player. It separated the lecture into reasonably sized sections and made it easy to know where to pick a lecture back up if I had to stop watching for a while.”

VII. DISCUSSION

Several videos were manually analyzed to understand why the screen text and speech text based algorithms sometimes provided incorrect index points in lecture videos. We illustrate some of the reasons with examples.

A. Speech Text Limitations

Figure 14 summarizes the reasons for the errors in segmentation with speech text.

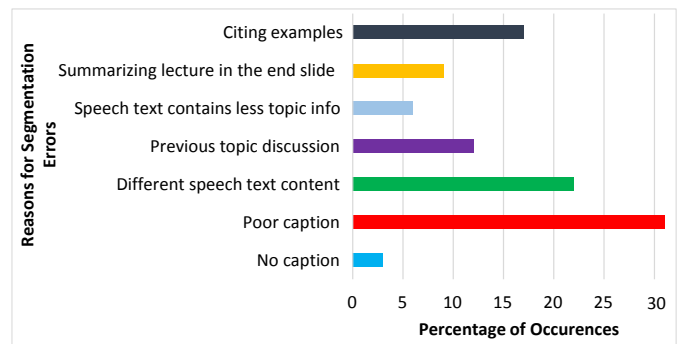


Fig. 14. Causes of segmentation errors with speech text

The most common reason for erroneous results in most of the lecture videos for speech text segmentation is the *poor quality of caption text* that leads to unrecognized text, incomplete sentences, incorrect technical words representing topic information, etc. Reduced audio quality predictably degrades the caption quality and segmentation accuracy as well. One possible solution is to manually correct the speech text but the process is labor intensive. *Different speech text content* such as instructor talking about weather, exams, or assignments, that are irrelevant to the topic flow is another leading cause of poor segmentation. This can potentially be minimized in the future by only using a glossary of subject terms for indexing. Other causes include switching to a topic away from the main flow of the lecture, such as citing examples and review of a topic discussed earlier.

B. Screen Text Limitations

Figure 15 summarizes the reasons for the errors in segmentation with screen text.

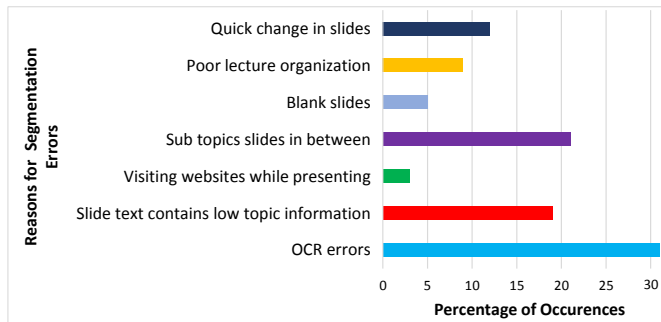


Fig. 15. Causes of segmentation errors with screen text

The largest source of errors in segmentation is *OCR errors* that lead to incorrect text data as a result of failure to recognize the text characters accurately, even though the OCR based text retrieval is overall fairly accurate. There could be various reasons for this, such as the size of the characters, presence of mathematical formula, or handwritten texts in a slide; an example of which is shown in Figure 16. Accuracy with manual correction of OCR errors is worth investigating but not a practical solution.

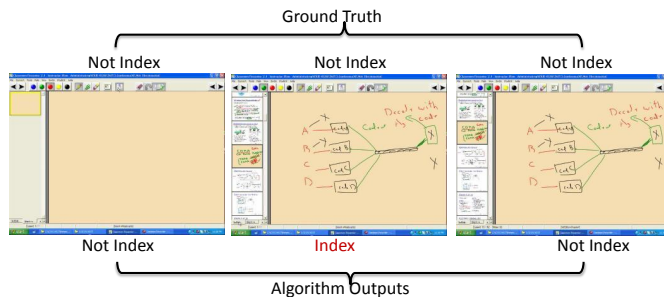


Fig. 16. Hand writing leads to OCR detection errors

Another problem with screen text is the scenario where the *screen text contains low topic information*. An important underlying reason is visual content with little textual information, such as the example shown in Figure 17. A hybrid approach of combining the text, image, and audio data could be a possible solution to solve this problem.

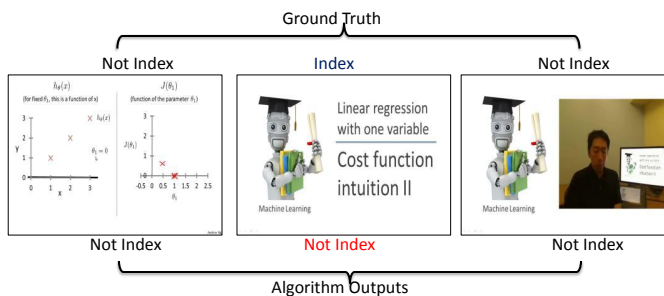


Fig. 17. Video frames with low volume of text lead to inaccurate indexing

Other reasons for errors that were discovered include visiting websites that leads to irrelevant text recognized by OCR, outline/subtopic slides in lectures, poor lecture organization such as browsing in a word file or switching windows, which again lead to irrelevant text recognition by OCR for the segmentation algorithm.

VIII. CONCLUDING REMARKS

The ability to automatically segment videos based on topics can significantly enhance the value of classroom lecture video as a learning resource. This paper investigates the use of screen text obtained with the help of Optical Character Recognition (OCR) tools and speech text obtained with Automatic Speech Recognition (ASR) tools to drive a text based segmentation process. The results show that screen text led to more accurate segmentation of videos in comparison with speech text from ASR tools, in large part because the errors in speech recognition far exceeded the errors in text recognition. Manually corrected speech text provided better data for indexing than screen text. Manual correction of screen text is not analyzed in this work. However, it should be noted that manual correction of screen or speech text are not practical options.

Screen text is typically based on instructor's viewgraphs and hence is well prepared and focused. Speech text, on the other hand, is improvised and not as focused, but the amount of text is plentiful. The conclusion is that screen text and speech text both contain useful information for lecture indexing. We believe that it should be possible to jointly use speech text and screen text for improved segmentation, but that is a subject for future research; our simple experiments did not show benefits of using them together over the better individual method.

More research is needed to achieve consistently good topic based segmentation. In this paper we have used a simple text based algorithm for video segmentation. Other algorithms, particularly those based on machine learning, hold significant promise towards achieving accurate topic based segmentation, perhaps close to what can be achieved by humans. Future improvements in OCR and ASR will have a great beneficial impact on the accuracy of topic based segmentation. Even for the topics addressed in this work, a set of twenty-five video lectures is not enough to derive firm conclusions and can only be considered preliminary work.

Finally student surveys in this project have shown clearly that classroom videos are an important learning resource and that segmentation by topics is very valuable. We hope future research will address the challenges involved, and lecture videos will be made widely available to students.

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Motivating students with new mechanisms of on-line assignments and examination to meet the MOOC challenges for programming

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Abstract—The advent of massive open online courses (MOOC) poses challenges for teaching and learning programming. This paper has analyzed these challenges and thereby proposed a self-motivating learning platform for students in the introductory programming course. Novel mechanisms of online assignments and examination have been introduced. Our platform provides functions for self-motivating learning and practicing in MOOC, which makes it distinguish from the others. For example, self-paced timetable with supervision, self-motivated exercise contents, exercise market, and relative ranking. The automatic grading approach is also a highlight. Programs even with syntactic or semantic errors can be automatically graded. Our platform gains popularity among both students and teachers. The platform has been used together with a programming MOOC. This course is ranked as the third most popular courses among over 500 courses. The platform has also been used by more than 100 other universities. The application of the platform in both MOOC and the traditional classroom courses has shown that students' self-motivation in learning programming has been greatly promoted, and their practical skills have also been significantly improved.

Keywords—MOOC; programming; learning platform; online assignments; online examination

I. INTRODUCTION

Massive Open Online Course (MOOC) is a recent development in the area of e-learning and distant education. In addition to creating an easy access to a standard curriculum, MOOC allow students to learn at their own speed and learn from each other using online social networking tools. As a result, some prominent MOOC, such as various classes from Stanford University, edX, Coursera, and Udacity, have attracted tens of thousands of participants. For instance, as of November 2012 more than 1,900,241 students from 196 countries have enrolled in at least one course by Coursera [1].

The huge popularity shows that the time is ripe for MOOC[2]. However, challenges exist and there is still plenty of room for improvement.

One challenge of MOOC is that the student retention rates are very low[3]. Adamopoulos et al. developed a hedonic-like

approach to identify important concepts that affect online course retention and estimate their relative importance based on textual reviews submitted by students on special online communities[1]. According to their research, the sentiment of students for assignments and course material has positive effects on the successful completeness of a course. Therefore, "how to design a course which will provide participants with positive experiences so as to motivate the students?" becomes an important issue.

The massive scale also poses significant technical challenges. One of these challenges focuses on homework exercises and exam problems: creating a large and diverse set of problems of varying difficulty, automatically grading them, and preventing plagiarism[4].

This paper describes our work towards addressing these challenges for the introductory programming course. The main contributions are as follows.

- The challenges brought by MOOC for programming have been analyzed in detail.
- A self-motivating learning platform has been proposed and developed by us. This platform is suitable for both MOOC and the traditional classroom courses.
- New mechanisms of online assignments and examination are proposed and implemented.

II. MOTIVATION

As programming courses are practice-based, the improvement and assessment of students' practical skills should become a priority[5]. At the same time, as the first computer professional foundation course, programming course also bears a heavy responsibility of cultivating students' interests in studying computation knowledge. Therefore, cultivating the students' self-motivated habit from the beginning of the course is very important for interdisciplinary talents for the future.

However, in traditional approach many teachers still prioritize lecturing theory instead giving the priority to practical work. Besides, many courses are dull and uninteresting with non-motivational exercises. Such courses result in high dropout rate.

Different approaches of teaching programming to overcome these problems emerged: game programming[6-10],

pair programming[11-13], visual programming [14], individual work, collaborative work, simulation tools, role games, test-first approach, test-driven approach etc..

Most of these methods focus on learning within the classroom, however, nowadays in the context of MOOC, new mechanisms are need. MOOC has changed the way of teaching and learning. Traditional teaching practice was always "dominated by teachers" whereas MOOC is "student motivated". Students can decide what, when and where to learn.

Besides, in our teaching practice of programming, we found that the following factors obstruct students' learning experience.

- The setup of assignments can not distinguish the students significantly. This sometimes leads to "lazy students".
- Lack of environment for supporting self-motivated practice.
- Lack of supervision and guidance for the students' self learning process.
- Lack of objective, fair assessment of students' performance.

As a result, the following issues need further study. This is the motivation of our research.

- How to provide a learning supporting environment to switch the programming teaching from a "narrow" to a "broad" class?
- How to provide a mechanism to motivate each student to take part in the programming practice?

- How to effectively supervise and guide student's self-learning process?
- How to avoid plagiarism that commonly appears in students' assignments?
- How to assess students' practical skills objectively and fairly?

III. SELF-MOTIVATING LEARNING ENVIRONMENT FOR STUDENTS

To solve the problems proposed in Section 2, we have done some research work on automatic grading [15,16], course management[17], and plagiarism detection of programming assignments [18], and transformed our research results into practice, to build a self-motivating leaning platform for students as shown in Fig. 1. It consists of the following supporting systems.

- **A self-motivated online assignments system** (<http://sse.hit.edu.cn/train> ID:12345 PSW:123123) supporting self-motivated online assignments submission, evaluation, and management.
- **An automatic grading system based program semantic analysis** (<http://sse.hit.edu.cn/exam/login.aspx> ID:demo PSW: demo) providing online examination and assessing students' practical skills.
- **An interactive network teaching platform based on Moodle** (<https://cms.hit.edu.cn/>) supporting course management, forums, lab submission and grading, etc.
- **A paper and exam management system** assisting the above systems.

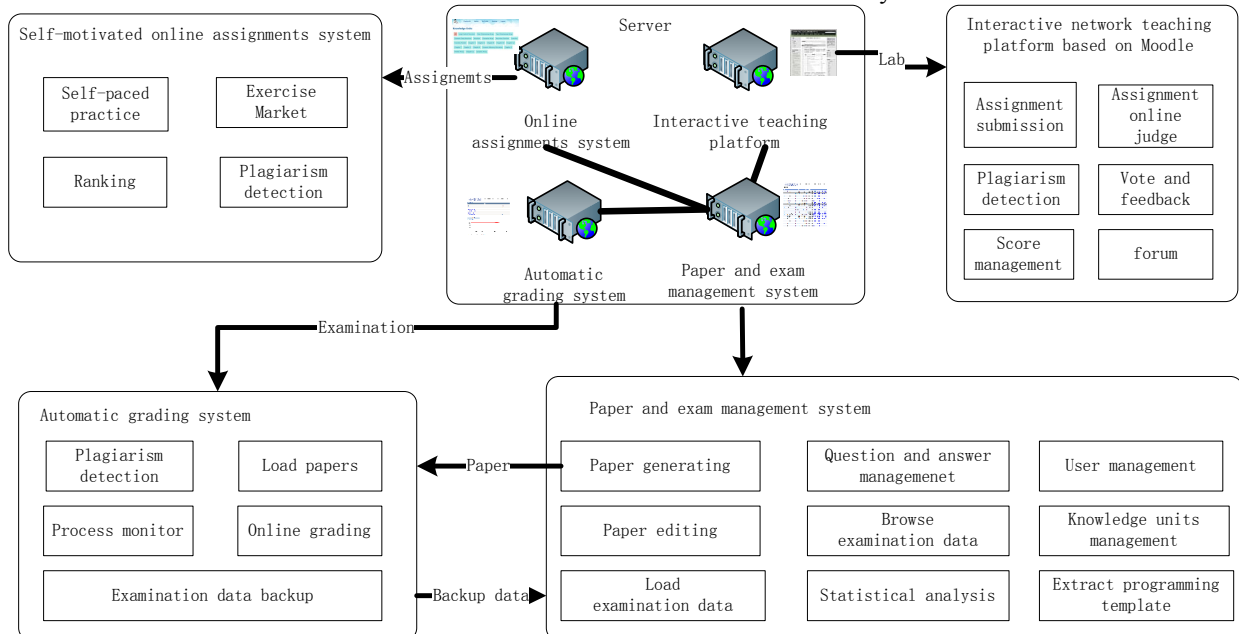


Fig. 1. The self-motivating leaning platform

All these systems have been widely used. Besides the traditional functions provided by a network platform, such as forums, online assignments submission, our network platform also provides some advanced functions. These advanced functions make our platform distinguish from the other network teaching platforms. Especially, the online assignments

system integrates many novel mechanisms for motivating students' self-learning and practicing in MOOC, such as self-motivated exercise contents, self-paced timetable with supervision, plagiarism preventing, iterative submission and automatic feedback, exercise market, and relative ranking. The automatic grading system is also a highlight of our work. It

adopts a new grading approach combining program semantic analysis and testing. Programs even with syntactic or semantic errors can be automatically graded based on the degree of implementing the specification. The initial version of the system adopted the client-server architecture. We extended it to the browser-server architecture to make it suitable for MOOC. In the following sections, we will focus on the mechanisms of the online assignments system and the automatic grading system.

IV. MECHANISMS OF MOTIVATING STUDENTS WITH ONLINE ASSIGNMENTS

The teacher manual evaluating student's programs is low efficiency and causes heavy workload. For a class with hundreds or thousands students this is mission impossible. In MOOC, peer grading serves as a critical tool for scaling the grading of complex, open-ended assignments. Despite promising initial trials, it does not always deliver accurate results compared to human experts [19,20].

In addition, the traditional assignments setup usually limits the students to do the same assignments during the same period. This is not suitable for MOOC, as students are allowed to learn at their own speed.

Moreover, how to motivate the students participating in not only programming practice but also assignments setting is not sufficiently considered.

In response to these issues, we have developed a self-motivated assignment online evaluation system. The system runs on a network server, teachers and students can use a standard web browser to access the system anywhere.

A. Self-paced timetable with supervision

Students can use a supervised self-paced timetable for the assignments. Different from completely self-paced timetable, which allows students to do the assignments anytime (e.g. completing all the assignments in one day, even if this is not good for the students), our online assignments system gives some supervision to the learning process, while giving the students some degree of freedom.

Exercise Settings	
Exercise Time	40 Minutes
Repeat Times	1
Daily Exercises Limit	5

Fig. 2. Teachers can set the number of daily exercise and time limit for each exercise

As shown in Fig. 2, the teacher sets the minimum number of assignments to be finished before final examination, the maximum number of daily exercises, the maximum repeat times for an exercise, and the time limit to finish each exercise.

A student can choose the days to do the assignments when he is available, but he can not do all the assignments in only a few days as limited by the daily maximum exercise number. Besides, the time for finishing an assignment is strictly setup. If a student does not correctly finish the assignment in time, he will fail the assignment and need to practice more. This mechanism gives students some degree of freedom to schedule their assignments, meanwhile, promotes the students to develop a good habit of practicing and correctly finish the work as soon as possible.

B. Self-motivated exercise contents

As shown in Fig. 3, daily homework is no longer arranged by teachers, instead, students choose which type of exercise to do in accordance with their studying progress (by chapter number or knowledge units).

More important, the contents of daily exercises and practice subjects are no longer all identical for all the students. They are randomly extracted from the subject pool by chapter or knowledge unit chosen by the students.

Knowledge Units

All Loop Control Structure One-Dimensional Array Two-Dimensional Array

Dynamic Data Structure Structure Character Array Recursive Function Function

Function Pointer Chapter 3 Chapter 6 Chapter 8 Chapter 10 Chapter 12

Chapter 7 Chapter 5 Chapter 4 Dynamic Memory Allocation Chapter 9

Pointer Array Chapter 11 Dynamic Array

Fig. 3. Students can choose the type of exercise to be done by knowledge units

C. Iterative submission and automatic feedback

00:20:00

Submit

Q1308. (Prime number) A natural number 1, 2, 3, 4, 5, 6, ... is called a prime number if it is greater than 1 and has exactly two divisors, 1 and the number itself. According to the definition 0, 1, and negative integers are excluded as a prime number. For example, 5 is prime, since no number except 1 and 5 divides it. On the other hand, 6 is not a prime (it is composite), since 6 = 2 x 3. 1) Write a function that determines if a number is prime. the prime number is no more than 10¹²; 2) Use this function in a program that determines whether the input number from keyboard is a prime number.

Fig. 4. Students can resubmit their programs within the specified time

The process to complete exercises is self-motivated. The students' programs are automatically evaluated by the online test-driven automatic grading system (ACM Online Judge). A student can immediately see the score, after submitting his program. As shown in Fig. 4, within the specified time, he can modify, resubmit, and retest the program again and again, until

a satisfying score is got. The iterative mechanism helps students to cultivate the habit of independently thinking and self-motivated learning.

D. Introducing marketing mechanism into exercises

Experience has shown that example code can not only help students become familiar with programming language syntax, but also can help students to understand the essence of programming language. In fact, programming starts from reading and studying other people's code.

The market mechanism of exercises is introduced as shown in Fig. 5. The mechanism is to support and encourage students to publish their own designed subject for the other students. The student published a high quality subject can earn some “golden points” as a bonus. This mechanism has three advantages.

Firstly, it can motivate students’ learning experience. In order to provide high quality subject, the students must master the corresponding knowledge. This promotes the students to study harder.

Secondly, students can use the “golden points” earned in the exercise market and choose whether to view the topic sample code. This can promotes their understanding of the essence of the knowledge they are not familiar with.

Thirdly, it helps in creating a large and diverse set of problems of varying difficulty.

For a seller:

- It will take 1 golden coin when you apply to put a self designed exercise on sale.
- The application will be verified by the administrator.
- Besides the golden coin paid by the buyers, extra reward will be given by the administrator if you publish a high quality exercise.

For a buyer:

- You need to pay the designer 1 golden coin when you buy a exercise.
- If you passed the exercise, you can get the bonus.
- Besides the bonus set by the seller, extra reward will be given by the administrator if you give a high quality answer.

Home My Sales My Orders

Reward: 2 3 4 5 6 7 8 9 10

Date: All This Week This Month This Year Earlier

Input 10 integers into array a by the keyboard, and print the maximum integer.

```
##Input Prompt: NA
##Input Format: %d
##Output Format: %s\n
```

Created by admin at 2012/11/12 10:42:36 maximum value

02 4

Buy

Fig. 5. The marketing mechanism to encourage students to publish subjects

E. Various ranking mechanisms

In order to promote students’ enthusiasm in participating in the programming practice, a variety of ranking mechanism is introduced as shown in Fig. 6. The teachers can motivate students to practice more and difficult exercises by setting scores for assignments, number of self designed excises, degree of attention got by the self designed excises and so on. A relative ranking mechanism is adopted. A student with the best performance can get the highest score. By contrast, the students with the poorest performance get the lowest score. The competition element increases the motivation of the students to complete the task to the best of their ability. Students feel like “they are playing an online upgrading game”,

so that they become positive, especially top-notch students come to the fore.

Ranking

Assignments Marketing No. of self designed excises Degree of attention

Rank	ID	Name	Assignments	Marketing	No. of self designed excises	Degree of attention
1	1130310410	贺祖光	2761	497	0	0
2	1130310128	杨尚斌	2672	670	5	8
3	1130310203	李子勤	2624	411	1	0
4	1130310428	孙路畅	2600	747	0	0
5	1130310127	许家超	2306	563	0	0
6	1130310126	李明远	2266	634	0	0
7	1130310123	李佳河	2232	489	0	0
8	1130310326	胡哲婷	2179	562	0	0

Fig. 6. A variety of ranking mechanisms

F. Feedback of exercise difficulty

As shown in Fig. 7, the exercise difficulty marked by each student and the passed ratio are feedback to the online assignments system, to be used as a reference for teachers to adjust the difficulty score for the exercise.

View records

Return Reference answer

Total score 10

Q1308. Tom goes abroad, and Harbin recent weather Centigrade(C) degree solve this daily

The conversion of C to F is: F=9/5×C+32

C=5/9×(F-32)

Please use the virtual button to choose the directions of conversion. The virtual button of Fahrenheit to

Mark the exercise difficulty

★★★★★

Normal

3.0

OK

Fig. 7. Students can rate the difficulty of each subject

G. From anti-plagiarism to plagiarism prevention

The plagiarism detection function of our platform can automatically detect similar source code. However, we found that this post hoc anti-plagiarism did not agreeable in practice. We hope to prevent plagiarism before it happens.

As demonstrated earlier, assignments are randomly extracted from the subject pool, and the time for finishing each assignment is strictly setup. By doing this, the chance of plagiarism is greatly reduced, because the students who want to copy programs from others can seldom wait in front of the computer everyday. Besides, they may not have enough time to modify and submit the copied programs within the time limit. This forces students to think independently.

V. MECHANISMS OF MOTIVATING STUDENTS WITH ONLINE EXAMINATION

A. Fair and impartial assessment of students’ practical ability

The traditional automatic grading systems usually only test the running results of programs, rather than evaluating the

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syntactic structure and semantics of programs. To overcome these drawbacks, we have developed an automatic grading system as shown in Fig. 8. It not only evaluates the running result but also evaluates whether a program meets the programming specification by analyzing and understanding the program structure and semantics. In the examination, students programming and debugging on a computer, and then submit their programs to the automatic grading system, scores are shown to them immediately. With our system, the students can get fair scores, which evaluates their practical ability more objectively.

At the same time, our automatic grading system can strengthen the monitoring of the entire process of the examination. It performs real-time monitoring of the IP of the student machine, to check out whether it has a portable hard disk, and disables the portable hard disk, so as to prevent cheating.

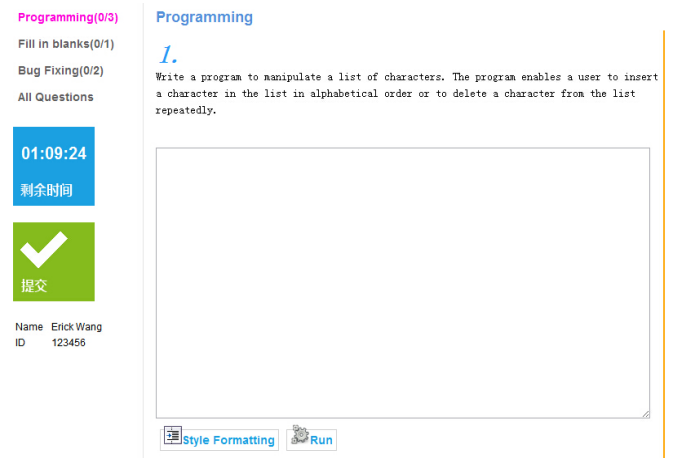


Fig. 8. Automatic grading of student programs

B. Double examinations

We provide two online examinations during the term, i.e. the midterm and the final exam. The objective of the midterm examination is to provide students with the opportunity of “finding themselves inadequate, and then making progress through hard work in the next examination”, so as to achieve the purpose of enhancing students’ programming practical ability.

VI. APPLICATION AND BENEFITS OF THE PLATFORM

The self-motivating learning platform has been used together with our C language programming course on the MOOC platform established by the Chinese Ministry of Education. As shown in Fig. 9, this course is ranked as the third most popular courses among over 500 courses.

Our platform has also been used in the traditional programming courses. In particular, the automatic grading system has been used in the final examination in the C programming courses and the graduate enrolment examination in our university. It has also been used by more than 100 universities, such as Beijing University of Posts and Telecommunications, and Northeastern University.



Fig. 9. The C programming language course is ranked as the third most popular courses on the Chinese MOOC platform

In order to evaluate whether our platform can enhance the students’ self-motivation in learning programming, we did some statistical analysis on one class with 138 students. These students were trained with the platform. And the corresponding mechanisms of on-line assignments and examination were carried out. In this class, the students had to finish 6 lab experiments. The assignments were optional, and a relative marking mechanism was carried out. The programs for the experiments and the assignments were automated graded.

Fig.10 shows the number of programming assignments correctly solved by the students in ten weeks’ class. 41 percent of the students correctly solved over 20 assignments per week. The new mechanisms has effectively promoted the programming practice of students.

Number of correctly finished programming assignments

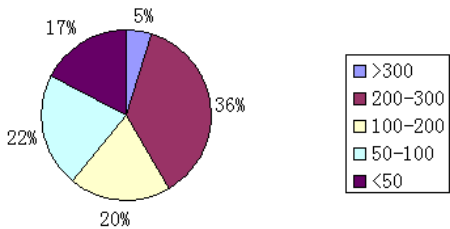


Fig. 10 Statistics on the number of correctly finished programming assignments

Table I . STATISTICS ON THE GRADES OF LABS

above 90	80-90	60-80	below 60
124	7	4	3

Table I shows the grades for the labs. As the students had done much programming practice, most of them they got high lab scores. 127 of the 138 students got marks of above 90 (The full score is 100). Their programming skills have been greatly improved.

We also collected online questionnaire based on the students’ experiences. Totally 102 questionnaires were returned. More than 80% of the students had fun in learning programming using our platform. 71.6% of the students said

that using the platform improved their programming skills. 82% of the students agreed that the self-paced timetable with supervision mechanism helps them in arranging study time more reasonable. 98% of the students like the automatic grading mechanism. 78.4% of the students worked harder stimulated by the relative ranking mechanism. In general, the results were positive, showing that using the platform enhanced both the learning experience and motivation.

VII. CONCLUSION

In this paper, we discussed the MOOC challenges for programming and the importance of motivating students to practice programming. A self-motivating learning environment for students has been developed. The novel mechanisms of the online assignments and examination have been demonstrated in detail. The platform gains popularity in both MOOC and the traditional classroom courses.

In the future, we will collect more data to evaluate and improve our platform as well as the mechanisms.

ACKNOWLEDGMENT

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Supporting Real Open Educational Resources in Edu-AREA

Different Views About Open Educational Resources

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Abstract—The Open Educational Resource concept was proposed several years ago as a way to develop the Open Movement principles in the educational domain. Despite the open and participative view underlying this proposal, there has not been a significant adoption of this concept by users. Many problems and barriers have been considered and analyzed. Nevertheless, we consider that a main issue is the contradiction among the definitions proposed and the real support provided by platforms. In addition, there exist also different approaches to the concept by users and organizations. In this paper we call for a real open approach to the Open Educational Resource concept and introduce a platform where specific functionalities have been introduced to support its development.

Keywords—Open Educational Resources, Open Movement, Creative Common Licenses

I. INTRODUCTION

The term Open Educational Resources (OER) was coined at UNESCO's 2002 Forum on Open Courseware [1] to designate "*teaching, learning and research materials in any medium, digital or otherwise, that reside in the public domain or have been released under an open license that permits no-cost access, use, adaptation and redistribution by others with no or limited restrictions*". More than a decade after the issue of this definition, current implementations of the OER concept are not fully compliant with all the ideas embodied in it. There are a contradiction between the principles of the Open Movement, the real understanding by users and the functionalities provided by supporting platforms. These contradictions can be more clearly observed in contrast to the development of the Open Movement in other fields, specially in Open Software.

From a practical point of view, this contradiction can be observed in web platforms supporting users to store and share OER. Some relevant examples are: OpenStax, MERLOT or OER Commons. These sites do neither allow users to adapt the resources hosted nor to access the source files. For a resource just a printable or preview version (e.g., a document in PDF) is usually provided. Nevertheless, the provision of source files is a key principle in the open culture. In the open

software domain, the availability of the source code is recognized as a key factor for the successful development of the openness spirit. Similarly, the use of Creative Commons (CC) licenses has been spread, but their management is not easy when we consider combinations or adaptations.

A possible consequence of this situation is the low success of the OER movement. Several inquiries have been published about this [2, 3, 4]. Similar, the European Commission has funded several projects that also identify this issue: Ariadne, OrganicEdunet, Open Science Resources, Concede, KPP, OERTest, OpenDOAR, OPAL, ROLE and Open Discovery Space. The questions that we are bringing here are about the OER adoption by teachers and the poor support in existing platforms. We ask for the development of new systems providing a better OER support more aligned to the real open principles. In concrete we propose a Edu-AREA, an OER platform that embodies some key points: sharing of source files, online editing, resource linking, license management and referencing management.

The paper is organised as follows. Next section introduces the Open Movement, taking into account its development in different fields. Next, OERs are reviewed, taking into account platforms and user views. In section IV Edu-AREA functionalities are described focusing on the support of OER. The paper finishes with some conclusions.

II. THE OPEN MOVEMENT

A. The Open Concept

Nowadays there is an Open Movement in several domains. that share a set of common values [5], namely:

- Open exchange. People can learn more from each other when information is open. A free exchange of ideas is critical to creating an environment where people are allowed to learn.
- Collaborative participation. When we are free to collaborate, we create. People together can solve problems that a single person may not be able to solve on their own.

- **Rapid prototyping.** Rapid prototypes can lead to rapid failures, but that leads to better solutions being found faster. People learn by doing.
- **Meritocracy.** In a meritocracy, the best ideas win. Everyone has access to the same information. Successful work determines which projects rise and gather effort from the community.
- **Community development.** Communities are built around a common purpose. They bring together diverse ideas and facilitate the sharing of work. Together, a global community can create beyond the capabilities of any one individual. Together, we can do more.

Adopting these values, the Open Movement has been quite meritorious in the following domains:

- **The Open Movement** was initiated in the software community. The term Open Source was proposed as a way to provide open access to software source code. In this way, others can view the code, copy it, learn from it, alter it and share it. This means an opportunity to modify and evolve software in accordance to cooperative and collaborative models. Many people prefer open source software not just because the development process. In addition, they can have more control over the code as they are allowed to examine it to ensure it is not doing anything they do not want it to do. Some people also find open source software more secure and stable than proprietary software, because a large community is involved in the continuous detection and correction of errors. Some relevant projects are GitHub [6], Git repository supporting collaboration in software development; OpenStack [7], an open community of questions and answers.
- **Open Hardware.** In the same way as open software grants access to source code enabling its modification and redistribution, open hardware makes available all information required to replicate a hardware device or to design a new device as a variation of the original one (e.g., mechanical and electrical schematics, bills of material, programmable logic's source code, etc.). Most frequently, the software that drives the hardware, is also released according to a free/open license. In many cases, free and open-source hardware projects rely on existing open-software licenses [8] instead of creating new ones. Note that these licenses may clash with patent-based protection laws. Some relevant open hardware projects related to education are Arduino [9], NetFPGA [10] or Raspberry Pi [11].
- **Open Science.** The academic peer review process involves research authors evaluating one another's work, often anonymously. The open approach applied to this area demands to perform this process in a more transparent way, so readers can better understand how and why a piece of research have been considered valuable and suitable for publication. In other way, open principles also call for publishing through "Open Access" formulas. Often, researchers are asked to transfer the copyrights on their work when they agree

to let the journals to publish it. Then, researchers are charged by publishers when they get access to research materials on journals and libraries. Sometimes these fees are very high and research is only available to people that can pay for it. To tackle this situation, some institutions have promoted and adopted open access policies to grant public access to research publications. Some relevant projects are Open Journal Systems[12], journal management and publishing system based on Open access principles; OpenBEL [13], a language that represents scientific findings from the life sciences in a computable form.

- **Open Health.** Open initiatives related to the health sector are focused on two directions. First, on supporting the use and development of open software. Second, on providing open access and sharing of medical information. This is a main challenge as medical records usually involve sensible data and hard constraints. Some relevant projects are GNUHealth [14], a free Health and Hospital Information System with several functionality; Openhealth [15], about eHealth/mHealth solutions based on the management of wireless biomedical devices in Body Area Networks under the IEEE standards and Open Mobile Terminal Platform.
- **Open Government.** The Open Movement applied to the government calls for more transparency. As technology allows people to communicate in much better, faster and free ways (i.e., not just from a publisher to a large number of readers), governments have an opportunity not only to be transparent, but also to go a step further and become more participative.
- **Open Data.** Data should be freely available to everyone to use and publish. It is usually focused on non-textual material, such as maps, genomes, chemical compounds, etc. This can be related to open initiatives in Science, Government, etc. Linking Data is about using the Web to connect related data that wasn't previously linked or to lower the barriers that limit other linking methods. Some relevant projects are LinkedOpenData [16]; open-data.europa.eu, the European Commission open data initiative.

B. The Open Movement in Education

The Openness Movement is also very active in education [17]. This has promoted a philosophy about how people should produce, share and build value education. Barriers such as financial costs, proprietary technologies and legal mechanisms that prevent collaboration among scholars and educators should be removed.

The following initiatives related to the Openness Movement in Education are considered as the most relevant:

- **Open Educational Resources (OERs).** They are educational materials that are provided following the principles of the open movement. A key point from our point of view is that resources should not just be easily accessible to be used by others, but also in a form that

facilitates their modification, adaption and evolution to support their localisation to new contexts and needs. Next sections provide an extended discussion about this initiative.

- OpenCourseWare (OCW). It is a “free and open digital publication of university-level educational materials. These materials are organized as courses, and often include course planning materials and evaluation tools as well as thematic content”. The reference institution insofar OCW is concerned is MIT. It initiated this program in 2002 offering online its course contents for free. Since then, dozens of universities worldwide also offered their contents online and joined around the The Open Education Consortium.
- Massive Open Online Courses (MOOCs). MOOCs are free online courses without formal entry requirements nor participation restrictions. They include interaction, feedback and assessment (via automated quizzes or peers), but do not necessarily lead to official credentials. In some cases educational materials are not free and modification by others is not allowed. Most of the MOOC movement is based in the US, although many universities around the world also joined these initiative.

There are some key differences among the three initiatives above:

- MOOCs and OCWs are basically oriented to online learning, while OERs are also applicable to blended and face to face education.
- MOOCs involve the provision of services and functionalities to support the development of the courses (e.g. registration, assessment, collaboration, feedback), while OERs and OCWs are mainly about educational materials.
- The OER movement is focused on supporting collaboration and sharing of resources among teachers. The goal is to promote innovation, creativity and the development of a participatory community where all the people can contribute. The idea of the openness movement is more clear, not just openness of the materials or services.

III. OPEN EDUCATIONAL RESOURCES

The OER concept has been proposed from the openness movement trying to adopt its principles, but it is a multifaceted idea that different users and initiatives consider in different ways. In addition to the UNESCO, other international organisations have already proposed their own views (e.g., William and Flora Hewlett Foundation, OECD, Commonwealth of Learning, European Commission, etc). A main discussion topic is about the level of openness and the availability of the source files. Licensing is another common issue, but Creative Commons (CC) is being adopted as the reference to define usage conditions and also to provide attribution based on commercial, share-alike and no-derivation terms. These terms are not fully aligned to the open movement principles, but at least

they require users to reflect and be aware of them. It is important to notice that if a material is provided with no copyright nor licensing information, by law it cannot be used, modified or distributed by others. An option to solve this limitation in the U.S. could be the Fair Use doctrine, that allows others selected uses of copyrighted material without copyright holders' consent, but it is open to interpretation.

There are other topics relevant to OER. This section analyses a variety of views considering types of OER, supporting tools and end-users.

A. Types of Open Educational Resources

Different type of OER can be considered [18]:

- Resources created for educational purposes. This includes multimedia documents, simulations, educational games, podcasts, webcasts but also simple HTML resources. Currently, a main research field is how to make learning objects (i.e., specific digital objects created for learning purposes) available and reusable, transforming them into real OERs.
- Articles, textbooks and digital equivalents. This type of resources contains typical objects provided by libraries, such as articles, papers, books or journals. When becoming freely available, this class of objects is connect to the concept of Open Access (cf. Sect. II.A).
- Software tools and web applications are used for different purposes, such as producing or authoring learning resources, such as simulations, but also for communication and collaboration. Objects of this class are usually referenced as Open Source (see section II.A).
- Instructional/educational designs and experiences. Educators are highly dependent on successfully planning and designing their learning experiences. This type of resources includes access to instructional designs, didactical plans such as lesson plans, case studies or curricula. It also includes one of the most valuable resources: sharing experiences about materials and lessons between colleagues.
- Web assets. This class of objects refers to simple resources (i.e., assets) like pictures, hyperlinks, videoclips or short texts that are not usable on their own in a learning context but can be used to clarify or illustrate a certain topic. For example, these are the typical objects found by using a Web search engine (e.g., Google).

B. OER Platforms

According to the rapid pace of technology evolution, we can consider that the OER concept was proposed many years ago. In addition, it is something not completely new, but more or less an evolution or adaptation of similar concepts in other fields, including e-learning. For example, at the beginning of the century it was very popular the learning object concept. This can be a reason why there exist a quite large number of

platforms that are related to the OER movement. Some of them, as MERLOT, are even previous to the UNESCO definition. Table I provides a view of some of the most relevant platforms. They are featured in columns as follows:

- URL: web address of the platform.
- Source. If the platform enables users to include the source files of the resources. In many cases NS is included to indicate (that the authors are) “Not Sure”. Notice that only Openstax clearly enables to include source files.
- Tools. If the platform provides tools to create and edit resources online or offline. These functionalities are instrumental to support the openness principles.
- Repository. If the platform can be used to store, search and retrieve resources. Most of the platforms provide this functionality. In some cases they also act as Referatories, including just references to resources in other locations.
- Courses. If the platform manage not just assets, but also resources that are combinations of other resources in higher aggregation units.
- Community. If the platform includes functionalities and services to promote the communication and collaboration among users.

We can extract some conclusions from this table. First, the variety of views reflected in the different options, and second the lack of a winner platform that provides the best support in all categories. From our review, the best platforms are OER Commons, Openstax and MERLOT.

C. User Views: Survey Results

Similar to the existence of many OER platfoms, several surveys have been carried out during the relative long live of the OER concept. In October 2014 a large survey was published referred to the U.S. collecting answers from 2 144 higher education teachers [19]. Between two-thirds and three-quarters of college faculty members say they are unaware of OER.

As part of our research, we conducted a survey among primary, secondary and high school teachers in Galicia (Spain) and Northern Portugal. The survey is available in Galician, Portuguese and Spanish (check it at the bottom of the following page <http://www.edu-area.com>). We collected answers from 565 teachers about questions related to lesson planning and monitoring. In addition, some questions about OER were included. Results obtained show teachers’ awareness about OER, but also their understanding of the implications of the OER idea.

A first question asked was “Do you know what are Open Educational Resources (OER)?”. Options include “No” and three types of “Yes” to capture the level of experience: “I have already heard about them, but I have not used them yet”; “I have already used OER created by other teachers”; and “I have already created and used OER, and shared it with other teachers”. Fig.I shows the results obtained. More than a third of the teachers answered “No”. If we add to this number the number of teachers that heard about OER but never used them, we get a figure between two-thirds and three-quarters, as in the U.S. survey. The number of teachers that already have created and shared some OER is around 10%. This result shows the low awareness about OER.

TABLE I. OER PLATFORMS AND KEY FEATURES CONSIDERED IN THIS PAPER

Platform	URL	Source	Tools	Repository	Courses	Community
OER Commons	https://www.oercommons.org/	NS	Yes	Yes	Yes	Yes
MERLOT	http://www.merlot.org/merlot/index.htm	NS	Yes	Yes	Yes	Yes
Academic Earth	http://academicearth.org/	No	No	No	Yes	No
Saylor Foundation	http://www.saylor.org/	No	No	No	Yes	No
Open Education Consortium	http://www.oeconsortium.org/	No	Yes	No	Yes	No
Leeds Met Repository Open Search	http://repository.leedsmet.ac.uk/main	NS	No	Yes	No	No
CURVE Resource Centre	http://curve.coventry.ac.uk/open/access/home.do	No	No	Yes	No	Yes
Openstax	http://www.cnx.org	Yes	Yes	Yes	Yes	NS
Curriki	http://www.curriki.org	NS	Yes	Yes	Yes	Yes
Jorum	http://www.jorum.ac.uk	No	No	Yes	No	No
NDLR	http://www.ndlr.ie	No	No	Yes	No	Yes
Cloudworks	http://cloudworks.ac.uk	No	No	Yes	No	Yes
WikiEducator	http://wikieducator.org/Main_Page	No	No	Yes	No	Yes
JISC Digital Media	http://www.jiscdigitalmedia.ac.uk/	No	Yes	Yes	No	No
OpenLearn	http://www.open.edu/openlearn/	No	No	Yes	Yes	No

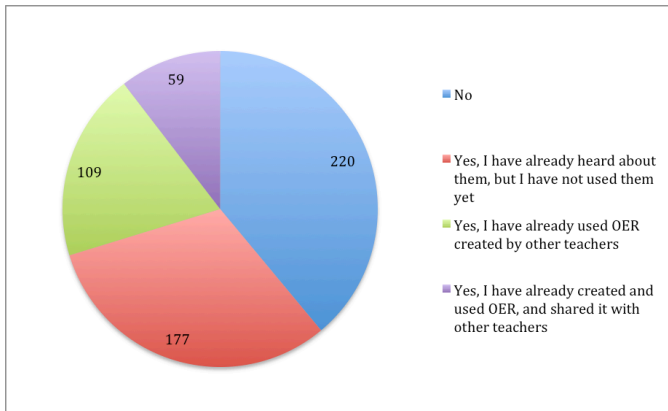


FIGURE I. . NUMBER OF ANSWERS TO THE QUESTION “DO YOU KNOW WHAT ARE OPEN EDUCATIONAL RESOURCES (OER)?” IN A SURVEY AMONG 565 TEACHERS

We included in the survey a set of questions to try to check teachers’ understanding about the OER concept. These questions have a common starter: “If you had to describe the OER concept, how would you do it ...?”. Then, several issues were included. “OER are available for free”; “OER can be edited and modified”; “It is possible to use parts of an OER to create other resources”; “OER should include some license”; “It is important to provide attribution”. Possible answers are: “Not necessarily”; “It could be”; “It should be”. From our view of the OER concept all issues should be answered as “It should be”. Fig. II shows the results to these questions. Almost all the issues have a similar answer pattern. In general the answer “Not necessarily” was chosen by a low percentage of teachers and the answer “It should be” between two-thirds and three-quarters of the teachers. Note that teachers consider that OER should be available for free and it should allow modifications. Surprisingly, the issue that receives less consideration is

licensing. This can be critical, because as it was highlighted, if no license is provided, copyright restrictions prevail.

IV. EDU-AREA

Edu-AREA is a Web platform whose goal is to promote teaching innovation. The approach to achieve it is to provide an environment where users can participate, share and collaborate during the preparation and use of their educational materials. This platform was described in previous papers [20, 21].

Edu-AREA provides users with typical OER storage and sharing functionalities. In addition, it also includes online editing functionalities for some types of educational resources. In Edu-AREA, OER are grouped and managed in accordance to two categories: (i) Resources, about what can be used, and (ii) Plans, about what can be done.

Different categories of Resources, digital or otherwise, are further recognised: (i-a) documents (text, images, sound, video, etc.); (i-b) software applications; (i-c) hardware devices; (i-d) guests, people from outside the school that can be involved in an educational activity; and (i-e) trips, places or events from outside the school that can be visited. Some of these Resources can involve source files, such as documents, but others clearly not, such as guests and trips.

As for Plans, several categories are also identified: (ii-a) Activities, as the basic building blocks; (ii-b) Lesson Plans, made up of Activities focused on the achievement of certain learning goals; and (ii-c) Courses, made up by several Lesson Plans; etc. All these types of Plans may include a reference to the Resources involved.

In Edu-AREA we do not support users editing any of the Resources online, but just storing and sharing them, because there already exist very good and specialized tools for the different types of documents (e.g., images, videos).

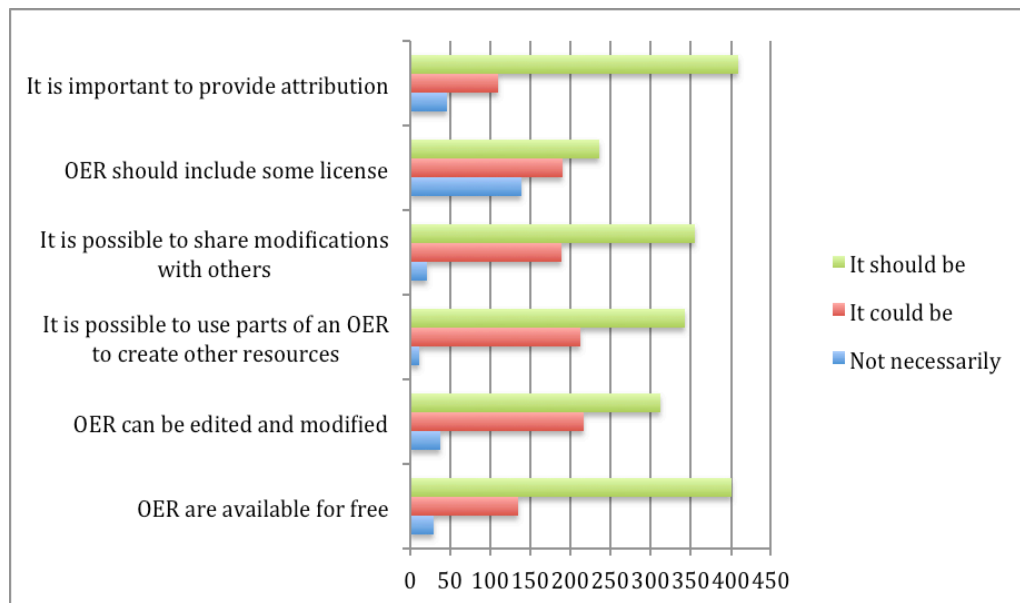


FIGURE II. . ANSWERS TO THE QUESTION “IF YOU HAD TO DESCRIBE THE OER CONCEPT, HOW WOULD YOU DO IT ...?” IN A SURVEY AMONG 565 TEACHERS

Nevertheless, in the case of Plans users are allowed to modify them as actual OERs, remixing and editing them online. Moreover, CC licenses are automatically controlled in order to detect possible incoherencies.

Here, the main focus is on the features related to the support of the openness principles related to OER. This involves to support the creation, modification and reuse, the management of licenses and also to provide attribution and recognition.

A. Creating, Modifying and Reusing OER

Edu-AREA includes functionalities to support the 5 Rs rights [22]. Namely: retain, reuse, revise, remix and redistribute. Users can make a copy (clone) of any of the resources publicly available in the platform. This copy belongs to the user that requested the cloning. Users can also revise any resource, and they can redistribute their resources. As for the reuse and remix features, we need to make some considerations depending on the nature of the resource: Document (assets), Lesson Plans or Activities and Courses. In addition, it is important to indicate that users in Edu-AREA can choose to maintain their resources in a private state, not visible to other users. At any time, they can change the visibility to public and the resource will become visible to everybody as an authentic OER.

1) Documents

A Document refers to any piece of information that can be contained in a file, like a slide presentation, a video clip, a sound record, a questionnaire, etc. Documents in Edu-AREA cannot be directly online edited in the platform. There are available many tools to edit these documents, some of them even online. When Edu-AREA was designed, it did not make sense to provide an editor for each one of the possible document types in Edu-AREA platform. In order to support Documents in Edu-AREA from the openness perspective, it was decided to manage two different kinds of elements related to documents. First, a “Product”, that can be included in the platform or referenced, being the document in a external location. For example: a video in Vimeo, a presentation in Slideshare, a PDF in Dropbox, etc. Second, “Source” files of the Document. This is shown at Fig. III. At the top of the figure, several options are available to include the Document view (Url, Snippet or File). At the bottom, source files can be included. In this way, a user who wants to reuse or remix a Document provided by other user can easily get the source files, download them, edit them and modify the document or create a new document reusing some of the parts. This facility is not available in almost any of the platforms analysed at section III.B.

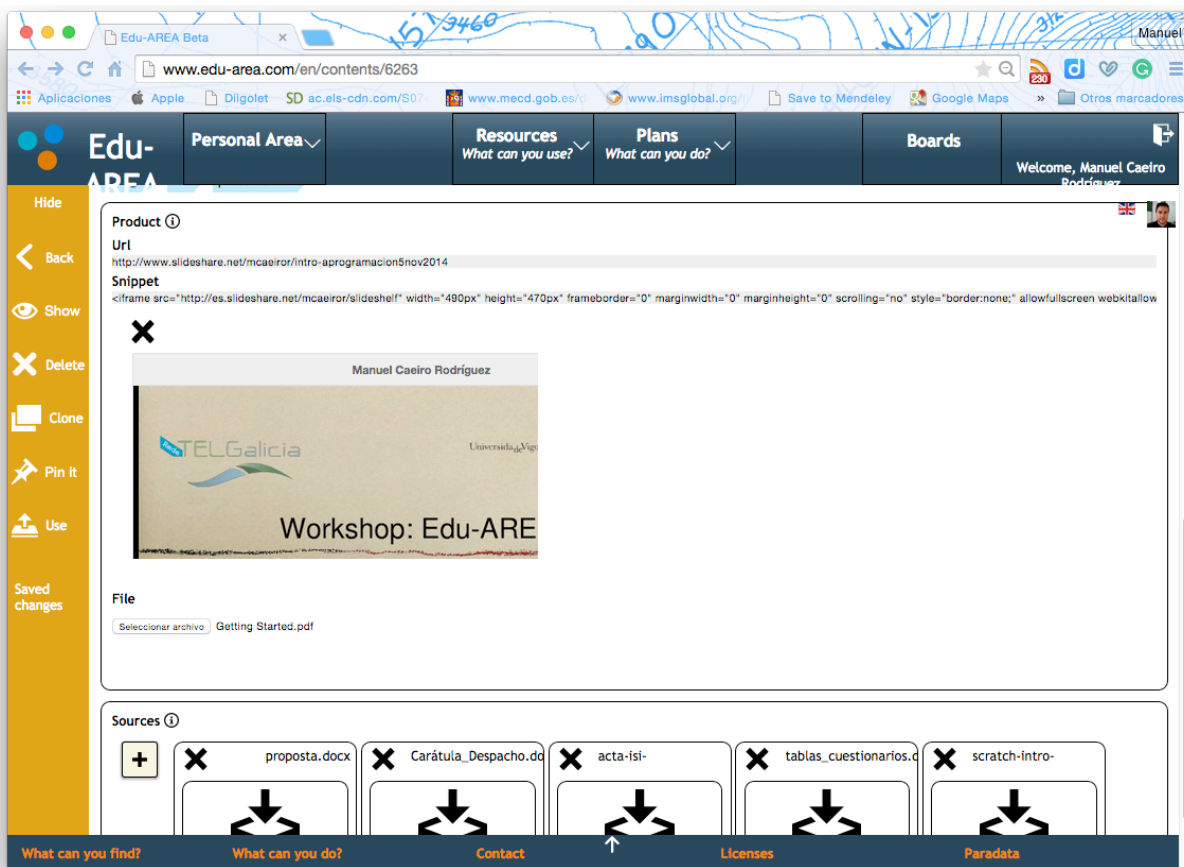


FIGURE III. SCREENSHOT OF EDU-AREA RELATED TO A DOCUMENT. PRESENTATION AND SOURCE FILES CAN BE INCLUDED

2) Lesson Plans and Activities

Lesson plans and Activities can be edited and remixed online in Edu-AREA. The platform provides templates to support the arrangement of Lesson Plans and Activities. Each template has a specific arrangement of text fields, text areas, item lists, etc. All these fields can be edited online. In addition, Lesson Plans and Activities can include other resources, such as Documents. This inclusion is managed as a “transclusion”, a concept that indicates a copy of a document inside other. These resources cannot be edited directly online in the platform, but as explained in the previous section. In any case, they can be remixed online directly.

3) Courses

The Course concept, or experience, can be considered as a step forward in the development of the open concept around OER towards a kind of “living” concept. The idea is to allow users to provide observations, evidences and reflections about the use of the OER in a real educational experience. For example, attaching pictures or videos of the students while playing an educational game, or commenting about the more difficult parts. This information can be very valuable for other users and we would like to promote its collection and sharing.

B. Licensing under Creative Commons

Edu-AREA provides their users with a mechanism to license correctly their works. In this way, teachers can share OERs with the certainty that they are not infringing any copyright law. In addition, as we have explained, they are required to license the resources. This is very important, because if a resource is not licensed it cannot be reused by

others. To the best of our knowledge, no platform in section III.B provides the licensing controls discussed.

It is important to have a clear view of some concepts managed in Edu-AREA and the way in which Creative Commons (CC) licenses can be managed on them. Documents may be licensed under CC. Lesson Plans and Activities may also be licensed under CC terms, but as they may include Documents, specific issues may be involved in their licensing. These issues appear when adaptation, collection and combination of resources have to be considered.

1) Assigning Author Attribution

When creating a new element, after assigning the correct license, if the user is not the original author, he/she should assign the proper attribution to the real author. To do this, the user must choose the No option as an answer to the question “Are you the original author?” located just below the image of the license. Right after choosing “No”, two input text boxes are shown and for the user to introduce the author’s name and the author’s URL.

In case of an adaptation, the right attribution is automatically assigned to the resource (cf. Fig. IV). Both original author and the author who made the adaptation appear in the attribution, with their correspondent links. The title of the “adapted” resource has a link to the Edu-AREA section where it was created, a link to the Creative Commons license is also included with every license, and a link to the author’s profile page in Edu-AREA or any other URL provided is also included.

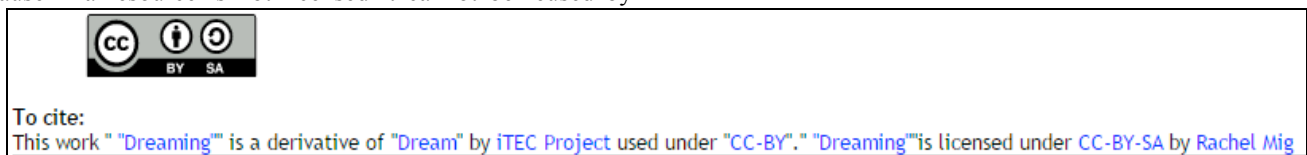


FIGURE IV. CLOSE-UP OF LICENSE AND AUTHOR ATTRIBUTION IN SHOW VIEW OF A DOCUMENT

2) Assigning Licenses to Derivative Works

The platforms described in section III.B do not provide any assistance to users while choosing a license for adaptations, collections or combinations. The user needs to know the rules and valid options, and this can be quite complex and cumbersome.

In Edu-AREA the licenses that can be assigned to a derivative work are controlled and checked by the system in adaptations and combinations. In this way, if the user tries to assign a license that is not in accordance to the licenses of the included elements or to the license of the original work, an alert is triggered and the action is aborted. Similarly, if an element with a license not in accordance to the license assigned to the combination wants to be added by the user, an alert is triggered and the action is aborted. This is continuously checked by the system to always maintain the licenses under the CC compatibility rules.

A key issue is that in case the user is the author of some of the works to be adapted or combined, the CC license requirements are no longer applied.

C. Linking Resources

Another feature included in Edu-AREA devoted to promote the openness principles in Edu-AREA is automatic referencing. This corresponds to the generation of links among resources in accordance to their use. For example, if a document is included in a lesson plan, this will be annotated in the document. As a result, given a document, users could see where it has been included. Similarly, links about adaptations are also included, so given a resource we could go to the “parent” and “child” ones.

These links are related to the concept of paradata, as data about the usage of a resource. For each Resource, paradata are maintained as adoptions, adaptations, views, comments, tags, communications to social networks and annotation into Boards. We are trying to develop algorithms to provide quality indicators of the resources taking into account these paradata. Quality concerns are a main barrier for users that wonder about adopting OER.

V. CONCLUSIONS

This paper discusses about the contradictions in the way the Open Movement is being developed in the educational domain. There are several initiatives related to this movement that demonstrate a variety of interests and points of views. The differences are more relevant if we consider the proposals in relation to initiatives in other fields. From our point of view is necessary to open a debate about the existing platforms and to define clearly the functionalities to provide an appropriate support to the Open Movement.

The paper provides some data to understand the development of the Open Movement and OERs. Functionalities available in existing platforms and results of a teacher survey are presented. These data highlights the different points of view. In addition, we introduce the Edu-AREA system where our views and proposals towards OERs are embodied. We consider that the Edu-AREA functionalities promote an innovative change in the educational culture towards a more open approach, similar to the already successful open software culture.

Edu-AREA is proposed in a transversal way, for any field, but we think it can be specially valuable for Engineering and STEM education promoting a more active role by teachers and the sharing of proposals. Teaching innovation can be largely supported by technology, and this is directly an opportunity to approach students and teachers to these fields, supporting the technology literacy. In addition, the consideration of applications and devices as educational resources is very important for STEM and engineering. Many educational practices in these fields involve the use of these elements and they should be easily integrated in the lesson plans and courses.

One of the main tasks related to the future of Edu-AREA is its evaluation. We plan to organize some teacher events, such as hackatons, in order to populate the platforms with real OERs by real teachers. Then, we will promote the use of the platforms by these and other teachers and eventually we hope to arrange some communities of interest. The experience of these teachers using the platform will be surveyed in order to get an evaluation.

ACKNOWLEDGMENT

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On the Effectiveness of Using Midterm Examinations Strictly for Formative Feedback

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Abstract—Research shows that, when it is conducted properly, formative assessment can have a significant impact on student learning. Examinations administered throughout the course, defined here as midterm exams, can be used effectively for formative assessment. However, misconceptions about the differences between the purposes of formative and summative assessment often lead to faulty application of midterm exams for summative assessment. The purposes of this paper are to clarify the pedagogical differences between exams used for formative and summative purposes, and to present data that illustrate that when midterm exams are used strictly for formative purposes, they can significantly enhance student learning, as measured by student performance on summative final examinations.

Keywords—*formative assessment; feedback; examinations.*

I. INTRODUCTION

The purpose of this Work-in-Progress paper is to present and discuss the results of an on-going study to quantify the benefits of formative midterm examinations. By “midterm examination” is meant any examination given during the semester or quarter during which the course is being taught, excluding the final, summative examination. Formative assessment is, by definition, used to provide feedback to both instructors and students in order to enhance student learning and produce greater achievement of learning outcomes [1 - 3]. In [4] the effectiveness of various forms of formative assessment are analyzed via surveys of students and faculty. Summative assessment, on the other hand, is used to measure how well students have achieved one or more learning outcomes, and it is used to determine an associated grade. It is not used for feedback to improve student learning. Although the most common form of summative assessment is the final examination, some instructors structure their courses in units, and do a summative assessment after each unit. In that model, each unit of the course is essentially a self-contained mini-course.

Midterm examinations are often used for both summative and formative purposes. For example, in a course having two midterm exams and a final exam, the midterms may each be used to determine ten to twenty percent of the final grade (while the final exam, laboratory scores, homework, and other items determine the remainder of the grade). This is the summative component. At the same time, the results of the

midterm exams are often used to provide feedback that helps students improve their learning in anticipation of the final exam. This is the formative component.

This dual usage of the midterm exams is problematic for two reasons. First, learning outcomes are usually expressed in terms of what students should know and be able to do at the end of the course. By assigning permanent credit to midterm exams, the instructor either rewards the student prematurely (if he or she does well on the exam) or penalizes him or her unfairly (if they do poorly), because the learning outcome explicitly gives them until the end of the course to demonstrate achievement of the outcome. In many countries outside the U.S., there are no midterms, only the summative final exam. This practice is consistent with the learning outcome statement. Secondly and perhaps more importantly, formative assessments work best when students can take risks and make errors without fear of penalty [1]. For the instructor to provide useful feedback, it is helpful to know the students' incorrect thought processes. Midterm exams with a summative component discourage students from taking such risks and thus deny the described feedback opportunity.

This difficulty raised the question as to whether midterm exams, used properly for formative purposes, would be effective at improving student learning, as measured by performance on summative final examinations. Thus, while adapting the teaching and learning strategy known as team-based learning (TBL) to basic electrical engineering courses [5 - 7], an important change to the basic process has been to use strictly formative midterm exams. In the following sections, the manner of using formative and summative exams in those TBL-based courses will be described; and formative and summative assessment data from the two most recent offerings of one course and the four most recent offerings of another one will be presented and discussed. In all cases considered, the student scores were significantly higher on those portions of final exams that corresponded to earlier midterm exams; and that when formative midterm assessments were not used for certain (the final two) learning outcomes, the scores on the summative final exam were significantly lower than those portions of the exam for which there had been an earlier formative midterm exam.

II. COURSES AND ASSESSMENTS

For this paper, average midterm and final exam scores from

the four most recent offerings of a required junior-level course in electric circuit theory and from the two most recent offerings of an elective senior-level course in electric power systems were analyzed. Each course has six intended learning outcomes [1] (ILOs). Briefly, in the electric circuit theory course, they are that by the end of the course, students should be able to analyze linear circuits containing operational amplifiers and transformers (ILOs 1 and 2); analyze RLC circuits in the time- and complex frequency domains (ILOs 3 and 4); and determine the impulse and frequency responses of simple passive and active filters (ILOs 5 and 6). In the electric power systems course, students should be able to use the per unit concept to calculate power in balanced three-phase systems (ILOs 1 and 2); calculate the physical properties and electrical behavior of three-phase transmission lines (ILOs 3 and 4); and use the method of symmetrical components to analyze unbalanced three-phase systems.

In all six offerings of both courses, achievement of the first two ILOs were assessed formatively with a midterm exam approximately one-third of the way through the semester, and similarly for the third and fourth ILOs approximately two thirds of the way through the semester. Ideally, a third formative midterm exam should also be administered for the final two ILOs, but that would occur at the end of the course, just a few days before the comprehensive summative final exam. This usually places an excessive labor burden on the instructor, so in the six course offerings used in this study, the third midterm exam was not administered.

Originally, the midterm exams were used formatively in the strictest sense. That is, the exams were graded to provide instructional feedback, returned to the students, and reviewed in class carefully, thus providing both instructor and students with the immediate opportunity to correct misconceptions and improve student learning in preparation for the course grade-determining final exam. Scores from the midterm exams had no bearing on final grades. That practice encountered two practical problems, which were identified in student course evaluation surveys [5 - 7]. The first was that many students would simply not take the midterm exams seriously or prepare well for them, because their scores didn't contribute toward the final course grade. Impending tests or even graded assignments in other courses (where scores contributed to the final grade) often took precedence over the formative midterm exams in the TBL-taught courses. The second problem was that many students objected to the heavy grade-determining emphasis attributed to the summative final exam and the test anxiety associated with such a format.

To solve both problems, a compromise was adopted, by which, if a student's score on the portion of the final exam corresponding to a specific ILO is higher than the corresponding score on the earlier formative midterm exam, the final grade for that learning outcome is determined solely by the final exam score. If not, however, then the final grade for that outcome is determined by the average of the two scores. This treats the midterm exam scores as a back-up of sorts in case of a "bad day" on the final exam or a portion thereof. The effectiveness of this solution was illustrated in

student course evaluation surveys [5 - 7], which showed that, before instituting the compromise, 69% of students in the TBL-taught courses studied seriously for the formative midterm exams and only 32% of them were comfortable with the heavy emphasis given to the summative final exam. Since introducing the compromise, over 90% of students in those courses now treat the formative midterm exams seriously and are comfortable with the final grade-determining policy. This compromise was used in all six course offerings analyzed and discussed here.

III. DATA AND DISCUSSION

The data in question are given in Tables I and II, respectively, for the electric circuit theory course and the electric power systems course. The first two columns of each table give the semester of the course offering and the number of students completing the course that semester. The fourth and fifth columns of each table show, respectively, the average scores on the midterm exam and the portion of the final exam corresponding to the pair of ILOs identified in the third column. (The data were combined in ILO pairs this way to simplify instructor work load.) The sixth column (Percent Change a) shows the percentage change in the scores in Columns 4 and 5. Thus, for example, in the electric circuit theory course in Spring '13, the class average on the portion of the final exam corresponding to ILO pair 1,2 (0.762) was 26.2% higher than the class average on the earlier midterm exam on the same two outcomes (0.604). All twelve percent

TABLE I
DATA FROM ELECTRIC CIRCUIT THEORY

Semester	No. of Students	Course ILOs	Midterm Average	Final Exam Average	Percent Change a	Percent Change b
Spring '13	42	1,2	0.604	0.762	+26.2	
		3,4	0.736	0.750	+1.9	
		5,6	-----	0.667		-11.8
Fall '13	52	1,2	0.619	0.874	+41.2	
		3,4	0.619	0.793	+28.1	
		5,6	-----	0.671		-19.5
Spring '14	42	1,2	0.613	0.817	+33.3	
		3,4	0.632	0.760	+20.3	
		5,6	-----	0.662		-16.1
Fall '14	45	1,2	0.601	0.777	+29.1	
		3,4	0.603	0.678	+12.4	
		5,6	-----	0.634		-12.8

TABLE II
DATA FROM ELECTRIC POWER SYSTEMS

Semester	No. of Students	Course ILOs	Midterm Average	Final Exam Average	Percent Change a	Percent Change b
Spring '13	39	1,2	0.629	0.736	+17.0	
		3,4	0.704	0.827	+17.5	
		5,6	-----	0.649		-17.0
Fall '14	27	1,2	0.604	0.686	+13.6	
		3,4	0.709	0.790	+11.4	
		5,6	-----	0.644		-12.7

change values in Column 5 are positive, with an average value of 21.0%, which suggests that the strictly formative midterm exams may have helped to improve student learning.

That suggestion is further supported by the negative percentage change values given in the final column (Percent Change b) of both tables. As stated above and shown in Column 4, midterm exams were not given for the ILO pair 5,6 of either course during any of the course offerings in question. The average scores on the portion of the final exam for that ILO pair are shown in Column 5; these values are smaller than the mean value of the two portions of the same final exam for ILO pairs 1,2 and 3,4 by the percentage given in Column 7. In the Spring '13 offering of electric circuit theory, for example, the average scores on the final exam for ILO pairs 1,2 and 3,4 were, respectively 0.762 and 0.750, with a mean value of 0.756. The average score on the same exam for ILO pair 5,6 was 0.667, which is 11.8% smaller than 0.756. Similar results were obtained for each of the six course offerings described in Tables I and II, with an average negative Percent Change b value of 15.0%.

V. CONCLUSION

In the six course offerings studied, final exam scores for ILOs 1 through 4 improved by an average of 21% over earlier midterm exam scores on the same ILOs; and final exam scores on ILOs 5 and 6, which had not been formatively assessed prior to the final exam, were an average of 15.0% lower than the mean value of the final exam scores on ILOs 1 through 4. These results suggest that midterm exams, used properly for formative assessment, can be effective at improving student learning, in response to the above-stated question.

Further supporting evidence for this conclusion will be obtained by administering formative midterm exams after the

third segment, i.e., ILOs 5 and 6, of each course, and examining how that exam affects the data in Tables I and II. This will require solving the above-mentioned end-of-semester practical problems.

The important features of this work to the engineering education community are that it underscores the error in trying to simultaneously use an exam for both formative and summative purposes, and it suggests that, when midterm exams are used correctly for formative assessment, they can have a significant positive impact on student learning.

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An Assessment Architecture for Competency-Based Learning: Version 1.0

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Abstract—The U.S. Department of Education (DoE) asserts that one way to improve student achievement is to consider competency-based learning. The DoE describes competency-based learning as “a structure that creates flexibility, allows students to progress as they demonstrate mastery of academic content, regardless of time, place, or pace of learning.” Competency-based learning focuses on outcomes and skill-sets. Students are encouraged to learn in a way that allows them to employ reproducible skills sets to generate tangible outcomes.

Our group is early in an initiative to provide alternative learning environments in STEM higher education. The group consists of faculty from several academic units including liberal arts, libraries, and technology. One of the learning experiences currently being tested involves the tight coupling of all forms of communication and information literacy with technological skills and concepts. We develop an integrated learning experience that cultivates learner’s capacities of interpersonal communication and social and cultural awareness in a seminar environment.

We will describe our process of generating competencies from AAC&U inspired rubrics and how these were mapped to learning outcomes and learning activities in the seminar environment. The institutional (and in some cases legal) constraints associated with the spirit of competency-based learning will be discussed.

I. INTRODUCTION

Students acquiring STEM degrees often graduate school academically prepared in their fields; business leaders however have been stating that they often lack the more intangible qualities such as teamwork, critical thinking, communication skills, and ability to manage interpersonal relations [1], [2]. These “soft skills” are tightly coupled with professional performance and career growth.

Derek Bok has claimed “it is impressive to find faculty members agreeing almost unanimously that teaching students to think critically is the principle aim of undergraduate education” [3]. However, several recent reports cast doubt on the effectiveness of universities in delivering this goal. For instance, the 2011 book *Academically Adrift* claimed 21st century graduates are woefully underprepared for the workforce in regards to these “soft skills” [4].

Furthermore, these so-called soft skills are all connected to basic interpersonal communication skills, commonly referred to as oral and written communication, and their close

counterparts, listening and reading. Such skills are not merely “add-ons” to a STEM job; they can make the difference between a successful and a failing team, career, or even corporation. In the last decade there have been efforts such as Project Kaleidoscope by the Association of American Colleges and Universities (AAC&U) to advance broad-based systemic innovation to build and sustain strong undergraduate education in the STEM fields [5].

Our group is in the early stages of an innovative initiative to provide alternative learning environments integrated with competency-based components at the main campus of a traditional undergraduate residential STEM higher education university. The group consists of faculty from several academic units including liberal arts, education, libraries, and technology. The mission of the group is to create learning experience that enhance learners capacities of interpersonal communication and social and cultural awareness in a seminar setting. Transferrable skills, such as inquiry and analysis, design, ideation, and quantitative analysis are also cultivated in a studio environment. In addition to focusing on integrating the liberal arts and libraries into STEM environments, we have embarked on designing an architecture for the implementation of competency-based learning.

This paper describes the design and implementation of a competency-based architecture for learning and assessment. The paper first describes our Polytechnic initiative by articulating its vision and key values. Section III then discusses the design of our initial competency-based system for learning and the assessment of student work. Early results are presented in section IV, then the paper concludes in section V with a discussion of observations conclusions, and plans for future work.

II. THE POLYTECHNIC INITIATIVE

“The Purdue Polytechnic is an educational initiative aimed at creating an exemplar of the undergraduate education of the future” [6]. The initiative was proposed in the summer of 2013 and has been supported by the President and Board of Trustees of the university. The Polytechnic was initiated in the College of Technology (now called the Purdue Polytechnic Institute) with several strategic partners within and outside Purdue. Internal partners include the College of Liberal Arts,

the Libraries, and the College of Education. The initiative has also benefitted from cooperation by the Mathematics and Physics and Astronomy departments in the College of Science. External partners have included Olin College [7], the University of Illinois Urbana Champaigns iFoundry program [8], and the University of California San Luis Obispo's SUSTAIN program [9].

The Polytechnic is motivated by the conviction that undergraduate education has become misaligned with the needs and aspirations of the students and the demands of future economies such that nothing short of a significant overhaul will make a substantive difference. In this paper we articulate the values, the guiding principles, and the signature characteristics of the Polytechnic undergraduate education.

A. Values and Characteristics

The vision and several characteristics unique to this new program were established as a portion of the guiding principles the faculty kept in mind while developing the learning experiences for the first year cohort that arrived in the fall of 2014. In particular, some of our values include valuing diversity, learning, and experiences, student autonomy, and goal setting [10]. For the new program this means program and faculty roles would focus more on working with the student to provide opportunities for each one to pursue a particular interest that furthers the understanding of a situation or location and helps the student explore possible future careers or areas of more in-depth study.

The core values and strategies of the program are:

- 1) An architecture that supports the student in exploring and identifying a contemporary issue around which they design their learning plan combining technology with other fields of study.
- 2) Self-paced learning that allows the students to learn as fast as they can without barriers and as slow as they need without penalties.
- 3) A focus on learning outcomes educational attainment ensuring that students graduate when they can demonstrate expertise in a set of key competencies. The competency-based approach is also the vehicle for this aspect.

In addition, the learning experiences for the program were conceived of as a spiral of developing knowledge and skills, where learning opportunities continually bring students back to the same types of activities with expectations of additional skill in applying those skills and demonstrating knowledge application to particular situations.

III. COMPETENCIES AND BADGES

A. Competencies

Focusing on learning outcomes and demonstrable skills, the group made the programmatic choice to evaluate student work via a methodology based on competency. The AAC&U VALUE rubrics [11] formed the foundation of several competencies that have been adopted into our university core learning outcomes [12]. We took this as opportunity to create a new learning experience that encompassed the competencies of

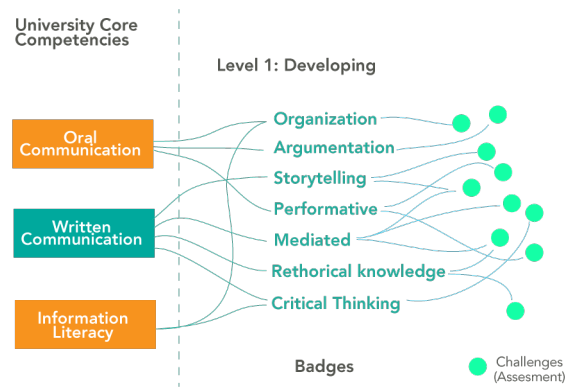


Fig. 1. Competency Map

Oral Communication, Written Communication and Information Literacy. Instead of having each of these competencies as separate courses (as it is traditionally done), we designed a new integrated learning experience called Culture, Communication, & Digital Narratives.

Figure 1 shows how the core competencies (oral communication, written communication, and information literacy) were mapped to 7 different sub-competencies. The sub-competencies were defined as a collaborative effort between a group of faculty from English, Communications, Technology, and Libraries. They represent combinations of learning outcomes from traditional courses which also map to rows in the VALUE rubrics. For example, the storytelling competency shown in figure 1 maps to rows in the oral communication rubric (Figure 2 while also mapping to rows in the written communication rubric shown in Figure 3.

We created an environment where these competencies were learned and practiced concurrently, where learning how to write effectively is not done sequentially after or before learning how to speak or design web mediated messages or web-pages. Students learn how to write while they learn how to integrate written messages in online multimedia delivery vectors or how to adapt them for oral delivery.

B. Badges

Digital “badges” were developed using our OpenPassport system [13], a derivative the Open Badges system developed by Mozilla [14]. While very similar to Open Badges, OpenPassport is currently restricted to local users.

Badges are certificates of competency mastery. They break down the learning material into discrete, yet coherent, modules, each attached to a specific skill-set or body of knowledge that result in a clear ability to analyse, understand, or perform a skill or procedure effectively and timely. Our use of the OpenPassport badge system differs from other online learning management systems (LMS) such as the Open Learning Initiative (OLI) [15] in that we used OpenPassport more as a repository for student deliverables and a means for assessing and providing feedback. Students rarely actively interacted

ORAL COMMUNICATION RUBRIC

Definition

Activity of conveying meaningful information verbally; communication by word of mouth typically relies on words, visual aids and non-verbal elements to support the conveyance of the meaning. Oral communication is designed to increase knowledge, foster understanding, or to promote change in the listener's attitudes, values, beliefs, or behaviors.

	Proficient 3	Emerging 2	Developing 1
Organization	Organizational pattern (specific introduction and conclusion, sequenced material within the body, and transitions) is clearly and consistently observable and is skillful and makes the content of the presentation cohesive.	Organizational pattern (specific introduction and conclusion, sequenced material within the body, and transitions) is clearly and consistently observable within the presentation.	Organizational pattern (specific introduction and conclusion, sequenced material within the body, and transitions) is intermittently observable within the presentation.
Language	Language choices are imaginative, memorable, and compelling, and enhance the effectiveness of the presentation. Language in presentation is appropriate to audience.	Language choices are thoughtful and generally support the effectiveness of the presentation. Language in presentation is appropriate to audience.	Language choices are mundane and commonplace and partially support the effectiveness of the presentation. Language in presentation is appropriate to audience.
Delivery	Delivery techniques (posture, gesture, eye contact, and vocal expressiveness) make the presentation compelling, and speaker appears polished and confident.	Delivery techniques (posture, gesture, eye contact, and vocal expressiveness) make the presentation interesting, and speaker appears comfortable.	Delivery techniques (posture, gesture, eye contact, and vocal expressiveness) make the presentation understandable, and speaker appears tentative.
Supporting Material	A variety of types of supporting materials (explanations, examples, illustrations, statistics, analogies, quotations from relevant authorities) make appropriate reference to information or analysis that significantly supports the presentation or establishes the presenter's credibility/authority on the topic.	Supporting materials (explanations, examples, illustrations, statistics, analogies, quotations from relevant authorities) make appropriate reference to information or analysis that generally supports the presentation or establishes the presenter's credibility/authority on the topic.	Supporting materials (explanations, examples, illustrations, statistics, analogies, quotations from relevant authorities) make appropriate reference to information or analysis that partially supports the presentation or establishes the presenter's credibility/authority on the topic.
Central Message	Central message is compelling (precisely stated, appropriately repeated, memorable, and strongly supported.)	Central message is clear and consistent with the supporting material.	Central message is basically understandable but is not often repeated and is not memorable.

Adapted from AAC&U Core Value Rubrics

Fig. 2. Oral Communication Rubric [12]

WRITTEN COMMUNICATION RUBRIC

Definition

Written communication is the development and expression of ideas in writing. Written communication involves learning to work in many genres and styles. It can involve working with many different writing technologies, and mixing texts, data, and images. Written communication abilities develop through iterative experiences across the curriculum.

	Proficient 3	Emerging 2	Developing 1
Context of and Purpose for Writing <i>Includes considerations of audience, purpose, and the circumstances surrounding the writing task(s).</i>	Demonstrates a thorough understanding of context, audience, and purpose that is responsive to the assigned task(s) and focuses all elements of the work.	Demonstrates adequate consideration of context, audience, and purpose and a clear focus on the assigned task(s) (e.g., the task aligns with audience, purpose, and context).	Demonstrates awareness of context, audience, purpose, and to the assigned tasks(s) (e.g., begins to show awareness of audience's perceptions and assumptions).
Content Development	Uses appropriate, relevant, and compelling content to illustrate mastery of the subject, conveying the writer's understanding, and shaping the whole work.	Uses appropriate, relevant, and compelling content to explore ideas within the context of the discipline and shape the whole work.	Uses appropriate and relevant content to develop and explore ideas through most of the work.
Genre and Disciplinary Conventions <i>Formal and informal rules inherent in the expectations for writing in particular forms and/or academic fields (please see glossary).</i>	Demonstrates detailed attention to and successful execution of a wide range of conventions particular to a specific discipline and/or writing task (s) including organization, content, presentation, formatting, and stylistic choices	Demonstrates consistent use of important conventions particular to a specific discipline and/or writing task(s), including organization, content, presentation, and stylistic choices	Follows expectations appropriate to a specific discipline and/or writing task(s) for basic organization, content, and presentation
Sources and Evidence	Demonstrates skillful use of high-quality, credible, relevant sources to develop ideas that are appropriate for the discipline and genre of the writing	Demonstrates consistent use of credible, relevant sources to support ideas that are situated within the discipline and genre of the writing.	Demonstrates an attempt to use credible and/or relevant sources to support ideas that are appropriate for the discipline and genre of the writing.
Control of Syntax and Mechanics	Uses graceful language that skillfully communicates meaning to readers with clarity and fluency, and is virtually error-free.	Uses straightforward language that generally conveys meaning to readers. The language in the portfolio has few errors.	Uses language that generally conveys meaning to readers with clarity, although writing may include some errors.

Adapted from AAC&U Core Value Rubric

Fig. 3. Written Communication Rubric [12]

with the system in ways that provide immediate or near immediate feedback, like walking the learner through a problem as is often the case in other systems like OLI. Rather, most

formative and many summative assessments were conducted using performance-based theories and methods consistent with those in [16].

Figure 4 illustrates what the learner sees when logging into the system. Here there are 33 badges available to the learner. Badges seen in the figure are those related to a seminar learning experience described later. Figure 5 shows a particular badge in Information Literacy. Here one of the challenges is exposed showing the required activity along with resources attached to the badge for learners to study and work with to demonstrate their level of competency. Also notice there are five challenges that the students must demonstrate successfully to earn the badge.

The development group encountered struggles in determining the 'size' of badges, where size denotes the quantity of content a particular badge or competency should incorporate. There was a hope of achieving a certain amount of uniformity across different courses in the size of the badges, despite development by multiple faculty members in different fields. After many conversations, the notion of one badge equaling one credit hour seemed to be the most acceptable to faculty, addressing concerns, and is supported through other CBE structures such as Western Governors University - Indiana [17]. The more discussion around competencies, badges, and credit hours, the more the one credit hour equal to one badge seems to make sense, as most 3 credit classes have between 3 and 9 learning outcomes, so there appeared to be a natural fit between one or more learning outcomes and a badge that would encompass that content. Thus we were able to map learning outcomes to badges in a way such that badges could be grouped in logical ways to map to traditional courses.

Figure 6 illustrates the badge/challenge arrangement for a competency in Fundamentals of Imaging Technology. This series of three badges was mapped to the learning outcomes of a similarly named freshman level course in Computer Graphics Technology. Note that several of the challenges contain "OR" clauses, meaning that students had the choice to complete these challenges in ways that stimulated their individual intrinsic motivation.

During development, the badges each contained between 2 and 5 challenges. The idea is that competencies and the badges attached to them are not simple constructs, but complex skill sets and abilities that need to be defined and practiced before mastery is to be achieved. For badges, a challenge is a particular activity or artifact that needs to be completed to succeed at the challenge. Once all the challenges for a particular badge are earned, then the badge itself is earned.

In addition to the size of the badge, an agreed upon measure of success was necessary for determining that a student achieved a particular competency. In the initial implementation, the faculty agreed that the threshold of achievement would be an A, so if a student succeed in completing all the challenges for a particular badge, they had an A for that competency. In a parallel fashion, successfully completing all badges for a course or learning experience meant the student earned an A for that course.

The logic of this approach is that mastery is for every given level of competence is a binary phenomenon: you either demonstrate it or not. To avoid the disqualification of the students if the challenges are too high, badges and competencies are structured on three levels: developing, emerging, and proficient, which correspond to the benchmark, milestones and

capstone levels shown in figures 2 and 3. Most competencies are demonstrated at each of the three levels and badges are awarded to certify the progress from one level to another.

IV. EARLY RESULTS

As stated earlier, assessments were performative in class in some cases while others were more in the context of written feedback. Formative assessments were also continuously provided during class time. In most instances, student work took many submissions before it was assessed as meeting a sufficient level of competency to be judged appropriate for collegiate work at a developing level for particular skills. An example of written feedback to a student submission demonstrating rhetorical knowledge looked like

"You did add comments, and this is good, but say a bit more about the principles. What is rhetorical about this? Are you talking about Aristotle's rhetoric? Can you connect it to Barthes' study of an image? How about the readings/principles you were given? Don't describe the image (the reader can see that), but discuss the design principle that creates a context, describes a story, etc."

In this case the submission was "reset" so the student could try again. Often the student and faculty would review work prior to submission but it became clear that first year students are not accustomed to a situation where work could be continually returned for revision and refinement. Students were generally not accustomed to having submissions returned for additional work. The current primary education system trains our students to get work completed on time, turn it in, and just accept the grade received as the course moves on to new material. This is the attitude and process a competency-based education model is intentionally designed to challenge.

Conversely, when a student's work was approved the assessor (faculty) would also provide feedback and recommendations for continued improvement.

"I like the feminist thread you've chosen this semester, great job. You certainly cover the basics of ethos, pathos, logos – that's certainly sufficient. I would challenge you in the future to really delve into a text, pick out the nuances of On Rhetoric (ask yourself, why has this two hundred page text been studied for thousands of years, certainly not for three simple concepts e, p, l...)."

It is important to note that in the example above the student has demonstrated a "developing" level of mastery of the competency of rhetorical knowledge. The developing level represents attainment equivalent to completing a similar learning outcome or small set of outcomes at an "A" level in an entry level (freshman) course in written composition.

V. OBSERVATIONS AND CONCLUSIONS

One struggle with implementing a competency based education model in a traditional university is how to fit the expected average of 15 credit hours per semester and 30 credit hours per year of schooling. There is a learning curve to getting students accustomed to this model of working. It is not uncommon for the first semester or two to be lower earning through the credit hours / competency lens, while later years far out earn the traditional model of 15-19 credit hours in a

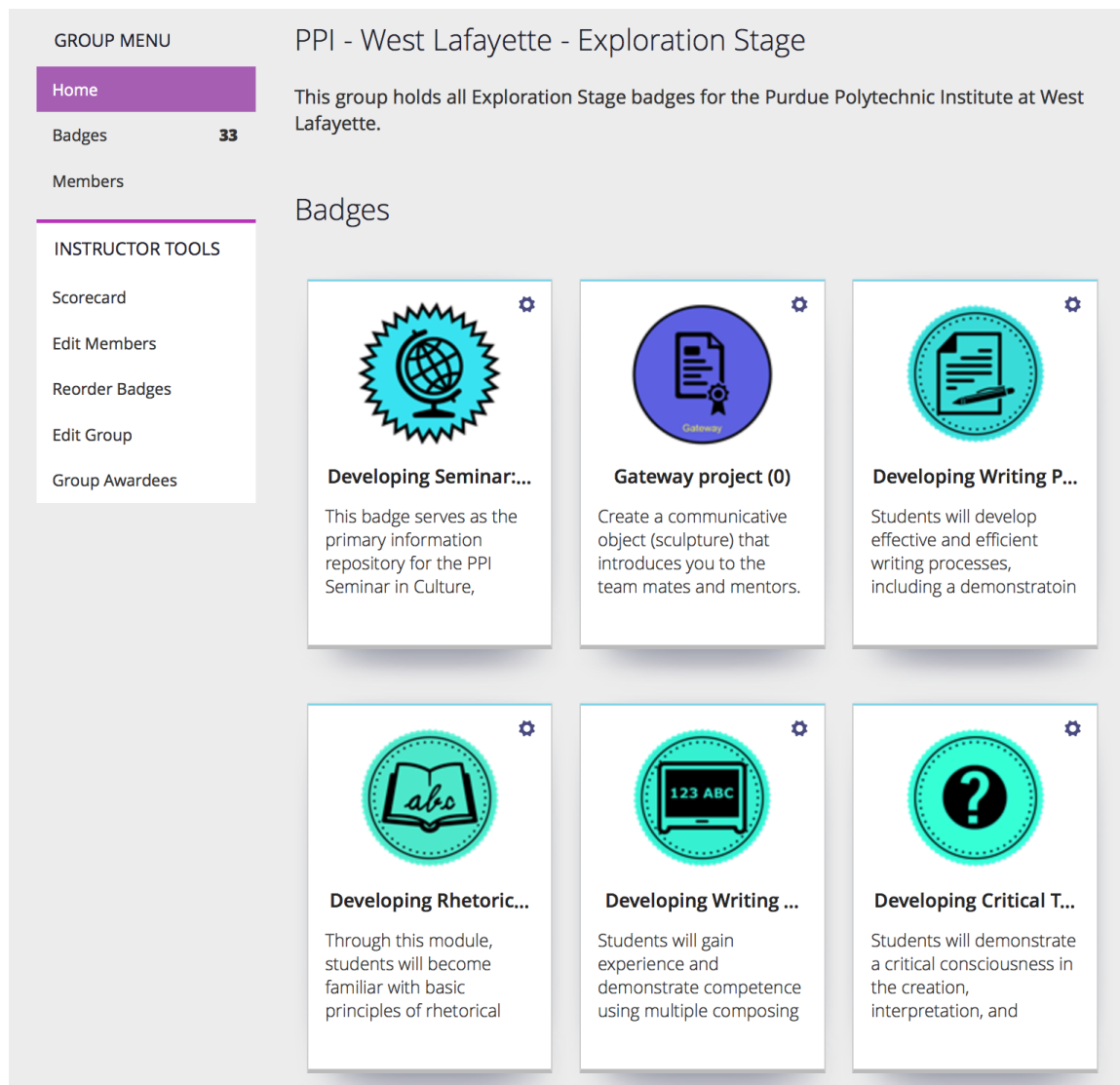






Fig. 4. Open Passport

semester. When trying to develop a new system like this that still has students and faculty restricted by a semester model that requires particular credit hour milestones to be met for student scholarships, faculty teaching load assignments, and similar administrative task, there is a challenge in balancing diverging requirements.

Another struggle, which in some ways also stems from needing to fit within the larger structure of an existing university, is the number of students who did not complete work during the first semester. The amount of incomplete work was due to a need for more time and more revisions on particular assignments to meet the threshold of the work submitted showing actual learning gains equivalent with an A in a traditionally structured class. Allowing the room for the learning to take place through additional revisions has added stress for several students as the workload has increased in the second semester while they try and stay on track with the university expectations and meet the learning expectations for the competency based program.

Badging systems are generally not a good substitute for a comprehensive learning management system. As a faculty, for example, we discovered there is no consistently clear place to maintain a course syllabus and organized class readings in a badge structure, particularly if the badge challenges are written so they can be achieved through submission of several different artifacts, potentially from different learning experiences (classes). To keep badges more general, information and resources for particular course activities needed to be presented and stored in another mechanism. Since we were not using another system, we created an umbrella badge that was used a resources container and was not expected to be earned by students. The syllabus and a variety of course readings were attached in this space.

Additionally, our badging system showed all available badges in a given group. Since the students in the first semester of this learning experience had a variety of introductory discipline specific courses available to them, and students were expected to complete all of the badges in all of the disciplinary fields, the list of outstanding work to be completed for a

Developing Information Literacy

☆ Get started

This badge certifies students' competency in using information appropriately to complete tasks. It corresponds to the university core curriculum foundational outcome in information literacy.

☆☆ Challenges

- Exploring a Topic ▾

For this challenge, you will turn in your explorations of a topic as you develop a research question.

You will be submitting the following to meet this challenge: Mind Map, Preliminary Environmental Scan, and a Refined Research Question.

Attached Resources

 - Mind Map Efficient Automobiles.pdf
169.9KB
 - Template for Topic Challenge.doc
32KB

Learning Outcomes

In the course of this challenge, you will be learning how to refine a research question, doing an initial brainstorming activity, followed by some preliminary information gathering, which yields a more focused, well-defined research question.
- Searching for Information ▾
- Evaluating Information ▾
- Using and Acknowledging Information ▾
- Know Your Intellectual Property ▾

Issuer:
Passport by Purdue

Organization:
Purdue University

Created by:
Michael J Fosmire, Aug 07 2014

Learning Outcomes

This badge certifies the information literacy core competency outcomes in the context of the PPI framework. Students will meet competencies in the following areas:

Seek: Identify a learning need and effectively locate material to address that need

Evaluate: Determine quality and relevance of sources selected

Apply: Use information gathered in an appropriate manner, neither claiming too much or too little from the source used, to help solve a problem

Document: Acknowledge the work of others appropriately and completely; ethically access and use information

Fig. 5. Information Literacy Badge

student was misleading, as all of the challenges for badges in the group were presented, whether a student needed to succeed at those particular challenges or not.

A. Epilog

During the spring semester of 2015 it became apparent that while mapping competencies at our level of granularity was both feasible and tractable, it was clear that this was a large challenge in terms of the many to many relationship between very granular competencies and the large number of courses available to students on our campus. Looking forward

to version 2.0 of our architecture, we are planning to decouple competencies from courses, thereby allowing learners to take advantage of traditional and other means of scaffolding their knowledge and skill so they can demonstrate higher order cognitive and meta-cognitive capabilities in the form of a smaller number of broad competencies like design thinking, systems thinking, effective communication, and ethical reasoning. We plan to continue developing learning environments in studio and seminar formats geared toward making the connections between learning in traditional environments and demonstrating broader competencies in the context of open-ended, real-world problems.

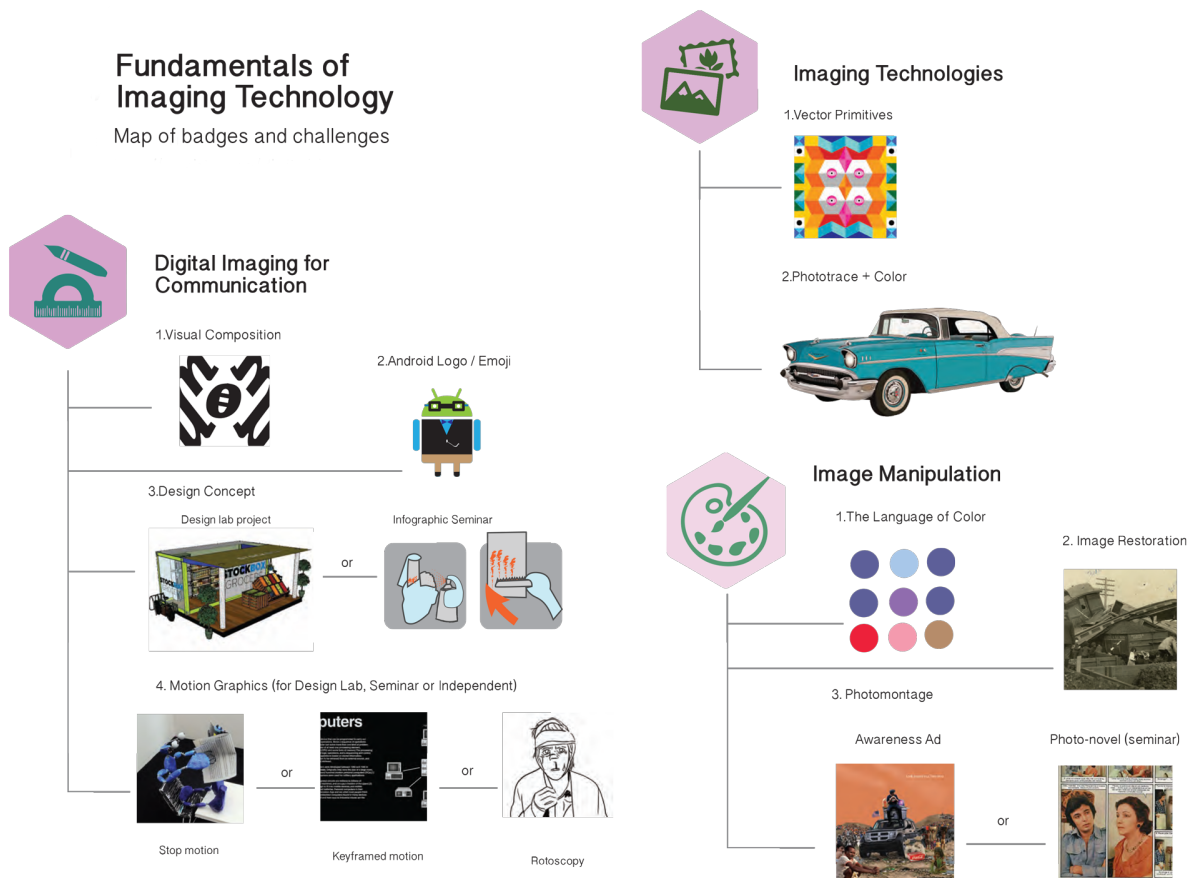


Fig. 6. Badges for Fundamentals of Imaging Technology

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Systems Thinking Skills of Undergraduate Engineering Students

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Abstract— It is widely acknowledged that systems thinking skills (STS) are critical competencies that enable engineering students to solve problems, communicate, use data, and design components and systems, with greater success. Yet few studies have focused on examining the ST survey of engineering students in higher education. This preliminary study is aimed at investigating the STS of undergraduate engineering students and comparing the effectiveness of the instruments used to assess those skills. The primary research question is: how can we effectively measure the STS of engineering students?

Data were collected via a Background questionnaire and a Systems Thinking (ST) questionnaire that 117 engineering students finished, as well as a basic Systems Engineering diagnostics activity (SEDA) that 23 sophomore engineering students completed. Cross-comparisons were conducted between the ST survey and the SEDA to test the validity of the survey questions. Both quantitative and qualitative analyses were employed to assess the degree of STS of the engineering students that participated in the study. The findings from the current study contribute to the knowledge and assessment of undergraduate engineering students' STS.

Keywords—*Systems thinking; systems engineering; engineering undergraduates*

I. INTRODUCTION

Developing high performing, cutting edge products and systems requires engineers that, in addition to being proficient in their particular discipline, have a solid background in product development, systems engineering, and systems architecting [1-3]. Although many engineering programs in the US provide an introduction to the engineering design process itself in the context of a formal course, the development of system-level thinking skills is seldom emphasized in the undergraduate curriculum [4-12]. As a consequence, most engineering graduates are ready to do the technical calculations needed to design a specific component or simple product but struggle to design well-functioning products or systems of moderate or high complexity [13-18]. The lack of exposure to the concepts and tools of systems engineering and systems architecting frequently leads to system integration issues that demand design changes late in the development process. Unfortunately, those "last minute" design changes usually result in sub-optimal or degraded system performance and substantially increased cost.

Relatively few studies related to assessing and improving systems thinking skills (STS) were found after conducting a literature search in commonly-used literature databases. Among the notable works, Lammi [19] investigated the STS of high school students through an engineering design challenge by collecting data from engineering design sketches and interviews. Huang[15] reported that he successfully used systems modeling as a cognitive tool to enhance the STS of 15 graduate students. Davidz [2] conducted structured interviews and background surveys with senior engineers to research the enablers, barriers, and precursors to systems thinking development in engineers. The results showed that experiential learning and a supporting environment at work are primary factors that enhance engineers' systems thinking development. However, none of the studies found were focused on undergraduate engineering students and all of the assessment instruments used required someone with expertise in systems engineering to measure the students' systems thinking skills.

While STS are included in the ABET criteria for engineering programs, there is a dearth of literature on effective means of assessing undergraduate students' engineering STS. Systems engineering skills are implicitly evaluated in design classes when assessing project success; however, such evaluations are subjective and vary greatly between evaluators. What is needed is validated assessment instruments that can objectively assess students' competence in systems engineering; these instruments can then be used to guide the design and evaluate the effectiveness of curricular changes.

The work presented here is part of an effort to address the lack of study of STS in undergraduate students and the need for STS assessment tools that can be used by non-experts. The primary research question of the study is "*How can we measure the STS of engineering students?*" and this work-in-progress paper presents the authors' initial efforts to develop assessment instruments for that purpose.

II. SYSTEMS THINKING AND ENGINEERING

Good STS is crucial for the design of successful products and systems. Some elements of engineering design practices have been widely employed in engineering education to improve students' understanding of engineering concepts and principles, to develop students' "ability to apply knowledge of mathematics, science, and engineering," to train students to "function on multi-disciplinary teams," and to help students be

familiar with design processes. It is now clear, however, that a systems perspective is necessary to respond to the dynamic environment caused by the globalization of the economy, technological developments, and increasingly interdisciplinary collaborations [20-21]. This need for systems engineering skills is reflected in the ABET requirement that the curriculum of accredited engineering programs must allow students to “carry knowledge further toward creative application ... Engineering design is the process of devising a system, component, or process to meet desired needs [22].”

There is still little penetration of systems engineering instruction into the undergraduate engineering curriculum, and the result is a group of young engineers that, while competent in the design of components, does not have the knowledge and skills needed to deal with the interactions and tradeoffs that are inherent in the design of complex systems. Design of systems such as cars and aircraft require much system-level thinking and architecting before component design may commence. For practical reasons, students cannot design systems of such complexity during their academic careers. They can, however, be exposed to the design and analysis tools from systems engineering that can be brought to bear when faced with such challenges, and they can be provided with opportunities to practice with these tools on projects of lower complexity levels. One of the authors’ long term goals is to infuse the undergraduate curriculum with systems engineering education, starting at the freshman year.

III. METHODOLOGY

Two assessment instruments were developed and used for the study presented in this paper: 1) A systems thinking (ST) questionnaire, and 2) a basic Systems Engineering diagnostics activity (SEDA). This section provides summary information about the characteristics of both of those instruments.

A. ST Survey

To develop a survey instrument to measure undergraduate engineering students’ STS, meta-analyses of literature were conducted with the guidance of the research question: What are the primary components of systems-level thinking? The following subscales were identified as the primary features of system-level thinkers based on engineering education curriculum and students’ experience in the U.S.

Thinking Holistically: Identify and understand connections and interactions among the elements/ components/ subsystems in a complex system. A system-level thinker does not focus on components of a system in isolation but views them in the context of the system’s performance, including interactions with other components.

Interdisciplinary Knowledge: Understand the value of various disciplines, interpret a system from multiple perspectives beyond the engineering level, and conceptualize problems from a broad range of viewpoints [23-24]. For example, when solving engineering problems, it is essential to be aware of the environmental, marketing, economical, ethical, and cultural issues and their impacts on the selection and implementation of the designs.

Optimization: Consider system improvement and balance with tradeoffs while developing, selecting, and finalizing design solutions. The tradeoffs include, but are not limited to, technical challenges, cost of developing and maintaining, operation, schedule, and environmental constraints.

Communication and Interpersonal Skills: Effectively communicate and/or collaborate with people involved with the whole system, such as other engineers, colleagues in different departments, and customers. Communication and interpersonal skills are critical personal traits for systems thinking development in engineers [25-26].

The overall structure of the survey is a 30-item 6-point Likert scale (1: Strongly disagree; 2: Disagree; 3: Slightly disagree; 4: Slightly agree; 5: Agree; 6: Strongly agree) questionnaire. It has subscales with 6-10 items per subscale. To control acquiescence and minimize non-substantive responding, at least one item per subscale is reversely coded. One male M.S. and one female Ph.D. student were involved in reviewing the items. The items were adjusted according to the students’ feedback before being implemented in this preliminary study.

B. Systems Engineering Diagnostics Activity (SEDA)

A toaster was selected for the basic systems engineering diagnostics activity (SEDA) because the majority of the students were expected to be familiar with its purpose, appearance, and primary function. To avoid any disparities that could result due to varying degrees of familiarity with graphical tools used for the schematic representation of systems, a table was used instead of a concept map for this activity. One author lead the activity while another author observed the class.



Figure 1. Pegboard with Toaster Components

First, the class instructor spent about 20 minutes presenting to the students a series of pictures showing the disassembly of a toaster. Then a pegboard with all the toaster components was introduced (see Figure 1) and a list of all the toaster components was provided. A table template was then given to the students to complete. Using the information mentioned above, the students were asked to name the subsystems that comprise the toaster, identify the components that form each subsystem, and list the other subsystems that interact with each subsystem listed explaining their interactions.

IV. DATA COLLECTION AND ANALYSES

A. Quantitative Data (ST Survey)

Collection: Students in four undergraduate mechanical engineering courses at freshman to junior levels at a 4-year engineering college participated in the ST survey using Qualtrics, an online survey platform. Only students who finished at least 85% of the survey questions were included in

this study. The missing data were replaced by the overall mean of the individual's responses.

Analyses: Statistical descriptive analyses were employed to analyze the quantitative data using Stata 13. Reliability of the survey instrument was calculated with Cronbach's alpha. Cronbach's alpha reflects the internal consistency of the survey questions, that is, whether the questions in one subscale are closely related [27].

B. Qualitative Data (SEDA)

Collection: A total of 30 students in a sophomore-level Engineering Mechanics Dynamics course participated in the systems engineering diagnostics activity (SEDA) described in the previous section. Seven (7) student responses were excluded because they either did not identify interactions among subsystems or they collaborated on the activity and provided identical results. Four datasets were collected from each student's responses to four items: 1) naming the subsystems (Item 1), 2) listing the components involved in each subsystem (Item 2), 3) listing other subsystems that interact with a specific subsystem (Item 3), and 4) explaining the interactions of the other subsystems that interact with a specific subsystem (Item 4). Considering the many valid ways the toaster subsystems could be defined, a depth of grouping (minimum/maximum number of subsystems) was not required.

Analyses: Five mechanical engineering faculty independently evaluated the students' performance during the system engineering diagnostics activity. A student could receive one point if he/she provided reasonable responses, as perceived by the faculty, to Item 1 (naming the subsystems), Item 2 (listing the subsystem components), or Items 3 and 4 combined (identifying the interactions among subsystems). Consensus is achieved for each aspect assessed if 80% (4 out of 5) faculty assigned the same grade (1 or 0).

Summing the individual grades assigned by the five faculty evaluators to each aspect that was assessed, the total grade that a student could receive ranged from 0 to 15. A sophomore-level student was considered to have high performance in systems thinking skills if his/her total grade was higher than 10, moderate if between 8-10, and low if below 8.

V. RESULTS

A. Quantitative Data (ST Survey)

A total of 117 students finished the ST survey online. As shown in Table 1, over 85% of the students were males and most students did not come from homes where the parents were engineers or scientists.

Table 2 shows the reliability coefficients by subscales in the ST survey.

Table 1. Student demographics

Particip- ants	Gender		Parent is an engineer or scientist	
	Female (%)	Male (%)	Yes	No
ME 110 (N = 26)	1 (3.8%)	25 (96.2%)	4 (15.4%)	22 (84.6%)
ME 210 (N = 20)	1 (5.0%)	19 (95.0%)	4 (20.0%)	16 (80.0%)
ME 221 (N = 23)	0 (0%)	23 (100%)	3 (13.0%)	20 (87.0%)
ME 322 (N = 15)	2 (13.3%)	13 (86.7%)	1 (6.7%)	14 (93.3%)
ME 352 (N = 33)	4 (12.1%)	29 (87.8%)	5 (15.2%)	28 (84.8%)
Total	117			
*ME 110:	Introduction to Mechanical Engineering			
ME 210:	Statics of Mechanisms			
ME 221:	Dynamics of Mechanisms			
ME 322:	Machine Design			
ME 352:	Introduction to Dynamics System			

Table 2. Reliability Coefficients of the ST survey

Subscales	Cronbach's Alpha Value	Sample Item
Thinking Holistically	0.65	Testing a design in the laboratory cannot guarantee its functionality when it is used in a real environment.
Interdisciplinary Knowledge	0.67	What I am learning as an engineering student is relevant to politics or economics.
Optimization	0.60	Risk assessment is not necessary until the end of the project.
Communication and Interpersonal Skills	0.65	It is more difficult to communicate with students from non-engineering majors than with engineering students.

B. Qualitative Data (SEDA)

All students defined between 4 and 9 subsystems for the toaster; while 18 (78.3%) students listed 6 or more. The majority of the students (70%-100%) identified the following five subsystems: packaging, exterior covering, electronic, heating, and interior support.

Consensus among the evaluators was achieved for 56.5% of the students on naming the subsystems (Item 1), 47.8% for listing subsystem components (Item 2), and 82.6% for identification and explanation of subsystem interactions (Items 3 and 4 combined). Table 3 shows the distribution of students' systems thinking skills.

Table 3. Distribution of students' systems thinking skills

Systems Thinking Skills	High	Moderate	Low
Number of Students	4	8	11

Of the 4 students with high systems thinking skills, only one missed assigning a component (out of a total of 32) to one of the subsystems that he/she identified. Three (3) of the 8 moderate-skilled students, and 4 of the 11 low-skilled students, didn't assign at least one component to one of the subsystems that they identified. Almost 70% of the students that participated in the systems engineering diagnostics activity had at least one component listed in multiple subsystems.

C. Cross Comparison

The results of the SEDA were used to categorize and aggregate students' responses to the ST survey. Students with high, moderate, and low systems thinking skills were compared in terms of their average responses to the subscales of the survey (Figure 2). The results of the ST survey basically align with those of the SEDA: students recognized as low in their systems thinking skills in the SEDA also received the lowest scores in most of the subscales in the ST survey.

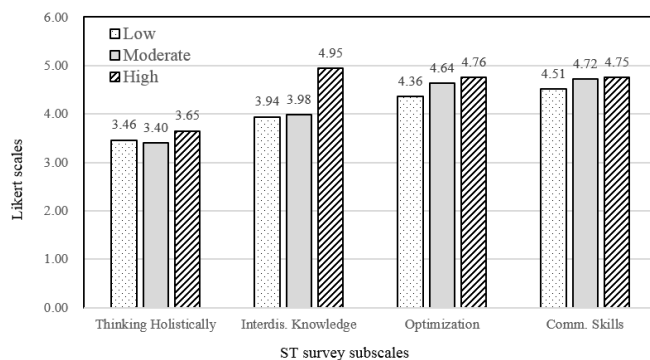


Figure 2. Cross validation of ST survey

D. Discussions and Future Study

This paper presented the preliminary results of a study aimed at assessing the systems thinking skills of undergraduate engineering students. Cronbach's alpha values and a systems engineering diagnostics activity (SEDA) were used to provide a preliminary test for the reliability and validity of the ST survey. Initial results from both the ST survey and the SEDA showed that there is a need to improve the systems thinking skills of engineering students.

E. Systems Thinking (ST) Survey

The Cronbach's alpha values, ranging from 6.0 to 7.0, indicate low internal consistency of the survey questions. Two reasons that can affect the Cronbach's alpha values are discussed below. First, the survey was answered by engineering students from the freshman to the junior levels. Although the influence from the background of the parents was controlled in the analyses, student responses to survey questions in the same subscale can vary significantly depending on their prior exposure to the product development processes in courses that they have already taken. Second, considering the complexity of engineering systems and the different phases of the product development processes, 6 to 10 questions for each subscale could be insufficient. In this regard, Cronbach's alpha increases with the number of items in the scale [27].

F. Systems Engineering Diagnostics Activity (SEDA)

The authors noticed four factors during the systems diagnostics activity that can impact the results. The factors are discussed in the following paragraphs.

First, the activity assumes that all the students are sufficiently familiar with the main functions and components of a toaster. However, the authors found that several students were unfamiliar with the purpose of certain components. For example, while conducting the activity more than 5 students asked for additional information about the location and/or function of some components.

Second, the pictures of the process of disassembling the toaster and the list of components provided to the students may have influenced the responses of the participants. For example, during the activity none of the students missed the packaging subsystem. This was most likely the result of showing pictures of taking the toaster out of the box and including the packaging materials in the list of components. The authors feel that without that input, some students would have missed that subsystem since they don't view the packaging as part of the product. It is important to keep in mind that for products like a toaster, the design of the packaging is part of the product development effort.

Third, communications among students could have affected the responses provided by some participants. Due to the limited time available during the class session, many students continued working on the activity after class. Although student responses that were almost identical were excluded from this study, it is possible that some of the responses used in the analyses were influenced by informal interactions among the participants.

Finally, assessing systems thinking skills using the SEDA can be subjective since the grades assigned to the items that were evaluated are affected by the experience of the evaluator and can be significantly influenced by external factors.

VI. FUTURE STUDY

To address the issues mentioned above, future studies will: 1) include more questions in each subscale in the ST survey; 2) use the updated ST survey to collect longitudinal data from students taking the same course with the same instructor but in different semesters; 3) provide students with a list of components that includes a picture and, when deemed appropriate, a brief high-level description of the general purpose/function of each component; 4) strategically group students in small teams and analyze teams' responses to the ST survey and the SEDA; and 5) evaluate students' responses to the SEDA by comparing them with typical responses of practicing engineers with systems engineering expertise. Finally, structural equation models will be developed to investigate the impact of engineering courses on students' systems thinking skills.

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An analysis of the provision of context within existing remote laboratories

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Abstract— Laboratory work is a well-accepted component of science and engineering programs. One emerging trend has been the increasing utilisation of remotely accessed laboratories, where the students can remotely monitor and/or control physical apparatus, typically across the internet. This supports greater flexibility of access for students as well as the possibility of sharing of facilities between institutions. One additional benefit is greater flexibility in designing the learning context within which the laboratory can be positioned. As the interaction is computer mediated, it becomes simpler to modify this interface and hence change the laboratory context.

Research has shown that context can have a significant effect on learning outcomes, students' retention of information, engagement with learning and on knowledge transfer from one domain to another (see, for example, [1],[2]). Despite this there has been little consideration given to understanding contextual information provided in laboratories in general and remote laboratories in particular.

In this paper we report on an analysis of contextual information provided within remote laboratories. Consideration is given to the ways in which the contextual information provides a connection between the real-world concepts being explored and the laboratory as a proxy for those concepts. The analysis shows that there is a diverse range of approaches and representational forms and suggests a new taxonomy that may be useful in describing the context found in laboratory activities for future analysis and design.

Keywords—laboratory; remote; context

I. INTRODUCTION

All learning occurs within a context, irrespective of whether that context has been actively constructed or is an incidental or unintended consequence of either the learning activity or the learner's history. The nature of the context and how this context relates to the concepts being learnt has been widely shown to have an effect on learning outcomes [3], [4]. Whilst this effect has been studied in a number of disciplines and over a range of different types of learning activities, we are specifically interested in how context can be used in laboratory activities – an area in which there has been relatively little written.

In previous work [5] it was argued that the provision within laboratory experimentation of an explicit domain context that can clarify the relationship between the experimental apparatus and a real-world situation which it can represent, could potentially support improved learning outcomes. In particular, this is based on the development of a clearer understanding of the relationships between the aspects of reality being investigated, the laboratory apparatus that is acting as a proxy for that reality and the conceptual model that describes some aspect of that reality.

Contextual elements that aim to clarify these relationships between the laboratory, its underlying model and the real world (including, importantly, where the relationships break down) are present in many laboratory activities but often their inclusion is done without systematic consideration of the design of these elements.

In order to begin reasoning about context in laboratories it would be beneficial to analyse existing laboratory activities to determine the different forms and functions that exist in the contextual elements of a range of laboratories. This would support the development of a framework that can be used to analyse and subsequently strengthen contextual aspects of existing laboratories as well as design contexts for new laboratories in such a way as to support laboratory learning outcomes.

Remotely accessed laboratories which, by necessity, have computer mediated interfaces, have provided educators with the opportunity to modify lab interfaces and supply contextual information in new formats (as opposed to laboratory notes and instruction). The literature presents a number of learning activities using remote labs that have been enhanced in such a way to support learning outcomes, however few of these specially look at the nature of the context provided [6]. Remote laboratories provide a suitably varied range of contextualisation to begin this analysis.

In this paper we look at the types of contextual elements that are relevant to laboratories, and the ways in which these might be classified. We begin by analysing existing literature to determine how context is currently described, with a particular emphasis on considering science education. Focusing on domain context, the ideas are then applied to a diverse range of remote laboratories in order to develop a

taxonomy that can be used to describe contextualisation within labs and provide the basis for future work in the analysis and design of contextualised laboratories.

II. CONTEXT

An appropriate discussion on context will need to be based on an understanding of the types of contextual elements that are relevant to laboratories, and the ways in which these might be classified.

Approaches in the literature range from identifying broad contextual categories (e.g. social or historical contexts [7]) to discussions on the effect on learning outcomes of specific contextual elements [8]. In earlier work by the authors [5] literature on contextualised learning was analysed, resulting in the definition of two broad categories of contextual information. The first is situational context, or those factors that relate to the environment within which the learning is occurring but which are independent of the specific learning tasks. An example of this might be learning taking place in the context of a noisy classroom setting. The second form of context is domain context, or those contextual elements which have a connection to the concepts that form the focus of the learning activity being carried out. An example of this form of context might be studying the concept of acceleration due to gravity in the context of a skier on a ski slope.

This paper is specifically interested in investigating the domain context of laboratory learning activities, considering how an enhanced understanding of the domain context in laboratories can eventually lead the inclusion of sensibly designed contextual information into lab activities in a way that improves learning outcomes.

A. How is context used in learning?

Context and related concepts have been studied within the educational literature for a considerable period. As an early example, Ausubel's theory of "advance organisers" [9], whilst not explicitly referring to context, does provide a mechanism for exploring context, albeit a context that has a direct subsuming relationship to the concepts being explored. Of particular interest is the notion of comparative organizers, which are used to activate existing knowledge schemas and hence "to increase discriminability between the new ideas and the previously learned ideas by pointing out explicitly the principal similarities and differences between them" [10]. We can conceive of an explicitly provided context as a form of advanced organizer.

Novak [11] takes this a step further, introducing the concept of a cognitive bridge:

"Cognitive bridges are short segments of learning material that provide guidance to the student as to which concepts in his cognitive structure might best be employed to learn meaningfully. They also help to signal what will be the key concept(s) in the new material and how these may bear a subordinate or superordinate relationship to concepts the learner already possesses."

In other words, in the setting of laboratory experimentation, we can recognise that an explicit domain context can, in effect,

act as a cognitive bridge, priming the learner to make associations between the laboratory concepts that are evidenced in the experiment and broader concepts in the scientific domain being explored and which are part of the learners existing knowledge, but which are not explicit in the experiment.

Often these associations are the result of analogical reasoning [12]. For example, a deforming beam in a physics experiment might be described analogously as a bridge across a river, thereby priming the student to think of a load on the beam as a car crossing that bridge. Considering a provided context as a form of cognitive bridge is useful in that we can then draw on the insights provided by Novak in relation to the design of these cognitive bridges. For example, Novak indicates (based on the underlying theory from Ausubel) that *"the crucial test for meaningful learning is the ability to solve relevant novel problems ... We see, then, that problem-solving ability derives from cognitive structure differentiation and that it is concept specific"* [11].

Kokinov's [2] classification of context also has parallels with Novak's cognitive bridge. Kokinov approaches context from the point of view of how the state of the environment is perceived and then internal representations of this are constructed. Kokinov discusses the role of three different processes involved in the mental construction of context and which are in turn affected by the context: perception; memory; and reasoning processes. "Perception-induced" context is that contextual information available through the current perception of the environment. This is potentially of most interest to us as it is this aspect that we have most control over. "Memory-induced" context is information obtainable from memory and previous context representations that are recalled. "Reasoning-induced" context is information derived through reasoning. Learners will use these context representations in the learning process [2],[13].

The approaches that Novak and Kokinov take to classifying context allow us to better appreciate how context is used by students in learning. These frameworks provide a link between the nature of the context and the learning process that occurs when students complete contextualised learning activities. However, whilst these frameworks provide useful insights we have to look further to find a means for determining the specific contextual elements that are relevant for a particular learning activity, or how these contextual elements relate to the concepts under study.

B. Which contextual elements are useful?

Numerous researchers have considered what information or artefacts may play a role in providing a context to learning activities.

Ausubel [10] provides clear indications for the type of information that is useful for advance organisers, that is that they provide introductory material that is "at a higher level of abstraction, generality and inclusiveness" than the content being learnt. Novak [11] goes on to identify several additional aspects that are relevant for context design: *"the advance organizer ... should ... serve to link the new information to be learned with existing concepts in cognitive structure. ... They*

also help to signal what will be the key concept(s) in the new material and how these may bear a subordinate or superordinate relationship to concepts the learner already possesses."

Klassen's [7] approach looks at which broad categories of contextual elements are relevant within specific activities. Klassen describes context in learning as including practical, theoretical, social, historical and affective context. Based on these categorisations, and how each factor can be influenced, Klassen developed the Story-Driven Contextual Approach (SDCA). He argued that learning can be contextualised by providing a "story". Delivered by a narrative, the story provides focus and motivation. Students then engage in self formulated or teacher supplied investigations involving a number of activities, all of which take place within the five types of contexts being supplied by the story and the students' own knowledge, ideas and experience.

Klassen's work provides insight into the different elements that construct the total context and how they can be categorised, as well as broadly arguing for a specific approach (contextualisation through narrative). It does, however, lack an effective mechanism for determining the specific contextual elements that are relevant for a specific laboratory, or how these contextual elements relate to the concepts under study. This is an aspect that is important in supporting the design of specific laboratory activities.

Van Oers [14] takes a different approach. Rather than considering context as any element that affects the interpretation of concepts, Van Oers looks at how content (or meaning) and context are related, describing two functions of context in learning. These functions are to support the "*particularization of meanings*" and to "*provid[e] for coherence*". Context particularises meaning by supplying additional information that focusses the learning on the appropriate interpretation of the concept being learnt and aims to eliminate ambiguities or possible misinterpretations not appropriate to the specific meaning. Context can provide coherence by relating content to a "larger whole" so that the knowledge is not restricted to a particular meaning or situation.

Van Oers distinguishes three different approaches that can be taken towards how context is related to the meaning being sought, each of which aim to achieve the two main functions of context.

- Using pre-existing cognitive structure as an anchoring point for embedding new material so that it can provide particular meaning and coherence. In this case Ausbel's advanced organisers are "externalisations of elements of cognitive structure" [14, pp.476].
- "Situation-as-context" - A meaningful experienced situation, one that makes "human sense", provides particularisation and coherence.
- "Activity-as-context" - Context is "embeddedness in activities".

Barab et al. [15], similarly to Van Oers, focus on the relationship between scientific formalisms (the focus of the learning) and the situations of use which provide a context for

those formalisms. Consideration is given to the nature of the relationship between the formalism and the "context of use".

A formalism may be directly experienced by the learner such that the meaning is inherently bound up with the specific instance. In this case the formalism is considered to be embodied by the context of use. Conversely, if the formalism is drawn out of, and understood as a separate concept from the specific instance in which it might be explored, then it is considered to be embedded. Embedding and embodying the formalism can be said to achieve Van Oers' function of "particularizing meaning". Once the formalism is further related to other contexts of use, beyond the one in which might have been originally learnt, then it is considered to be abstracted. The context that provides an abstracted formalism provides Van Oers' "coherence" by placing the content being learnt within a larger representation of reality.

Barab et al. further describe that the specific relationship between the formalism and the context of use can be either explicit or implicit.

Whilst Barab et al. [15] commence with a similar objective to that described in this paper – specifically "to establish a rich context through which scientific formalisms are embodied, embedded, and eventually abstracted" – their focus shifts to exploring the extent to which narratives can fulfil this purpose. Their work nevertheless provides some interesting insights into the design of contexts – represented as design principles that assist in embedding/embodying formalisms into authentic contexts of use:

- Establishing embodiment that provides a clear and legitimate role that gives value and meaning to actions;
- Illuminating context-context relations;
- Fostering of an analytical stance through encouraging a sense of participation;
- Development of multiple representations of formalisms, potentially through derivative contexts.

Barab et al. acknowledge that there is a balance that needs to be achieved when designing contextual elements for a curriculum between the "quality of the context" and the "quality of the formalism". The context can be detailed at the risk of being distracting (or noisy) and the formalism can range from explicit (and potentially quite formal) to implicit (and potentially inefficient).

C. How can context be represented?

The diverse approaches to classifying and defining what makes up context illustrate the wide range of contextual elements that are present in many learning activities. Narrowing this down to domain context still allows for context to be represented in a number of ways.

Looking at all laboratories, the equipment itself always provides domain context for the activity. The investigation of scientific models can often be done using different experiments and equipment, for instance the Inverse Square Law of radiation intensity at a distance can be investigated using a radioactive radiation source, or a light source. The selection and design of the equipment that makes up the laboratory

serves to particularise the learning by focusing the student on a specific interpretation of the concept under study. The laboratory, as a proxy for reality, represents only a small part of the real world and the instance it embodies exists in a broader domain context.

For instance, if we chose to investigate the Inverse Square Law using a radiation source, the laboratory equipment focusses the learning on the application of the model to radioactivity, but by itself provides no context linking the experiment to real world radiation sources, such as naturally occurring radioactive minerals, or radiation within a nuclear power station. Additionally, the laboratory equipment does not capture the alternative applications of the model, nor the limitations of the model were it to be applied in the real world, such as the fact that in reality there is always background radiation sources and radiation absorption. It is this link to existing knowledge and experiences of students, and an illumination of new information the model provides and how it can be applied, that context should aim to achieve. Existing remote laboratories provide contexts that differ in what type of real world context is being highlighted to student.

Many laboratory activities have associated learning material that may include diagrams, supplementary reading material, instructions, or links to information sources (such as videos and books) that provide further examples and details of the application of the model and can serve to provide further context. This scaffolding provides a cognitive bridge to existing knowledge or situates the learning in a broader frame, providing coherence. The computer mediated interface of remote laboratories can provide rich and varied contextual information to students during the laboratory activity, and it is of interest to consider how these can be represented.

Remote laboratories exist with a simple camera and control panels as the user interface, through highly realistic virtual representations of real control and measuring equipment, to laboratories that are fully embedded within virtual worlds. It is expected that context representation in remote laboratories would fall along a spectrum such as the mixed reality continuum [16] with the real equipment at one end and a completely virtualised, non-realistic, stylised or abstract representation at the other.

The ideas presented here on how context is used in learning and how contextual elements can be designed and represented provide a starting point for analysing context within existing remote laboratories. The next section will look at five different remote laboratories and identify the contextual elements by determining whether they fulfil any of the functions of context (van Oer's functions of particularisation and coherence, or Novak's concepts of cognitive bridge) and how this is achieved. These will then be described in terms of how they are represented: where they fall on a spectrum of 'realism', how closely the context elements are related to the model being studied and what the nature of this connection is. The analysis will be used to derive a taxonomy for describing context in laboratories and so contribute to the field.

III. LABORATORY ANALYSIS

Five different remote laboratories were selected for analysis from the literature as representative of the wide range of laboratories that exist. The first is a remote Hydroelectric Energy laboratory hosted at the University of Technology, Sydney (UTS) and its associated lesson to teach the concept of energy transformations to high school students [17]. Secondly, we will look at the Circuit Warz project which is a game based remote laboratory teaching electrical and electronic theory and principles, specifically in this case the principles of positive feedback in op-amps [6]. Thirdly, we will take a look at NetLab at the University of South Australia (UNISA) which aims to teach circuit design and analysis [18]. Further, we look at the UTS Inclined Plane laboratory and, lastly, at the Virtual Chocolate Factory [19].

A. Hydroelectric Energy Experiment

The LabShare remote Hydroelectric Energy laboratory is hosted at UTS and accessed via the Sahara laboratory sharing platform. The remote laboratory can be used to study the principle of the conversion of kinetic energy of flowing water into electrical energy. The lab consists of pump which lifts water to fill a tank, another pump which the student can control to force water into a pipe where the flow rate is monitored. The flowing water rotates a turbine (Pelton wheel) connected to an electromagnetic generator and falls into a lower tank where the first pump lifts it up again. The electrical output of the generator is used to power the LEDs placed in a model house. The LEDs can act as a digital monitor of power output, or as the load for the generator's output circuit depending on the laboratory lesson.

When conducting the laboratory, students log on remotely to the lab and will typically have access to: a live video stream of the real equipment with multiple views showing the water flowing, the real gauges and valves and the LEDs within the model house; a simulated control panel that allows students to manipulate the second pump and thereby change the water flow rate and simulated gauges which mirror the measurements of the real equipment gauges. All these are displayed within a web browser by the Sahara lab sharing platform (though the videos can be dragged to different positions). This is illustrated in Fig. 1 below.

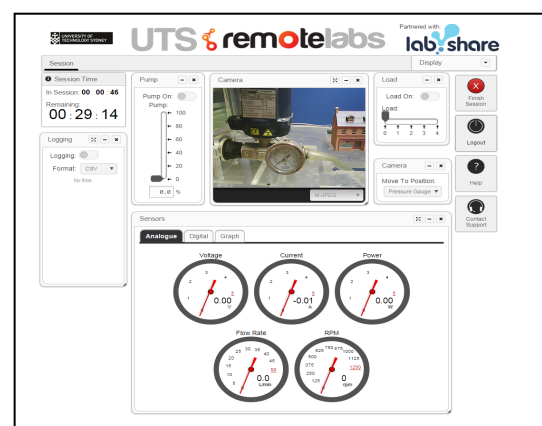


Fig. 1 Hydroelectric Energy Remote Laboratory (screenshot obtained on April 24, 2015)

Students also have a lesson plan with assessment questions and an illustration of other forms of energy conversion. The diagram is shown in Fig. 2.

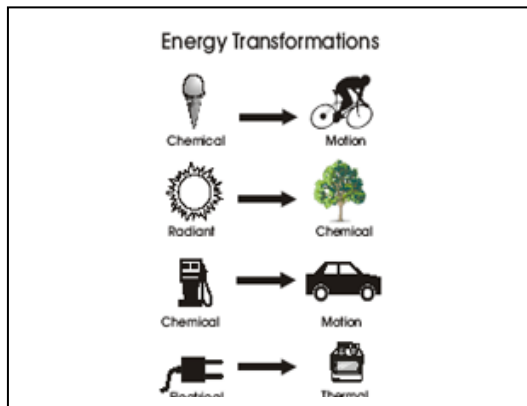


Fig. 2 Excerpt from Hydroelectric Energy conversion lesson (obtained from <http://www.labshare.edu.au/catalogue/lessondetail/?id=7&version=1> CC BY 3.0)

1) Identifying the domain context elements

The concept under study is the basics of the theory of energy transformation. Domain context therefore, in this case, is those contextual elements throughout the laboratory activity that relate to the understanding of energy transformation. Probing the lab activity to determine which contextual elements fulfil the functions of particularising and providing coherence, allows us to identify and further assess the domain context elements. The following contextual elements can be argued to comprise the domain context:

- The laboratory equipment presents a scaled and simplified model of a real world hydroelectric power generation.
- The visual of moving water, turning wheel and lit LEDs explicitly illustrates a number of the energy conversions in the system with real-time video.
- The user interface presents a simulated control panel, gauges and LEDs. The user can see analogue, digital or graphs of the outputs of the gauges.
- Information provided with the lesson plan.

2) Describing the domain context elements

The elements that provide the context for this laboratory can be considered to fall into two categories. First is those contextual elements that are included within the lab equipment itself, represented physically in the form of the model house, the flowing water and the LEDs turning on and off which. These are displayed to the user very realistically in the form of the video panel showing the live video feed of the equipment. They provide an illustrated use case of the energy transformation. The model house included in the equipment extends the context by situating the energy conversion example into its real world context (that is energy conversion in hydroelectric power stations can result in lights turning on in a home).

The simulated control panel, gauges and LEDs however, are augmentations. The controls for the experiment are simplified to buttons and sliders which turn the motor on to

selected values and off again. The gauges are stylised representations of gauges showing the actual values measured. The simulated LEDs are also stylised representations. The layout makes control of the lab and visualization of the output simple and clear but they do not replicate real measuring or control equipment. There is limited representational ‘integration’ between the simulated controls and the real equipment – simulated gauges show the actual gauge readings but their physical representation is not connected.

In this case, the lesson plan explicitly illustrates different use cases of energy conversion with the use of the picture shown in Fig. 2.

This laboratory is typical of many labs that have control and display panels that mimic the laboratory equipment.

B. Circuit Warz

This laboratory aims to teach students the electrical and electronic theory using game based learning within an immersive, collaborative virtual world. The lab is set within Second Life and consists of students forming teams, taking quizzes and competing in designing oscillator circuits. It is considered a remote laboratory because the environment is linked to real hardware and the teams are working with physical circuits [20]. The game is set within an arena and each team has to answer quiz questions before competing against other teams to see who is most accurate at biasing the oscillator to achieve target peak-peak voltage and waveform periods. A screenshot is shown in Fig. 3.

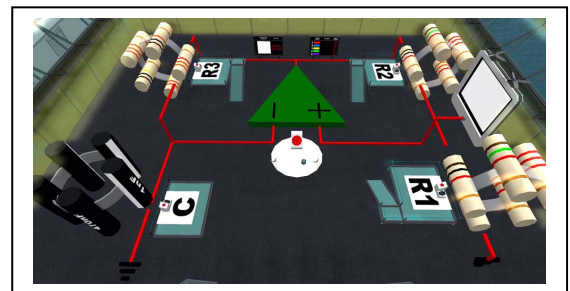


Fig. 3 Circuit in virtual game arena (screenshot obtained from <https://www.youtube.com/watch?v=2Y3ghidy0j8>)

1) Identifying the domain context elements

The concept under study is the basics of the principle of positive feedback in op-amps. The contextual elements which meet the functions of particularising and providing coherence identify the domain context elements:

- The quiz used to provide feedback on the theory via multiple choice questions.
- The stylised resistors and capacitors which illustrate the real equipment that exists.
- Markings on the arena showing the op-amp circuit and where the resistors and capacitors sit in the circuit.
- The display boards showing the how accurate the value calculations for each team were.

2) Describing the domain context elements

This laboratory investigates positive feedback in op-amps by allowing students to manipulate values in an op-amp circuit

and seeing the results but it does not provide either specific use cases for op amp or alternative effects of these components in other types of circuits. The context in this laboratory serves to engage students more closely with the content and understand the components that make it up in more detail.

This laboratory does not display any of the real equipment to students. It is only the feedback from the actual values that show that the students are working with real hardware. The circuit however is displayed graphically in the arena with a schematic circuit diagram. Stylised resistor and capacitor objects are used in the virtual world for students to manipulate. Interaction with the resistor and capacitor components in selecting their values is not as it would be in the real world and does not reflect the physical form of the underlying hardware. No measurements are displayed during the game (such as oscilloscope measurements, though these are available for other laboratory activities within the environment).

In the Circuit Warz example the ‘integration’ between the controls and the real equipment is complete but hidden. Students manipulate the virtual world which effectively configures real hardware to their specifications but there is no distinction between the controls and the hardware as none of the real equipment is visible.

This laboratory is unusual in not providing a visual of the real remote equipment. It is representative of a small number of labs and appears from the interface very much like a simulation laboratory (although the real equipment values will affect how students learn from the lab).

C. Netlab

NetLab is a remote laboratory developed at UNISA. It consists of an interactive, collaborative environment designed to support experiments in electrical engineering such as circuit design and analysis. NetLab has a user interface that allows the design of circuits using a range of variable value components that can be dragged, configured and connected. There are a number of instruments that can be connected within the circuit and these are represented by very accurate images. Users can manipulate the controls of the measurement equipment through their virtual representations. The circuit builder interface and oscilloscope panel are illustrated in Fig. 4.

1) Identifying the domain context elements

The components that make up the domain context for this experiment must support circuit design and analysis: They are:

- Circuit components available for circuit design represented by symbols and icons.
- Highly realistic instrument panels.
- Live camera feed.

2) Describing the domain context elements

As for the Circuit Warz remote laboratory, there is no close connection with the execution of the circuit design in the interface and the underlying hardware in this remote laboratory. The live camera feed does however link the activities performed in the remote lab with the real hardware being manipulated.

Also, a characteristic of this laboratory is the very realistic instrumentation panels that exist and allows students to manipulate the components similarly to real world components.

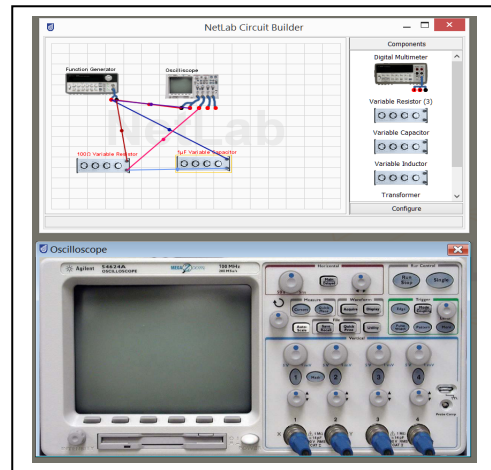


Fig. 4 Screenshot of a NetLab Session (obtained April 27, 2015)

The equipment and the context allows students to explore a range of circuit designs, placing the concepts of electrical circuits in a broader range than only a single configuration of components (as for Circuit Warz). There is no information supplied within the context of the real world application of these circuits however.

This laboratory is representative of a small number of proprietary labs that have been developed. Much work has been done to make the computer interface look and perform like real world controls.

D. Inclined Plane

The inclined plane experiment at UTS is a remote lab accessible through LabShare’s Sahara lab sharing platform. The lab consists of inclined plane with a track that allows sliding blocks to move along it when it is tilted. Students can select the blocks (each of which have different materials in contact with the plane) and the angle of the plane. They are able to take measurements of the block velocities and can therefore work out coefficients of static and kinetic friction, as well as calculation of acceleration due to gravity or calculation of the value of gravity. The inclined plane is shown in Fig. 5.

1) Identifying the domain context elements

Looking specifically at the calculation of acceleration due to gravity as the underlying model that can be investigated using this lab equipment within a laboratory activity, the following domain context elements can be identified:

- Laboratory equipment.
- Live camera feed provide particularisation.

2) Describing the domain context elements

This remote laboratory provides a use case for acceleration due to gravity. There is no additional context that allows the user to link the model for acceleration to other applications, nor is the inclined plane linked to similar real-world examples such as a playground slide or a skier down a slope.

The video feed supplies a real-time view of the equipment that is not augmented in any way with contextual information. The controls and output display are clear but not similar to real world measurement or control instruments.

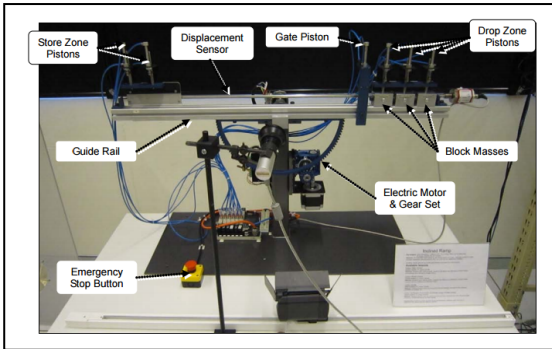


Fig. 5 Inclined Plane (obtained from http://www.labshare.edu.au/library/past_rigtypedetail/?id=3&version=1)

E. Virtual Chocolate Factory

The Virtual Chocolate Factory [19] is a “virtual mirror” world of a real-world chocolate factory and its processes. The virtual world replicates the factory and includes real time data from sensors within the actual factory and real-time video from the factory. It was designed to be used, amongst other things for trainees to learn about the machines and processes within the factory. A screenshot is illustrated below in Fig. 6.

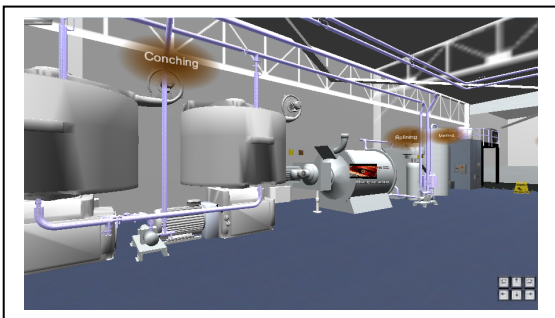


Fig. 6 Screenshot of Virtual Chocolate Factory (image obtained from vr.fxpal.com, Maribeth Back, FX Palo Alto Laboratory)

1) Identifying the domain context elements

Looking specifically at how the Virtual Chocolate Factory can be used to teach trainees about equipment and processes, the following domain context elements can be identified:

- Real time data from the real chocolate factory displayed in “Data Spots” (floating text in a transparent cloud next to the model the sensor is attached to).
- Live video from 10 cameras in the real chocolate factory.
- Faithful virtual replicas of machines and buildings are modelled in the virtual world.

2) Describing the domain context elements

The Virtual Chocolate Factory context provides a complete environment for the use of the processes and procedures being taught. While it does not expand the information to use in

other factory environments, the context situates the learning in an environment in which it will be used by replicating the factory in the virtual world.

The live video feeds link the virtual context and the data streams to the actual factory floor and the real world environment in which the knowledge will be used.

This laboratory is unusual in the level of fidelity and integration between the real world being measured and the remotely accessible learning environment.

IV. DISCUSSION

Having looked at a number of remote laboratories, we can see that although there are many common elements to how context can be presented, the degree to which this implementation is done varies greatly. The authors would suggest there are a number of descriptors that can be applied to laboratories that can capture the nature and depth of the context-content relationship. These are:

- Function – how the context fulfills the function of particularising or providing coherence.
- Fidelity - how realistic the representations of real world objects are.
- Level of Integration – how much integration is there between the three facets of context, content and the real equipment.

These descriptors only serve to provide a coherent way to analyse the laboratory content and make no judgement on the suitability or appropriateness of each. What level of each of these descriptors is ‘best’ is very dependent on the learning objectives being targeted within the learning activity. In some cases, the particularisation function of context best serves the key learning outcome such as in the Virtual Chocolate factory where trainees are expected to learn about the very specific machines and processes in the factory. In other cases, such as the Hydroelectric Energy experiment, it is hoped that students learn the broader concept of energy conversion than just the specific use case being investigated within the lab. The learning objectives of the laboratory will play a large role in the form that the context takes and which function it aims to fulfill.

A. Function

In the laboratories examined here, the laboratory equipment itself often provides a context which particularises the learning content to a specific use case. The lab equipment is a proxy for the real world and its form identifies which real world aspect of the model under investigation it aims to represent. In the case of the Inclined Plane experiment, this context is not expanded further by other domain context elements, however labs such as the Virtual Chocolate Factory and the Hydroelectric Energy rig do provide domain context that situates the laboratory equipment in a wider real-world scenario for which it is acting as a proxy. The context provides information about the real world environment for which that lab is a proxy that is not obvious from the lab equipment itself. We can consider this type of information to be *environmental domain context*.

Environmental domain context adds information linking the laboratory equipment and its underlying model to the real world environment for which it acts as a proxy.

The Hydroelectric Energy experiment is the only one with the associated lesson plan details. This shows that additional context has been supplied in the form of a diagram illustrating more use cases for the concept of energy conversion. This type of domain context provides an *alternative expression* of the model. While the lab equipment itself is a proxy for a small portion of the real world, domain context which provides an alternative expression provides coherence by linking the model under study to other real world scenarios.

Experiments such as NetLab provide contextual information that allows students a more in depth understanding of the concept under study. The range of components and the realistic nature of the instrument panels highlight aspects of circuit design not obviously available in experiments such as Circuit Warz. This type of contextual information serves to clarify the model under study, providing information not obvious from the equipment alone. This can be considered *elaborative domain context* where additional information serves to elaborate on the phenomenon under study.

To illustrate these ideas, we can consider a remote radiation laboratory as an example. The lab measures radiation intensity at a distance from a source to investigate the Inverse Square Law model. The lab equipment itself will provide the context of looking at this model specifically as it applies to radioactive sources. Examples of the types of context that could be added to provide further particularisation or coherence are:

- Environmental domain context: situating the lab in a virtual nuclear reactor links the lab to the real world environment for which it is a proxy.
- Alternative expression domain context: enhancing the remote radiation laboratory with other examples where the Inverse Square Law applies, perhaps by adding a microphone and illustrating how sound volume decreases with distance.
- Elaborative domain context: the user could be supplied with a dynamic model of radioactive decay to illustrate that while the Inverse Square Law is a good approximation, it does not take into account the stochastic nature of radioactive decay in the model.

B. Fidelity

How realistic are the representations of real world objects being presented as contextual information to students? On one hand this can be purely symbolic, such as the circuit diagram in the Circuit Warz experiment. On the other extreme are the incredibly realistic instruments mimicked in NetLabs and the models used in the Virtual Chocolate Factory. Fidelity of representation is a spectrum running from the symbolic or abstract representation, through a range of scaled or stylised representations, to a realistic copy of the real world environment.

C. Level of Integration

What stands out in the analysis of the labs here is how varied the level is of content integration into the context

provided. In many cases the lab equipment itself provides some domain context and these are obviously intertwined. In Barab et al.'s description, the lab equipment 'embodies' the content under study. For additional scaffolding context that is provided however, there is, once again, a continuous spectrum that runs from the extremes with labs like the inclined plane experiment on one hand and the Circuit Warz experiment on the other.

The Inclined Plane experiment context is provided the camera view of the equipment and the control panel which is designed for remote control of the equipment and not to mimic and real world object. The context supplied by these user interface elements is not linked by any additional information to the content under study. The only context that is linked to the content is the laboratory equipment itself which fully embodies the concepts under study.

On the other hand, the Circuit Warz context completely subsumes the real equipment to the extent that there is no realistic representation of the underlying hardware. The content itself is also completely integrated into the Circuit Warz game format – there is no interaction with the equipment other than through navigating through the game format.

In between these lie the laboratories such as the Hydroelectric Energy rig. While closer to the Inclined plane side of the spectrum, the Hydroelectric Energy laboratory includes a model house and stylised representations of the controls and gauges that link the real equipment to the context being supplied in the user interface. The graphics show real equipment values and this can be seen in the video panel too.

Closer to the fully integrated end of the spectrum is the Virtual Chocolate Factory. While the virtual world replicates the chocolate factory very realistically, the user interface provides a link to the real equipment by the use of live camera feeds and the display of live data.

V. CONCLUSION

Having analysed existing remote laboratories in terms of the form and function of the context provided, this paper has shown that there is a taxonomy that can be applied to describe the range of context found in labs.

Context fulfills its functions of coherence and particularisation by adding information in the form of environmental, alternative expression or elaborative domain context each of which address a link between the real world, the laboratory equipment and the model under study. Additionally, a wide range of representative forms was found ranging from purely symbolic to very realistic. This fidelity in the representation is related to but distinct from the level of integration between the remote laboratory equipment and its context. Laboratories ranged from immersive virtual worlds, to labs that mimicked hands-on labs in their form.

These three factors of function, fidelity and level of integration describe a large range of remote laboratories. Future work would attempt to apply this taxonomy to other remote laboratories including lesson plans and utilise the taxonomy in the design of context for new laboratories.

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Evaluation and Continuous Improvement in a Multidisciplinary S-STEM Program Focusing on Professional Skills, Goals & Mentoring

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Abstract—Four years of student feedback from participants in a sponsored scholarship program is evaluated to assess perceived benefit of program activities that go beyond awarding scholarships. The program is structured to help students develop professional skills such as communication, teamwork, job readiness, and goal setting in a context that allows for formal and informal mentoring. Annual themes often related to current issues affecting society provide a setting to motivate these skills. Results show that students value skills and experiences outside of their major requirements. This work describes the program and its process for continuous improvement and provides insights into student willingness to participate in personal and professional activities on top of rigorous STEM major requirements.

Keywords—professional development; mentoring programs; active learning; multidisciplinary teams

I. INTRODUCTION

Providing STEM students with professional skill development in the traditional classroom setting has proven challenging due to time constraints and basic curriculum requirements. Technical professional skills, such as resume development and interviewing ability, are often met by a university's career services department, through workshops and individual coaching. Non-technical professional skills, such as interpersonal collaboration and decision making, can be met through various extra-curricular programs. A student interested in professional skill development must take the initiative to seek out these experiences outside of the classroom environment.

The Mentored Academic Experience (MAX) program was implemented at Minnesota State University, Mankato, which is a comprehensive university in the Midwest, to provide both technical and non-technical skill development in a community setting that fosters student engagement. This multidisciplinary peer mentoring support system was developed in conjunction with scholarship and program funding provided by two National Science Foundation (NSF) S-STEM grants. The MAX Scholars program was launched in 2007 with the first S-STEM grant (DUE-0631111) that provided funding for 67 students from 2007-2011. A renewal grant awarded in 2011

(DUE-1060659), has funded 76 students in total, including 17 also partially funded under the first grant.

Since its inception in 2007, the MAX Scholars program has supported students financially through scholarship funding and developmentally through a one-credit seminar. The weekly seminar helps scholars with the familiarization of university support services; allows participation in multidisciplinary discussions addressing broad academic and career issues; and promotes building connections with other scholars from diverse STEM disciplines. Multidisciplinary, investigative team projects are the main avenue of professional development in the weekly seminar. In addition to the weekly seminar, faculty mentoring is provided and peer mentoring is developed. These supports add dynamic avenues of professional development by providing more individualized feedback, as well as creating unique leadership opportunities.

A small group of faculty oversees the seminar, administers the program, and selects the scholars. Each academic year, the scholars cohort consists of 26-30 students with the proportions being approximately 1/3 sophomore, 1/3 junior and 1/3 senior. Cohorts remain diverse, as defined by the program criteria, with students majoring in many different STEM disciplines. Also represented are a diverse mix of gender, race, religious affiliations, socioeconomic backgrounds, and cultural experiences. Our program has demonstrated past success in addressing issues important to STEM fields and accreditation boards, such as functioning on multidisciplinary teams, understanding ethical responsibilities, developing a sense of the global and societal context of STEM work, and supporting the idea of life-long learning [1-4]. Qualitative data from 2014 was analyzed and pointed to the importance of this complementary educational experience that was outside of student major requirements. Students have commented positively on a range of experiences including: learning necessary professional skills for multidisciplinary team functioning, developing a feeling of connectedness to the broader science community, and valuing faculty-mentoring for professional and personal development [5].

Over the years, the program has developed and adapted through a continuous improvement process that revolves around faculty observation, reflection and received feedback.

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One aspect of the feedback is end-of-semester evaluations which have informed the changes to support overarching program goals. In this work, we present a brief quantitative analysis of survey results over the past four years, and a qualitative analysis of the short answer survey responses to the improvements implemented each semester. These results provide insights into programmatic best practices that complement traditional classroom experiences to support the academic, professional, and personal development of STEM students.

II. PROGRAM DESCRIPTION

A. Overview

The goals, structure, and continuous improvement process of the MAX Scholars program serves second-, third-, and fourth-year students majoring in mathematics; biology; chemistry; physics; information technology; electrical, computer, civil, mechanical and integrated (general) engineering; and automotive, computer, electronics, and manufacturing engineering technology. Students in the multidisciplinary cohort are awarded a \$5,000 scholarship, which is renewable for up to three years. Eligibility is based on demonstrated financial need, but selection priority is given to students who help create a diverse scholar cohort.

The multidisciplinary nature of the program extends to the program administrators as well. Faculty mentors have represented various disciplines, such as biology, computer science, computer information science, engineering, engineering technology, math, and English. In addition to the faculty, a graduate assistant from the Department of Experiential Education helps coordinate the seminar and other activities. The inclusion of a diverse mix of faculty and staff serves as one structure that supports MAX program goals. The specific intervention of including a graduate assistant in education was implemented as a result of the continuous improvement process, which is one of the structures used to support overall program goals (Table I).

Some major structural changes throughout the history of MAX have included adding distance students in an off-campus program 280-miles away, adding an annual retreat, increasing the number of majors eligible for the program, and funding a half-time graduate assistant. These changes were implemented to directly support community development, student engagement, and professional development.

TABLE I. PROGRAM GOALS AND STRUCTURAL SUPPORTS

Program Goals	Community development
	Increase student engagement
Structural Supports	Personal/professional development
	Weekly seminar
	Multidisciplinary group projects
	Annual retreat
	Mentoring

Yearly themes serve as the main catalyst for achieving program goals through the outlining structure (Table II, which includes changes discussed later in the paper). In 2014, the annual retreat, the weekly seminar, and group projects revolved around the theme of water. The annual retreat consisted of a 2.5 day bus tour in southern Minnesota to experientially explore water issues in the region. The group studied stream ecology on the Minnesota River, sustainability via riverboat on Lake Pepin, and land use research at a Discovery Farm. As part of the weekly seminar, students worked in multidisciplinary teams to explore water issues, which was proposed in a Pecha Kucha presentation and culminated in a research poster. Group projects covered topics such as desalination techniques, hydraulic fracking, and bottled water.

TABLE II. YEARLY PROJECT THEMES & IMPLEMENTED CHANGES IN THE MAX SCHOLARSHIP PROGRAM FOR THE ANALYZED YEARS

THEME	Major Changes Implemented
2010-11: Natural Disasters & Impact on Society	Fiction: <i>I Robot</i> by Isaac Asimov Conference attendance (Nobel Conference, local alternative energy conference)
2011-12: Sustainability & This I Believe statements	2 of 4 faculty on sabbatical or leave; 1 interim mentor participated Distance students included All eligible STEM majors included in the program Began annual retreat Graduate Assistant support began (10 hours per week) Non-fiction: <i>This I Believe: The Personal Philosophies of Remarkable Men and Women</i> edited by Dan Gediman & Jay Allison
2012-13: Election Process & Major focused Ethics Case Studies	Elevator speeches Initiated ethical framework Non-fiction: <i>The Immortal Life of Henrietta Lacks</i> by Rebecca Skloot
2013-14: Garbage & Personal Finance	Required meetings with assigned faculty mentors Ethics embedded in project work Phone interviews Non-fiction: <i>Young, Fabulous & Broke</i> by Suze Orman
2014-15: Water & Leadership	Theme of water strongly integrated into retreat to support information gathering during group time Included faculty mentor from Technical Communication Non-fiction: <i>Leadership for Engineers: The Magic of Mindset</i> by Ronald Bennet & Elaine Millam

B. Structures Supporting Goals

1) *Weekly Seminar*: The curriculum increases familiarity with university resources, provides useful information about a variety of personal and career issues, and fosters relationships with students and faculty across disciplines. In order to promote overall program goals, the seminar has

expanded from a traditional classroom seminar to include more topic-based, free discussion time for students to learn from each other. Topics such as time management, study skills, and work-life balance have been incorporated to increase personal and professional development. Guest presentations from additional faculty and staff, industry partners, or alumni scholars supplement the topic based curriculum. Community development is fostered through team building activities that focus on teamwork and leadership skills. The overall adaptive structure of the weekly seminar is motivated by best educational practices, especially for a diverse STEM community [6-11].

Emphasizing active learning in the MAX program has been a priority for program administrators and supervisors. The weekly seminar focuses mainly on activities, panel discussions, and group project work. In a meta-analysis of STEM education literature, Scott Freeman, et. al. found that active learning improves student performance. A consensus definition of active learning was created for their analysis: *“Active learning engages students in the process of learning through activities and/or discussions in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work.”* [12] The MAX seminar provides this type of learning experience for the interdisciplinary cohort.

Another active learning approach is based on David A. Kolb’s experiential learning theory (ELT). A four-part “learning cycle” is used for understanding the learning process: 1) Concrete Experience, 2) Reflective Observation, 3) Abstract Conceptualizations, and 4) Active Experimentation [13]. The MAX weekly seminar is the underlying structure that provides the basis for applying ELT in multidisciplinary group work throughout the semester and on retreats. Group projects, which address issues related to S-STEM fields, serve as one type of experience students engage in with the program. Students reflect on the quality of work, leadership skills, and the overall group process. Feedback is conceptualized and the group adjusts and actively experiments in order to reach stated goals.

2) *Multidisciplinary Group Projects*: Scholars use their developing technical experience to analyze different societal issues in teams. Students grow both personally and professionally by developing collaboration, leadership skills, and technical communication skills. Project themes, content, and presentation expectations change every year in order to present students with novel challenges and increase student engagement. In 2011, students began working in geographically dispersed teams after a distance cohort was added. This experience continues to help students develop collaboration skills that are necessary for the geographic dispersion seen in the current workforce [3].

3) *Annual Retreat*: The annual retreat was implemented during the same academic year that the distance cohort was added in order to allow for community, personal, and professional development. Retreats help build community amongst scholars through face to face project work, industry tours, and social activities [3]. In 2012, the group also participated in structured team building activities in order to

develop communication skills and build trust amongst the group. In 2014, the retreat introduced the year’s theme by examining sites around Minnesota to learn about regional water issues.

4) *Mentoring*: As an essential facet of the MAX program, students are assigned a primary faculty mentor who is closely related to that student’s field of study, and returning scholars serve as role models and peer mentors for the new scholars. Faculty mentors meet with their mentees at the beginning of each semester and throughout the academic year, which provides an avenue to help students create and achieve both personal and professional goals. These meetings also allow faculty to remain aware of student engagement. When more majors were added in 2011, there became fewer opportunities for peer-mentoring amongst students within academic majors. In response, the weekly seminars regularly break up for discussion into groups clustered by major or academic year, as well as by affinity relationships based on common experiences such as hobbies, learning styles, and research vs. industry experiences.

Mentoring in the MAX program provides students with another form of social support which serves as an avenue for communal reflection on goals and career options. Research on the outcomes of mentoring have looked at entire student populations, as well as focusing on minority or underrepresented groups. There is a great deal of literature on mentoring available (e.g., [14,15] for reviews), but it has specifically been linked to an increase in student retention rates, self-efficacy and program satisfaction. Additionally, students’ adjustment to college has also been found to be positively linked to frequency of mentor meetings for underrepresented students [16,17].

C. Continuous Improvement Process

The continuous improvement process is informed by feedback collected throughout each year, which results in applying specific and timely interventions to the supporting structures of MAX. This process works to improve the overall quality of the program while maintaining organizational goals. Feedback is gathered through faculty observation and reflection, end-of-semester surveys, large group seminars, individual meetings between students and their mentors, and students’ reflection journals.

Each semester, the faculty mentors and graduate assistant observe weekly seminars and reflect on what is working well and where improvement is needed. Weekly faculty meetings allow for planning, assessment, and the initiation of interventions when necessary.

An annual assessment meeting serves as a forum for faculty to discuss major changes for the next program year. Some yearly additions have included a “common read” to connect students through a shared reading experience; the annual retreat to support community development; yearly themes to increase student engagement; and phone interviews to increase professional development. Refer back to Table II for an outline of major changes made to the MAX Scholars program over the past four years.

Since the beginning of the program in 2007, end-of-semester surveys have measured student outcomes in relation to program goals and outcomes influenced by supporting structures. The survey includes 19 Likert scale items and between three and four open-ended questions. In the fall of 2014, an additional end-of-semester assignment allowed students to reflect more thoroughly about questions that related to program goals. This assignment helped students internalize their learning over the semester, and provided a more in depth look into individual student experiences [5].

III. METHODS

A. Research Questions

What aspects of the program are, according to the students, most beneficial? This is a key question for the continuous improvement process. Providing value to the students can increase engagement and participation. Since these are typically highly engaged students who are willing to work hard in their education, creating a safe space of learning that is motivated by having a learning experience rather than a grade is valuable. The flip side of examining responses to this question looks at aspects that are missing from responses. It is possible that students are not finding some of the MAX activities valuable, even though faculty or alumni/ae recognize the value in these activities. An approach for improving the program would seek to find how those activities could be better presented to support student engagement in activities that might not seem to have immediate benefit to the students.

In general, are students receiving the program positively? This question is addressed in the context of the four key areas of relationships, working with goals, mentoring and professional skills. While students may experience other aspects of the program, these four areas address the programmatic goals of community development, increasing student engagement and personal/professional development.

B. Procedures

Data was collected from 151 end-of-semester student surveys of MAX Scholar seminar participants from spring semester 2011 (the last semester of first S-STEM grant) to fall semester 2014 following procedures approved by the Minnesota State University, Mankato Institutional Review Board. Descriptive statistics of all semesters is reported to provide an overall view of student experiences. Fall and spring data from three academic years (2011-2012, 2012-2013, and 2013-2014) were used to qualitatively map student experiences. All surveys consisted of 19 Likert scale questions and three qualitative questions. Several students did not complete the additional qualitative responses, which resulted in the collection of 92 qualitative responses (out of 103 in the examined set) for mapping to programmatic areas and annual themes. Qualitative questions asked students about aspects that were most beneficial, areas for improvement, and other thoughts they wished to share with the faculty mentors. Student data from Likert questions was included even if they did not complete all 19 questions ($N=151$). See Table III for Likert questions and descriptive statistics. Further quantitative

analysis, including changes across years and perceptions and experiences by class year is left for future work.

C. Qualitative Mapping

The open ended responses to the surveys were coded by the authors for positive, neutral and negative responses related to key programmatic areas: professional skills, goals, mentoring, relationships, project experiences, team/group work, and comments related to the semester or annual theme. Five coders worked independently to evaluate semesters or academic years. A set of eight response samples was used to assess reliability across coders. Inter-rater reliability was suspect, and researchers noted that responses that indicated a request for more of a particular type of programming were coded as negative.

To address these concerns, one researcher coded all years to ensure reliability. Data was analyzed thematically and a priori codes were used that corresponded to the goals and activities of the MAX scholars program: *relationships, mentoring, personal goals, groups/collaboration, research project, and professional skills*. During analysis, two other codes emerged: *guest speakers* and *interaction with students located at the Iron Range Engineering* program, a five hour drive away. Within each theme, comments were labeled as *positive, suggest change/increase, and suggests other change*.

IV. RESULTS

A. What aspects of the program are, according to the students, most beneficial?

Analysis of the qualitative responses to all questions show that 42% of the respondents indicated that they enjoyed the professional skills activities, which consist of lectures, guest speakers, and assignments designed to help students learn to write resumes and job application letters, present technical information to various audiences, and participate in job interviews in person and on the phone. Responses to which aspects of the program were beneficial include:

"I feel the MAX program is an excellent program. It has helped me reach outside my comfort zone and grow as a person. I now feel more educated and confident in my interview skills and finances as well as more aware of ethical issues."

"I feel the resume writing workshops really improved my marketability to the workforce."

"The resume and interview skill building lessons were very beneficial to me, and have helped me already in pursuing a career."

Analysis also revealed that 34% of the respondents had positive remarks about the relationships that they were able to develop with their peers in the program. Yet 11% indicated that they wanted more interaction with their peers at IRE and that the teleconferencing measures in place were not quite satisfactory. Responses to which aspects of the program were beneficial include:

"Working with students in different majors with different backgrounds and/or degree completion levels."

TABLE III. DESCRIPTIVE STATISTICS OF LIKERT QUESTIONS

Questions	Fall semester		Spring semester	
	Sample Size	Mean (Standard Error)	Sample Size	Mean (Standard Error)
I have improved my connections to faculty members in the MAX program.	79	4.04 (0.09)	72	4.28 (0.08)
I have improved my connections to faculty members in my academic program.	79	4.04 (0.10)	72	4.22 (0.10)
I have improved my connections to other students inside the MAX program.	79	4.37 (0.08)	72	4.33 (0.084)
I have improved my connections to other students inside my major.	78	4.10 (0.09)	72	4.28 (0.09)
I have improved my connections to other students outside my major.	79	4.00 (0.09)	71	4.08 (0.09)
Summary: Relationships	79	4.11 (0.05)	72	4.24 (0.06)
I have outlined goals for my academic year that will move me towards my ultimate career goals.	79	4.30 (0.07)	71	4.38 (0.08)
I have outlined goals for my academic year that will move me towards my ultimate personal goals.	79	4.27 (0.07)	71	4.34 (0.08)
I have met the goals I outlined for this semester.	79	3.67 (0.095)	72	3.94 (0.10)
I feel I will meet the goals I outlined for the academic year.	79	4.05 (0.08)	72	4.15 (0.10)
Summary: Goals	79	4.07 (0.06)	72	4.21 (0.07)
I have experienced being mentored by a faculty member in the MAX program.	79	3.99 (0.10)	72	4.01 (0.10)
I have experienced being mentored by a faculty member in my academic program.	79	3.91 (0.10)	72	3.86 (0.12)
I have experienced being mentored by a student in the MAX program.	79	3.24 (0.12)	72	3.35 (0.12)
I have experienced being mentored by a student in my academic program.	79	3.30 (0.12)	71	3.51 (0.14)
I have experienced being a mentor to other students in the MAX program.	79	3.43 (0.11)	72	3.57 (0.12)
I have experienced being a mentor to other students in my academic program.	79	3.75 (0.11)	72	4.06 (0.10)
Summary: Mentorship	79	3.60 (0.09)	72	3.73 (0.08)
In the MAX program I have developed my resume writing skills.	79	4.27 (0.10)	72	4.28 (0.10)
In the MAX program I have developed my skills in interviewing.	78	3.74 (0.12)	72	4.13 (0.11)
In the MAX program I have developed my skills in organizing information.	77	3.94 (0.10)	70	4.03 (0.10)
In the MAX program I have developed my skills in presenting information.	76	4.00 (0.10)	71	4.21 (0.09)
Summary: Professional skills	79	3.99 (0.09)	72	4.16 (0.09)

“The entire idea of meeting other students that have the same academic background and goals was a huge benefactor to me. It was very nice to see that others cared about the well being of MnSU as well as its community.”

“I also found it very beneficial to interact with students within my major who are juniors and seniors.”

Responses indicating a desire for more/better interaction with the Iron Range Engineering Program include:

“A trip back up to Iron Range. It would be fun. Last year it was a large bonding experience.”

“I think the overall idea of the students in both places interacting is a good one, but it is very hard to implement. Talking over Skype and the ITV camera can make conversations difficult when it is hard to hear.”

15% enjoyed guest speakers, and 7% requested more guest speakers in the future. Responses concerning guest speakers include:

“I greatly enjoyed the times when a member from one of the various departments of the university came to present a concept (such as philosophy and physics). These gave me a unique insight I might not have otherwise developed.”

"I really enjoy hearing from previous scholars or other people who are working in related fields or chose to continue studying. It not only gives me information but drive as well."

"Involve more industry people and speakers to talk about the project we are working on. Or to talk about how to go about pursuing a career."

"I would suggest we host people who work in the science field so that we can ask them career questions."

Although 12% found the mentoring beneficial as described in their qualitative responses, four students requested more mentoring and direct involvement by the faculty. Responses addressing mentoring include:

"The ability to connect with important faculty members in a stress-free setting."

"I appreciate the mentors' efforts to make this class engaging, interesting and beneficial to the students in terms of professional and personal development."

"A way to improve the course overall would be providing more information about the mentors. I would like to see a faculty panel where we could ask any question to the mentors. It would be interesting to see how the mentors got to be where they are today."

One of the issues in planning seminars that some students may participate in for two or three years is deciding which activities are worth repeating each year, such as resume development, team projects, and common reads, and which might not be, such as having the faculty talk about themselves too often. One change addressing this request was that faculty do brief presentations on their technical and personal backgrounds at the beginning of the academic year.

All key aspects of the program were mentioned by students, although the development of goals and work reflecting on the process of meeting them, done in small groups in seminar, were the least commented on in the qualitative portion of the survey.

B. In general, are students receiving the program positively?

The descriptive statistics shown in Table III indicate a general positive response to questions about the program. No questions are reverse coded, so there is the potential for a positive bias in the responses. However, when students do not like some aspect of the program, we do see a willingness to indicate that with responses of 1s and 2s. The highest response across all of semesters was related to the experience of relationships. This indicates that students are part of a developed community.

The area with the second highest response is goals. Since there are specific goal assignments, it is not surprising that they have developed goals. However, the higher value shows that even at the end of the semester and academic year, they are still connecting those goals to their career aspirations.

The biggest difference between fall and spring semesters is in the category of professional skills. This is in part due to programming since interview skills and practice are typically addressed in the spring semester.

V. CONCLUSION & IMPLICATIONS

This study provided insights to current student experiences in the MAX program, specifically finding which aspects of the program they find most beneficial. Students clearly saw the skills they developed as important and worthy of comment, but the highest Likert response was for experiences of relationships. This allows us to make conclusions about benefits to current students of the program, but does not allow us to know what is actually beneficial. Ascertaining overall program benefits will require inquiring about former scholars' experiences to find which experiences and skills were transferred to work life.

Professional skills were reported by students as the main benefit of the MAX program. Providing professional skill development while creating a supportive community through peer relationships and faculty mentoring has been a priority of the program. Responses showed that many students found relationships to be one of the main benefits of the program. Comments suggested frustration at the limitations that distance and technology placed on their ability to connect with peers. This can be addressed by providing technology training, having multiple backups available, and creating more opportunities for on and off-campus students to meet face-to-face.

Several students reported positive aspects of faculty mentoring in the program. Even though only a few requested more mentoring and interaction with the faculty, any requests for more interaction with faculty are taken seriously and have been addressed in following iterations of the course. Primary mentors and scheduled meetings at the beginning of the semester were responses to this feedback.

Guest speakers have been used throughout the history of the program in order to further develop a specific year's theme. Students responded positively to guest speakers and some requested more interactions.

Many programs are available to support community development, and career resource centers and some major courses offer job search support. Few programs combine these factors, especially in a multidisciplinary setting. Our evaluation shows that the MAX scholar program meets the goals of community development and personal/professional skills development, with engaged students actively participating in a weekly, co-curricular seminar.

Given these results, addressing development of professional skills in engineering programs could benefit from increased relationship building amongst students and their peers as well as with faculty mentors, whether within or across disciplines. Structures that support relationships as well as content delivery appear to be important to students. Providing a framework for reflection, specifically concerning goals, has a positive impact on students. Students benefit from active learning strategies used for professional skills, specifically resume building and mock interviews. Future work will investigate the long-term impact of relationships in a multidisciplinary setting with an alumni survey.

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A Comparative Analysis of Two Globally Distributed Group Projects:

A Perspective from CSCW/CSCL Research

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Abstract—Globally distributed group projects are becoming an attractive and increasingly common feature in computer science education. They provide opportunities for students to engage in activities that enhance both their technical skills and wider professional competencies with concomitant benefits for graduate employability. There have been some previous attempts to investigate these projects in terms of theories of technology use and collaborative learning, and this paper continues this process by examining globally distributed group projects from the perspective of salient issues in the fields of computer-supported cooperative work (CSCW) and computer-supported collaborative learning (CSCL). After detailing CSCW models that discuss the dimensions that characterise interaction and technology use in groups, we examine aspects of group learning from the perspective of theories of CSCL. Issues of cooperation versus collaboration, motivation for learning and models of group cognition are discussed in the context of two specific group projects. Analysis of these examples allows us to characterise behaviour within groups and provide insights that can facilitate the formation and effective development of project teams. This has important educational implications for the success of these distributed group projects.

Keywords—computer supported cooperative work; computer supported collaborative learning; globally distributed group projects; global software development education

I. INTRODUCTION

Collaborative group projects now have a well-established role in undergraduate Computer Science and Information Systems courses where they are used as the main educational setting for students to learn important professional competencies [1, 2, 3]. Over the last decade, prompted partly

by rapid globalisation in the computing profession, there have been attempts to integrate this kind of collaborative learning experience with opportunities for students to participate in authentic team working activities in geographically distributed settings. The technical and professional competencies developed in this type of learning environment have taken on greater importance as CS and IT education has responded to changing business practices within the industry. For example, the use of distributed software development models has now become the norm, while the implementation of large-scale information system projects often requires collaboration across considerable geographical distance and across conventional disciplinary boundaries [4]. Consideration of such factors has led to a recognition that student employability is significantly enhanced by participation in these type of distributed group projects, and as a consequence, there has been growing interest both in their operational aspects and in the particular learning activities around which they are built.

From an educational perspective, these projects present a fascinating environment in which to observe the interaction of students as they respond to a variety of novel and challenging situations. These may range from coping with intercultural differences in project management practices [5] to making decisions about the appropriation and subsequent use of collaborative technologies [6]. While specific projects throw up a variety of different problems, there are, nevertheless, common features which arise from the nature of the activity itself. The geographically-distributed nature of the project necessarily requires the use of some form of collaborative technology; the desire to provide students with an authentic experience of professional practice means that effective work processes are needed; the fact that these group projects are part

of a university programme promotes an emphasis on collaborative learning. While some work has been done investigating specific challenges to collaboration in these projects, there have been relatively few attempts to situate such learning environments within the broader educational framework provided by related research areas which also focus on collaborative work and group learning mediated by technology. Two such disciplines are Computer-Supported Cooperative Work (CSCW) [7] and Computer-Supported Collaborative Learning (CSCL) [8]. Both areas overlap with the practice of globally distributed group projects, although in different ways and with different emphases, and both can provide important insights into their design and successful implementation. In this paper, we investigate some of the issues that have arisen over a number of years in the operation of two different globally distributed group projects. The first is an established setting based on a collaborative information systems project, while the second is more recent and centres on a global software development task. We give a brief overview of the different projects as well as an account of relevant CSCW and CSCL research. We compare elements of each course unit from these perspectives and make suggestions for future iterations of the projects.

II. BACKGROUND

In this section, we provide a brief description of some of the main issues in the fields of Computer-Supported Cooperative Work and Computer-Supported Collaborative Learning that are relevant to our subsequent examination of international group projects. It is not our intention here in this paper to give a comprehensive account of either research field but rather to draw attention to those areas which we consider to be of use in the subsequent analysis.

A. Why CSCW/CSCL?

A major goal of higher education is to help students bridge the gap between theory and practice and perhaps, more importantly, between the types of convergent, highly structured learning exercises of the classroom and the reality of open-ended and less structured activities that they find in the workplace as graduate professionals. To do this, universities need to offer students opportunities to develop the competencies that professionals exhibit, which for those in the computing disciplines, include the ability to participate effectively in a globalised working environment, often using a range of information technology to assist productivity and facilitate collaboration.

For the university sector, this will involve the active search for, and purposeful cultivation of, pedagogical activities that foster the knowledge, skills and attitudes necessary for collaborative group working with colleagues at a local level, as well as in teams whose members may be separated by large geographical distances. To do this effectively inevitably involves the use of information technology. Early studies of technology assistance in education was based on individual learning. This has changed over the last 10-15 years as the importance of the social dimension to learning has been realised. In recent years, ICT in education has focussed on the way in which technology can facilitate such interaction.

Globally distributed group projects are a relatively recent phenomenon relying as they do on the use of information and communications technologies which have only become widespread in educational settings within the last twenty years. Whether in the context of an IT design and implementation group or a software engineering team, the geographical and temporal separation between individual team members brings a reliance on technology that impinges on the achievement of project goals in a much more critical way than with a collocated development team. The precise nature of the course aims and learning objectives of such projects will clearly depend on the specific context of the programme of studies in which each is situated. However, it is possible, even if only from a historical perspective, to draw some conclusions about what the underlying educational benefits of such activities are deemed to be. Firstly, they are set up to provide an environment in which students can attempt to gain an experience of work which has a higher degree of authenticity compared to more conventional classroom exercises. The authentic nature of these projects is often generated through the use of some kind of work-based learning pedagogy [9]. There is an emphasis on experiential learning [10] through mechanisms such as open-ended, problem-based and negotiated learning [11] and on the observation of, and reflection on, that experience [12] using reciprocal peer learning.

A number of observations can be made about this process. Firstly, the group projects' use of a work-based learning approach has a focus on both learning and on work (where by "work" we mean the technical, professional and social competences that are needed in graduate employment). Secondly, there is an irreducible cooperative or collaborative aspect to the learning. While there may be some variation on the cooperation/collaboration axis held by individual instances of a globally distributed group project, both the academic learning objectives and the development of work-based competencies are contextualised in terms of a collective approach rather than individual one. Together with strong reliance on a ICT infrastructure, this gives a characterisation of these projects in which information technology plays a critical role in support of team-based working and group learning. These are precisely the areas which CSCW and CSCL study and some researchers [13] have suggested that this overlap area of collaborative work-based learning will provide a key focus for such research in the future.

III. COMPUTER-SUPPORTED COOPERATIVE WORK

The growth in importance of globally distributed teams in major industries such as software engineering means that a large body of academic work has been developed investigating various issues and practices that lead to operational success. One component of this is a good understanding of the technological support structures that underpin communication across distance, and the way in which these structures facilitate collaborative work between individuals within teams. The field of Computer-Supported Cooperative Work (CSCW) [14, 15], is an attempt to systematise this research area and encompasses both the systems that are used to collaborate ("groupware") and the social component that such collaboration entails. Over the

last thirty years, it has developed into a mature research field which has given rise to important insights into the successful practice of globally distributed teams.

A. Factors Affecting Interaction: Matrix Models

One aspect of the research that has become widely known is its attempts to classify the independent components of interaction that are relevant to cooperative work. The most well developed of these is the so-called Space-Time diagram, usually just called the “CSCW Matrix”, devised by Johansen [16, 17] which became the de facto standard taxonomy with which to analyse tools and technology [18, 19, 20].

The work attempts to characterise cooperative systems according to time and spatial relationships. A cooperative or collaborative interaction is construed as having a time component which states when the interaction takes place, either synchronous or asynchronous, while its spatial component takes a locational classification, namely colocated or distributed. This therefore admits a fourfold decomposition with time and place axes which gives a matrix structure to the classification of technologies used in the interaction (see tab 1).

	Synchronous (same time)	Asynchronous (different time)
Co-located (same place)	Face-to-face meetings Live/IRL Classroom teaching	Shiftwork Shared representation, bulletin boards Shared workspaces, project walls
Distributed/ dispersed/remote (different place)	Parallel teaching, Dispersed collaborative teams Breakout rooms	Individual self-study Email Discussion forums, Wikis, blogs Content Management Systems

Table 1. The basic CSCW Matrix (Johansen, [16]; this version adapted from: Jørno et al, [21])

It is worth noting that, while ostensibly classifying interaction, the matrix is more commonly used to classify the temporal and spatial affordances of the technologies that enable this interaction.

While providing useful information in some cases, the overriding focus on the time and space characteristics of technologies may not give us useful information about the way in which those technologies actually contribute to the interaction, especially to elements of learning which may well be the primary concern. For example, as pointed out by Jørno, a telephone and a video chat both overcome geographical constraints and provide synchronous communication, but

grouping these technologies together does not really provide an insight into their different learning affordances.

Other classifications have been proposed (see Cruz et al, [22] for an extensive review). An interesting development is categorisation based on a technology’s mode of use rather than its properties. For example, Jørno et al [21] describe a “codification/articulation” matrix which uses a horizontal axis (codification) based the control mechanism that is used to achieve the maximum level of coordination among cooperating parties. This differentiates between central and decentralised control where centralised control is usually established through some form of leadership perspective while decentralised control is a more local and autonomous feature. An independent vertical axis is formed from a focus on the mechanism used to gain and exhibit proficiency. The axis differentiates between standardised articulation in which there are verifiable criteria for gauging success and attentive articulation in which evaluation is performed on a case-by-case basis, e.g. through some kind of mentorship or apprenticeship method.

B. Multidimensional Models of Interaction

The array structure of both the Space-Time CSCW matrix and the Codification-Articulation matrix arises from the abstraction of two orthogonal components from an analysis of the main features of a cooperative interaction. There are however, multidimensional models (where the number of dimensions, N, is greater than 2) that try to capture a broader conceptualisation and so extend the number of components considerably. One recent example of this is the Model of Coordinated Action proposed by Lee and Paine [23] which uses a seven dimensional framework of factors affecting interaction (see Table 2). The first two dimensions, “Synchronicity” and “Physical Distribution”, are essentially the time and location components of Johansen’s space-time matrix and are characterised by degrees of synchronicity and proximity respectively. The third is “Scale”, which is the number of participants involved, while the fourth is termed the “Number of Communities of Practice”. Here, Lee and Paine use a slightly unorthodox terminology and have extended Wenger’s original concept [24]. They put the idea of communities of practice to use as a measure of diversity, referring to the number of culturally distinct subgroups within the cooperative interaction. The concept of culture is taken to operate in both the macrocultural and microcultural sense, e.g. including subgroups based on ethnicity, as well as others based, for example, on the “work culture” found in different academic disciplines, or on shared personal histories or practices. Culturally homogeneous teams would be one end of this spectrum while the other would be extremely heterogeneous teams which would occur where the coordinated action of the group was greatly influenced by the expectations, norms, and practices of the individuals. The fifth dimension is “Nascence”: this attempts to encapsulate the degree to which the work of the group is static or changing and emerging over time, and denotes a spectrum of activities between routine tasks and those that are new to the group members or developing over time. The sixth dimension, “Planned Permanence”, tracks the intended permanence of the group itself, i.e. whether there

is an expectation that the collaborative action will be short-term or long-term. The last component is “*Turnover*” and refers to the relative stability of the participant makeup. It measures the rapidity with which participants enter and leave the group. This is different from both the Planned Permanence component, which is a characteristic of the group itself, and Nascence component which is a property of the production process for the collaborative artefact produced by the group.








Dimension	Continuum
Synchronicity	 asynchronous synchronous
Physical Distribution	 same location different location
Scale (number of participants)	 2 N
Number of Communities of Practice	 0 N
Nascence	 routine developing
Planned Permanence	 short-term long-term
Turnover	 low high

Table 2. Model of Coordinated Action (Lee & Paine, [23]).

The basic CSCW matrix has proved useful for describing the relationship between the affordances of technology and the process of cooperation but from a classification perspective, it is hampered by a reliance on just two components based on physical constraints. For our purposes, a more complex, multidimensional model, such as the coordinated action model proposed by Lee and Paine, which acknowledges the influence on interaction of factors other than synchronicity and proximity, would potentially provide a richer taxonomic framework to describe features of globally distributed group projects. It should be noted that we are not claiming that there is a unique attribution for each component for the group activity as a whole. Instead, each technology used to facilitate interaction will be represented on the synchronicity and location dimensions (in the same way that it is represented in one cell of the Space-Time matrix). The remaining dimensions would then provide a representation of the collaborative components.

The models and theories of cooperative and collaborative professional practice that underlie the field of CSCW produce valuable insights into the use of technology and its effect on group interactions. However, given the educational context of globally distributed group projects, it is natural to look to enhance these descriptions of cooperative activity with others which make specific reference the effects on learning. While CSCW does address some of these issues, especially in the context of organisational efficiency and workplace learning, it is a fact that the main focus is on the the design and use of technologies that affect groups, teams and networks. If, instead, we require a greater emphasis on the educational components of group work, we can turn to the related field of computer-supported collaborative learning.

IV. COMPUTER SUPPORTED COLLABORATIVE LEARNING

The subject matter for CSCL is how collaborative learning supported by technology can enhance the interaction of peers working in groups, and how collaborative technologies facilitate sharing and distributing of knowledge and expertise among community members. [25]. As with CSCW, we focus on a small number of issues with direct bearing on the globally distributed group projects rather than giving a general review of the background work.

A. Cooperation versus Collaboration

The first issue that should be addressed is the distinction made between cooperative and collaborative activities. According to Dillenbourg [26], “*in cooperation, partners split the work, solve sub-tasks individually and then assemble the partial results into the final output*”. By contrast, a collaboration is “*a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem*”, [27]. In collaborative situations, learning is a social process and individuals engage in group activities such as negotiation and sharing. These member interactions are themselves mediated by information and communications technology. This shift from cooperation, which can be performed as an individual activity prior to incorporation into a communal endeavour, to collaboration, which is fundamentally directed towards shared action is significant, and represents a important departure in a CSCL theory of learning. It also allows us to use it as a major classificatory tool for describing student activity in group projects.

B. The Issue of Motivation for Learning

A second issue suggested by approaches from CSCL is the origin of motivation for the collaborative work itself, i.e. what makes the learners feel they need to contribute to the work of the group. In their review of cooperative work and achievement, Slavin et al [28] identified four major theoretical perspectives on the achievement effects of collaborative work. The first two of these share a common emphasis on the importance of motivation as the key element in determining the success of a learning activity although they differ in ascribing to a source which is intrinsic or extrinsic to the group itself. The last two are more easily described in terms of cognitive development.

The underlying presupposition of the first viewpoint, sometimes called the *Motivational* perspective, is that it is the individual's desire to accomplish a task that is the single most important factor in accounting for group success. Group members are required to cooperate in order to further their own personal interests and consequently, when developing groups, there is an emphasis on building reward structures which promote alignment between the self-interest of the individual members and the stated aims and objectives of the group itself. Creating such cooperative incentive structures means that the only way group members can attain their own personal goals is if all the members of the group are successful. One interesting feature of this perspective is that individuals do not have to explicitly collaborate with other group members in order for the group to function effectively. It is the group members' behaviours in response to group oriented tasks that elicits praise or approbation based on the interpersonal reward structure that has been set up. The interdependence of group and personal goals is considered sufficient to induce students to act in ways that are conducive to group success. This type of individual motivation may lend itself more to cooperative ventures rather than full-blown collaboration (which may be a difficult goal to achieve in a globally distributed setting).

In contrast to the motivational perspective, which emphasises optimisation of cooperative performance as an extrinsic result of aligning group aims with that of individuals, the *Social Cohesion* perspective suggests that the effectiveness of individual participation in a group is mainly dependent on its level of social cohesiveness. Individuals contribute to group objectives insofar as they are drawn into its social structure and start to become intellectually and emotionally invested in the group. Instead of motivation arising from extrinsic factors such as external incentives and individual accountability, it is generated intrinsically as individuals come to see their own self-identity and goals, and that of their colleagues, as being bound up with that of the group. Again, this perspective has important implications for group formation and suggests that activities such as team-building that promote this sense of mutual interdependence are an important part of the group development.

While these two perspectives stress motivation (in either its intrinsic or extrinsic form) as the main explanatory factor for success in group learning, there are two others that can broadly be termed cognitive perspectives as they focus on the cognitive processes that occur when collaborative work takes place. The first of these was termed the *Developmental* perspective by Slavin and draws on the theories of developmental psychologists such as Piaget and Vygotsky to explain why interaction among team members would enhance learning. Both the Piagetian theory of learning through assimilation, accommodation and, finally, equilibration, and Vygotsky's theory of the zone of proximal development, involve an understanding of learning enhancement through interaction with peers. In the case of Piaget, interaction with other members of the group can provide occasions for disequilibrium, the basic prerequisite state for learning to occur, through cognitive conflict with previously learnt schemata. Vygotsky's theory also suggests that learning initially occurs through a social interaction which then leads to

a process of individual internalization and understanding. In both cases, group-based learning activities allow peers to provide feedback to individuals which encourages them to go beyond misconceptions (whether through a Piagetian or Vygotskian mechanism) and proceed to a more stable understanding of phenomena. In this context, group work provides an environment for members to gain an experience of peer communication which can enhance social learning skills such as participation, argumentation, verification and criticism [29].

The fourth perspective is that of *Cognitive Elaboration* [30]. In a similar way to the developmental perspective, this approach holds that, for learning to take place, new information has to be connected with related material held as prior knowledge. However, the most important driver for learning is considered to be the fact that collaborative interaction requires learners to explain their ideas and clarify potential misconceptions to other group members. This process of elaboration allows students to improve their understanding of relevant issues within the group and also serves to provide opportunities in which they can observe, and give and receive critical feedback from peers on learning strategies that are in use.

The point of discussing these four approaches to understanding motivating factors which lead individuals to contribute to the group is because they have implications for how project groups are created, how the learning activities are devised, how communications channels are set up and how the interaction among members are maintained.

C. Models of Collaborative Knowledge Building

A third element from CSCL research that we feel has an important bearing on the educational success of distributed group projects is its emphasis on group learning as a qualitatively different phenomenon compared to learning in individuals.

A key feature of collaborative learning is the process of knowledge building. Within the group, there will be elements of knowledge creation in multiple contexts. This is nicely illustrated in a diagram by Stahl [31] (Fig. 1.) which attempts to visualise the interdependent relationships between individual cognition and the process of "meaning-making" in small groups and again in the wider social context.

Much of the cyclic nature of knowledge creation is familiar to observers of how individuals learn in group projects. At the level of the individual, prior knowledge and beliefs, which are often tacit and held in a pre-articulated form, undergo some form of disequilibrium process when subject to the kind of experiences thrown up by group involvement. Some of this is dealt with at the individual level while some of it feeds into a new knowledge creation cycle involving rational discourse, argumentation, critical interaction with other members of the group as they go about their task. The key features here for the collaborative process are the articulation of the shared problem, discussion of different solution strategies, clarification of alternative viewpoints and the formation of a negotiated perspective with the other members of the team as a part of the production of whatever artefact the group task required.

Moving to a wider societal arena, the solution of the task then invites participation in a larger social context through the development of shared cultural perspectives such as professional competencies and institutional practices.

This view of different layers of value and meaning creation contributing to the goals of the group is a powerful one. While it may seem at first sight to be somewhat divorced from the practicalities of group activities, it nevertheless provides an underlying framework for understanding the many aspects of learning that emerge in these activities.

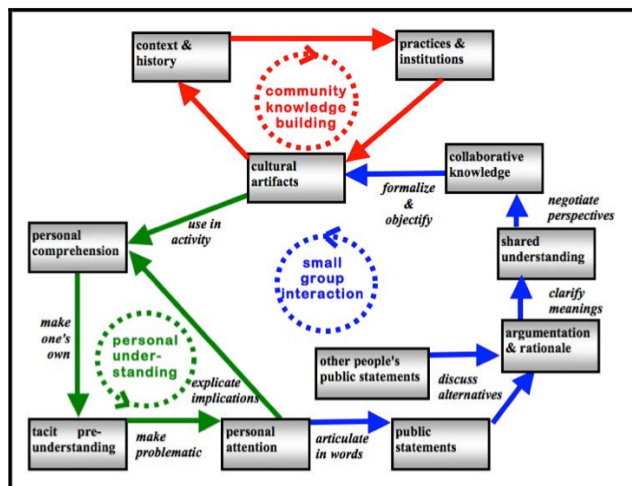


Fig 1. A Model of Collaborative Knowledge Building (Stahl, [31]; adapted from Stahl, [32], Ch. 9)

V. TWO EXAMPLES OF DISTRIBUTED GROUP PROJECTS

The objective of this paper is to use those aspects of the theories presented in the previous section to establish a framework for describing globally distributed student projects and appropriately characterising the salient features of the collaborative learning environments. We will do this in two cases. The first of these is the well-established "IT in Society" course unit which has been developed by Daniels and his collaborators at Uppsala University, Sweden, in conjunction with Rose-Hulman University, USA. The second is a newer collaborative course unit undertaken by computing science students at Robert Gordon University (RGU), Aberdeen, UK and their counterparts in the Indian Institute for Information Technology at Bangalore (IIITB), India. While the focus and content of the group project is different (the Uppsala /Rose-Hulman is an IT project whereas that involving RGU/IIITB students is a software engineering project), there are similarities in the approaches taken and with some of the difficulties which the newer collaboration has faced.

A. The Uppsala/Rose-Hulman Collaboration

The "IT in Society" course at Uppsala University was designed to meet demands from industry regarding improved communication competence among graduating engineers. This included the ability to work in heterogeneous groups and to

communicate in an appropriate and effective manner, both orally and textually. The course has had a focus on competencies from the very start, and had its starting point in the Open-Ended Group Project (OEGP) framework [35]. The focus on competencies is therefore explicit in the course and learning goals related to their development are found in the course description.

An element of international collaboration was introduced to the course in 2005 with a partner course unit called "IT in a Global Society", which was developed at Rose-Hulman Institute of Technology. The collaboration between these universities has been running for ten years, and has developed through the use of action research oriented series of changes [33]. Some examples of these are the introduction of personal learning contracts [2], written individual reflections [1] and speed dating exercises based on the constructive controversy theory [34]. The course has developed iteratively with a series of action research cycles each year as the teachers on both sides of the Atlantic are researchers in the area of computer science education. The course unit itself consists of an IT project and work-based learning activities that are related to understanding technological solutions in context and from a holistic perspective. Students are given a specific task, asked to investigate the background problem area, analyse and evaluate possible options and to suggest a solution. Design and implementation of software itself are not typically part of the project, even though some prototypes have been built to illustrate the proposed solution.

The projects themselves are grounded in real-world applications and, since 2004, the client has been Uppsala County Council. Typically the client requires the students to address a problem in some area relevant for their current practice, such as eHealth. One example of this was an investigation into unauthorised use of medical records prompted by the Swedish Data Inspection Board which had demanded improvements to processes related to illegal intrusion. As a result of this, the students were given the task of investigating the problems of access control, looking at possible solutions inspired by other organisations, and suggesting improvements. Another example of a project in this area was an investigation into issues of "interoperability of eHealth" processes when integrating medical systems.

The class is introduced with a two hour lecture explaining the set-up of the course, where the learning outcomes are presented together with an explanation of the Open Ended Group Project's framework and the international collaboration. Most students have never worked in a project of this kind, and often have many questions regarding the requirements, tasks and set-up. During the initial lecture, the students are given documentation explaining the framework of the course, and the project requirements, e.g. that all groups must have weekly meetings with faculty, that meeting must take place when all international students can participate (which is difficult due to time differences) and that weekly meetings with the whole project and with the client are required. The open ended course setting requires the use of scaffolding for the students in order to work well. For example, two sets of individual meetings take place with all students regarding the nature of the learning contract that they write. The IT in Society course has not run

without problems, but has now reached a mature state where changes made are minor and related to circumstances, context and the students or faculty participating in the course.

B. The RGU-IITB Collaboration

The RGU-IITB collaboration is a globally distributed software engineering group project in which a development task is shared between students in Scotland and India. The project itself has now completed four main action research cycles. The first was an initial pilot, in which a small number of students from RGU undertook a software development task in collaboration with a similar number from IITB. This was done as an extra-curricular voluntary activity associated with a software engineering module. The second iteration involved six student volunteers from each institution and the task that they were asked to complete was credit-bearing. Assessment of the module involved examination of both the technical capabilities of the participants as well as their project management skills. The latter were assessed using a reflective journal which included entries made at critical points throughout the project. These journal entries were then reviewed, coded and analysed [35]. In addition to these, students were asked to complete an open-ended survey questionnaire which was used to elicit feedback from students on both the technical and project management challenges faced by participants. The third iteration involved a scaling up of the numbers in both institutions with an entire class of about twenty students from RGU and the same number from IITB. The groups comprised an equal number of students from each institution. Training on agile software development methods was provided to group members. The academic supervisors acted as product owners for the project using the scrum agile method. The product owners provided a prioritized list of the softwares functional requirements. However, the academic supervisors did not project manage the teams, as such. The fourth and latest iteration is ongoing at the time of writing but has reverted to a smaller number of participants mainly due to logistical difficulties associated with technology failure in the previous iteration.

The groups were responsible for establishing a project manager role, which was rotated through different group members during the project. Each of the groups had online meetings. Further, the decisions taken in such meetings were documented through meeting minutes. Each group was asked to produce the requirements and design documents, implemented software, testing results, and a project report. Interactions during group meetings were scheduled through timetabled class time as this simplified the process of arranging real-time conversations between group members. Groups were also encouraged to arrange additional meetings outside class.

Each of the teams was required to build a software application consisting of an online survey environment involving mobile phone client software for asking questions which was then collated into a server for storing survey results in a database. The quality of the final software deliverable was assessed and, together with an assessment of project management aspects of the activity, contributed to the final module grade.

VI. DISCUSSION

The basic classification scheme that we adopt is constructed from the features of CSCW and CSCL research that were elaborated in sections III and IV. The first element of this is a description of the potential for group activity in terms of the independent components that characterise the interactions. We choose to use a multidimensional continuum model ($N > 2$) rather than a matrix structure since the descriptive power of such a model outweighs the reduction in complexity that arises when restricting constraints to, say time and space factors. We therefore use the seven dimensional Model of Coordinated Action of Lee and Paine to describe the parameters that affect interaction and, by extension, the technologies that facilitate this interaction.

The second element of description is a determination of whether the activities of the group are cooperative or collaborative. This can be ascertained through identification of the mode of working of the individuals within the group. However, it should be noted that, for student projects with a remit to provide a positive educational experience (as opposed to, say, professional software engineering teams, where other commercial factors may be at play) it is proximity relations (together with the reliability of communications technology) that determine the extent of collaboration among the group members. This may mean, for example, that in situations where half the group members are collocated in one place and the rest collocated in another, genuine collaboration occurs only within each collocated subgroup. However, technological difficulties and the need for a positive attainment of learning goals in the course unit may mean that each collocated subgroup has its own specific learning objectives which can be fulfilled independently from those of the other subgroup. This would then tend to reduce the relationship between the two subgroups to one of simple cooperation.

A third characteristic of the interaction among the students is the motivation for learning. Intrinsic or extrinsic motivational factors, or developmental or elaborative cognitive factors may drive the learning and it is probable that this aspect is determined at the level of the psychology of the individual group member. For example, it is highly likely that some students will mainly be motivated by extrinsic factors while other will place more emphasis on a sense of belonging. Moreover, there will be a relationship between these motivational drivers and the cognitive factors described previously. Nevertheless, an understanding of the general disposition of group members in this area will enable the academic in charge to incorporate elements of appropriate scaffolding into the initial group exercises. Group goals could be clearly stated and shown to be aligned with individual learning objectives, or team-building exercises used to develop a sense of group identity. From a cognitive perspective, exercises which challenge hidden or unarticulated views might be appropriate as would some kind of peer interaction to promote elaboration.

Finally, while not part of the classification scheme per se, it is interesting to look at the knowledge creation cycles for both individuals and the group, as well as the way in which

completion of the group task relates to wider issues of professional competence and employability.

If we turn to the Uppsala/Rose-Hulman group project, we see that the relative maturity of project infrastructure allowed for some degree of regular synchronous communication, although asynchronous methods were used as well due to time-zone differences. The physical distribution dimension for students in Sweden and the USA was clearly distributed but this was mitigated by a collocation event at the start of the project when the American students visited Uppsala for a week to meet their Swedish counterparts. The number of people in the teams varied from year to year. The number of communities of practice, that is the measure of diversity within the project group was somewhat skewed since while the American contingent was relatively homogeneous from year to year, the subgroup from Sweden was often made up of a variety of nationalities as well as native Swedes. The task chosen each year was different and unfamiliar to the students comprising the project group. In terms of group structure, it was relatively short-term, lasting one semester but the students were expected to remain within the allocated subgroup.

The fact that there was an initial face-to-face meeting between members of the Swedish class and those of the American class meant that the potential to set up relationships which bound individuals to the group was much greater than if this had not occurred. Genuine collaboration was certainly possible while the subgroups were collocated and this may have continued after separation due to the availability of synchronous communications channels. Moreover, the greater potential for self-identification with group goals also meant that motivation intrinsic to the group was possible.

Examining the RGU/IITB group project, we find that although there was some use of synchronous technology, the difficulties with logistics, specifically with the network infrastructure at both RGU and IITB, meant that there was a much greater reliance on asynchronous technologies after the initial contact stage. The split between the two collocated subgroups in each development team also impacted on the technology used. The number of participants within each team varied with each iteration of the course and the make up of both the software development group and the collocated subgroups was culturally diverse leading to high scores on the number of communities of practice scale. The activity itself was unfamiliar to almost all students and the groups were clearly set up to be relatively short-lived, being dependent on the length of the module itself (twelve weeks). Finally, once the groups were set up, it was not anticipated that the membership would change and where this was not the case, the reason was because of lack of student engagement.

The two distinct locations for the software development subgroups meant that some collaboration took place at the local level but the main interaction between RGU and IITB students was cooperative. Finally, in terms of motivation for learning, there was little opportunity to build up personal relationships between members of the distributed teams and so the course relied on extrinsic factors such as compliance with

university assessment regulations to align group and individual learning objectives and so encourage engagement in the project processes.

VII. CONCLUSION

We have discussed in some detail a range of issues arising from CSCW and CSCL research which have an impact on our understanding of globally distributed group projects within a higher educational setting. These have been used to analyse the learning activities and use of collaborative technologies undertaken by group members and lead to a preliminary classification scheme for different aspects of the group project. The scheme was then applied to two examples of group project to see what insights could be gleaned from framing a discussion of their effectiveness in these terms.

We conclude by noting that, given the rapid spread of globalisation that has occurred in the world-wide Computing industry coupled with the advent of reasonably cheap and accessible communication technology, it is highly likely that universities will look with greater urgency to activities such as distributed group projects as a way of enhancing graduate employability in Science and Engineering industries such as Computing. Elaborating the nature and scope of those parameters that characterise the successful outcome of these projects will be extremely important as a step towards understanding the problem and so being able to control the learning environments using the technical infrastructure and appropriate pedagogies. We anticipate that this characterisation problem is one that will preoccupy academics in the future and this paper is a preliminary attempt to develop a framework in which this can be done..

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A Quasi-Network-Based Fly-by-Wire Simulation Architecture for Teaching Software Engineering

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Abstract—Undisciplined cohesion and coupling undermine countless aspects of quality software. Students, however, unfortunately tend to gravitate toward such approaches. This system mitigates this problem by forcing them to communicate with their components through a well-constrained hierarchical virtual network of networks. The application is a dynamic, plug-and-play aircraft fly-by-wire system that processes a wide variety of commands to design, construct, and manipulate sensors, actuators, controllers, and communication buses concurrently in a flexible model-view-controller architecture. It successfully employs many systems-engineering concepts of modeling, simulation, visualization, and analysis toward the goal of instilling disciplined design, implementation, testing, and evaluation practices in students. In particular, it provides the pedagogical and programmatic frameworks for creating, executing, presenting, and analyzing meaningful test cases as part of formal test plans carried out in controlled experiments via scientific method. The system can be adapted relatively easily to countless other real-world multidisciplinary domains for reuse in other projects. Extensive results from classroom deployments show that students overwhelmingly benefit from this approach.

Keywords—software engineering; control system; simulation

I. INTRODUCTION

Software, by its flexible virtual nature, allows programmers to make quick and easy changes, at least compared to related physical disciplines like engineering. Unfortunately, without appropriate self-discipline, it is all too easy to produce messy spaghetti code with endless nasty interconnections. The equivalent rat's nest of wires in an electrical system would be immediately apparent to anyone, but in a software system, no such obvious red flags exist without first learning to recognize them. The goal of this system is to instill disciplined design, implementation, and testing practices in software-engineering students by forcing them to work within a Java model-view-controller architecture that behaves like a well-defined and protected physical plug-and-play network.

The overarching philosophy is to use a systems-engineering approach of modeling, simulation, visualization, and analysis respectively to build a solution, execute it in a controlled way, present the results visually, and analyze what they mean as part of testing and evaluation. The model, in particular, is a simplified aircraft fly-by-wire system that controls a variety of flight components in complex real-time ways. This context,

supported by background research, provided students in an undergraduate software-engineering course with a holistic understanding of the problem space such that they could create a corresponding clean implementation in the solution space. The objectives are typical of any software system: to separate the concerns, maximize cohesion, minimize coupling, and delegate responsibility appropriately. These considerations are further complicated by the need for uniform, safe, and repeatable concurrency among the components. Building and testing single-threaded code is difficult enough for most students; multithreaded (or the appearance of such here) absolutely requires a disciplined approach.

II. BACKGROUND

All control systems take inputs of some sort and produce corresponding outputs of some sort. In traditional (non-electronic) systems, the connections from the former to the latter are mechanical linkages like cables, pushrods, and shafts. For example, a car steering wheel directly drives the gearbox to deflect the front wheels. There is little possible dynamic variation in the operation, like changing the steering sensitivity based on vehicle speed, because the configuration of the static system is fixed. A “by-wire” system, on the other hand, translates the input from a sensor into an electronic signal that travels via a network to an actuator, which acts upon it as output. In this form, any amount of computer processing is now possible for dynamic real-time reconfiguration.

In a fly-by-wire system, the primary control sensors are located in the cockpit in the form of a stick or yoke, as well as pedals, switches, and levers. The actuators are located around the airplane. Fig. 1 shows a basic configuration, which also includes the engines and landing gear.

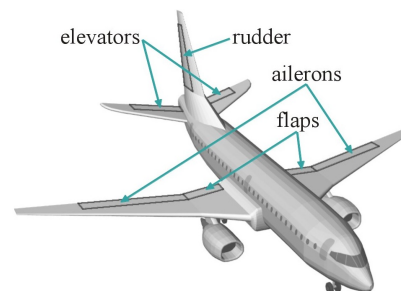


Fig. 1. Basic airplane actuators [1]

This work focuses on the behavior of the control system only, not on its effect on the airplane in flight. In other words, the airplane is basically stationary on a test stand. As a result, its degrees of freedom of motion and aerodynamics are ignored. For background, however, the elevators affect pitch (nose up or down) to change altitude; the ailerons affect wing roll to turn; and the rudder affects yaw to coordinate turns, much like the front wheel of bicycle does.

III. MODEL

This work uses a model-view-controller architecture. The model is the module that defines the machine being manipulated. The plug-and-play nature of the architecture allows it to accommodate other by-wire systems with relatively little difficulty. Further supporting this goal is the extensive use of well-established, reusable software design patterns [2]. For example, a subsequent offering of the same course used it as the basis of a toolkit for building and controlling heavy construction equipment. Follow-on work is planned for modeling railroads and railway equipment.

A. Datatypes

Significant, consistent anecdotal classroom evidence shows that students have a major problem with abstracting, maintaining, and manipulating data properly. Java primitives are appropriate in earlier low-level courses, but at higher project-based levels like software engineering, they lead to a proliferation of problems. For example, units, magnitudes, and limits are not applied consistently, error handling is inconsistent or almost nonexistent, and code bloats from haphazard attempts at reimplementing similar solutions in multiple places.

To mitigate this situation, the architecture provides a rich set of self-contained concrete datatypes for every kind of relevant data; e.g., Acceleration, AngleHorizontal, AngleVertical, FlapPosition, Identifier, Percent, Power, Rate, Speed, and many dozens more not directly in play in this paper. Each maintains its own error checking and helper methods for manipulating and converting it appropriately. This approach lends itself to convenient unit testing in isolation. It also reduces the burden of documentation; e.g., avoiding having to state and enforce everywhere that horizontal angles are in mathematical degrees (as opposed to navigational degrees or radians) because AngleHorizontal always uses this form.

Another consistent problem students have is with indiscriminate coupling and undisciplined, unprotected sharing of objects. Changing a mutable object in one place may have countless unexpected consequences throughout an entire system. To mitigate this problem, datatypes employ a functional paradigm, which makes them immutable. Any mutable action on them produces a new object via copy-on-write semantics [3]. It is therefore exceedingly difficult for students to interact with the system outside the prescribed network infrastructure, intentionally or not.

Finally, datatypes extensively use Java generics to constrain their application to appropriate contexts. Students are prone to hard-coding dangerous runtime casts and making decisions based on querying objects for their type with the

instanceof operator instead of properly utilizing the object-oriented principles of inheritance and polymorphism. Explicit casting should be avoided as much as possible in a dynamic, plug-and-play system.

B. Intervals

An interval is the data-structure equivalent of the presumed motive force that moves an actuator from one state to another. The basis is kinematics, or geometry in motion without regard to its causes [4]. Actuators play different roles and therefore have different state types, which the datatypes define, and intervals directly map onto and control.

An interval has implicit or explicit limits; e.g., a Percent interval always ranges inclusively from 0 to 100, whereas a Speed interval ranges inclusively from its specified minimum to maximum values. In all cases, the current state must always reside on the interval. It is impossible for a student to cause an inconsistent state without detection and notification.

Change in state as a delta is also configurable to account for slower or faster movement. In the linear variant, the delta never changes. In the nonlinear, it does so to account for acceleration or deceleration. Again, it is impossible to cause an inconsistent state. The interval always reflects a continuous function; e.g., it cannot achieve maximum delta without accelerating to that value by the rules. Likewise, it cannot change direction without decelerating to zero first. This behavior reflects the reality of the mechanical system that the interval represents.

An interval is like an operating-system process in several ways. A nonpreempting request submitted to it is queued for execution. For example, requesting it to go to maximum value and then immediately to minimum value would entail increasing to completion (with initial acceleration and final deceleration) and then similarly decreasing to completion. A preempting request, on the other hand, would cause the currently executing request to complete gracefully with deceleration to zero as soon as possible, followed by servicing the new request. A terminate request functions in the same way, except that it schedules no subsequent action. A cancel request kills the currently executing request immediately with no graceful shutdown. It is not an option for normal interaction because it violates the kinematics; i.e., infinitely fast deceleration from the equivalent of dividing by zero in

$$rate = distance / time \quad (1)$$

Fig. 2 notionally depicts the state and delta (top and bottom lines of each graph, respectively) for a variety of combinations of linear and nonlinear movement in increasing and decreasing directions with intervening terminate and cancel actions. To demonstrate the value of using the architecture-supported intervals over their own ad hoc implementations, the students had to solve the basic elements of this problem as a standalone proof-of-concept Java program. The results were telling: their solutions were overwhelmingly large, unmanageable hacks, not one worked completely, and the average grade was 11%. They said it was an extremely eye-opening experience and acknowledged the value of the orthogonal approach in this work: one solution applicable to many problems [5].

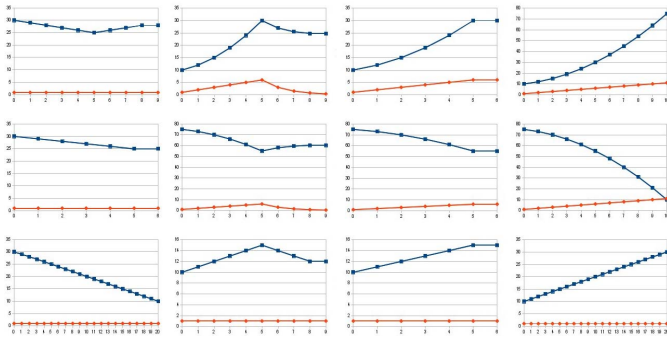


Fig. 2. Sample kinematics intervals

C. Buses

Every interval (as part of an actuator) resides on a communication bus that transfers requests. Three types of interval servicing are possible:

- *Oneshot*: service a request once, then expire automatically; e.g., instantaneous on/off actions.
- *Definite*: service a request until a specified end condition, then expire automatically; e.g., movement.
- *Indefinite*: service a request continuously, ending only upon a terminate or cancel request; e.g., engine rotation.

In addition, requests may specify in detail the timing of the interval servicing:

- *Lead time*: the amount of time that an interval should initially perform no action. This models initialization.
- *Duration*: the total amount of time that the request will be serviced. This applies to definite intervals only.
- *Frequency*: the rate at which actions are performed while being serviced. This allows them to operate at a fraction of the clock speed.

Requests are exactly that: *requests*. They are not imperative commands that must be honored (even though “command” is the conventional term used in flight control) [6]. In fact, the servicer decides how to process the request and responds to the submitter as follows:

- **IGNORED**: ignored and discarded the request because it was not considered applicable.
- **REJECTED_INVALID**: rejected the request, which normally would be serviced, but cannot be now because it is somehow invalid or inappropriate.
- **REJECTED_UNABLE**: rejected the request, which normally would be serviced, but cannot be now for some reason on the servicer’s side. The servicer may inform the requester when it is available again.
- **ACCEPTED_BLOCKED**: accepted the request, but it will be queued for later servicing because the servicer is busy.
- **ACCEPTED_SERVICING**: accepted the request, and it will be serviced immediately.

This handshaking approach was difficult for the students to embrace because they are used to shouting at their code imperatively to do what they want, and if it does not, then shouting louder. For example, one student admitted that his development process was to “[keep] throwing more code at the compiler until it shut up.”

D. Actuators

Actuators are the interval-based virtual mechanisms that cause the aircraft components in Fig. 1, as well as others, to change state appropriately. The presumed underlying motive force (electrical, hydraulic, pneumatic, thermodynamic, etc.) plays no role, only the resulting action. Section III.F addresses specific actuator behaviors in detail, especially in combination. In general, however, their data (what they are) and control (what they can do) adhere to the following constraints:

- *Rudder*: deflects left or right to an angle.
- *Elevator*: deflects up or down to an angle.
- *Engine*: changes speed as a percentage of maximum revolutions per minute.
- *Aileron*: deflects up or down to an angle; in roll mode, they are always paired antisymmetrically on the wings, so when one deflects, its counterpart deflects by the same amount in the opposite direction.
- *Speed brake*: deflects upward to an angle; on a real aircraft, separate dedicated actuators typically play this role, but for pedagogical reasons, ailerons do so here in speed-brake mode. There is no antisymmetry: all ailerons deflect upward to cause increased drag.
- *Main gear*: extends or retracts as a percentage of downward deployment.
- *Nose gear*: extends or retracts as a percentage of downward deployment, but also simultaneously rotates 90 degrees to stow sideways in the fuselage.
- *Flap*: deflects downward to an angle. As Fig. 3 shows, plain flaps rotate about a fixed point; for double-slotted flaps, this point moves backward, and the flap separates, requiring two coordinated intervals that are both simultaneous and sequential.

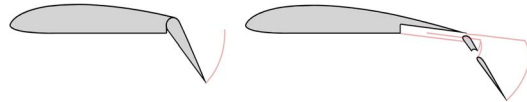


Fig. 3. Plain and double-slotted flap deployment [7]

E. Sensors

Whereas an actuator is an output device that changes state on command, a sensor is its complement as an input device to indicate this state by querying the actuator on command. Sensors do not play a significant role in the current manifestation of this work because the logger discussed in the next section already captures state data for analysis. Nevertheless, they do introduce interesting advanced safety

considerations into the flight-control system for future work on model reliability, for example.

For any number of reasons beyond the scope of this paper, a real-world mechanical system may erroneously exceed its specified design limits. An active preventative solution, in the form of a watchdog device, would immediately report any deviation as a fault [8]. A passive solution is also commonly present as mechanical stops that would physically prevent an actuator from exceeding its hard limits. However, it would still be possible to hit a stop and continue to try to move, likely resulting in wear or damage in the drive mechanism. A common hybrid approach is to monitor the actuator itself to see how hard it is working with respect to how much work it is performing: working hard with no effect likely means that it is at the limit, jammed, or otherwise interrupted. A garage-door opener is a good example.

F. Controllers

A fly-by-wire system is actually a hierarchical system of systems [9]. In this model, there is one master bus that runs from the cockpit throughout the entire aircraft, but no actuators are connected directly to it. Rather, it consists of controllers, which themselves have slave subbuses containing relevant actuators. This extra level of indirection allows for arbitrarily complex coordination at the receiving end (the actuators), where otherwise it would be the transmitting end (the cockpit) that would have to assume this responsibility. It also reduces bus traffic by sending consolidated requests to be interpreted, decomposed, and redistributed by the controllers as appropriate. The controllers are:

- *Rudder controller*: always contains a single rudder actuator on its subbus. A request to it (i.e., change deflection angle) passes untouched to the actuator.
- *Elevator controller*: always contains two elevator actuators. A request to it passes untouched to each.
- *Gear controller*: always contains two main-gear actuators and a nose-gear actuator. A request to it (extend or retract) passes untouched to each.
- *Flap controller*: contains an even number of symmetrically configured flap actuators, evenly distributed across the wings from left to right from the cockpit perspective. A request to it (downward deflection angle) passes untouched to each.
- *Engine controller*: contains any number of symmetrically configured engine actuators, distributed the same as flaps. A request to it (power percentage) has two interpretations. In gang mode, it passes untouched to each actuator; in isolation mode, it passes untouched to only the specified one.
- *Aileron controller*: contains an even number of symmetrically configured aileron actuators, also distributed the same as flaps. In standard roll mode, a request to it (upward or downward deflection angle) passes untouched to all actuators on the left wing, but the direction is inverted for the right wing. In mixed roll mode, the request addresses only the specified left

actuator, and the other actuators on the left wing deflect as a ratio of it, and likewise those on the right. (Section VII discusses this process in more detail.) Finally, in speed-brake mode, the request (deploy or retract) passes to all actuators to deflect upward to their maximum angle or downward to neutral, respectively.

Fig. 4 is an architecture for a typical two-engine passenger airplane, where L, R, and N respectively indicate left, right, and nose. Section V addresses the command generator.

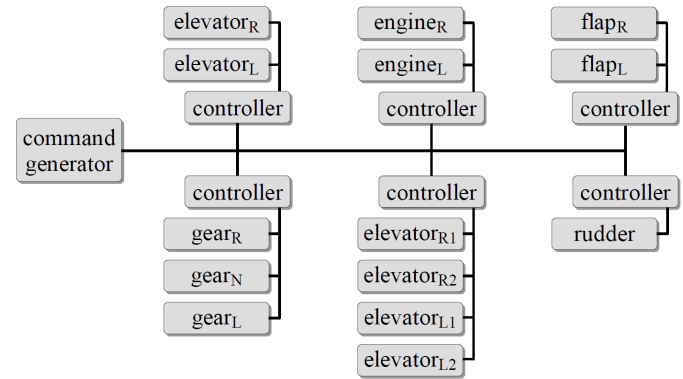


Fig. 4. Typical bus architecture

Additional levels of indirection (i.e., controllers containing controllers) could also be added for complicated decision-making. For example, in flight the appropriate amount of yaw from the rudder depends on the amount of roll from the ailerons with respect to airspeed. An aileron request could issue a secondary rudder request [10]. Similarly, roll reduces lift, which may be compensated for by the pilot or the control system. In general, Boeing's approach, for example, requires the pilot to introduce more pitch as a separate intentional action, whereas Airbus's does so automatically [11].

Although not part of this work, controllers in conjunction with sensors could monitor the behavior of actuators in concert. Symmetric configurations must be in identical (or identically inverted) states at all times; otherwise, the aerodynamic effects could be catastrophic. Similarly, advanced coordination of an autothrottle is possible [12].

Other complex monitoring relationships are also possible, but are deferred to future work. For example, in combination with flight data, the flight-control system could determine the operating limits that the pilot is permitted to reach [4]. Under normal circumstances, operating in so-called Normal Law, the system does not allow the aircraft to enter a region of unusual or diminished flight control. For rare cases, Alternate Law relaxes these restrictions, but it still would not allow the aircraft to exceed its maximum operating limitations. Direct Law basically disables automated oversight altogether for exceptional cases and allows the actuators to be driven as if the control system were purely mechanical.

IV. VIEW

The view module of the model-view-controller architecture depicts the state of the system in multiple forms. Its plug-and-play nature allows other implementations to be added or substituted relatively easily.

A. Log

The most basic — but also most informative — view is text output to a log file. This view supports arbitrary logging of any aspects of interest, but the built-in output is generally sufficient for most analysis. The relevant details of each state at each clock tick go to a text file that directly exports to Excel. Fig. 5 shows an abridged form, which actually contains many more columns, as well as typically thousands of rows of events.

tick	time	code	action	bus	servicer_id	s#	request	request_id	status	response	t#
53	0.053	C	submit	bus1	gear_ctrl1	0	Service	gear_ctrl1#1	UNBOUND		
53	0.053	C	submit	gear_ctrl1_bus	gear_nose2	0	Service	gear_nose2#2	UNBOUND		
53	0.053	D	respond	gear_ctrl1_bus	gear_nose2	0	Service	gear_nose2#2	ACCEPTED_SERVICING		
53	0.053	C	submit	gear_ctrl1_bus	gear_main1	0	Service	gear_main1#3	UNBOUND		
53	0.053	D	respond	gear_ctrl1_bus	gear_main1	0	Service	gear_main1#3	ACCEPTED_SERVICING		
53	0.053	C	submit	gear_ctrl1_bus	gear_main2	0	Service	gear_main2#4	UNBOUND		
53	0.053	D	respond	gear_ctrl1_bus	gear_main2	0	Service	gear_main2#4	ACCEPTED_SERVICING		
53	0.053	D	respond	bus1	gear_ctrl1	0	Cancel	gear_ctrl1#1	ACCEPTED_SERVICING		
53	0.053	B	notify	gear_ctrl1_bus	gear_main1	1	Service	gear_main1#3	SERVICE		0
53	0.053	B	service	gear_ctrl1_bus	gear_main1	1	Service	gear_main1#3	BLOCK		
53	0.053	B	notify	gear_ctrl1_bus	gear_nose2	1	Service	gear_nose2#2	BLOCK		1
53	0.053	B	service	gear_ctrl1_bus	gear_nose2	1	Service	gear_nose2#2	SERVICE		
53	0.053	B	notify	gear_ctrl1_bus	gear_main2	1	Service	gear_main2#4	SERVICE		2
53	0.053	B	service	gear_ctrl1_bus	gear_main2	1	Service	gear_main2#4	SERVICE		
53	0.053	B	notify	gear_ctrl1_bus	gear_main2	1	Cancel	gear_main2#4	SERVICE		1
53	0.053	B	notify	bus1	gear_ctrl1	1	Service	gear_ctrl1#1	CANCEL		
54	0.054	B	notify	gear_ctrl1_bus	gear_main1	2	Service	gear_main1#3	SERVICE		3
54	0.054	B	service	gear_ctrl1_bus	gear_main1	2	Service	gear_main1#3	SERVICE		
54	0.054	B	notify	gear_ctrl1_bus	gear_nose2	2	Service	gear_nose2#2	SERVICE		4
54	0.054	B	service	gear_ctrl1_bus	gear_nose2	2	Service	gear_nose2#2	SERVICE		
54	0.054	B	notify	gear_ctrl1_bus	gear_main2	2	Service	gear_main2#4	SERVICE		5
54	0.054	B	service	gear_ctrl1_bus	gear_main2	2	Service	gear_main2#4	SERVICE		
54	0.054	B	notify	bus1	gear_ctrl2	2	Terminate	gear_ctrl1#2	TERMINATE		

Fig. 5. Abridged bus log

Not only does this log represent the states of the controllers and actuators, but it also shows the bus traffic. The communication process involves submitting a request and getting one or more immediate responses from its servicer. If the request is subsequently serviced, notifications are sent back to the requester for specified conditions like decelerating for arrival at the final state, arrival at the final state, preemption, and so on. This information could be exported to other applications to generate timing and UML sequence diagrams.

B. Graph Visualization

The textual form of the log file is richly informative, but it is not intuitively understandable. However, its structure not only exports natively to Excel for a tabular representation; its fields are also strategically organized to allow event chains to be plotted as line graphs. Fig. 6, for example, depicts the actions of a rudder actuator at the following key time points:

1. at initial position 0° neutral; command to 45° left
2. arrives; command to 45° right
3. arrives; command to 0°
4. arrives; command to 30° left
5. at 15° left preemptively command to 45° right
6. arrives

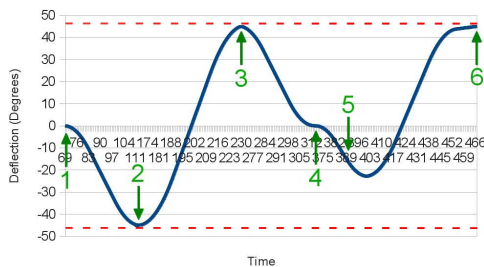


Fig. 6. Preemption test

Despite multiple requests, it is clear that at no time does the actuator find itself in an inconsistent state. i.e., above or below

the dashed lines depicting the physical limits. Moreover, the line represents a smooth, continuous function with no jerks or breaks through various acceleration, deceleration, and preemption actions. Such intuitive visual inspection is invaluable for testing and evaluation. Furthermore, mathematical analysis on the slope of the function would demonstrate that the performance remained within the specifications at all times.

C. Three-Dimensional Visualization

Visual representation in graph form is useful with respect to a localized part of the system like a single actuator or a group of related actuators. However, for a global systems-level view, three-dimensional visualization, as in Fig. 7, is far better.

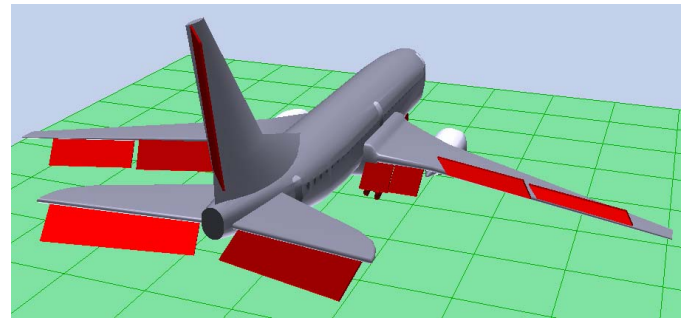


Fig. 7. Actuator visualization [1]

As the next section discusses, actuator configuration is highly dynamic and need not correspond to any particular aircraft. As a result, the visualizer is stylized with oversize control surfaces that represent the appropriate actions, not necessarily the appropriate appearance. The visualizer can also depict metadata like physical limits and breadcrumb tracks showing a history of state changes.

This OpenGL-based Java tool has seen extensive use in the author's artificial-intelligence and software-engineering courses, related pedagogical research, and industry work as a general-purpose world viewer [13,14]. It is freely available at shelly.edu.

V. CONTROLLER

The controller is the user interface for building the model and running the simulation. It is based on a regular grammar that employs the Interpreter and Command design patterns [2]. The instructor's solution defines the parser with JavaCC, but the students had to design and implement their own with standard Java. This effort entailed thoroughly understanding the problem domain of the commands and their proper usage, as well as the solution domain of the API for the provided architecture. It strongly discourages head-first, brute-force coding by making such an undisciplined approach obvious and unpleasantly difficult.

A. Creational Commands

Creational commands define and build the actuators via the Builder and Factory design patterns [2]. Each contains a unique identifier, the interval limits, a delta value for changing state on the interval, and an acceleration for changing the delta value.

All eight of these commands (for aileron, elevator, and rudder actuators, etc.) have the following form:

```
CREATE RUDDER id WITH LIMIT angle
      SPEED speed ACCELERATION acceleration
```

B. Structural Commands

Structural commands define and build the controllers from the actuators created above. Each contains a unique identifier and the actuators. The controllers with a fixed number of actuators are:

```
DECLARE RUDDER CONTROLLER id1
      WITH RUDDER id2

DECLARE ELEVATOR CONTROLLER id1
      WITH ELEVATORS id2 id3

DECLARE GEAR CONTROLLER id1
      WITH GEAR NOSE id2 MAIN id3 id4
```

The controllers with a variable number of actuators are:

```
DECLARE FLAP CONTROLLER id WITH FLAPS idn+

DECLARE ENGINE CONTROLLER id
      WITH ENGINE[S] idn+

DECLARE AILERON CONTROLLER id
      WITH AILERONS idn+ PRIMARY idx
      (SLAVE idslave TO idmaster BY
      percent PERCENT)*
```

All controllers must be added to the master bus:

```
DECLARE BUS id WITH CONTROLLER[S] idn+
```

And finally the configuration is locked to prohibit further creation or structural commands and to authorize most behavior commands:

```
COMMIT
```

It is at this point that students perform any late consistency checks to verify that the system is configured properly before any manipulation of it can occur. For example, the number of engines and their properties must mirror each other on the wings. From a practical design standpoint, such a check cannot be done earlier while the engines are still being added because the process is sequential. Determining what can be done immediately versus deferred for later, as well as how, is an important part of software design thinking [15].

C. Behavioral Commands

The behavioral commands send requests across the master bus to be interpreted by the appropriate controller(s):

```
DO id DEFLECT RUDDER angle LEFT | RIGHT
DO id DEFLECT ELEVATOR angle UP | DOWN
DO id DEFLECT AILERONS angle UP | DOWN
DO id SPEED BRAKE ON | OFF
DO id DEFLECT FLAP position
DO id SET POWER power
DO id SET POWER power ENGINE id
DO id GEAR UP | DOWN
HALT id
```

D. Miscellaneous Commands

The miscellaneous commands manipulate the execution of the simulation. The first set affects the system clock:

```
@CLOCK rate
@CLOCK PAUSE | RESUME | UPDATE
```

Especially important for testing is the capability to wait a fixed amount of time. The preemption tests, in particular, need to be timed exactly. Manually issuing a command would result in inconsistent results over multiple runs. The command is:

```
@WAIT time
```

Finally, commands may be supplied in text files for execution as scripts, which greatly simplifies repeatable testing:

```
@RUN "filename"
```

VI. CONTROLLED EXPERIMENTS

The primary goal of this work is to instill disciplined software-development behavior in students. However, it also naturally serves as an effective platform for systematically evaluating the performance of a model by using scientific method in controlled experiments as follows:

1. Design and carry out an experiment (a test) to investigate something of interest.
2. Visualize and analyze the results.
3. If the results are unsatisfactory, perturb one and only one parameter in the experiment and rerun it.
4. If the new results are more promising, continue down this line of investigation; otherwise, either perturb the parameter in a different way or reset it and perturb a different parameter.
5. Continue to refine the model until the results are satisfactory.

Consistent with the primary goal, students gain valuable experience with discovering patterns and building mental models that connect causes to effects [16]. This approach reduces the amount of random, uninformed generate-and-test cycles, which generally allows students to be more productive by getting better results with less effort.

VII. RESULTS

The students' project consisted of three parts: implement the parser, implement the controllers, and execute a detailed test plan. The results of the first two parts were straightforward because this system does not allow them to deviate much from proper coding principles. The third part—testing and evaluation of the entire system—is the emphasis here. The deliverable required a formal report describing the test plan and its results. Each of 27 experiments addressed eight points, where 1–4 related to planning, 5–6 to execution, and 7–8 to presenting the results:

1. The rationale behind the test; i.e., what it was testing and why it mattered.

2. A general English description of the initial conditions.
3. The commands for (2).
4. An English narrative of the expected results.
5. The actual results with at least one graph showing the most representative view of the states.
6. A snippet of the actual results from the log file with a supporting explanation, including statistics, metrics, and graphs, as appropriate.
7. A discussion on how the actual results agreed with the expected results, or if they disagreed, a hypothesis on why.
8. A suggestion for how to extend this test to address related aspects of potential interest.

The results themselves are not as relevant here as what the students learned from them, but the following examples help convey how they learned it. Fig. 8 depicts the behavior of a three-engine configuration (where the dashed lines overlap). At time point (1), all three engines were commanded to increase power from 0 to 70%. Upon reaching this target at (2), the center engine was commanded to reduce power back to 0%. At (3), while the center engine was still decreasing, all three were commanded to go to 100%, which took until (4) to achieve.

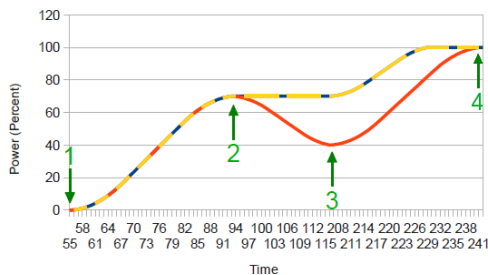


Fig. 8. Engine manipulation

Determining correctness (testing) and evaluating performance (optimization) require three critical components: the expected results, the actual results, and a meaningful way to compare the two. All too often students lack one, two, or even all three of these. While the technical act of acquiring such data is necessary, it alone is not sufficient to make sense of the data. Students must have a firm understanding of the subject matter and its context within the problem domain. The pedagogical approach in this work provides endless opportunities to ground the programmatic exercises to reality in order to help students develop and improve their critical-thinking skills in computer science.

For example, experiments in engine manipulation could be better understood by knowing that it is normal procedure for pilots of many commercial airliners to spool the engines initially to 50% power on takeoff and then wait until they all reach this point before going to full power. The natural variability in engine performance does not guarantee exactly the same behavior simultaneously, which could have adverse effects on controllability during the takeoff roll. With this knowledge, students may realize that they are not just generating graphs; they are generating graphs that mean

something, and if that something is not what it should be, then they have considerable insight into what may need fixing.

Another example in Fig. 9 shows a complex example of mixing eight ailerons with different performance properties in roll mode. At (1), with all ailerons at their neutral position of 0 degrees, the master aileron (M) is commanded to deflect upward to 45 degrees. The slave ailerons on the same wing move upward as a ratio of its movement, while those on the opposite wing correspondingly do so downward. Upon reaching 45 degrees at (2), the master is commanded downward to -40 degrees, which is achieved at (3). The graph convincingly shows that all ailerons remain antisymmetrically synchronized at all times.

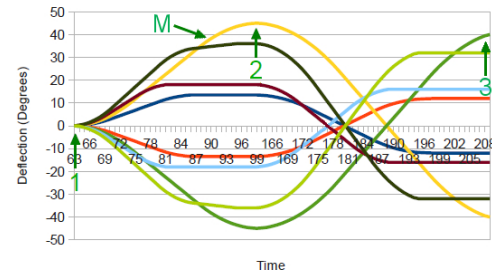


Fig. 9. Aileron manipulation

Fig. 10 shows the same ailerons acting in speed-brake mode. Starting again from neutral 0 degrees at (1), the eight ailerons deflect upward to their maximum limit of 90 degrees, which is achieved by all by (2). The master is then commanded to -20 degrees in roll mode, which results in behavior analogous to that in Fig. 9. The details of the action are beyond the scope of this paper, but again, the graph clearly demonstrates them to the students, who have the theoretical and practical foundation to know how to interpret it.

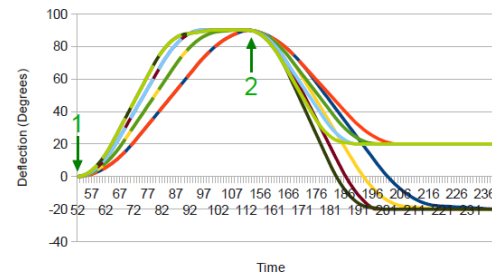


Fig. 10. Speed-brake manipulation

Finally, Fig. 11 shows a four-flap configuration, where two types of flaps differ in performance slightly. At all times through a variety of actions, the flaps of the same type remain synchronized, and the two types act appropriately with respect to one another. Such insight into the behavior of a complex system is invaluable in testing and evaluation.

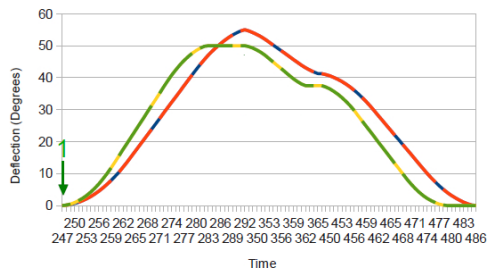


Fig. 11. Flap manipulation

Reporting and evaluating the results of human subjects in work of this scope must be summarized due to limited space. However, it is based on a significant breadth and depth of objective and subjective measures including anecdotal observation, individual contributions from a background survey, 11 assignments, and 10 anonymous weekly assessments, as well as individual and team contributions from 18 project status reports, a project reflection, a team evaluation, a self-evaluation, and a course evaluation.

Most telling, 90% (28 of 31) of the participating students indicated that the graphical form of the test report directly contributed to a better understanding of what their code was actually doing, where they otherwise would have had less confidence in their results. Overall, the students rated the project 4.6 out of 5 (excellent).

VIII. FUTURE WORK

Almost any complex physical system is characterized by input, processing, and output that could map to this architecture. For reuse in future projects, it should accommodate more complex interval behaviors, as well as other sensors, actuators, and controllers. Of particular interest within this application are detecting and handling faults and managing operating laws. For a graduate-level course, especially for software quality assurance, the evaluation framework based on controlled experiments could be significantly expanded for richer analysis. In particular, the introduction of probability would contribute to a powerful stochastic Monte Carlo methodology.

IX. CONCLUSION

This work mitigates the common problem-solving strategy of many students who undermine the design of a system by indiscriminately throwing more code at every issue they

encounter. The hierarchical quasi-network-based architecture effectively prevents them from communicating with their components by any means except the prescribed ones. Its datatype-oriented interval framework safely and elegantly manages complex physical behaviors concurrently. This unified approach, combined with an overarching framework of modeling, simulation, visualization, and analysis, further provides a disciplined strategy for creating, executing, presenting, and analyzing meaningful test cases as part of formal test plans based on a sound methodology of controlled experiments via scientific method. Extensive results from a classroom deployment support the conclusion that students overwhelmingly benefit from this approach.

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Peer instruction methodology for linear algebra subject: a case study in an engineering course

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Abstract— While the initial course in linear algebra plays a decisive role in an engineer's basic formation, it is often marked by high rates of student failure and dropout and thus constitutes an important issue in the field of engineering education. The present study aims to enhance the teaching and learning processes in the first phase of linear algebra in engineering curriculum, viz., matrices, systems of linear equations, notions of vectors, and line and plane equations. To address this end, a methodological teaching proposal, Peer Instruction (PI), is proposed to improve student comprehension, classroom interaction, cooperation among peers, and assimilation of fundamental concepts. The PI method was applied in the initial phase of a linear algebra course in the undergraduate Chemical Engineering program at the Federal University of Ceará, Brazil. To measure student prior knowledge, a conceptual pre-test was conducted. Subsequently, eleven 2-hour classes were taught using PI, and a final exam was then conducted. Comparison of pre- and post-test results shows significant increase in student performance. The incremental increase in student-teacher and student-student interactions played a significant role in methodology's success.

Keywords—Peer instruction; linear algebra; engineering education; active learning; previous knowledge.

I. INTRODUCTION

Failure rates among first-year engineering students are increasingly encountered in universities worldwide [1]. A contributing factor to these high rates is the inadequacy of the students' academic background in mathematics [2].

In general, students have difficulty in relating previous knowledge to new concepts that will be learned at university. In this regard, basic abstract concepts in linear algebra, a core course in the engineering curriculum, merit special attention. Linear algebra provides a foundational language for mathematical modeling of a broad number of problems. Thus mastering these concepts is crucial to the education of future engineers [3].

Such basic concepts from secondary education such as matrices, systems of linear equations, notions of vectors, and line and plane equations, form a set of prerequisites for the proper understanding of linear algebra [4]. Accordingly, it is critical that students master these concepts in order to develop their abstract thinking in linear algebra; otherwise major difficulties are certain to arise [5-6]. Providing an appropriate background to students should help them overcome barriers between the abstract and real worlds. Such initiatives foster a better understanding of linear algebraic concepts to the benefit of students' academic studies and subsequent professional careers.

The conventional teaching method, based on lectures given by an instructor addressing a class of passive students, has proven ineffective for linear algebra courses. It fails to motivate students and makes it more difficult for them to absorb abstract concepts, as evidenced by the unsatisfactory learning rates found in evaluations [5].

The present study applies a teaching method, Peer Instruction (PI) [7], to support alternative teaching and learning processes for fundamental concepts of linear algebra in the context of the engineering curriculum. PI's immediate benefits include increased motivation and interest in the subject.

The PI method was developed by Eric Mazur, a professor of physics at Harvard University [7]. Its objectives are to motivate students' class participation, their collaboration with their peers, and, in particular, their assimilation of fundamental concepts in linear algebra.

The PI methodology was implemented throughout the Linear Algebra course taught in the program of Chemical Engineering at Federal University of Ceará (UFC). The purpose of this study, however, is to analyze student performance improvement solely in the initial phase of the course, in which basic mathematical concepts, viz., matrices, systems of linear equations, notions of vectors, and line and plane equations, are taught. Since these concepts customarily

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are part of the secondary curriculum, students are expected to have previous knowledge of them. This is why analyzing the performance data restricted to the initial phase of the course is an effective way to assess PI's success.

Accordingly, it should be understood that references to the initial phase of the linear algebra course encompasses the previous knowledge acquired in secondary education.

The study finds that using different materials and alternative instruction strategies, based on PI, in teaching fundamental concepts of linear algebra enhances students' learning experience. This is particularly meaningful in regard to the initial phase of the course. Mastering these foundational concepts has a decisive impact in assimilating abstract ideas from the latter part of the course. Increased motivation has also been observed.

The study is divided into four principal parts. The introductory section consists of a brief history Peer Instruction and its systematization, while the second describes the implementation of PI techniques in teaching the initial phase of a linear algebra course. The third section presents the study's results and analysis, and the concluding section offers some thoughts about the study's result, implications, and further dimensions to be explored.

II. PEER INSTRUCTION

In the early 1990s, Mazur developed Peer Instruction as a teaching method to help his students improve learning in his introductory physics course. In view of its effectiveness [8-10], PI is now used in diverse courses in many countries [11-16]. Despite its international success, however, PI has not been sufficiently explored in linear algebra instruction in Brazil. In this study, Didactic Engineering (DE) [17] is combined PI to develop an efficient mechanism to teach the first quarter of linear algebra courses. This is the principal innovation presented in these pages.

PI's fundamental objective is to promote student engagement and cooperation in class, as well as the assimilation of fundamental concepts. The conceptual idea behind the method is to induce students to appreciate the importance of discovering for themselves the bases of theories covered in the classroom, thus honing their abstract thinking skills.

A PI lecture organizes its contents under critical topics. For each key concept, a brief explanation of about 10 minutes is provided, followed by a conceptual question using a multiple-choice format. Students are encouraged to think through their answers for 1 to 2 minutes, and then respond by a show of hands, flashcards, or electronic devices (clickers) directly connected to the instructor's computer. Subsequently, the instructor registers their responses for comparative purposes.

If at least 70% of the students select the correct answer, the instructor briefly discusses it without taking a further poll. As a rate below 30% implies students misunderstood the concept, the instructor explains it in further detail, often using another approach. Subsequently, the instructor poses another conceptual question. Ideally, students should answer it

correctly between 30 and 70 percent, implying that the question is challenging but not out of reach. In this situation, students are asked to discuss their responses with their peers, and endeavor to convince them to adopt their own answer. Simultaneously, the instructor should move around the classroom to foster fruitful discussions.

After two to four minutes, it is time for the next round of polling; if most students select the correct answer, the instructor can move on to the next topic; otherwise, he or she may elect to explain the question, analyzing each response. Fig. 1 summarizes the PI process [10].

Another important aspect of PI is that it requires students to prepare for class beforehand. Students must read material assigned by the instructor before coming to class. Such material might include text, videos, or bibliographic references that re-enforce the basic concepts to be discussed in the next class. Just-in-Time Teaching, developed by Novak, Gavrin, Christian, and Patterson [18], is used to incentivize such reading. Students are required to study the material, answer questions related to the complexities of the concepts, and provide their responses to the instructor by the deadline. For example, the instructor might ask, "Did you find anything difficult or confusing in the reading? If not, what did you find most interesting?" The goals of reading assignments are to encourage students to prepare for class, bolster student motivation, and provide the instructor sufficient time to adjust in-class activity to address students' difficulties.

As Mazur's experience confirms, Peer Instruction's successful implementation does not depend on the polling system. Fundamentally, PI is a student-centered teaching methodology that emphasizes the concepts of and provides a proper environment for peer discussion and collaboration. The instructor plays a role as a facilitator in the teaching-learning process, helping students' through their difficulties [19].

Vygotsky's theory empathizes that cognitive development is based on social interaction [20]. This concept is embodied in the Peer Instruction method, since the instructor, who plays the role of mediator in the learning process, seeks to stimulate student interaction. This enables student to actively participate and effectively cooperate with their counterparts, thereby increasing their own comprehension. These initiatives yield teacher-student interaction, student-student interaction, and a new interaction with previous knowledge.

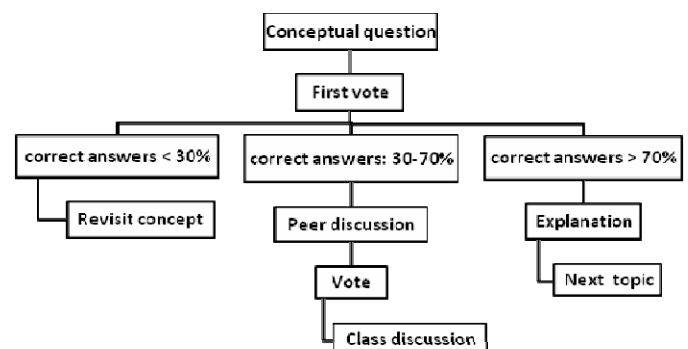


Fig. 1. Peer Instruction implementation process.

According to Ausubel's learning theory, to attain new knowledge, students must link it to relevant facts they already know [21]. When a new concept relates to existing knowledge gained in the classroom, the student will be better equipped to transform the knowledge into meaningful learning to be applied outside that milieu. Reading assignments have provided students the prior knowledge required for the absorption of a new concept. Hence, this methodology favors learning where students connect new content to pre-existing knowledge thereby generating meaningful learning.

III. METHODOLOGY

This study is based on the Peer Instruction method. The Just-in-Time Teaching method was applied as a reading incentive and the Didactic Engineering, methodology developed by Michèle Artigue [17], provided support in the organization, observation, and analysis required to prepare classes [22].

A. Learning Outcome and Course Description

The purpose of the lectures is to provide students with a sound background to the concepts of the initial phase of the linear algebra course. Their goal is to enable students to identify and solve linear equations, using matrix systems, highlighting geometric associations and physical interpretations. The reading assignments and conceptual and test questions are designed to meet expected learning outcomes described in Table I.

The study was conducted in a linear algebra course in the Chemical Engineering program at the Federal University of Ceará. Of the 70 students enrolled in the course, 64 were taking it for the first time. Student ages ranged from 17 to 21 years. There were 22 females and 58 males in the class.

The two-hour class met twice weekly. The lectures comprised 64 hours, of which 20 were dedicated to covering fundamental concepts required for the study of linear algebra. Table II shows the topics covered during the lectures.

TABLE I. EXPECTED LEARNING OUTCOMES

	Following the respective lecture, students should be able to:
S1	Identify types of matrices
S2	Operate matrices
S3	Distinguish between matrix and real number properties
S4	Solve linear equations using matrix systems
S5	Compute determinants of matrices and understand their importance in solving linear systems and inverting matrices
S6	Geometrically interpret solutions of linear systems via vectors, lines, and planes
S7	Write elementary mathematical proofs.

TABLE II. COURSE DESCRIPTION (INITIAL PHASE)

Lecture	Description
1	Explanation of study's methodology; Diagnostic pre-test
2	Matrix operations
3	Systems of linear equations Homogeneous systems
4	Row reduction and echelon forms Gaussian elimination
5	Inverse matrices and their applications
6	Determinants
7	Adjugate matrices
8	Vectors in n-space
9	Line and plan equations
10	Post-test

B. Peer Instruction Implementation

On the first day of class, the study's methodology and how it would be implemented in the class were introduced to students. The importance of their active participation and the need for pre-class reading was highlighted. Students reacted positively to the study's methodology and implementation.

A diagnostic pre-test, consisting of 10 true-or-false questions, was conducted to evaluate students' previous knowledge of basic concepts critical to the study of linear algebra. The same test was re-conducted subsequent to the lectures to assess student assimilation of these concepts.

Following the Just-in Time Teaching protocol, the reading material and assignment related to the content of their next class was periodically sent students via the university's Virtual Learning Environment, Sistema Integrado de Gestão de Atividades Acadêmicas (Integrated Academic Activities Management). The material provided was carefully designed to effectively and efficiently summarize a broad spectrum of online literature and content [23-27]. As an incentive to completing the pre-class reading, the assignments constituted 10% of the student's final grade. This credit was received by student solely on the basis of effort. An exam covering a significant number of conceptual questions was administrated at the conclusion of the initial phase.

The JiTT method recommends that students submit their completed reading assignment prior to class. However, such a task would hardly be in practical due to local constrains. Alternatively, the instructor used an alternative protocol from the Didactic Engineering methodology [17].

The students' completed assignments were received at the beginning of, rather than prior to, class. To compensate for this discrepancy, in preparing the lecture, the instructor predicted probable difficulties in assignment completion, based on teaching experience and current literature. This strategy, viz., a priori analysis, is part of DE's second phase [17].

In accordance with the final stage of DE, viz., a posteriori analysis and validation, following each class, completed assignments were analyzed by the instructor and compared with the anticipated results. Drawing on this analysis, the

instructor began the next class with a review of content inadequately assimilated as evidenced by the completed assignments.

Guided by the PI method, at the beginning of class, each student received a set of four cards for use in the polling process. After a brief discussion of the reading assignments and supporting material, the lecture main topic was divided into subtopics, followed by conceptual questions selected to advance the students' critical reasoning. The questions and multiple-choice answers were adapted from books and websites related to the course. Each question covers a specific concept or a property to be discussed in class [14, 23-26].

Following the PI strategy, the instructor presents a brief explanation of the content and poses a conceptual question to initiate the polling process. Students respond to the question without consulting textbooks or any other external sources.

If 30% to 70% of students answer a given question correctly, peer discussion in small groups of approximately two to three students is initiated. The groups are assigned with the goal of confronting students with different answers. After about 4 minutes of group discussion, the instructor polls the class again, explains the correct answer, and presents the next component of the lecture.

On the other hand, if the initial poll indicates that less than 30% of the class answered the question correctly, the instructor briefly explains the concept further, using a different approach. Subsequently, the instructor discusses each response to the question, guiding them to analyze them appropriately and thus arrive at the correct answer.

In the case where the rate of correct answers exceeds 70%, the instructor may elect to re-poll the class, following a peer group discussion as previously described, rather than simply moving on to the next topic. When this route is taken, the percentage of correct answers in the second poll generally surpasses 90%. This clearly indicates that the class has generally assimilated the lesson and there is no need for further clarification.

Student evaluation was performed continuously throughout the course. Student grades were based on reading assignments, class participation and the post-test. To validate the evaluation of the PI methodology, the test content was identical to that of the pre-test administered at the course's onset. Comparison of the results of the pre- and post-tests yields an accurate analysis on the progress of a student's knowledge and the success of the instructional method.

IV. RESULTS

In this section, the results obtained from the implementation of Peer Instruction during the initial phase of a university course in linear algebra are presented and analyzed.

A. Conceptual Questions

During the initial phase of the linear algebra course, a total of 20 conceptual questions were posed. To build student confidence and motivate them to participate in class, the difficulty level of the questions was gradually raised. Student responses were compiled on a worksheet for future analysis.

Of the 20 conceptual questions posed in this period, only 3 fell below the 30% threshold for correct responses in their initial poll. On the other end of the spectrum, 6 questions exceeded the 70% bound. Thus 55% of the questions fell within the 30% to 70% of range of correct responses sought by the PI method in their first round.

Review of responses indicated that questions involving matrix multiplication properties generated considerable doubts and discussion among students. Table III exemplifies one of those questions. Its initial polling generated a correct response rate of just 10%. An analysis of each potential response was carried out. Most students did not distinguish between the rules governing matrix multiplication and those applicable to the arithmetic multiplication of real numbers. This is a basic anticipated ability, as noted in Table I, S3. The question prompted a particularly stimulating discussion among the class, intensifying student's buy-in and motivation for active, collaborative participation in the course.

Student collective engagement in solving problems was not limited to this question. Indeed their increasing integration in addressing all questions was evident throughout the e period studied. Within a stimulating atmosphere, it was common to witness students attempting to convince their peers that their responses were correct. The increase in correct responses after discussion is illustrated in Fig. 2.

Peer discussions reflected progressive improvement in the rate of correct answers, as students became more confident in explaining their ideas to one another. A cooperative atmosphere pervaded the classroom.

B. Reading Assignments

In the initial phase of the course seven reading assignments covering matrices, linear equations systems, vectors, lines, and planes equations were completed.

Each assignment began with the question: "What did you find difficult or confusing about the reading? If nothing was difficult or confusing, what did you find most interesting?" This helped the instructor identify the principal challenges facing students.

Despite expected previous knowledge concerning these topics, students encountered substantive difficulties as evident in their completed pre-class assignments. A potential contributing factor could well be deficiencies in abstract mathematical reasoning.

TABLE III. CONCEPTUAL QUESTION ON MATRIX PROPERTIES. (correct answer :d)

- If a square matrix A is such that $A^2 - 4A^3 = 0$, then,
- a) $A^2(1 - 4A) = 0$
 - b) $A = 0$ or $A - 4A^2 = 0$
 - c) $\frac{A^2}{A^3} = 4$
 - d) none of the above.

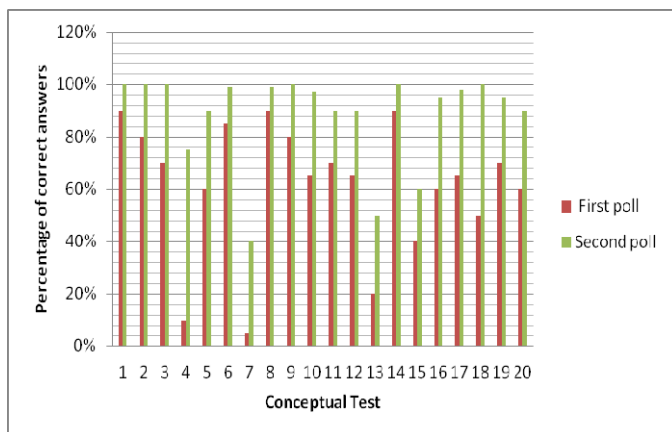


Fig. 2. Percentage of correct answers before and after discussion.

In this regard, particular attention should be accorded a question testing math proof testing ability presented in Table IV (see also, Table I, S7). An overwhelming majority of 90% of students failed to find the correct solution. In light of this result, the instructor provided another explanation of the concept, using a different approach, but not providing the solution. The question was then resubmitted as a reading assignment. In this second round, 75% of the students answered the question correctly. To re-enforce the learning experience, the instructor asked a student to present their solution on the blackboard. Students reacted quite positively.

C. Assessment of Student Learning

The diagnostic pre-test was administered to 60 students (85% of all enrolled students) on the first day of class. The test, described in Table V, consisted of 10 statements covering the secondary-school level concepts integral to understanding linear algebra. Students were asked to rate each statement as follows: T (true), F (false), DC (unknown content), NE (never studied) or NC (have studied content but cannot solve) content). For the purposes of this analysis, the last three designations were regarded as blank responses.

The data, depicted in Fig. 3, indicate that nearly 65% of students missed or did not know the answers of the statements, indicated a low-level of previous knowledge of these critical concepts. None of the questions produced a correct response rate above 57%. For the most essential topic, i.e., vectors and lines, only 19% of the students provided correct answers.

The same questions used as the diagnostic pre-test were given as the post-test at the end of the study period. A total of 58 students took both tests, and their aggregate data were used to compare student performance in the pre- and post-tests.

TABLE IV. READING ASSIGNMENT WITH VERY HIGH FAILURE RATE

Given a square matrix A and λ a scalar. Show that if and only if $Ax = \lambda x$ for some vector

TABLE V. PRE-TEST APPLIED IN A STATEMENT FORMAT

Question	Concepts	Statement	Goal ^a
1	Transpose matrix	The transpose of a lower triangular matrix is a lower triangular matrix.	S1
2	Multiplication of matrices	The product of the matrices $A(2 \times 3)$ and $B(3 \times 2)$ is a square matrix 2×2 .	S2
3	Properties of the matrix product	If a square matrix C is such that $C^2 - C = 0$, then $C(C-1) = 0$.	S2;S3
4	Inverse matrix	If A is an invertible matrix, then $A^{-1} = 1/A$ where I is the identity matrix.	S3;S5
5	Determinant	$\det(AB) = \det(BA)$, where A and B are square matrices.	S5
6	Geometric interpretation of a linear system	A linear system of two equations and two variables does not have solution when their graphs are parallel lines.	S4
7	Linear system	A linear system of three equations and five variables has solution.	S4
8	Vector	The length of every vector is a positive number.	S6
9	Line	The intersection between two planes is a line.	S6
10	Plane	The intersection of three planes cannot be a single point.	S6

^a Goal Learning according to Table I.

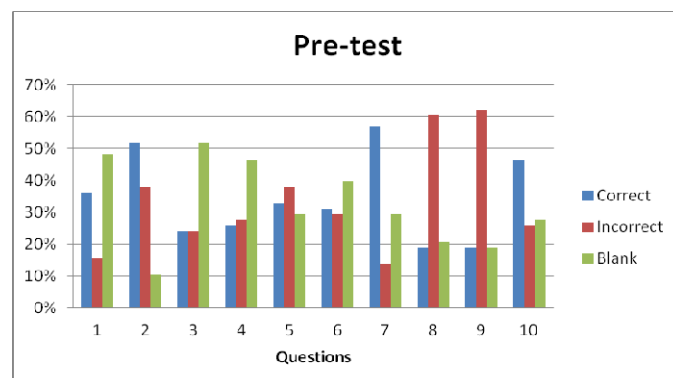


Fig. 3. Answers given to pre-test.

Fig. 4 portrays the rate of correct answers in the pre- and post-tests. It shows a significant post-test increase in correct responses for each question. Question 4, e.g., generated a 60% increase in its correct response rate. In regard to vectors and line equations, the most critical questions in the pre-test, post-test responses represented increases in correct responses rates of 38% and 33%, respectively.

The statistic t-test was used to determine whether there was a significant difference in students' pre-test scores, prior to the course's onset, and their post-test scores, following the initial phase of their instruction. As shown in Table VI, the p-value is 0.000 and t is 13.380. Since $p < 0.05$, the results are statistically significant. In other words, there was a significant increase in average score in student performance.

TABLE VI. MEAN ANALYSIS OF PRE- AND POST- TEST

	N (sample)	Mean	Std Deviation	t-test ^a	Sig (2-tailed)
Pre-test	58	3.293	1.5448	-13.840	.000
Post-test	58	6.638	1.4228		

^a. Result obtained using SPSS software.

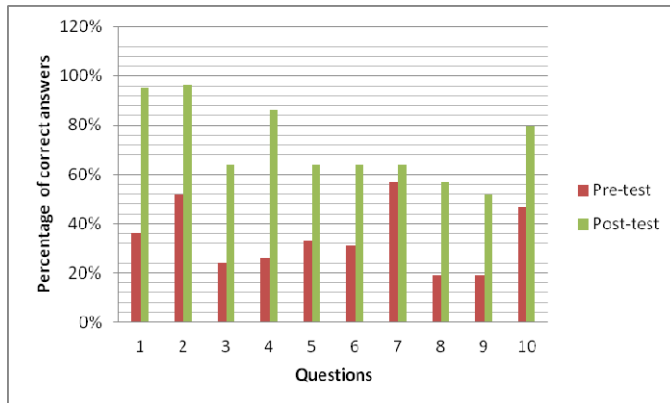


Fig. 4. Frequency of correct answers of pre and post tests.

Fig. 5 illustrates the overall result of students' performance in the pre-test and in the post-tests taking into account the frequency of the total number of correct, incorrect, and blank responses for each question.

The results of this comparison show a considerable improvement in student performance. As illustrated by Fig. 5, there was a 38% increase in the number of correct responses, a 6% decrease in incorrect responses, and a 31% decrease in the number of blank responses. The latter figure demonstrates the significant growth in knowledge acquired by students in the linear algebra course using the Peer Instruction methodology.

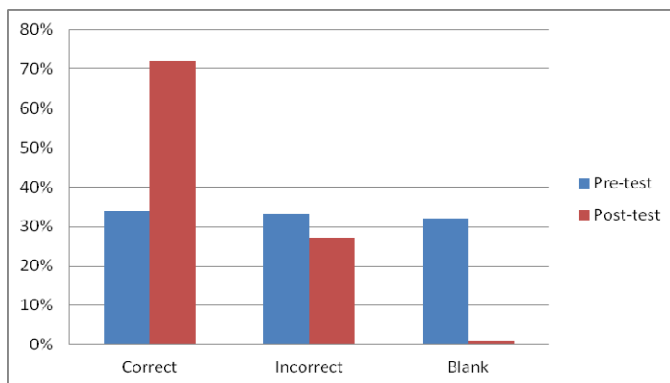


Fig. 5. Aggregate test results

V. CONCLUSION

Students were constantly encouraged to participate in class and share with others their solutions to the questions and the manner in which they arrived at them. Their positive response to such encouragement and their active participation enabled them to enrich their understanding of critical concepts in linear

algebra and to discuss them with confidence with their peers, thus contributing to their educational progress.

The results further demonstrate that the Peer Instruction methodology contributes to students' development of their abstract thinking capacities and facilitates collaborative learning, skills which will better equip them for their professional careers. This stands in contrast to the record of traditional approaches to education that too often regard students as passive recipients of infused content.

Research covering the methodology should continue to be developed to systematize its classroom application. In this regard, in a forthcoming work, the authors will present further analysis of the results noted herein and conduct a study of more complex conceptual questions. In addition, an evaluation of PI's application throughout the entire course will be undertaken and the perspective of students to this innovational instructional methodology will be analyzed.

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An Integrated Curriculum for Internet of Things: Experience and Evaluation

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Abstract—While most universities have courses in computer networks, embedded systems, and other related topics, few have courses dedicated to the uprising area of the Internet of Things (IoT). During the Fall quarter of 2014, Santa Clara University offered a graduate-level course on Internet of Things, whose curriculum was designed using an integrated approach in order to reflect the inter-disciplinary nature of the topic. The course composes of a series of lectures, which are taught by the instructor and guest lecturers, and a laboratory component.

In this paper, we will first define the description and the learning outcomes of the course, followed by our design rationale. We will then present the curriculum in details, and show the weekly schedule. We will also include a list of reference materials used in the course for easier adoption. Since the course is accompanied by a series of hands-on laboratory projects to enrich the learning experience, we will describe the design and development projects in details, including the vehicles used and the assessment criteria. Finally, we will present the feedback and comments received from the students as a form of initial evaluation of the performance of the course.

I. INTRODUCTION

The Internet of Things (IoT) has become the most hyped technology entering 2014, and according to Gartner Inc. [1], there will be nearly 26 billion devices on the IoT by the year 2020. The vision of the IoT has evolved due to a convergence of multiple technologies, ranging from wireless communication to the Internet and from embedded systems to micro-electromechanical systems (MEMS). This means that the traditional fields of embedded systems, wireless sensor networks, control systems, automation (including home and building automation), and others, all have contributions to enable the IoT [2]. The Internet of Things is also expected to have at least five to ten years before reaching “plateau of productivity,” and more and more universities are interested in offering courses on this subject (Figure 1).

However, while most universities have courses in computer networks, embedded systems, and other related topics, few have courses dedicated to the uprising area of this uprising area. During the Fall quarter of 2014, the author designed and the Department of Computer Engineering at Santa Clara University offered a graduate-level course on Internet of Things, whose curriculum adopted an integrated approach to reflect the inter-disciplinary nature of the topic. The course composes of a series of lectures, which are taught by the author as the principal instructor, and by some guest lecturers from the industry. The course also has a laboratory component.

The remaining of this paper is organized as follows: we will

first outline the basic description and the learning outcomes of the course, followed by the curriculum in details. We will also show the weekly topic schedule, and include a list of reference materials used in the course for easier adoption. Since the course is accompanied by a series of projects to enrich the learning experience, we will describe the design and development projects in details, including the tools used and the assessment criteria. Finally, we will present the feedback and comments received from the students as a form of initial evaluation of the performance of the course.

II. BASIC COURSE INFORMATION

In this section, we shall present the basic information about the course, which includes the catalog description of the course, its learning outcomes, and textbook and reference materials used.

A. Course Description and Learning Outcomes

The following course description is excerpted from the syllabus and was presented to the students on the course catalog:

This course introduces the design principles of the Internet of Things (IoT) and their device and infrastructure-related architectures, technologies and protocol frameworks that aimed at enabling the formation of highly distributed and ubiquitous networks with seamlessly connected heterogeneous devices. Student will learn to design and analyze such networks in order to support the development of intelligent services with given performance requirements in a variety of application domains. In particular, students will learn about the major architectures and paradigms for the Internet of Things, and protocols at the different levels of the IoT stack and also will learn to map those concepts with the OSI model by means of access layer (including sensor, vehicular and cellular networks for machine-to-machine communication) and network layer (with particular emphasis on IPv6-based solutions), and analyze their performance. The course will also introduce technologies and protocols at the service and application layers, which enable the integration of embedded devices in web-based, distributed applications. Students will get the notions for service creation, customization, execution and deployment in distributed IoT heterogeneous environments.

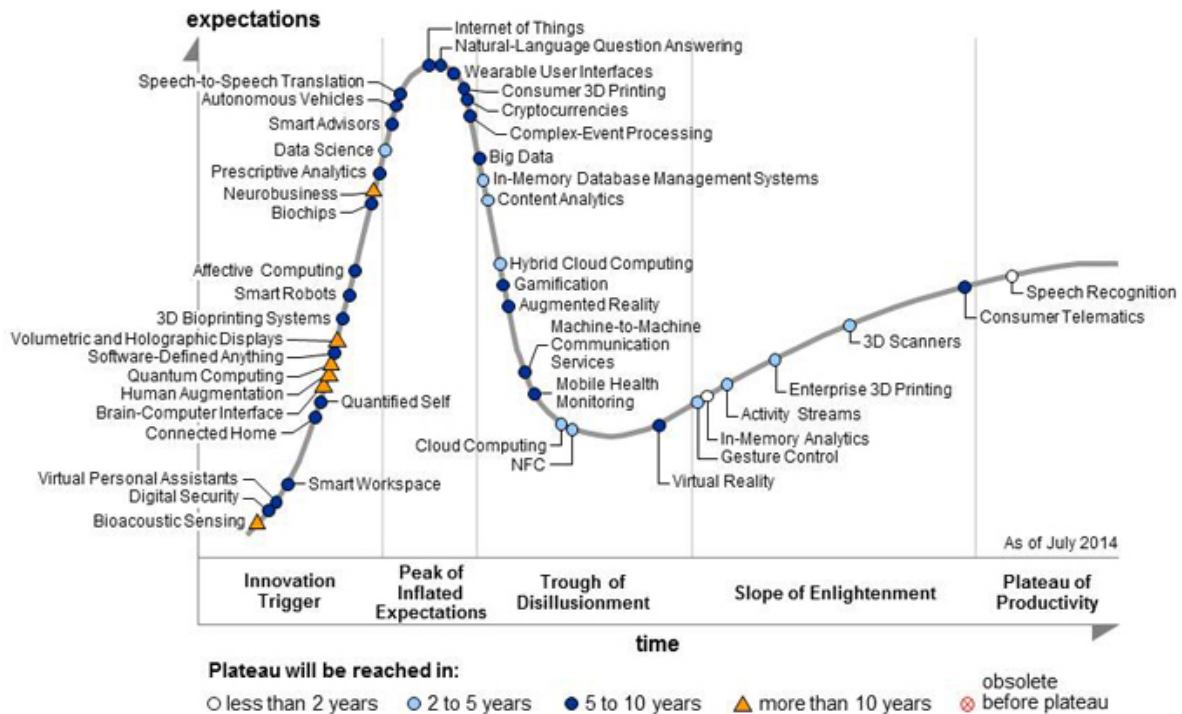


Fig. 1. Hype cycle for emerging technologies, 2014, according to Gartner Inc.

As a graduate-level topic course, conventional assessment vehicle may not be suitable to properly assess the learning outcome of the students. Besides, a significant portion of the learning outcomes were put on “design,” which calls for programming and implementation projects. In addition, it is very important to prepare graduate students on their literature survey skills and their academic writing skills, so after considering all these factors, we adopted the following grading scheme:

- A midterm written exam: 20%
- Programming project: 20%
- Industrial design project: 25%
- A survey paper: 35%

In order to better manage the instructions and facilitate the assessment, we also identified a set of learning outcomes for the course using techniques presented in [3] and shown to the students for their references:

Upon completion of this course, students should be able to:

- 1) *Characterize the Internet of Things (IoT) and enumerate its distinctive characteristics.*
- 2) *Demonstrate understanding of IoT and major machine-to-machine (M2M) communication protocols.*
- 3) *Demonstrate understanding of network layer support of IoT.*
- 4) *Design solutions for integrating smart objects into IoT framework(s).*

5) *Design IoT services and evaluate and analyze performances of IoT systems.*

Santa Clara University runs the quarter system, and there are ten weeks in each quarter. The week-by-week topic of coverage is presented in Table I:

TABLE I. WEEK-BY-WEEK LIST OF TOPIC FOR THE IoT COURSE AT SANTA CLARA UNIVERSITY

Week	Topic
1	Introduction to Internet of Things (IoT): Review of networking fundamentals.
2	Introduction IPv6: Motivations and current status. Structure of the IPv6 protocol and addressing and prefix notation. Introduction to Scala.
3	IP for Smart Objects: motivation and main challenges. IEEE 802.15.4.
4	Introduction to OpenIoT: Open Source Platform for the Internet of Things and Services.
5	RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks.
6	6LoWPAN architecture. Issues in determining IPv6 links in LLNs and illustration of the undetermined link-addressing model. IPv6 addressing in 6LoWPAN.
7	Prototyping embedded devices and physical designs on IoT.
8	ZigBee: Architecture, device profile, and applications.
9	The Constrained Application Protocol (CoAP): features, interaction model, messages and request/response sub-layers, packet format.
10	Issues on designing of a complex IoT architecture: security, micro- and macro-mobility, and proxy communications.

Each week students will be assigned readings to the topics of that weeks, and programming and industrial projects are assigned in between. The course readings assigned had a significant impact on the students’ preparedness to work on their final survey paper.

B. Textbooks and Reference Materials

1) *Books*: Internet of Things is really a new topic from a coursework perspective, so there are not a lot of established textbooks in the area. Due to this reason, the course did not have a required textbook, and instead, we listed some reference books that are discussing the latest trends of Internet of Things to the students. Among them, McEwen and Cassimally [4] and Hersent *et al.* [5] were most often referred to as a general competency text, while Hagen's book on IPv6 [6] is the *de facto* reference when the topic was discussed. The course also required students to work on projects using *Scala* (more details on projects later), so the *Scala* book by Odersky *et al.* [7] becomes another important reference book for the students. Other useful reference books include the books by Vermesan and Friess [8], [9] and Bassi *et al.* [10].

2) *Journal and Conference Articles*: Exposing students to academic writing is also an important component of a graduate-level course. To supplement the lack of textbooks, we have identified several survey and position papers on IoT ([11], [12], [13], [14], [15]), and some design and framework papers on the topic ([16], [17], [18]). In addition, papers on the topic correspond to the weekly schedule are also assigned as referencing materials to supplement the lectures.

III. COURSE ACTIVITIES AND ASSESSMENT

Each week the primary course activities were lectures. A written midterm exam was given on the fifth week of the course to test the students' foundation knowledge about Internet of Things. In addition to the midterm exam, three more vehicles were used to assess the students' competency in the topic, and we will describe each of them in this section.

A. Programming Project

Programming projects are smaller scale, class projects requiring students to implement and realize Internet of Things components. On the cloud platform level, Internet of Things are going to be dealing with a large number of devices, so we chose to require students to use the programming language *Scala* as the language for their projects. *Scala* was designed by Martin Odersky at the École Polytechnique Fédérale de Lausanne (EPFL) beginning 2001. It is an object-functional programming language for general software applications, which has full support for functional programming and a very strong static type system. This allows programs written in *Scala* to be very concise and thus smaller in size than other general-purpose programming languages. Many of *Scala*'s design decisions were inspired by criticism of the shortcomings of Java [7]. The name *Scala* is a portmanteau of "scalable" and "language," signifying that it is designed to grow with the demands of its users [19].

The project we asked the students to build is a user interface to register, manage, and control the behavior of different sensors, and the application is running on a cloud server. The criteria of assessing the registration service project include how scalable and how robust the design and implementation are, as well as how user-friendly and easy-to-use the interface is. Through this exercise students are exposed to the design of the Internet of Things frameworks, and prepare application-level server processes to run on these frameworks.

B. Industrial design project

Another major component of the course is an industrial design project. It is a large-scale design project partnering with two Silicon Valley-based company, Dew Mobility and ARM, as well as EU-based OpenIoT project [20]. Students were instructed to build industrial-grade projects using the equipment and the design requirements from the aforementioned groups, and they were given a theme "Assisted Living" to build their Internet of Things applications upon. Each group of three to four students were given five weeks to design and implement their project, and they are required to submit a proposal with a schematic during the first week and a final report by the end of the project. Students were also required to give a formal presentation to the industrial partners.

C. Survey Paper

Each student was required to write a survey or tutorial paper on an Internet of Things topic of their choice, with the approval of the instructor, due by the end of the quarter. It was emphasized to the students that a survey or tutorial paper is not the same as a white paper or product review, and the main content of the paper should follow the guidelines listed below:

1) Introduction

- Discuss the background
- Summarize the surveyed research area and explain why the surveyed area has been studied.
- Summarize the classification scheme you used to do the survey.
- Summarize the surveyed techniques with the above classification scheme.

2) Survey details

- Present the surveyed techniques using the classification scheme in details. The use of tables and figures are recommended. It should be noted that tables and figures are NOT a substitute of the descriptive text.
- Identify the trends in the surveyed area. Give evidences for your decision.

3) Conclusions and possible future work

- Summarize the conclusions of your survey.

4) References

- List all the citations referenced in your paper. Points will be deducted for each dangling reference (i.e., the reference not cited in the main text).
- The final paper should be formatted using IEEE conference proceedings style using L^AT_EX.

We also made previously published student survey papers, either on Internet of Things ([12], [21], [22], [23], [24], [25]) or other related topics ([26], [27], [28]), available to students for their reference, so that they have a better idea about how a survey paper should be written.

IV. REFLECTION AND CONCLUSION

In this paper we presented our design of a new graduate-level course on Internet of Things, an emerging topic and yet

no proper curriculum was available. We have also provided a list of references for other instructors who want to adopt the syllabus. Most students enrolled in the course find the programming project and the industrial design project very interesting and most fulfilling, while the survey paper provided an opportunity for them to engage in formal research and literature survey. The overall experience of the students were positive.

A similar version of the course is being offered by the Computer Science Department of California Polytechnic State University, San Luis Obispo, during spring of 2015. All the industrial partners continue to support the course the way it was first offered, and made improvement to some of the materials based on students' feedback from the last offering. Further evaluation and assessment information will be available once the course concluded.

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Using an Interactive Animated Tool to Improve the Effectiveness of Learning CPU Scheduling Algorithms

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Abstract—CPU scheduling is one of the most important topics in operating systems courses. However, the main problem in learning CPU scheduling from textbooks is that textbooks usually simplify the illustration of CPU scheduling algorithms by using an unrealistic process execution model. They also do not give concrete examples when discussing complex algorithms. As a result, students are not able to gain insight into exactly how the algorithms work in real-world operating systems. To address this problem, the author developed an interactive Java-based software tool that uses graphical animation to convey the concepts of various CPU scheduling algorithms for a single CPU. While many existing animation tools were designed to be closely aligned with the content in traditional operating systems textbooks, this tool is uniquely designed and different in a number of respects. In this paper, the impact of the tool on student learning is measured, analyzed and discussed in detail. The tool has been used in two sections of the operating systems course at the author's institute, and has demonstrated effectiveness in assisting student learning of CPU scheduling algorithms.

Keywords— *Educational Software; Animation Tool; Computer Science Education; CPU Scheduling Algorithms; Operating System*

I. INTRODUCTION

Modern general-purpose operating systems allow multiple processes to coexist in the systems. In a single CPU system, only one process can be running on the CPU at any one time. When more than one process is ready to run, the operating system must decide which one is to run first and for how long. The part of the operating system that is responsible for making this decision is called the scheduler and the algorithm it uses is called the CPU scheduling algorithm. A large number of CPU scheduling algorithms were designed in the past especially in the early days of operating system development, and several of them are described in operating system textbooks [1]-[7]. However, the main problem in learning CPU scheduling from a textbook is that textbooks usually simplify the illustration of CPU scheduling algorithms by using an unrealistic process execution model. They also do not give concrete examples when discussing complex algorithms that use more than one scheduling algorithm such as Priority Scheduling and Multilevel Feedback Queues. As a result, students are not able

to gain insight into exactly how the algorithms work in real-world operating systems.

To address this problem, the author developed an interactive Java-based simulator that uses graphical animation to convey the concepts of various CPU scheduling algorithms for a single CPU including First-Come, First-Served (FCFS), Round-Robin (RR), Shortest-Job-First (SJF), Shortest-Remaining-Time-First (SRTF), Priority Scheduling, and Multilevel Feedback Queues (MLFQ) algorithms. The simulator was designed based on knowledge gained from experiences in implementing a couple of CPU schedulers in the BSD kernel [8, 9]. The simulator is unique in a number of respects. First, it uses a more realistic process execution model — the execution of a process consists of alternating CPU bursts and I/O bursts, as opposed to a simplified model used in textbook examples — only one CPU burst per process. Through a graphical user interface of the simulator, the user can configure several sets of processes easily and use them in observing simulations of various CPU scheduling algorithms. Second, the simulator graphically depicts each process' state versus time. The state of a process describes the current activity of that process such as “the process is waiting for an I/O operation to complete” or “the process is currently using the CPU”. Various events can cause a process to change states; the simulator shows these events. Using this representation, it becomes much easier to understand what is going on inside the system, why, at any given time, some processes are candidates for a CPU allocation and some are not, and why the currently running process can or cannot continue to use the CPU. Third, the simulator allows the user to practice and test his understanding of the concepts studied in two ways. The first is by making a prediction about which process will be allocated the CPU next and why, and the second is by making his own scheduling decisions and receiving immediate feedback.

The critical question is whether the simulator is effective in aiding students in learning CPU scheduling algorithms? An opportunity to measure its usefulness in two sections of the operating systems course at the author's institute was taken. In this paper, the impact of the simulator on student learning is measured, analyzed and discussed in detail. The result of the statistical analysis using a t test to compare the means indicated

that using the simulator does increase student performance in a statistically significant way.

The remainder of this paper is organized as follows: section 2 discusses related work, section 3 gives a brief overview of the simulator, section 4 evaluates the simulator's impact on student learning, section 5 discusses the evaluation results, and section 6 draws some conclusions.

II. RELATED WORK

In this section, some animation tools for learning CPU scheduling algorithms that others have developed are discussed.

English and Rainwater [10] developed several animations using Adobe Flash and used them as part of their lecture in an operating system course. Among these animations, four of them are used in teaching FCFS, RR, SJF, and Priority Scheduling algorithms. The animations are also accessible through the web [11] for anyone to use. However, the user is not allowed to create his own set of processes or set scheduling parameters like time slice. In other words, the predefined set of processes and the predefined scheduling parameter are used, and the same animation plays over and over again.

The CPU scheduling simulators developed by Tran [12] and Ham [13] support all the algorithms the author's simulator supports except the MLFQ algorithm. Unlike the tool developed by English and Rainwater, both of these tools let the user create a personal set of processes. However, the tool developed by Ham is more flexible, because time slice in the tool developed by Tran is program coded and taken as 1 or 4 for each set of processes.

The animations displayed by the above tools were designed to be closely aligned with the content in traditional textbooks about operating systems. Therefore, all the above tools use the simplified process execution model similar to those found in textbooks, that is, each process consists of only one CPU burst. Since tradition textbooks show the result of each scheduling example using a Gantt chart, the above tools also use a Gantt chart to animate which process is using the CPU at what time. This approach makes the simulation results look very similar to the results of scheduling examples in textbooks.

The MLFQ Scheduling Algorithm Simulator [14] is a tool that supports only one scheduling algorithm, as the name implies. To the author's knowledge, this simulator is the first tool that attempted to use a more realistic process execution model, that is, it allows each process to alternate CPU bursts with I/O bursts, in a simulation. While the author's simulator allows the user to set the CPU and I/O bursts of a process to any value, the MLFQ Scheduling Algorithm Simulator fixes all the I/O bursts of a process to one value. The MLFQ Scheduling Algorithm Simulator displays animation using Gantt charts for both CPU and I/O activities. However, it reports I/O usage in a composite Gantt chart with little hint as to how multiple simultaneous I/O requests are handled. This can confuse the user. In other words, the Gantt-chart approach is not appropriate to represent the animation when the execution of a process consists of alternating CPU bursts and I/O bursts. Rather than focusing on the resource usage as the Gantt-chart approach does, the author's simulator focuses on

the processes' states, how long processes are in each state, and the events that cause them to change their states. Using this approach, the user will be able to gain insight into exactly how the algorithms work, that is, the user will be able to understand what is currently happening to the processes and why the currently running process can or cannot continue to use the CPU. Also, the author's simulator gives the user the choice of sharing I/O devices with FCFS queues or using unique I/O devices for each process. In addition, the author's simulator animates I/O activity to help the user understand the specific outcome for multiple simultaneous I/O requests.

Recently, a tool called AnimOS CPU Scheduling Simulator [15] has been developed. This simulator supports all the algorithms the author's simulator supports. It also allows each process to alternate CPU bursts with I/O bursts. Although it is the newest tool, it does not give the user as much flexibility to create a personal set of processes as the author's simulator does. That is, it allows the user to set all the CPU bursts to a single value and all I/O bursts to a single value. Although, the AnimOS CPU Scheduling Simulator also gives the user an option to specify a range of values, it randomly assigns a value in the range to a CPU burst or an I/O burst of a process during the simulation. This makes it very hard for the user to be able to predict what will happen at any one point of time during the simulation. The AnimOS CPU Scheduling Simulator animates how each CPU scheduling algorithm works in a somewhat similar manner to the author's simulator. In the author's opinion, the author's approach or a similar one is most appropriate way to present the animation when a more realistic process execution model is used.

Finally, none of the existing tools provide a similar functionality as the author's simulator that allows the user to make a prediction about which process will be allocated the CPU next and why and to make his own scheduling decisions.

III. OVERVIEW OF THE SIMULATOR

In this section, the implemented simulator is briefly described, in order to provide sufficient background for the paper. The detailed description of the simulator can be found in [16]. The simulator is written using Java 6 and has two operating modes: simulation and practice modes. Each mode is briefly described below.

A. Simulation Mode

Fig. 1 shows two snapshots of the simulator during a simulation in simulation mode. Within a simulation-mode tab, the user can select which algorithm to be animated through a drop-down list box located in the top left section. For each selected algorithm, the predefined set of processes and the predefined scheduling parameters will be loaded so that the user can start watching the animation immediately. The user can modify the predefined set of processes or create a new set of processes. Also, the user can view or change the predefined scheduling parameters.

The bottom area of the front snapshot in Fig. 1 contains the buttons that allow the user to control the animation. The user can start and stop the animation whenever he wishes by clicking on the "Start" and "Stop" buttons. Alternatively, the user can choose to trace the algorithm step by step, in order to

understand the details of the algorithm, by repeatedly clicking the “Next” button. Note that the user can use this step-by-step function of the simulator to practice and test his understanding of the concepts studied. In this case, the user should predict which process will be allocated the CPU next and why before clicking the “Next” button.

The bottom half of the front snapshot in Fig. 1 shows the *display area* that accommodates the animation that demonstrates how the selected algorithm works. The left side of the display area is the *state-diagram view* which displays the different states in which processes can be at different times. A process can be in one of the three states: running, ready, and waiting. A process is in the running state if it is currently using the CPU. A process is in the ready state if it could use the CPU if it were available. A process is in the waiting state if it is waiting for some event to happen, such as the completion of an I/O operation, before it can proceed. The right side of the display area is the *timeline view* which displays a colored block for each unit of time a process spends in any state. The color of the block which corresponds to one of the colors in the state-diagram view is determined by which state the process is in. During the animation, various events may occur and cause a process to change its state. Details about the event can be viewed in the “Event Message” panel.

In the simulation of Fig. 1, a user-defined set of processes, which is summarized in the process table located under the drop-down list box of the algorithms, was used. The user-defined set of processes contains processes A, B, and C, all of which have the same priority of 2 and arrive at time 0. When two or more processes have the same priority, the simulator puts them in the ready queue for that priority in alphabetical order. Process A requests only one burst of 10 units of CPU time. Processes B requests a burst of 1 unit of CPU time, then blocks on I/O for 4 units of time, then requests a burst of 1 unit of CPU time, then blocks on I/O for 6 units of time, and then requests one last burst of 1 unit of CPU time. Process C requests a burst of 5 units of CPU time, then blocks on I/O for 4 units of time, and then requests one last burst of 3 units of CPU time. Note that processes B and C are using different I/O devices in this simulation. When I/O devices are shared among processes, they will be scheduled on a First-Come-First-Served basis.

In the simulation of Fig. 1, the MLFQ algorithm is selected. The MLFQ algorithm chooses a process to run from the highest-priority, non-empty ready queue. When more than one process is in such a queue, the RR algorithm is used to schedule among them. The MLFQ algorithm also varies the priority of a process based on its observed behavior. Therefore, the scheduling parameters of the MLFQ algorithm are the length of time slice and the conditions for increasing/decreasing a process’s priority. In this example, time slice is set to 3 time units and any process that has just returned from its I/O will have its priority raised by one. In the state-diagram view, the priority levels of the ready queues are displayed in front of the queues and the ready queue with

higher priority level is placed over the one with lower priority level. Since the maximum number of processes is limited to four, the maximum number of ready queues is four.

Fig. 1 gives two snapshots of this scenario. The front and the back snapshots are at time 15 and time 16 respectively. The state-diagram view of the front snapshot shows the state each process is in at the beginning of time 15. That is, process A is in the running state while processes B and C both are blocked in the waiting state for their I/O requests to complete. The timeline view shows that processes A, B, and C have been in the current states since time 11, 9, and 11, respectively. As reported in the “Event Message” panel, at time 15, two hardware interrupts have been generated indicating that the I/O operations requested by processes B and C have been completed, and the priorities of processes B and C have been raised to 4 and 3 respectively. At this point, process B becomes the process with the highest priority; therefore, it preempts the CPU from process A and runs next. Various events occurring at time 15 cause all the processes to change their states; the state-diagram view will show such transitions. As shown in the timeline view of the back snapshot, all the processes spend a unit of time in their new states.

B. Practice Mode

The user can open a practice-mode tab by clicking the “File” menu and then clicking “New Practice”. To reduce the time the user has to devote to learn how to use the simulator, a practice-mode tab has been designed to look as much like a simulation-mode tab as possible. The major differences between a simulation-mode tab and a practice-mode tab are as follows. First, there is no state-diagram view in a practice-mode tab. Second, the timeline view of a practice-mode tab does not contain the speed-control slider, but instead, it contains the “Display Answer” button. Third, the timeline view and the “Event Message” panel become editable so that they can be used as interfaces for the user to predict when and for how long each process is in a particular state and why it is in that state.

Since the timeline view is editable in practice mode, clicking the blocks under the timeline will change the color of the blocks. The user can predict which state each process is in for each block under the timeline by repeatedly clicking each block until the color corresponding to the predicted state is displayed. The color green, yellow, and red are used to represent running, ready, and waiting states respectively. This feature allows the user to visually predict which state each process is in for each block of time. The user can also predict why the processes are in the states he predicted by checking relevant checkboxes and filling in the missing information in the “Event Message” panel for each time.

At any time while in practice mode, the user can check whether his answer is correct or not by clicking on the “Display Answer” button, which causes the answers to be displayed in the timeline view.

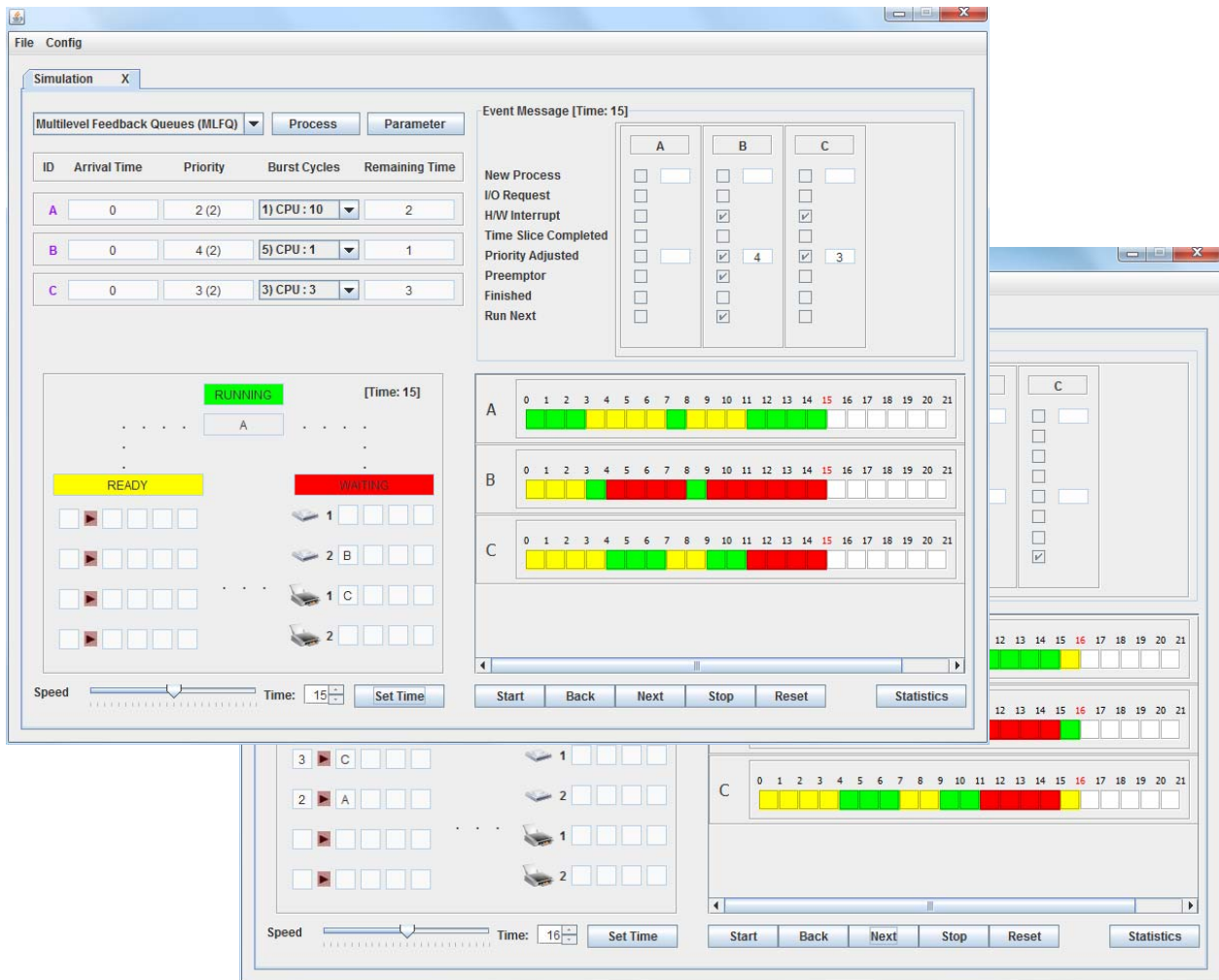


Fig. 1. Snapshots of the simulator during a simulation using the MLFQ algorithm.

IV. EVALUATION

The true usefulness of the simulator designed as a supplement to an operating systems course is in its effectiveness in aiding students in learning the concepts of CPU scheduling algorithms. The simulator was used in two sections of the operating systems course at the author's institute. The sample for the effectiveness study consisted of 37 students enrolled in one of the two sections of the operating systems course. Both groups of students took the operating systems course in the same semester but different sections. First, a section (control group) was randomly assigned to only use the textbook to learn CPU scheduling. The other section (simulator group) used the textbook and the simulator. The reason for selecting by clusters was to single-blind the control group to the simulator given to the other group. Once students were assigned to a group, all of the students were given a pretest; students who scored above twenty-five percent were excluded from the sample. The reason for excluding students was to block for students with some prior knowledge of CPU scheduling; six students were excluded for prior knowledge, one for withdrawing from the course.

After blocking for prior knowledge, nineteen students in one section ($n=19$) were in the textbook group (control group) that learned CPU scheduling only from the textbook. Eleven students ($n=11$) were in the simulation group (experimental group) that learned CPU scheduling from the text and through using the simulator. Students in both sections were given pretests and posttests. These tests assessed the same objectives but used different data. They consisted of basic and complex scheduling problems; complex scheduling problems involved using either Priority scheduling or MLFQ algorithm. Two experiments were conducted using basic and complex scheduling problems respectively and are discussed below.

A. Experiment 1

Our null hypothesis for the first experiment is that reading the textbook only and reading the textbook along with using the simulator will generate the same results — students in both groups will learn the basics at the same rate. First, all students were tested to establish a baseline. After that, the control group ($n=19$) was assigned to read the textbook over the next week while the simulator group ($n=11$) read the textbook and used the simulator during the same time. The two groups were then

retested on the same material with similar questions. The results are shown in Figs. 2 and 3. Fig. 2 shows the confidence intervals (CI) for the means of both groups. Fig. 3 shows the numerical summary for the two-sample t test outputted by Minitab.

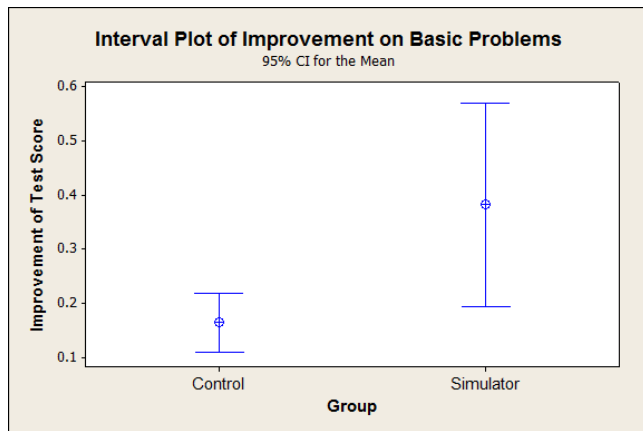


Fig. 2. The confidence intervals (CI) for the means of the control and the simulator groups in Experiment 1.

Group	N	Mean	St Dev	SE Mean
Control	19	0.163	0.112	0.026
Simulator	11	0.382	0.281	0.085

Difference = mu (Control) - mu (Simulator)				
Estimate for difference: -0.2191				
95% upper bound for difference: -0.0602				
T-Test of difference = 0 (vs <): T-Value = -2.48				
P-Value = 0.015 DF = 11				

Fig. 3. The numerical summary outputted by Minitab for the two-sample t test in Experiment 1.

When tested on basic problems, the control group had a mean improvement of 16.3 points out of 100 points whereas the simulator group had a mean improvement of 38.2 points, as shown in Fig. 3. When the improvement of the two groups was compared a p-value of 0.015 was calculated using a two-sample t test; with an alpha of 0.05, this means that the null hypothesis was rejected. The alternative, that the simulator group improved more than the control group on basic problems, was accepted. In Fig. 2, the data for the confidence intervals is graphed; the point estimate of the improvement was calculated to be 0.219 or 21.9 points on a 100 point scale. This

means that the simulator group improved about twice as much as the control group.

One area of interest was how well will students do at problems beyond the textbook? In other words, how well will students do the basic problems when the execution of a process consists of alternating CPU bursts and I/O bursts as opposed to the basic problems when the execution of a process consists of a CPU burst only? The data is displayed in TABLE I and in Fig. 4; from the table the simulator group outperformed the control group on average by 22 points out of 100. Although the simulator group did not improve as much when doing CPU and I/O problems as they did when doing CPU only problems; a two-sample t test generated a p-value of 0.015 which implies that the simulator helps students learn to solve more difficult problems better than just using the textbook.

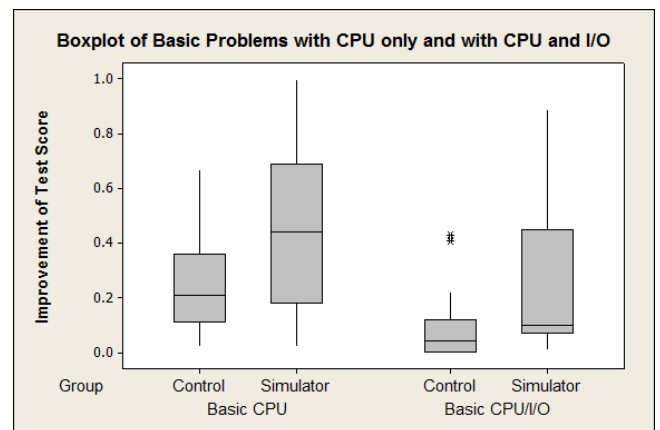


Fig. 4. The boxplots of the improvement of test score between the control and simulation groups when testing with the basic problems with CPU only, and when testing with the basic problems with CPU and I/O in Experiment 1.

B. Experiment 2

Our null hypothesis for the second experiment is that reading the textbook only and reading the textbook along with using the simulator will generate the same results — students in both groups will learn complex concepts at the same rate. First, all students were tested to establish a baseline. After that, the control group (n=19) read the textbook while the simulator group (n=11) read the textbook and used the simulator. The two groups were then retested on the same material with similar questions. The results are shown in Figs. 5 and 6. Fig. 5 shows the confidence intervals (CI) for the means of both groups. Fig. 6 shows the numerical summary for the two-sample t test outputted by Minitab.

TABLE I. DESCRIPTIVE STATISTICS: BASIC PROBLEMS WITH CPU ONLY AND WITH CPU AND I/O

Group	N	Mean	SE Mean	St Dev	Minimum	Q1	Median	Q3	Max
Control	19	0.1632	0.0256	0.1117	0.0200	0.1050	0.1150	0.2100	0.4250
Simulator	11	0.3823	0.0847	0.2810	0.0600	0.1050	0.3600	0.6650	0.9250

TABLE II. DESCRIPTIVE STATISTICS: COMPLEX PROBLEMS WITH CPU ONLY AND WITH CPU AND I/O

Group	N	Mean	SE Mean	St Dev	Minimum	Q1	Median	Q3	Max
Control	19	0.0947	0.0355	0.1548	0.0000	0.0000	0.0150	0.1450	0.5950
Simulator	11	0.493	0.118	0.390	-0.100	0.050	0.570	0.870	0.955

When tested on complex problems, the control group had a mean improvement of 9.5 points out of 100 points whereas the simulator group had a mean improvement of 49.3 points, as shown in Fig. 6. When the improvement of the two groups was compared a p-value of 0.004 was calculated using a two-sample t test; with an alpha of 0.05, this means that the null hypothesis was rejected. The alternative, that the simulator group improved more than the control group on complex problems, was accepted. In Fig. 5, the data for the confidence intervals is graphed; the point estimate of the improvement was calculated to be 0.398 or 39.8 points on a 100 point scale. This means that using the simulator helped students learn complex topics at a rate up to 5 times as fast as just using the textbook. It appears that this simulator helps students to apply what they read in the textbook to problems beyond the difficulty of the textbook examples.

Looking at TABLE II and Fig. 7, this data from the complex problems broken down between the problems when the execution of a process consists of a CPU burst only and when the execution of a process consists of alternating CPU bursts and I/O bursts. The data shows the limitations of studying just from a textbook. From the table, the simulator group outperformed the control group on average by 40 points out of 100 on complex problems. Also with the exception of a few outliers, the control group got zero on the complex problems with CPU and I/O bursts which shows a distinction between that group and the simulation group. This implies that the simulation group may have learned to adapt their learning to a variety of situations rather than rote memorizing a specific set of problems.

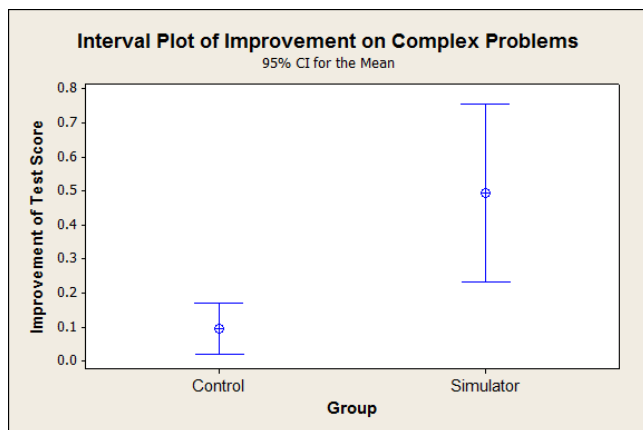


Fig. 5. The confidence intervals (CI) for the means of the control and the simulator groups in Experiment 2.

Two-sample T Test for Improvement on Complex Problems				
Group	N	Mean	St Dev	SE Mean
Control	19	0.0947	0.1548	0.0355
Simulator	11	0.493	0.390	0.118
Difference = mu (control) - mu (simulator)				
Estimate for difference: -0.398				
95% upper bound for difference: -0.178				
T-Test of difference = 0 (vs <): T-Value = -3.24				
P-Value = 0.004 DF = 11				

Fig. 6. The numerical summary outputted by Minitab for the two-sample t test in Experiment 2.

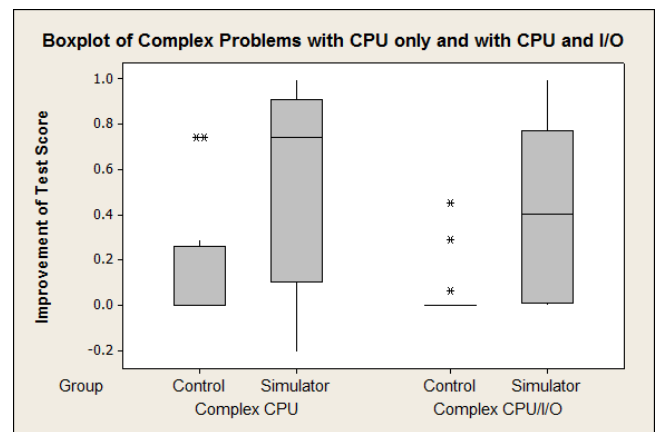


Fig. 7. The boxplots of the improvement of test score between the control and simulation groups when testing with the complex problems with CPU only, and when testing with the complex problems with CPU and I/O in Experiment 2.

V. DISCUSSION

In the past two decades, a number of visualization and animation tools have been developed and used in many areas of computer science education [17]-[20]. While the achievement of learning outcomes as a result of using visualizations and animations has been mixed, there is evidence indicating that carefully designed visualizations and animations can have beneficial learning outcomes. For example, engagement of the learners' attention [21]-[23] and the ability to control the visualization [24] appear to be key factors in building effective visualization and animation tools. Keeping these in mind, the simulator was designed with two operating modes: simulation and practice modes. In either mode, the user has control of the inputs. In simulation mode, the user controls the pace of the simulator such as the speed of simulation. In simulation mode, the user is encouraged to predict which process will be allocated the CPU next and why, and in practice mode, the user is asked to make his own scheduling decisions and receives

immediate feedback. Incorporating these research-based ideas — engagement and control — leads to greater student engagement, which results in deeper mastery of the course objective - understanding CPU scheduling.

Since other existing tools do not provide the level of engagement nor the degree of control like the author's simulator does, learning CPU scheduling algorithms using those tools might not be as effective.

VI. CONCLUSION

As an aid to the study of CPU scheduling algorithms for a single CPU, the author developed an interactive Java-based simulator that demonstrates the concepts of various CPU scheduling algorithms through animation. The author designed the simulator based on knowledge gained from experiences in implementing a couple of CPU schedulers in the BSD kernel and from research-based ideas in building effective animation tools — engagement and control. There are two operating modes for the simulator; the first is simulation mode and the second is practice mode. In simulation mode, the user can watch the simulation straight through from the beginning until the end, or watch it step-by-step. The user can also use this step-by-step function of the simulator to practice and test his understanding of the concepts studied. In this case, the user would predict which process should be allocated CPU next and why before moving to the next step. In practice mode, the user can predict when and for how long each process is in a particular state and why it is in that state through an easy-to-use graphical user interface, and check whether his answer is correct or not with the simulator at any time during practice.

The simulator was used in two sections of an operating systems class at the author's institute. A pretest and posttest were given to two groups of students — the group (control group) that learned CPU scheduling only from the text and the group (simulator group) that learned CPU scheduling from the text and through using the simulator. The pretests and the posttests consisted of basic scheduling problems and complex scheduling problems. The complex scheduling problems involved more than one scheduling algorithm such as Priority Scheduling and Multilevel Feedback Queues. When tested on basic scheduling problems, the simulator group improved a little more than twice as much as the control group. When tested on complex scheduling problems, the simulator group improved approximately 5 times as much as the control group. Therefore, the simulator appears to be effective in aiding students in learning CPU scheduling algorithms. The results also implied that the simulator helps students apply what they read in the textbook to problems beyond the difficulty of the textbook examples.

The current version (version 2) of the simulator will be made available to any interested instructor or student who sends a request by email.

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Another perspective for linear equations, matrices and the technological tools in learning

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Abstract—Matrices are important tools for many fields, and used in solving systems of linear equation. Technological tools are available to work with matrix operations, but still students avoid using matrices, specially in early stages. Moreover, they limit the use to solving linear equations. Using the field of electrical circuits, this paper introduces the advantage of looking at the systems of equations and solutions from other perspectives, thereby motivating students in the process of mathematical tasks. This approach is illustrated with examples.

I. INTRODUCTION

Application of matrices in solving systems of linear equations, has been in place for long time. Their use date back to the second, perhaps fourth century BC [1]. Applications are present in most scientific and engineering fields. Therefore, matrices are introduced in pre calculus books, for example [2].

But most students avoid matrices, mainly because of the tedious mathematical procedures for solving systems with three or more equations. Many books introduced MATLAB, Mathematica, or other software tools to work those systems. But then, again, fail in motivating students because, first, this requires the student to have tool available, and second the procedures usually focus in only solving the systems of equations.

Concerning availability of the tool, this is no more an excuse. Most graphical calculators have matrix capabilities that equate those of the above mentioned packages. Besides, students also have access to matrix calculations online [3].

But students need more motivation. One way of doing it is by showing applications where the advantage is highlighted not only by the easiness in equations' solving, but on how to set up the equations and see how this allows interpretations that facilitate the learning process, help them in simplifying steps, and so on.

To achieve this goal, it is necessary bring to the attention of students another way of looking at equations and matrix operations, that is, to adopt another perspective. This is precisely the goal of this paper.

No new theoretical results are presented. A previous work mentioned one of the techniques presented here for calculating two-port parameters [4]. This paper further extends the work in other ways. Specifically, by bringing up some properties

that have long been under appreciated in the sense that they are mentioned as mere properties.

I do not claim that the approach is original, since perhaps the reader has already used it, or find it quite obvious. Yet, my teaching experience indicates that it is not obvious for students, and neither for all practitioners. All I can say is that I have not seen elsewhere the approach taken here and used to motivate students. Namely, that of linking the properties with the settings of the equations and with the reading of the numerical results. This was one of the educational motivations behind [5].

This paper uses circuit analysis of resistive networks to illustrate the approach. But the perspective can be generalized to any field where systems of linear equations are used.

As a final remark, it should be emphasized that the author does not pretend to displace or diminish the importance of hand analysis in teaching. In fact, without theoretical fundamentals developed through these skills, the use of matrices becomes more a burden than a help.

II. MATRICES AND LINEAR EQUATIONS

Matrices and systems of linear equations are intimately associated. To simplify discussion and space, three variables are used for convenience in (1) without loss of generality. The system of equations

$$\begin{aligned}a_{11}x_1 + a_{12}x_2 + a_{13}x_3 &= b_1 \\a_{21}x_1 + a_{22}x_2 + a_{23}x_3 &= b_2 \\a_{31}x_1 + a_{32}x_2 + a_{33}x_3 &= b_3\end{aligned}\tag{1}$$

can be expressed in matrix form as

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix}\tag{2}$$

This form is abbreviated as

$$\mathbf{A} \mathbf{x} = \mathbf{b}\tag{3}$$

. Here the 3x3 matrix \mathbf{A} is the coefficient matrix, and \mathbf{b} the vector of “knowns”.

In abstract form, we denote an $m \times n$ matrix as $\mathbf{A} = [a_{ij}]_{m \times n}$, where a_{ij} is the general notation for the element in i -th row and the j -th column.

Observe that in expression (2), row i of \mathbf{A} shows the coefficients of the variables in the i -th equation, while column j shows the coefficients for variable x_j along the different equations. This remark, as trivial as it may seem, is not usually noticed by students, but is essential for the goals of this paper.

Another important remark, is that $\mathbf{A}\mathbf{x}$ alone, without the equal sign, is the set of linear combinations that constitute the left hand sides of (1)

The solution for (1) is expressed in matrix form as

$$\mathbf{x} = \mathbf{A}^{-1} \mathbf{b} \quad (4)$$

In the vector that results from this operation, row j is the solution for x_j . Another trivial but useful remark to consider later.

Up to this point, this is what is usually done in most basic undergraduate courses when it comes to use matrices. Now, let us exploit elementary matrix theory a little more to take advantage for applications.

A. Matrix operations and properties

Let us bring up known definitions and properties which are useful for our purposes. No demonstration is given.

1) *Multiplication of a scalar and a Matrix:* If b is a scalar, and $\mathbf{A} = [a_{ij}]_{m \times n}$, then the multiplication of the scalar by the matrix is defined as

$$b \mathbf{A} = \mathbf{A} b = [b a_{ij}]_{m \times n} \quad (5)$$

That is, every element in the matrix is multiplied by b .

2) *Multiplication of a Matrix and a vector:* The multiplication of the matrix \mathbf{A} and the column vector \mathbf{x} , which represents a set of linear combinations like that to the left of the equal signs in (1), can be expressed in another form as

$$\mathbf{A}\mathbf{x} = \mathbf{A}^{(1)} x_1 + \mathbf{A}^{(2)} x_2 + \dots + \mathbf{A}^{(n)} x_n \quad (6)$$

where $\mathbf{A}^{(m)}$ is the m -th column of the coefficient matrix \mathbf{A} and x_1, x_2, \dots are the elements of vector \mathbf{x} .

This property further justifies the previous observation that the columns of matrix \mathbf{A} are associated to variables.

3) *Multiplication of Matrices:* Let us express a matrix displaying its column vectors as

$$\mathbf{B} = [\mathbf{B}^{(1)} \quad \mathbf{B}^{(2)} \quad \dots \quad \mathbf{B}^{(n)}]$$

Then the matrix multiplication $\mathbf{A}\mathbf{B}$ may be done as

$$\mathbf{A}\mathbf{B} = [\mathbf{A}\mathbf{B}^{(1)} \quad \mathbf{A}\mathbf{B}^{(2)} \quad \dots \quad \mathbf{A}\mathbf{B}^{(n)}] \quad (7)$$

Combining the information from (6) and (7), it is possible to affirm that in a multiplication such as $\mathbf{A}^{-1}\mathbf{B}\mathbf{x}$ where \mathbf{x} is a vector, the columns of $\mathbf{A}^{-1}\mathbf{B}$ have already information necessary. This will be partial or complete depending on the vector elements.

Again, although the above mathematical results are well known [6], the above comment observing the relationship of columns with elements of a vector is important to read results according to our objectives. That is, the application of these

observations to make matrices attractive and more useful to students for applications.

III. APPLICATION TO A FIELD: LINEAR RESISTIVE CIRCUITS

Linear resistive circuits are used in this section to illustrate the use of the above properties. The approach is applicable to many other fields.

A. Proportionality

Let us start by associating well known properties of linear circuits to the operations. First consider circuits containing only one source, as illustrated in Fig. 1(a).

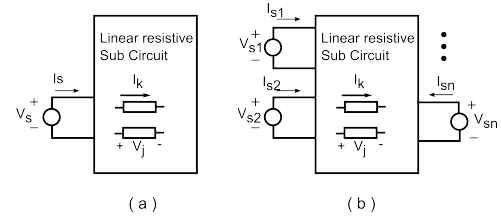


Fig. 1. a) One source circuit; b) Multiple sources circuit

Denote this source in general as z . It may be a voltage or current source. With the background that students already have from Algebra, it is easy to demonstrate early in a circuit course, that the circuit equations can be written in the form

$$a_{i1} x_1 + a_{i2} x_2 + \dots + a_{in} x_n = b_i z$$

In a very early demonstration, any matrix method used here would make use of sparse matrices, since most of the coefficients a_{ij} and b_i will be zero. This is the so called Tableau Formulation [7], and the variables are element voltages and currents.

The objective of presenting students with such theory at this point is not necessarily having a method of calculation, but to exploit the characteristics explained before, which for all purposes become useful even for analysis methods not involving direct work with equations but with other procedures such as parallel-series reduction. Later, the variables and coefficients will depend on the method used to set up the circuit equations. Variables x_j will depend on the method used, and may be unknown voltages, or currents, unknown node potentials, loop currents and so on.

Combining all equations, and because of (5), we can say that the system can be written in matrix form as $\mathbf{A}\mathbf{x} = \mathbf{b}z$, yielding the solution

$$\mathbf{x} = \mathbf{A}^{-1} \mathbf{b} z \quad (8)$$

As a consequence, we can state the following

Principle of Proportionality: In a linear resistive circuit with one source z , every voltage or current, x_j is of the form $x_j = k_j z$, where coefficient k_j does not depend on the source value z

Although it appears trivial, it is in fact a property that is exploited in textbooks, but without showing the relationship. Let us see how this result can be used.

First, it shows that linear resistive circuits satisfy the homogeneity principle for linear systems, which states the following:

Homogeneity Principle: In a linear system, if $x = f(z)$ then $f(kz) = kf(z)$

Hence, it provides a mathematical proof to a concept that is usually presented in axiomatic form in basic circuit textbooks.

But, there are also practical consequences from the numerical point of view. Let us state three interesting ones for students and practitioners:

Network functions: If the signal source in Fig. 1(a) is identified as an input, z_{in} (voltage or current), and a signal -voltage or current - is identified as an output x_{out} , then x_{out}/z_{in} is a network function. It is a transfer function if both signals are in different elements, and port function if both are in the source, with the relative directions shown in the figure.

These functions receive names such as equivalent resistance (V_s/I_s), equivalent conductance (I_s/V_s) and so on.

The principle of proportionality tells us that if the signal has a value of 1 A or 1 V, then the numerical value of the output is equal to the desired network function. This result provides a purely numerical method to find the function. Compare this result with the traditional teaching: "Insert an arbitrary source and solve for the output. Then divide by the source". Moreover, in the same process we can find *all* functions in just two steps.

Furthermore, if for some reason or other you have already done the calculations, the principle can be applied by directly dividing by the desired input.

Finally, unlike ideas that sometimes students have or are told, the source can be of any type. It is the division what matters!

Working symbolic and time function sources: When the source z is symbolic, that is, has no numerical value, the principle of proportionality states that we can assume a unit value, and simply multiply the result by z . Hence, no need to have symbolic algebra in your tool!

Also, for a source of the type $Kf(t)$, where K is a numerical constant, you make the source equal to K , and multiply the final result by $f(t)$.

Last but not least: From the point of view of calculations, the principle of proportionality means that for solving for one source value allows us to find the currents and voltages for any other source value. Also, changes in source value that are needed to adapt one signal to a specific result can be done without further circuit analysis.

We illustrate the above remarks with an example.

Example Assume that in a circuit with a 30 V source, using the terminology illustrated in Fig. 1(a), $I_s = 2$ mA, $I_k = 5$ mA and $V_j = 4$ V. Then for a symbolic source V_s , we have then $I_s = (2/30) \times 10^{-3}$ Vs, $I_k = (5/30) \times 10^{-3}$ Vs and $V_j = (4/30)$ Vs.

Here, we have divided by 30 to obtain the numerical value for a 1 V source, and then multiplied the symbolic Vs.

We keep further examples for the next section, where these approaches are combined with superposition.

B. Superposition

Now take a circuit with multiple sources, such as the one shown in Fig. 1(b). Again, in an early stage in a basic circuit course it can be shown that any equation of the circuit can be written as

$$a_{i1}x_1 + a_{i2}x_2 + \dots + a_{im}x_m = b_{i1}z_1 + b_{i2}z_2 + \dots + b_{in}z_n$$

All equations can be written then in matrix form as

$$\mathbf{A} \mathbf{x} = \mathbf{B}^{(1)} z_1 + \mathbf{B}^{(2)} z_2 + \dots + \mathbf{B}^{(n)} z_n = \mathbf{B} \mathbf{z} \quad (9)$$

where \mathbf{A} is the coefficient matrix of order $m \times m$, $\mathbf{B}^{(j)}$ is a column vector of order $m \times 1$.

Notice that if all z 's are zero, except z_h , then (9) reduces to

$$\mathbf{A} \mathbf{x}_h = \mathbf{B}^{(h)} z_h \quad (10)$$

which has the same form as (8).

From the practical point of view of numerical calculations, we see that solving (9) we have

$$\mathbf{x} = \mathbf{A}^{-1} \mathbf{B} \mathbf{z} \quad (11)$$

In this expression, $\mathbf{A}^{-1} \mathbf{B}$ has all the information concerning the individual contributions of the sources and thus what we need to obtain the desired results is there. The j -th column shows the contribution of source z_j . Therefore, multiplying by \mathbf{z} becomes a matter of choice in many applications.

If all or part of the sources are numerical, we can incorporate the value into the source. In vector \mathbf{z} , if multiplication becomes necessary, we use the value of 1 for that source. Thus, we can discriminate among the different contributions by simply assigning columns instead of additions in the setting of the equations. On the other hand, for symbolic sources, we use unit values, and for sources of the type $Kf(t)$ we can incorporate K in the column or not, as desired. Examples of application of these principles are given in the next section. For the moment, let us look at some theoretical amenities.

An immediate consequence of (9) is the following result:

Let x_j be a current or a voltage in a linear resistive circuit with sources z_1, z_2, \dots, z_n , then

$$x_j = k_{j1}z_1 + k_{j2}z_2 + \dots + k_{jn}z_n \quad (12)$$

where k_{jh} can be obtained by making all sources except z_h equal to zero.

Again, this becomes a formal proof that these circuits comply with the additivity property of linear systems:

Additivity Principle: In a linear system, if $x = f(z)$ then $f(k_1z_1 + k_2z_2) = k_1f(z_1) + k_2f(z_2)$

This is precisely why these circuits are said to be linear! It also provides a useful property:

Extended proportionality Let x_j be a current or a voltage in a linear resistive circuit with sources z_1, z_2, \dots, z_m , with

$$x_j = x_{j1} + x_{j2} + \dots + x_{jm}$$

where x_{jh} is the value that results when all sources except z_h are off. Then, for the set of values $\{k_1 z_1, k_2 z_2, \dots, k_m z_m\}$ the response will be

$$x_j = k_1 x_{j1} + k_2 x_{j2} + \dots + k_m x_{jm} \quad (13)$$

Let us illustrate this result with an example before proceeding to the next section.

Example A circuit has three sources: $V_1=2$ V, $I_2 = 4$ mA, and $V_3 = 1.8$ V. The response of interest is a current i_o . The following results are known:

- When I_2 and V_3 are turned off, $i_o = 2.8$ mA.
- When V_1 and V_3 are turned off, $i_o = 4.7$ mA.
- When V_1 and I_2 are turned off, $i_o = 6.5$ mA.

How can we express i_o as a function of the sources?

Solution: What we do is to express i_o as the sum of contributions without realizing the addition, normalize for unit input values and then multiply by the corresponding symbolic values:

$$i_o = \frac{2.8 \times 10^{-3}}{2} V_1 + \frac{4.7 \times 10^{-3}}{4 \times 10^{-3}} I_2 + \frac{6.5 \times 10^{-3}}{1.8} V_3$$

That is

$$i_o = 1.4 \times 10^{-3} V_1 + 1.175 I_2 + 3.61 \times 10^{-3} V_3$$

IV. EXAMPLES

The usefulness of proper setting up of equations will show hot interpretation of results are easier and faster. Not only time is saved, but also results are examined to bring up applications.

A. First example

For the circuit of Fig. 2, find the nodal voltages and the power generated by sources using superposition.

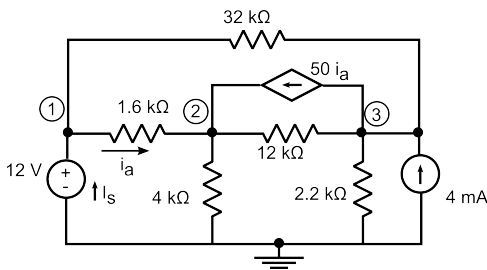


Fig. 2. Example using superposition

We can write the matrix equation separating the sources instead of writing one total value, already including the voltage source current I_s .

$$\begin{bmatrix} 1 & \frac{1}{1600} & \frac{1}{32000} \\ 0 & \frac{51}{1600} + \frac{1}{4000} + \frac{1}{12000} & -\frac{1}{4000} \\ 0 & -\frac{1}{4000} - \frac{50}{1600} & \frac{1}{4000} + \frac{1}{2200} + \frac{1}{32000} \end{bmatrix} \begin{bmatrix} I_s \\ V_2 \\ V_3 \end{bmatrix} =$$

$$\begin{bmatrix} \frac{12}{1600} + \frac{12}{32000} & 0 \\ \frac{12 \times 51}{1600} & 0 \\ -\frac{12 \times 50}{1600} + \frac{12}{32000} & 0.004 \end{bmatrix}$$

The solution, found with any matrix handling tool, yields

$$\begin{bmatrix} I_s \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} 492.1 \times 10^{-6} & -293.9 \times 10^{-6} \\ 11.87 & 63.2 \times 10^{-3} \\ -1.093 & 8.142 \end{bmatrix}$$

From this matrix, we can say that when the current source is turned off, the first column applies to I_s , V_2 and V_3 . Also, when the voltage source is off, the second column applies. We can add both columns to obtain the total $[I_s \ V_2 \ V_3]^T = [198.2 \times 10^{-6} \ 11.93 \ 7.049]^T$. The power generated by the voltage source is $p = (12 \times 198.2) \mu\text{W} = 1.38 \text{ mW}$, and that of the current source is $(4 \text{ mA})(7.049 \text{ V}) = 28.2 \text{ mW}$.

Up to here, the only novelty consists in a faster solution because the sources have been dealt with separating columns for them. Let us look now why the solution tells us much more than that.

To simplify our discussion, let us show three different situations:

- (a) when the current source is 1 A,
- (b) when the voltage source is 1 V, and
- (c) when both sources have unit values.

The three are derived directly using the “extended proportionality” property mentioned before. All we need to do in the previous solution is to divide by 12 the first column in cases (b) and (c), and by .004 the second column for (a) and (c). This exercise is only to show how looking at the matrix results give us interesting information. We have:

$$\begin{bmatrix} I_s \\ V_2 \\ V_3 \end{bmatrix}_A = \begin{bmatrix} 492.1 \times 10^{-6} & -73.48 \times 10^{-3} \\ 11.87 & 1.8 \\ -1.093 & 2035 \end{bmatrix} \quad (14)$$

$$\begin{bmatrix} I_s \\ V_2 \\ V_3 \end{bmatrix}_B = \begin{bmatrix} 41.01 \times 10^{-6} & -293.9 \times 10^{-6} \\ 0.989 & 63.2 \times 10^{-3} \\ -91.09 \times 10^{-3} & 8.142 \end{bmatrix} \quad (15)$$

$$\begin{bmatrix} I_s \\ V_2 \\ V_3 \end{bmatrix}_C = \begin{bmatrix} 41.01 \times 10^{-6} & -73.48 \times 10^{-3} \\ 0.989 & 15.08 \\ -91.09 \times 10^{-3} & 2035 \end{bmatrix} \quad (16)$$

Notice that in fact we do not need to work these matrices for the exercise that follows. It has been done here just for the sake of clarity.

Case A: Since the current source is 1A, we can interpret $V_3 = -1.093 + 2035 I_x$, where I_x could be any value for the current source. The first term corresponds to the case when $I_x = 0$, i. e., an open circuit. Hence, it is the open circuit voltage between node 3 and ground, also known as Thevenin's Voltage. On the other hand, the second term corresponds to the case when the source voltage is 0. Therefore, the resistance seen by the current source is 2.035 kΩ. In conclusion, the row

corresponding to V_3 provides us the Thevenin's voltage and resistance at that port.

Case B: Now the voltage source is 1 V. Following a similar reasoning to Case A, the row for I_s shows the information for the Norton Equivalent seen by the voltage source. The input resistance is $1/41.01 \times 10^{-6} \Omega = 24.34 \text{ k}\Omega$. The Norton, short circuit, current is $293.9 \mu\text{A}$. The change of sign obeys to the direction of I_s .

Case C: Both sources have unit values. Therefore, with a change of name for I_s as I_1 , we can say that

$$\begin{aligned} I_1 &= 41.01 \times 10^{-6} V_1 - 73.48 \times 10^{-3} I_3 \\ V_3 &= -91.09 \times 10^{-3} V_1 + 2035 I_3 \end{aligned}$$

In other words, the inverse hybrid parameters can be read as the submatrix formed with the rows for I_1 and V_3 , with port 1 at node 1 and the other port at node 2.

As it can be seen from these cases A, B, and C, proper setting up of equations results in finding out that there is a lot of information available and easy to read.

B. Second example

Assume that in the circuit of Fig. 3a, the initial voltage $v_C(0) = 2 \text{ V}$. Let us find the transient response of the capacitance voltage and current, the node potentials, and current I_s for $t \leq 0$.

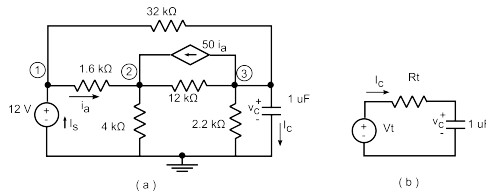


Fig. 3. A transient example using superposition

One traditional way of doing this is by getting the Thevenin Equivalent seen by the capacitor (see Fig. 3b) to find the time constant $\tau = CR_t$. In this circuit, simple analysis introduced in the textbooks yields

$$v_c(t) = V_t + (V_o - V_t)e^{-t/\tau} \quad I_c(t) = \frac{1}{R_t}(V_t - V_o)e^{-t/\tau}$$

for $t \geq 0$.

Usually, from this result, two circuits are then analyzed. However, it is possible to proceed as follows with the information already available.

To obtain the Thevenin equivalent seen by the capacitor, we can substitute this one by a 1 A current source. The topology would be the same as in Fig. 2, and this was done in Case A, where the equivalent circuit was read from the solution (14). Therefore,

$$R_t = 2035\Omega; \quad V_t = -1.093 \text{ V}$$

and

$$\tau = R_t C = 2.034 \text{ ms}; \quad \frac{1}{\tau} = 491.6 \text{ s}^{-1}$$

With this information,

$$v_c(t) = -1.093 + 3.094 e^{-491.6t} \text{ V}$$

and

$$I_c(t) = -1.52 e^{-491.6t} \text{ mA}$$

Now, the substitution theorem [8] states that if the current entering a port from another two-terminal element is known, a current source with the known value may substitute the two-terminal element. In other words, we can go back to Fig. 2 and use for the current source the value $-I_C$, the sign being because of the direction. No need to repeat the analysis. Just take again (14) and multiply the second column by 1.52×10^{-3} , obtaining

$$\begin{bmatrix} I_s \\ V_2 \\ V_3 \end{bmatrix}_A = \begin{bmatrix} 492.1 \times 10^{-6} & -111.7 \times 10^{-6} \\ 11.87 & 24.01 \times 10^{-6} \\ -1.093 & 3.094 \end{bmatrix} \quad (17)$$

This result should be interpreted as

$$\begin{aligned} I_s &= 492.1 - 111.7 e^{-491.6t} \mu\text{A} \\ V_2 &= 11.87 + 24.01 \times 10^{-6} e^{-491.6t} \text{ V} \\ V_3 &= -1.093 + 3.094 e^{-491.6t} \text{ V} \end{aligned}$$

V. CONCLUSION

The purpose of this paper has been to bring up to our attention the convenience of looking at the setting of equations and interpretation of results with a renovated perspective. In particular, two properties were brought to show how applications stem out faster. By doing so, not only are we capable of deriving fast and convenient methods for solving problems where matrices are used, including the interpretation of results, which is what makes an engineer an engineer. We can also motivate students to see matrix applications with renovated interest and better appreciate the tools available.

The field to illustrate the approach was that of linear resistive circuits. Similar procedures can be applied in other fields. Also, other considerations such as transformations, mapping, etc., may be introduced as criteria to approach problems. The important point here is to associate tools with applications in such a way that results have immediate meaning in the branch of interest.

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How Many Points Should Be Awarded for Interactive Textbook Reading Assignments?

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Abstract—New college engineering textbooks and other online learning materials use activities like interactive questions to engage students and improve learning. Some such materials use a "safe" learning approach where activity solutions are readily available to students, as opposed to being graded like a homework assignment. Instructors have inquired how few course points are sufficient to ensure students complete such assigned activities. Furthermore, some wonder if assigning course points might lead students to "cheat the system" by revealing solutions to quickly earn points, rather than earnestly attempting to answer the questions. We analyzed behavior data of 1,394 students in 8 engineering classes at different colleges. We found that surprisingly few course points—just 5 or 10 points, and as few as 2 points—were sufficient to achieve over 90% average completion of activities by students. For comparison, assigning no points yielded only about 50% completion. Furthermore, we found that assigning points had only a minor impact on students earnestly attempting to answer questions, versus showing themselves the answer first, with earnestness changing only modestly from 92% to 86% when points were assigned.

Keywords—reading assignment; reading earnestness; interactive textbook; course points; homework; cheating the system, online learning.

I. INTRODUCTION

Engineering and other subjects increasingly use interactive textbooks and other online learning material from academic groups [12][14][15] and companies [5][9][19][20]. Interactive textbooks contain activities such as embedded questions that teach and reinforce the subject matter. Instructors commonly require such activities by assigning some homework points for completing the "reading". Reading completion is sometimes required before lectures, leading to more engaged students, and optionally supporting a "flipped" classroom.

We have developed such online learning material for several computer science/engineering subjects, presently used at over 250 colleges. The material emphasizes a "safe" learning environment where question solutions are available to students via a simple button click, where students can attempt questions as many times as desired without penalty, and where showing an answer incurs no penalty.

Given that courses have numerous items for which course points are awarded (exams, labs, projects, quizzes, written homeworks, etc.), a common question from instructors is how

few points are sufficient to cause students to complete the assigned readings. Furthermore, another question is whether assigning points might cause students to just show themselves the answers to quickly earn those points, i.e., to "cheat the system".

Our material includes multiple questions types, including true/false, multiple choice, short answer, and definition matching. Figure 1 shows three short-answer questions, which provide a hint if an incorrect answer is entered, or an explanation if a correct answer is entered. The user can reveal the answer by clicking the "Show answer" button.

Fig. 1. Three short-answer learning questions on integer arithmetic with the question and feedback on the left-hand side, and input field on right-hand side. User entered the correct answer for question 1, an incorrect answer for question 2, and showed the answer for question 3.

#	Question	Your answer
1	13 / 3 ✓ 4 3 divides into 13 four times, yielding 12 with remainder 1 thrown away.	4 Show answer Check
2	4 / 9 ✗ How many times does 9 divide into 4?	 Show answer Check
3	(5 + 10 + 15) * (1 / 3) 0 1 / 3 performs integer division, evaluating to 0. Thus the entire expression evaluates to 0. Correct expression would be (5 + 10 + 15) / 3.	 Answer shown. Show answer Check

Short-answer questions can be used to measure reading earnestness because if a student just shows the answer without first attempting an answer, then the student is clearly not trying. Reading earnestness could also be defined for true-false and multiple-choice questions by comparing the student's correct answer rate to the expected correct answer rate if guessing. However, that approach is prone to more data noise due to some earnest student activity appearing as guessing, whereas short-answer questions have an explicit button. Thus, this study focuses on short-answer questions.

II. BACKGROUND

Reading assignments improve students learning [1][11][16]. For example, in an engineering design course, students who were assigned textbook reading were more sophisticated in their problem solving strategies for a given problem than students not assigned the textbook reading [1]. Though students believe the course textbook is important for learning [4], researchers have found that many students tend to complete assigned readings only while preparing for an exam, whereas completing the reading as scheduled [2][6][7][8]. Such postponement may hamper a student's ability to understand lecture material as presented, and other assignments during the course's progress. The effectiveness and usage of textbooks have been published more for psychology education than engineering education; hence, the reference to some psychology education works. However, textbooks are commonly used and assigned for reading in engineering classes.

Researchers have developed subjective metrics to measure student perspectives of textbooks [3][10][11]. For example, Gurung [11] developed the Textbook Assessment and Usage Scale (TAUS) to measure students' textbook evaluations. TAUS includes over 20 questions that a student answers after having used a textbook. The questions ask about the quality of specific elements (e.g., Figures and Tables) and whether the placement of the specific elements was appropriate and visually appealing. In contrast to the subjective metrics previously developed, this paper introduces an objective metric that measures a student's reading diligence.

Numerous academic groups [12][14][15] and companies [5][9][19][20] are developing interactive textbooks for engineering. Open Learning Initiative offers free courses that come with an interactive textbook that includes multiple choice questions and interactive activities that are recorded [15]. Learning with Python [12] includes a programming environment, practice questions, a code visualization tool, and videos. For Dummies eLearning includes multiple choice quizzes at the end of sections [9]. Zyante's zyBooks include animations, interactive tools, and practice question sets [20]. zyBooks record student activity, and contain a student and instructor dashboard for monitoring activity. Many instructors assign homework points for completing readings according to a particular schedule, to keep the students up to date in the course and have them come to lecture better prepared.

Numerous online homework systems have evolved in recent years, such as MyMathLab (Pearson) [13], WebAssign [17], WebWork [18], etc. Those systems are mainly intended for homework submissions. Solutions are typically not available, or a solution may be viewed but then a new problem is generated. Such systems differ from the online "reading" activities that are growing in popularity and are studied in this paper.

III. PROPOSED METRIC: EARNESTLY-COMPLETED READING

Instructors commonly assign reading assignments with the intention that students will diligently read the assignment. We introduce the metric *earnestly-completed reading* to quantify a student's reading diligence, which is how much of the assigned

reading a student spent time working through, as opposed to skimming through. Earnestly-completed reading is a combination of two metrics:

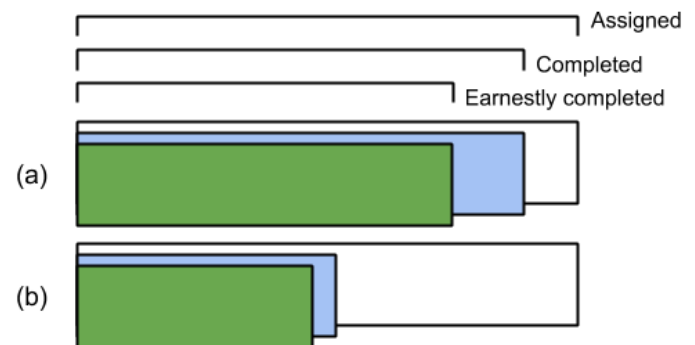
- *Reading completion* – The percentage of assigned activities that the student completed. For a short-answer question, the question is completed if a correct answer was eventually submitted for that question.
- *Reading earnestness* – Of the completed assigned activities, the percentage of activities that the student earnestly completed. For a short-answer question, the question is earnestly completed if the student attempts the question before eventually possibly showing themselves the answer. An attempt is a submission with more than whitespace. An unearnest completion is when the student shows the answer before attempting.

Earnestly-completed reading is then defined as:

$$\text{earnestlyCompleted} = \text{completion} * \text{earnestness}$$

Figure 2 shows the relationship between the amount of reading assigned, completed, and earnestly-completed. Figure 2(a) is for an assignment worth some points; Figure 2(b) is for an assignment worth no points. Ideally, a student would earnestly complete the entire assigned reading.

Fig. 2. Relationship between the amount of reading assigned, completed, and earnestly-completed for an assignment (a) worth points and (b) not worth points.



IV. PARTICIPANTS

We initially considered 26 classes across 23 universities for potential inclusion into our analysis. We tried to find a group of classes with similar reading assignment structure. We used the following inclusion criteria to mitigate potential confounding factors:

- Used an interactive textbook by zyBooks [20] and required the textbook for the class.
- Used the textbook for reading assignments regularly throughout the term.
- Assigned points proportional to completion, such as completing 50% of the reading earned 50% of the

points, as opposed to a threshold beyond which students receive full credit.

- Used a scheme with a single deadline per assignment, as opposed to awarding more points before lecture than after lecture.
- Contained at least 30 students in the class.

We found 8 classes meeting all the inclusion criteria. The 8 classes were offered in Fall 2014 and contained a total of 1,394 students. Table I shows the number of students per course points awarded. We determined the number of course points by a survey given to the instructors of the classes.

TABLE I. NUMBER OF CLASSES AND STUDENTS ACROSS THE COURSE POINTS AWARDED.

Points awarded	Number of classes	Number of students
0	2	250
2	1	54
2.3	1	437
5	1	380
10	1	69
17	1	90
20	1	114

V. RESULTS AND DISCUSSION

We classified each class by points awarded, such as 0, 2, 5, or 10, including merging 2 and 2.3 points awarded. Then, we compared the categories with respect to reading completion, reading earnestness, and earnestly-completed reading.

For each points awarded, we computed the average reading completion, average reading earnestness, and average reading earnestly-completed, which are defined as follows for each points awarded:

- Students are numbered $1 \dots n$
- C_i : Reading completion by student i
- E_i : Reading earnestness by student i
- Average completion: $\frac{\sum_{i=1}^n C_i}{n}$
- Average earnestness: $\frac{\sum_{i=1}^n E_i}{n}$
- Average earnestly-completed: $\frac{\sum_{i=1}^n (C_i \times E_i)}{n}$

The average earnestly-completed averages the earnestly-completed per student, as opposed to multiplying the average completion by the average earnestness, which would yield a different statistic.

Table II shows the average student reading completion and reading earnestness, and student earnestly-completed reading for a given points awarded.

TABLE II. AVERAGE STUDENT READING COMPLETION, EARNESTNESS, AND EARNESTLY-COMPLETED PER POINTS AWARDED. 5 TO 10 POINTS HAD THE HIGHEST READING EARNESTLY COMPLETED.

Points awarded	Average completion	Average earnestness	Average earnestly-completed
0	53%	92%	50%
2	90%	86%	77%
5	93%	89%	83%
10	94%	95%	89%
17	88%	72%	64%
20	94%	86%	80%

For reading completion, nearly any number of assigned points—as little as 2 course points—seemed sufficient to achieve completion of about 90%. Note that 100% completion is not expected due to some students skipping low-value items like readings, homeworks, or even quizzes, and due to some students who drop the class but remain subscribed to the material. As such, 90% completion is quite high. The conclusion here is that students merely need a small number of points to tip the scales in favor of students taking the time to do the reading activities.

With respect to earnestness, the student earnestness remained quite high, around 86% for classes that awarded some points for reading (versus 92% for classes that awarded no points). This value is also quite high, because not all "Show answer" clicks are due to not trying; some are due to legitimately not knowing how to answer a question. As such, one sees that awarding points seems to have little impact on earnestness.

Of course, such earnestness is dependent on the quality of the questions. We have observed in the past that questions that are confusing or unreasonably hard have low earnestness ratings. Likewise, questions that are viewed by the student as repetitive/drill have lower earnestness. Via earlier analyses, we have eliminated most of both such kinds of questions from our material.

Based on these findings, we recommend assigning between 5 and 10 course points for reading completion. Although 2 points seems to be sufficient, we note that such a small number may be viewed as odd by students. More than 10 points is reasonable but may not be necessary, with such points being reserved perhaps for assessments (written homeworks, quizzes, exams, projects, etc.).

Many factors other than the number of points awarded can affect completion and earnestness. For example, a class that is on a topic for a particular major and taken mostly by students in that major is likely to have higher completion and earnestness; such was the case for the class awarding 10 points, for example. In contrast, a class that is taken mostly by students in a major differing from the class' topic are more likely to be less earnest due to not being as vested into learning the subject matter; such was the case for the class awarding 17

points (a class on programming for non-computing majors). Other factors may include: the instructor explaining the benefits of the reading assignments; the instructor painting the reading material in a positive light such as, “This is modern learning material that’s been shown to really help students learn.”; the amount of workload that the class gives; and the quality of the lectures.

Future work may seek to account for the instructor, such as including many different instructors in each point awarding category. Future work also includes continued data collection and analysis to determine other impacts on completion and earnestness. A similar analysis of student work completion and earnestness may be conducted with massive open online courses, commonly referred to as MOOCs.

VI. CONCLUSION

Interactive learning material is becoming more readily available to instructors as a replacement to a textbook. A common question is how many points should be awarded to insure the students complete the reading assignments. We found that very few points are sufficient to yield high completion rates of about 90%, while earnestness remained high. Based on the analyses, we recommend awarding between 5 and 10 points for reading completion. Awarding fewer points may be viewed as odd by students and awarding more points may not be necessary.

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Combining MATLAB[®] Simulation with Telecommunications Instructional Modeling (TIMS[™]) in a Senior Level Communications Course

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Abstract— In this work we present some of our successes in combining MATLAB[®]-based simulation methods with Telecommunications Instructional Modeling (Emona-TIMS[™]) experimental methods to enhance student learning in a senior-level communications systems laboratory. While faculty have discussed the relative merits of simulation versus real experimentation in recent years, we find that combining these approaches has multiple advantages: (1) A TIMS[™] based approach (where we have chosen to use “real-world” demodulated audio from local radio stations as the local message signal) makes students feel that they are engaged in “real-world modulation/demodulation;” (2) The TIMS[™] based approach inherently reinforces a “concept map” (block diagram) view of communications modulation and demodulation; (3) The MATLAB[®] simulation approach forces students to think about how to perform a proper simulation (e.g. set appropriate sampling rate, set appropriate specifications for digital filter design for envelope detector or discriminator, etc.) for both analog and digital simulation; and (4) The MATLAB[®] simulation approach sets a starting point for our students as they pursue software defined radio (SDR) communications applications in some of their senior design projects. We find synergy in combining the two pedagogical approaches in most of the labs in our communications systems course, and this typically results in enhanced student comprehension.

While more formal assessment will be conducted over the next two years, at this point we know from course feedback that students very much appreciate both learning tools. Students commonly remark that the TIMS[™] really highlights the “big picture,” and helps them understand what to expect before they start the MATLAB[®] simulations, while coding up the MATLAB[®] simulations gets them “into the weeds,” and gives them the tools to test out ideas that support their senior projects.

Keywords—electrical engineering education, communication engineering education, student experiments

I. INTRODUCTION

As faculty who teach undergraduate courses in the Electrical Engineering major, we routinely search for ways to enhance student learning and excitement for the subject matter. Sometimes students appreciate seeing simulations, while other times they appreciate experimentation, and the debate continues as to the appropriate mix in undergraduate education [1], [2].

Some researchers have commented [3] that a TIMS[™] based experimentation approach (in a very similar course as ours) garnered high marks for student satisfaction, and students acquired more skill and confidence in experimental methods. Our experiences are consistent with these observations. In our work, however, we suggest that a mix of simulation and experimentation has multiple advantages, and we take this approach in our senior-level undergraduate electrical engineering course called Communication Systems.

We see that an “experimental” TIMS[™] based approach [3] makes students feel that they are engaged in “real-world modulation and demodulation.” Furthermore, the very nature of the TIMS[™] based approach (where every TIMS[™] module has a specific function) [4] is a self-reinforcing “concept map” or block diagram view of the entire modulation/demodulation process.

We also see value in having our students do MATLAB[®] simulations, because such (digital) simulations force students to grapple with the details of setting up a proper simulation (e.g. setting appropriate sampling rate, using reasonable vector lengths for use in an FFT, design of an appropriate digital filter for use as a frequency discriminator, etc.) Since many of these same students are also learning about software defined radio (SDR) concepts for use in their senior projects, we see merit in our students understanding how to perform MATLAB[®] and Simulink[®] simulations.

We find synergy in combining the two pedagogical approaches in most of the labs in our communications systems course, and our experience suggests this results in enhanced student comprehension. Typical student comments are that the TIMS[™] experiments help to reinforce the concept maps for modulation/demodulation, and MATLAB[®] simulations force students to learn how to do proper simulations, while forcing them to recall information from previous courses.

Preliminary assessment suggests that students gain considerable insight from both the MATLAB[®] simulations and TIMS[™] experiments, however more formal assessment needs to be garnered over the next two years.

II. OVERVIEW OF OUR EQUIPMENT SUITE FOR COMMUNICATION SYSTEMS LAB

The primary equipment suite used for our Communication Systems labs is shown in Figure 1. Equipment listed from top to bottom include: EMONA TIMS-301, Agilent DSO 6034A Digitizing Oscilloscope, Agilent 89410A Vector Signal Analyzer, Agilent 33220A Function Generator, Rolls 35 Watt Stereo Power Amplifier, an AM/FM tuner, and stereo speakers. The general strategy for our labs is that students use low frequency sinusoidal and digital signals from the EMONA TIMS-301, and relatively narrow-band audio signals (demodulated audio) from the AM/FM tuner output, as message signals, as they study various modulation and demodulation methods in each lab. Labs using our primary equipment suite include Review of Fourier Series, Amplitude Modulation and Demodulation, Frequency Modulation and Demodulation, Pulse Code Modulation, and AM Single Sideband Modulation and Demodulation. Here we will focus on three labs: Amplitude Modulation/Demodulation, Frequency Modulation/Demodulation, and AM Single Sideband Modulation/Demodulation.

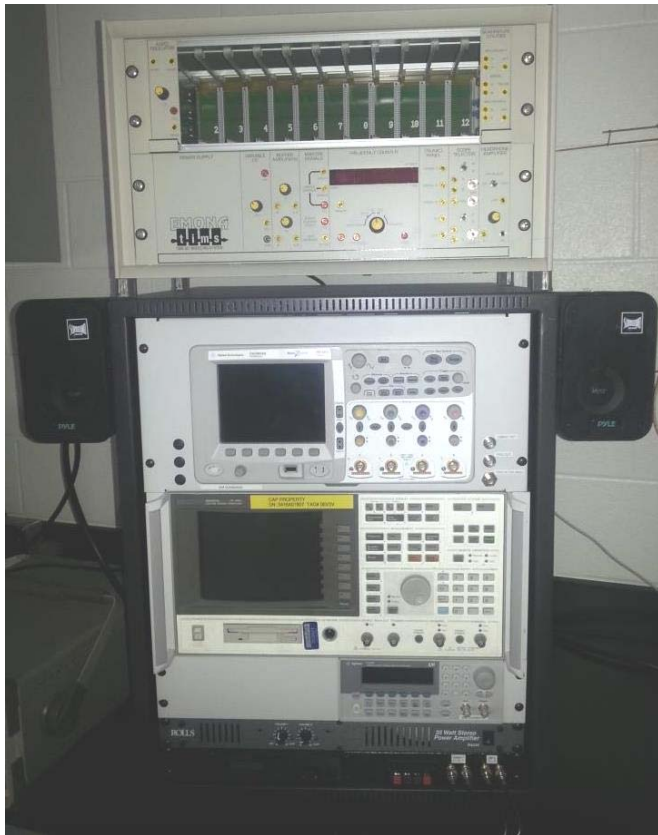


Fig. 1. Communication Systems laboratory primary equipment suite

In addition to the primary equipment suite, students have access to Windows 7.0 work stations where they are able to transfer data from the Agilent 89410A Vector Signal Analyzer to MATLAB[®] for later analyses. Students also have access to laboratory computers in order to perform the MATLAB[®] coding portion of each laboratory.

III. AMPLITUDE MODULATION (AM) AND DEMODULATION

This lab consists of several parts: (1) A MATLAB[®] study of AM generation, (2) a MATLAB[®] study of envelope detection, (3) a MATLAB[®] study of I & Q demodulation, (4) a TIMS[™] study of AM DSB-LC (large carrier), (5) a TIMS[™] study of AM DSB-SC (suppressed carrier), and (6) a TIMS[™] study of demodulation using product detection methods.

A. Studying AM using MATLAB[®]

Students are asked to write a short MATLAB[®] M-file which generates an AM (DSB-LC and DSB-SC) signal, with carrier frequency of 3kHz, a sinusoidal modulating frequency of 100Hz, a modulation index of 0.2 (for DSB-LC), and a sampling frequency of 50kHz. After successfully generating this signal and viewing it in both the time and frequency domains, they learn how their plots change as a function of modulation index and modulating frequency. They are also asked to consider why the sampling rate was chosen to be that value for purposes of simulation.

Students then use MATLAB[®] to demodulate the signals (using I&Q demodulation and envelope detection for the DSB-LC, and product detection for the DSB-SC.) They perform graphical comparisons of the original message and demodulated waveform, and draw conclusions based on their observations. Student feedback tells us that the MATLAB[®] simulations teach them a lot about how one can write code to perform simulations and test ideas.

B. Studying AM Using TIMS[™]

Students then use TIMS[™] to generate AM DSB-SC, using the audio oscillator as a (low frequency) sinusoidal message signal, and a 100kHz carrier. They use an analog multiplier on the TIMS[™] to generate the AM signal, and they view the DSB-SC signal at a center frequency of 100kHz in the frequency domain. They vary the amplitude and frequency of the low frequency sinusoidal message signal, and observe the effects in both time and frequency domains. At this point we have the students switch the message signal, from the low frequency sinusoidal message, to the (demodulated) audio signal coming out of the FM tuner, and they observe the DSB-SC signal in both the time and frequency domains.

Finally, we have the students demodulate that signal, by routing the DSB-SC signal to a “multiplier” module (which performs the function of a product detector), and then to a low pass filter module. The “multiplier module” multiplies the DSB-SC signal by a (variable) phase shifted carrier on the TIMS[™], and students learn about the importance of aligning the phase of the carrier and the local oscillator during product demodulation. The output of the “multiplier module” is sent through a low pass filter on the TIMS[™], and the output of the low pass filter is routed to the audio amplifier and speakers, so students are able to listen to their demodulated audio, while observing all signals in the time and frequency domains.

At this point, students begin adjusting the low pass filter bandwidth and gain, and begin shifting the phase of the local oscillator. Student feedback suggests that they very much appreciate the full sensory immersive experience of the

TIMSTM portion of this lab, as it helps them to remember important concepts.

IV. FREQUENCY MODULATION (FM) AND DEMODULATION

This lab consists of several parts: (1) A study of FM using the Agilent DSO 6034A Digitizing Oscilloscope, Agilent 89410A Vector Signal Analyzer, and the Agilent 33220A Function Generator, (2) a MATLAB[®] investigation of FM demodulation from I & Q data, (3) a MATLAB[®] generation of FM and demodulation via a frequency discriminator, and (4) a TIMSTM investigation of FM modulation and demodulation using Phase-Locked Loop (PLL) demodulation and frequency discriminator demodulation methods. Here we will focus on parts (2)-(4).

A. Studying FM using MATLAB[®]

After students study FM signals in both time and frequency domains using a signal generator, oscilloscope, and dynamic signal analyzer, they learn about three methods for FM demodulation: (1) Demodulation from base band In-Phase and Quadrature (I&Q) data, (2) Demodulation using a phase-locked loop (PLL), and (3) Demodulation using frequency discriminator techniques.

For FM demodulation from I&Q data, we ask students to turn to MATLAB[®] for additional insight. We provide them a MATLAB[®] data file (.mat file) that is a “baseband” I&Q signal (commonly referred to as a “complex envelope” for the FM signal), sampled at 25kHz, and we ask them to demodulate and play the resulting audio file.

As we present in class, if one is presented with “base band” in-phase (I) and quadrature (Q) data, a classic way to perform FM demodulation is to perform operations on the vector $I+jQ$. We tell our students since FM is a form of “angle modulation,” it seems logical to examine the angle of the vector $I+jQ$ in order to begin demodulation. We ask students to develop a simple function in MATLAB[®] which will perform the desired demodulation. Recognizing the “angle” function provides a return argument from $-\pi$ to π , we ask them to consider “unwrapping” the angle of the $I+jQ$ vector to avoid discontinuities. Finally, we remind them that they are not interested specifically in the “angle” of $I+jQ$ (in radians), but more interested in changes in that angle as a function of time (instantaneous frequency – radians/sec). After some thought (and considerable coaching), they come up with a single line of code that accomplishes the desired demodulations: $y = \text{diff}(\text{unwrap}(\text{angle}(S)))$, where S represents the baseband $I+jQ$ vector. At that point they use the MATLAB[®] commands “sound” or “audioplayer” to listen to the message, and they usually take some time to think about why that methodology worked so well! Student feedback on this part of the lab is tremendous.

In addition, we have our students generate an FM signal with carrier frequency 5kHz, modulating frequency 100Hz, a modulation index of 1.0, with sampling frequency 22050Hz. That signal is then used as the FM signal input to a frequency discriminator (that they must design!), and the simulation is accomplished completely in MATLAB[®]. This portion of the lab requires that they remember something about digital filter

design (studied in earlier courses), and it requires that they design the filter such that the frequency of interest is in the center of the transition band of the filter they design. Students were less than enthusiastic in their feedback for this part of the lab!

B. Studying FM using TIMSTM

For this module, students use the Voltage Controlled Oscillator (VCO) module on TIMSTM to generate an FM signal at a 100kHz center frequency. Both the center frequency and the frequency deviation (VCO “gain”) can be adjusted on the VCO card. The “message input” to the VCO is taken from the demodulated audio from the FM tuner at the bottom of the equipment suite (from Figure 1), and we have the students generate a relatively narrow band FM signal (small modulation index). After students view the FM signal in both the time and frequency domains, we give them the assignment: demodulate that signal by building a Phase-Locked Loop (PLL) detector, and play the demodulated audio through the stereo amplifier and speakers.

At this point, students are initially confused, and I refer them to a standard block diagram for a PLL detector (Figure 2). We tell them that each block of the PLL diagram consists of one or two modules from the set of TIMSTM modules, and they then begin to build their PLL. We explain that the phase detector is implemented as a multiplier cascaded with a low pass filter, and the input to the PLL is the FM signal they just created.

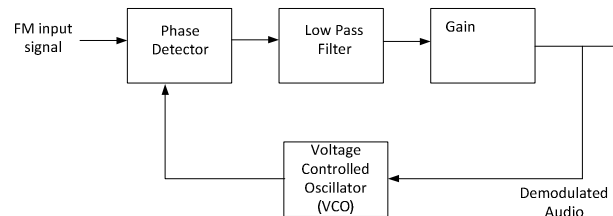


Fig. 2. Basic block diagram of phase-locked loop (PLL) for FM demodulation.

To assist them in getting a working PLL, we advise them to follow these steps: (1) Make sure the VCO in the feedback path of the PLL is set to the same frequency as the center frequency of the incoming signal, (2) set the “gain” of the VCO in the PLL feedback path at roughly the same “gain” as the VCO that is generating the FM (relatively low), (3) make the low pass filter relatively wide in the feed-forward path of the PLL, and (4) lower the gain of the gain block in the feed forward path. At this point we explain to students that the input to the VCO block is the demodulated audio of interest, and we are interested in listening to that signal.

By slowly adjusting the VCO gain and the bandwidth of the low pass filter, students are usually able to get their PLL’s working perfectly within 15-20 minutes, and they feel such a sense of accomplishment when they can hear the demodulated audio output. Furthermore, they are always amazed to hear how perfect the demodulated audio sounds. At this point we have a “teachable moment,” and we ask our students to make the PLL “break lock” by (1) reducing the VCO gain or low

pass filter gain, (2) reducing the bandwidth of the low pass filter, or (3) changing the frequency of the VCO in the feedback path. By the end of the lab, students have obtained considerable insight into the workings of a PLL, and it is at that point we draw parallels for them between concepts they have seen in Computer Controls class (e.g. P, PD, PID controllers) and PLL demodulation. Feedback on this part of the lab is overwhelmingly positive, and students remark that they gained tremendous insight into PLL theory and operations from this lab experience. Assessment data taken from their FM lab reports and hourly exams also suggest that students have a more solid understanding of PLL concepts.

Finally, students disconnect their PLL TIMSTM configurations, and reconfigure the VCO that generates the original FM signal to a center frequency of 70kHz. Students then use the 60kHz low pass filter module from TIMSTM to implement a “frequency discriminator.” Since the center frequency of the FM signal now lies in the transition band of their low pass filter, they are generating a signal that varies in amplitude and frequency. By passing this signal to the “utilities module” (which has an envelope detector), students learn that they have performed FM detection by performing envelope detection on an “AM-like” signal. Again, they listen to the demodulated audio output, and again they are impressed at the audio quality.

V. AM SINGLE SIDEBAND GENERATION AND DEMODULATION

This lab consists of two parts: (1) A MATLAB[®] study of single sideband (SSB) amplitude modulation and demodulation, and (2) a TIMSTM investigation of single sideband amplitude modulation and demodulation.

A. Studying AM-SSB using MATLAB[®]

During the AM lab, students wrote MATLAB[®] code to generate an AM DSB-SC signal with a carrier frequency of 3kHz, and a sinusoidal message signal of 100Hz. Here they modify their code to produce the AM-SSB signal, either upper (“-”) or lower (“+”) side band, by using the equation

$$s(t) = A_c [m(t)\cos(\omega_c t) \mp \hat{m}(t)\sin(\omega_c t)] \quad (1)$$

where A_c is a scaling factor, $m(t)$ is the message, and $\hat{m}(t)$ is defined as the Hilbert transform of the message. Students write their own “Hilbert transformer” by using the “fft” function, multiplying positive frequency components by “-j” and negative frequency components by “j”, and then inverse transforming the result by calling the “ifft” routine. Using a sinusoidal signal for $m(t)$, students see that they can elect to generate either the upper or lower sideband signal by changing the sign on $\hat{m}(t)$ from equation (1). Students also see that they can multiply the SSB signal by a (coherent) carrier signal, low pass filter, and retrieve the original sinusoidal message.

B. Studying AM-SSB using TIMSTM

Using the TIMSTM modules (specifically the 100kHz sine/cosine waveform generators, the audio signal generator, and the quadrature phase shifter module), students generate an

AM-SSB (lower) signal at 100kHz using the Hilbert transform or “phasing method” discussed in class. Using the audio signal generator as the $m(t)$ initially, students view the SSB signal in both the time and frequency domains. After students are convinced that their phasing method is working, they use the audio signal from the FM tuner in the primary equipment suite, and view the results in both the time and frequency domains. At this point, students are impressed that this “phasing method” works so well in completely eliminating one of the sidebands. They finish the lab by using a product detector (with oscillator that is coherent with the carrier) in order to demodulate the AM-SSB signal. They route the signal output to the amplifier and speakers, and enjoy the resulting music.

Feedback from this portion of the lab suggests that our students appreciated both the MATLAB[®] and TIMSTM sections of the lab, and assessment results from lab submissions and exams suggests to us that student comprehension of AM-SSB concepts has improved over the last several years.

VI. CONCLUSIONS

We presented some of the ways we have combined MATLAB[®] based simulation with Telecommunications Instructional Modeling (Emona-TIMSTM) experimental methods to enhance student learning in a senior-level communications systems laboratory at the U.S. Coast Guard Academy. While relative merits of simulation versus experimentation have been debated over the years, our experience suggests that students very much appreciate that the TIMSTM based approach inherently reinforces a “concept map” (block diagram) view of communications modulation and demodulation. Furthermore, they also see value in doing MATLAB[®] simulation, because they see it as a first step towards testing senior project research ideas, and they see value in learning how to perform a proper simulation. Although we are in the early stages of assessment, we do see advantages in combining these two pedagogical approaches, based on student feedback and improved student comprehension.

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MORE THAN JUST RIGHT OR WRONG:

USING CONCEPT QUESTIONS TO DISCERN STUDENTS' THINKING IN MECHANICS

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Abstract—This paper outlines five concept questions from Statics and Mechanics of Materials from which instructors can easily learn about student thinking when the students select incorrect answers. These questions represent vertical transfer assessment tools and show the potential of using such questions. They can be used as part of a pre-test or in some other manner such as a warm-up exercise. The questions discussed here all show good correlation between students' answer selections and the misconceptions or specific difficulties that they are exhibiting with the concept covered in the question. Simply by assessing the answer distributions instructors can easily learn enough about student thinking to tailor instruction and classroom activities.

Keywords—concept questions; concept inventory; pre-test; warm-up exercise

I. INTRODUCTION

Concept questions have become a staple of assessing students' understanding of engineering fundamentals. Well-established concept inventories for Force, Statics, Dynamics, and other areas provide means to assess students' learning gains and understanding at the end of a class, and are often used to establish students' baseline understanding at the beginning of a class [1]-[4]. While there is no denying the value of using concept questions or concept inventories for summative assessment, there are also many opportunities to use concept questions for formative assessment that frequently go by the wayside. Concept questions with well-written distractors can have a strong correlation between students' specific difficulties and/or misconceptions and their incorrect answer selections [5]-[9]. Studying patterns in answer choices for select questions can give instructors insight into students' patterns of thinking while there is still time to address those students' specific difficulties in the class.

To determine patterns of student thinking in their selection of incorrect answers on concept questions, it is necessary to have students explain their answer choices in order to establish if correlations exist between students' reported thinking in selecting a specific answer and what those correlations are. Once correlations between student thinking and answer selection are established, an instructor can gain insight into the thinking of individual students or groups of students simply by studying the distribution of the answers to the question. This

technique can be very valuable when students answer concept questions or take concept inventories as pre-tests, and also when concept questions are used as warm-up exercises [10]. Warm-up exercises are a good complement or alternative to pre-tests, especially in cases such as with the Concept Assessment Tool for Statics (CATS, formerly known as the Statics Concept Inventory or SCI) where overall pre-test results on CATS correspond to random guessing and CATS includes symbols and terms that are not familiar to students at the beginning of a Statics class. In the case of CATS, the Force Concept Inventory (FCI) is recommended as a pre-test [6],[11]. Therefore, rather than give a pre-test that has dubious overall value as a measure of incoming student preparation, purposefully chosen concept questions may be given as warm-up exercises instead, and the same valuable information about students' thinking can be obtained.

This paper outlines four examples of Statics concept questions and an example of a Mechanics of Materials concept question for which studying students' explanations to their answers to concept questions has been used establish strong correlations between students' answer selections and the thinking that led them to that answer choice. The paper will also give examples where distractors do not strongly correlate with a particular line of thinking, and an example of how a small adjustment to a distractor was able to solve that problem and improve correlation between students' answer selection and their lines of thinking. In Statics classes the patterns of student answers to concept questions given as warm-up exercises was used to focus class discussions and exercises to address the specific difficulties that students' displayed through their answer selections [12]. The results of this approach were improved student conceptual understanding of the course material, which was established through the inclusion of concept questions on the final exam for the class and through the use of the CATS as a post-test. While there is still plenty of room for improvement, students in these classes scored well above national averages on concept questions involving equilibrium and equivalence with this approach [13]-[14].

II. TRANSFER, MISCONCEPTIONS, AND SPECIFIC DIFFICULTIES

Transfer is the term commonly used to describe a student's ability to apply knowledge gained in one context in a different

context. Fundamentally when students are asked to take a pre-test for a class, the instructor is trying to assess what Bransford and Schwartz refer to as students' "preparation for future learning" [15]-[16]. This concept from the modern transfer literature is one that acknowledges that novices might not initially be able to apply their knowledge from one setting in another, but if they are prepared to learn how to apply that knowledge in the new setting, they are well enough prepared to eventually succeed in the new setting. Relative to the traditional model of transfer, this is focusing on the student's perspective of the transfer, or actor-oriented transfer, rather than the expert's perspective [17]-[19]. This idea of actor-oriented transfer was further refined by Rebello et al. to differentiate between situations where a pre-existing knowledge structure can be applied, which they dubbed as horizontal transfer, and situations where the mental model must be created rather than referenced, which they dubbed as vertical transfer [20]-[22]. So giving students the FCI as a pre-test in a Statics class is an example of trying to assess their horizontal transfer ability from Physics, while giving students CATS as a pre-test is an example of trying to assess their vertical transfer ability. Using a pre-test to assess students' horizontal transfer ability is more likely to give an instructor a clear picture of students' level of preparation from a pre-requisite class, but less likely to give a clear picture of the specific difficulties and misconceptions the students have about the material in the new class than trying to assess their vertical transfer ability. While the aggregate score on a pre-test for horizontal transfer may provide more accurate information for comparative learning gains from the beginning of a class to the end of it, there is much to be learned from assessing students' answers to vertical transfer assessments in terms of being able to tailor class activities and assignments to address students' misconceptions and the specific difficulties that they exhibit. This dichotomy that exists between using pre-tests to try to assess students horizontal or vertical transfer ability is why alternate approaches such as using warm-up exercises to supplement pre-tests may be the best solution to uncovering students' misconceptions and the specific difficulties that they exhibit.

Misconceptions and specific difficulties are different types of problems students may have or exhibit when attempting to master new material or transfer concepts from one context to another. The term 'misconception' is commonly used in engineering education to describe an incorrect understanding that must be unseated and replaced with a correct understanding, but there is an alternative theory in Physics Education Research that student difficulties are influenced by context if not outright context dependent [23]-[28]. In this view students' incoming understanding is made up of bits of loosely connected knowledge referred to as phenomenological primitives (p-prims) [23]-[27] or facets of thinking [28]. These p-prims, or knowledge elements, are triggered by context; while they may individually be correct in some circumstances, they may be applied in the wrong circumstances or combined improperly to form incorrect conclusions. According to this view, students do not need to have misconceptions unseated; instead they must learn which elements are correct in which contexts. These elements provide building blocks for reaching the desired mode of thinking. In this terminology, instead of misconceptions, students exhibit "specific difficulties" [29] –

some more commonly than others. In order to design effective instructional material and techniques, one should take students' specific difficulties into account [30]-[31].

Misconceptions and specific difficulties are not mutually exclusive models, and they are both things that an individual student may exhibit. For example, a student assessing equivalence in a Statics class may enter the class with the misconception that an equivalent rotational system must maintain a center of rotation rather than moment equilibrium, and use that criteria to try to identify equivalent systems. The same student may also exhibit the specific difficulty of only assessing moment equilibrium in a static system when cued to do so. This may not be an indication that the student has the misconception that force equilibrium satisfies all equilibrium conditions, but that he or she has not developed a complete enough mental model to consistently assess moment equilibrium without a cue, although then he or she might only assess moment equilibrium when given that cue. It is common for students at the end of Physics, at the beginning of Statics, and, more common than one would like, at the end of Statics to conflate force and moment equilibrium, but without more information about those students' approaches and/or answer selections to equilibrium questions it may not be possible to determine if a student has a misconception or is exhibiting a specific difficulty that is linked to context or an incomplete mental model [7]-[8], [32]-[33]. Examining students' answers, and sometimes their explanations, to conceptual questions designed to assess students' vertical transfer ability can provide instructors with insight that will allow them to address the issues elucidated by those questions through class activities and assignments.

III. EXAMPLES OF INFORMATIVE CONCEPT QUESTIONS

Concept questions with well-posed distractors can tell an instructor quite a bit about students' approach to and thinking about a problem when the students' answers are incorrect. This section describes four concept questions that have been used in Statics and one that has been used in Mechanics of Materials to allow an instructor to discern and address students' incorrect thinking on the underlying topics. In all of these examples, students were initially asked to explain their thinking, which allowed the patterns of thinking to be correlated with the answers. Once the correlations have been established, the student explanations are no necessary, although requiring explanations does seem to engage the students in the problems a bit more. It should be noted, however, that it is common for students' explanations to not match their answer selections in up to 10% of responses, so this information is generally much more reliable for determining common patterns of misconceptions or specific difficulties in a group of students than the exact misconceptions or specific difficulties of an individual student [13].

The first three examples discussed below are from CATS and cover equivalence, free body diagrams, and equilibrium respectively. The fourth example is a matched pair of rigid body motion questions that were developed to see if students' ability to describe dynamic motion could be used as a measure of their preparation for learning Statics. The fifth and last example was developed for Mechanics of Materials to see how well students could apply stress and strain concepts from a pre-

requisite Introduction to Materials Science and Engineering course to rank order stress and deflection in simply supported beams with the same cross-sectional area, but with the beam's material distributed differently. All of these are examples of questions that can quickly give instructors reliable information regarding student thinking. Not all concept questions give such clear and consistent results as these examples, although sometimes only a small modification is required to improve the correlation between a distractor and the errors in thinking that students are exhibiting by selecting those answers.

A. Static Equivalence

Static equivalence is a concept for which students commonly exhibit one of the following errors: a) they assume that to maintain equilibrium the value of an applied couple must change if it is applied at a different location; b) they use a force to balance a change in the magnitude of a couple, but ignore force equilibrium; or c) they assume that there is a 'center of rotation' that must be maintained. Figure 1 shows a concept question from CATS that includes distractors that correlate well with students' explanations of those errors [7].

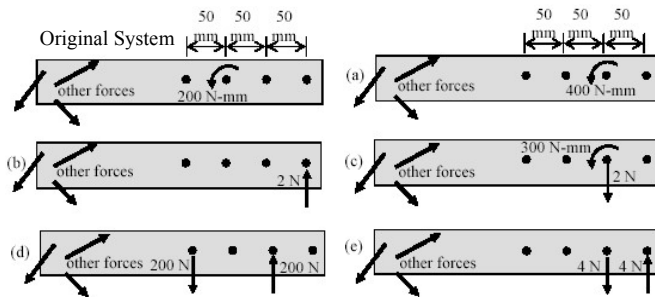


Fig. 1. Static Equivalence concept question from CATS

In this question students are asked to select the system that will maintain equilibrium for the original system (upper left image) with the 'other forces' shown on the left side of the bar when the 200 N-mm couple is replaced. The correct answer is (e), but at the start of statics students most commonly pick (d), the answer that maintains the presumed center of rotation. This misconception was also documented independently in the work of Brose and Kautz [9]. Students also frequently select (a), which changes the magnitude of the applied couple when its location changes, and (b), which maintains moment equilibrium, but ignores force equilibrium.

When studied in some detail in [7], this question showed good correlation with students' erroneous thinking and answer selection. 146 student explanations were coded for four different student errors: 1) assessing moment equilibrium without assessing force equilibrium, 2) stating that only couples can balance couples, 3) stating that the magnitude of a couple must change if it is moved, and 4) specifying a center of rotation. Of the 146 responses, 18 were too ambiguous to code for errors. For the remaining 128 responses that were coded: 26 of 31 (84%) students who answered (a) displayed error (3) and 11 of 31 (36%) displayed error (2), 28 of 28 (100%) students who answered (b) displayed error (1), and 39 of 46 (85%) students who answered (d) displayed error (4). 17 of 18 (94%) students of students who answered (e) gave a correct explanation.

Whether the issue is a misconception, such as maintaining a mythical center of rotation, or a specific difficulty, such as forgetting to assess force equilibrium, this question is a good example of a question that gives an instructor reliable information about student errors simply by knowing which answers students' selected. The information can be easily obtained whether the question is used as a warm-up question, as it was for the study in [7], or whether the information is pulled from pre-test responses if CATS is used as a pre-test. Once the answer distribution for a specific group of students is known, an instructor can use the information to tune class activities and assignments to address the conceptual errors and specific difficulties that are commonly exhibited in the class.

B. Free Body Diagrams

The static equivalence question outlined above is a good example of a relatively clean question for which students commonly exhibit a single error. In other cases, students may exhibit multiple specific difficulties or misconceptions, so to be effective, the question(s) used to assess that likelihood needs to be able to differentiate between two errors, but also allow for a student to exhibit both of them. Free body diagrams are an example of this. Two very common specific difficulties that students exhibit at the start of Statics are including internal forces and including indirectly applied forces explicitly. Figure 2 shows a concept question from CATS that includes one distractor for each of those errors individually, and one for those two errors combined [5],[7].

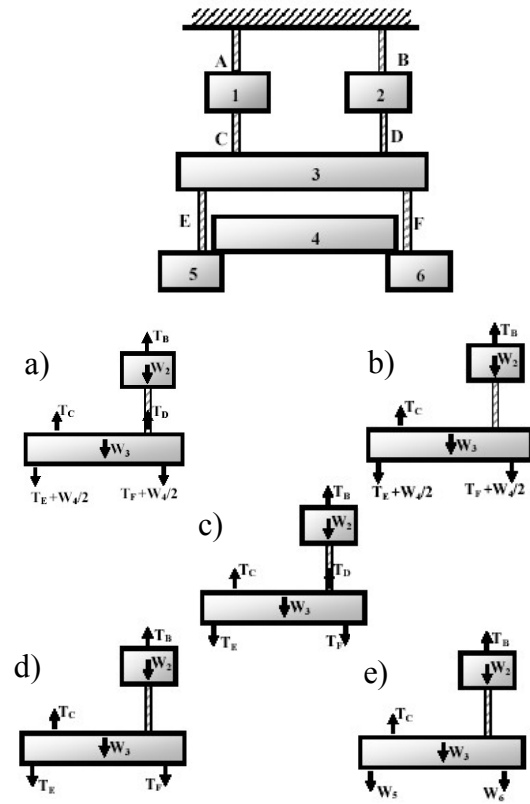


Fig. 2. Free Body Diagram concept question from CATS

In this question students are asked to isolate blocks 2 and 3 and the cord, D, that connects them. Answer (d) is correct. Answers (a) and (c) both include the error of inclusion of the internal force, and answers (a) and (b) both include the error of explicit inclusion of indirectly applied forces. This question is a good example of how a small modification can have a big impact on the information that can be gleaned from students' answer selections. The early version of this problem had a different distractor for (a) that contained a specific difficulty that almost no students exhibited [5]. At that time the students who selected (b) or (c) sometimes commented that none of the answers were correct, because they had to choose between including the force in cord D or the weight of block 4. When the distractor for (a) was changed to include both specific difficulties, it gave those students who exhibited both a way to do so on this problem, and it gave the instructor that information. Table I shows the change in answer distribution from the original answers to the answers shown in Figure 2.

TABLE I. COMPARISON OF ORIGINAL AND NEW ANSWERS

Answer	n	a	b	c	d	e
Original	35	0.0%	11.4%	54.3%	31.4%	2.9%
Modified	129	20.9%	4.7%	58.9%	13.2%	2.3%

Once modified, this question showed very good correlation between students' answer selection and their explanations [7]. The 129 responses shown in Table I were coded for two errors: 1) A force is 'missing' from the other choices, and 2) cord tension is equal to the weight of the object hanging directly off of it. In the 129 responses, 13 were too ambiguous to code. For the remaining 116 responses that were coded: 22 of 25 (88%) students who answered (a) displayed both errors (1) and (2), 6 of 6 (100%) students who answered (b) displayed error (2), and 65 of 66 (98.5%) students who answered (c) displayed error (1). 16 of 17 (94%) students who answered (d) gave a correct explanation. It is interesting that 22 of 30 (73%) of students who answered (a), (b), or (c) and displayed error (2) also displayed error (1), while only 22 of 89 (25%) who displayed error (1) also displayed error (2).

C. Equilibrium

The free body diagram question outlined above is a good example of where a question can be easily modified to provide instructors more specific information on student thinking. In other cases it is not possible to clearly discern all common student errors from a single concept question. Equilibrium assessment is an example of where this sort of thing can occur. There are five types of specific difficulties that students commonly exhibit when analyzing equilibrium: a) assess force or moment equilibrium, but never both, and only the latter when something in the questions cues that analysis; b) assess force and moment equilibrium as separate events that do not need to occur simultaneously; c) assume that a couple also contains an unbalanced linear force; d) always assess only force equilibrium; and e) always assess only moment equilibrium [5],[7]-[8],[33]. Figure 3 shows a concept question from CATS that includes one distractor each for specific difficulties (d) and (e), but with a distractor that conflates specific difficulties (a), (b), and (c).

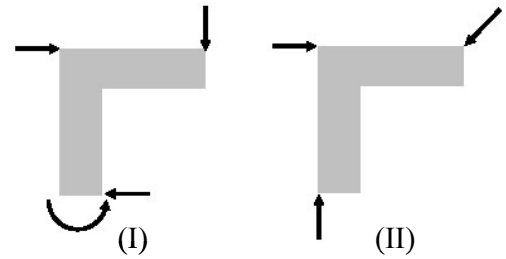


Fig. 3. Equilibrium concept question from CATS

In this question students are asked, given the directions of the loads indicated, whether one, both, or neither of these bodies can be in equilibrium. The correct answer is that neither body I nor body II can be in equilibrium, and students who say so are almost always consistently assessing both force and moment equilibrium. Students who answer that body I can be in equilibrium but that body II cannot are almost always assessing only moment equilibrium, but not force equilibrium. Correspondingly, students who answer that body II can be in equilibrium but that body I cannot are almost always assessing only force equilibrium, but not moment equilibrium [7]-[8],[10],[33].

The largest study of this problem, [33], examined 289 student explanations to the problem from final exams at three different universities. There were 83 students (29%) who answered correctly, 82 of whom had answers that could be coded. Of those students, 94% correctly assessed force equilibrium and 90% correctly assessed moment equilibrium. There were 58 students (20%) who selected the answer biased towards moment equilibrium, 55 of whom had answers that could be coded. Of those students, 96% correctly assessed moment equilibrium, while 76% of them did not address force equilibrium at all, and another 7% only addressed force equilibrium on body II. There were 93 students (32%) who selected the answer biased toward force equilibrium, all of whom had answers that could be coded. Of those students, 96% correctly assessed force equilibrium, while 59% did not address moment equilibrium at all, and another 24% only addressed moment equilibrium on body I. The remaining 57 students (19%), of whom 55 had answers that could be coded, said that both bodies could be in equilibrium. Of those students, 56% addressed force equilibrium only on body I and 65% address moment equilibrium only on body II, so that at most 56% clearly displayed specific difficulty (a), while the remainder displayed specific difficulties (b), (c), or a combination.

The challenge is when students say that both bodies I and II can be in equilibrium they can reach that conclusion in multiple ways. One way for a student to reach this conclusion is to only assess moment equilibrium for body I, cued by the inclusion of the applied couple in the loading, and to only assess force equilibrium on body II, not cued to assess moment equilibrium due to the lack of an applied couple. Another way is for the student to assess force and moment equilibrium as separate, decoupled events. For example, for body II a student may say something to the effect that the forces as shown can satisfy force equilibrium, and then if the horizontal and vertical components of the force on the top right corner can be adjusted then the forces can also satisfy moment equilibrium. A similar

though reversed argument can be made using the force on the top left corner of body I. Finally, for body I a student may also indicate that the applied couple also contains an unbalanced force. In support of the argument that symbols like couples are inappropriate for pre-tests, this approach appears much more often at the start of a Statics class than at the end of it [7]-[8]. With that duly noted, however, the main point here is that all three of these, sometimes the second and third simultaneously, get captured by the same distractor, and there is not a simple way to parse out what the students' specific thinking is without getting more information. Given that at the start of Statics that almost as many students say both bodies can be in equilibrium as all of the other answers combined, this question is much more effective at letting an instructor know the rough fraction of students who struggle to assess equilibrium consistently, than the exact part of equilibrium with which they are struggling, which makes it a much better pre-test or early warm-up question for Mechanics of Materials than for Statics.

D. Rigid Body Motion

Using questions from the pre-requisite class, such as using the FCI to assess students' preparation for future learning in a Statics class implies that the students should all be comfortable with the symbols used on the assessment. Sometimes, however, there are interesting things to be learned by asking students to stretch outside of their pre-requisite course material. Here is an example of a dynamics question developed to explore whether students' ability to correctly assess the motion of unconstrained rigid bodies gives an indication to how well prepared students are to learn equilibrium concepts in Statics. The initial theory was that a student who recognized that an unconstrained body would both translate and rotate would be better prepared to master static equilibrium. Figure 4 shows two unconstrained rigid bodies lying on a frictionless surface and subjected to loadings that are designed to entice students to think translation first for the one on the left and rotation first for the one on the right, but that actually have resultant forces and moments that differ slightly in magnitude, but not in direction.

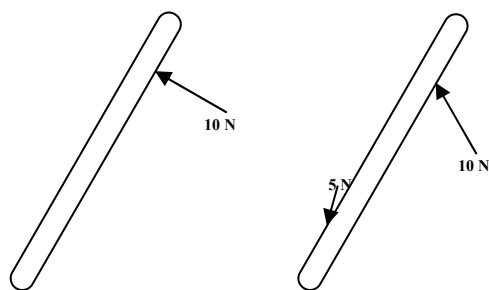


Fig. 4. Paired unconstrained rigid body concept questions

For a multiple choice pre-test or warm up questions, these two bodies are more easily asked as two questions, with the gist of each being will the bar: a) not move at all, b) translate without rotating, c) rotate without translating, d) rotate and translate, or e) something else, and, if there is interest in a deeper understanding of the rotation of the bars, one can add: if there is rotation, will it be around the end of the bar, center of the bar (i.e. center of mass for a uniform bar), or another point?

The idea was that students who recognized that both bars would both translate and rotate would be better prepared to correctly model and analyze statics equilibrium, but the results turned out to be somewhat different [34].

While the results to date are based upon a relatively small sample size of 92 students, the predictive outcome was potentially very useful. There were 83 students that applied a consistent model to their analysis of the two bars, and, as a group, they did well in Statics. There were 9 students that did not apply a consistent model to their analysis of the two bars, and they struggled in Statics. Specifically, even if the first bar was seen to translate or rotate and translate and the second bar was seen to rotate or rotate and translate the student proved to be well prepared to learn Statics; as long as the model was consistently applied the student registered learning gains. However, if either bar was indicated as not moving or doing 'something else', or if the first bar only rotated and the second bar only translated, the student struggled in Statics and showed minimal learning gains. The group of 9 students who struggled on the concept questions performed significantly worse than the other students on the equilibrium ($p = 0.082$) and equivalence ($p < 0.002$) concept questions on the final exam, and on CATS ($p = 0.004$), both overall and on the equilibrium section of CATS. The average learning gain on CATS from the pre-test to the post-test for the former group was 7.5 points (out of 27), while for the latter group it was 0.4. Although this does not give the same specific information as the questions outlined in the first three examples, it does provide instructors with a tool to identify students who are not well prepared for Statics.

E. Stress and Deflection (Strain) Relationship

Statics is not the only course for which well selected concept questions can give instructors useful information. While there is not a concept assessment tool for Mechanics of Materials that is analogous to CATS for Statics, there are concept questions for Mechanics of Materials that can be used as warm-up questions that can also give instructors valuable information about student thinking. One specific difficulty that students entering Mechanics of Materials often exhibit is that they do not have as strong of a mental model of the relationship between stress and strain as they do between forces and stress.

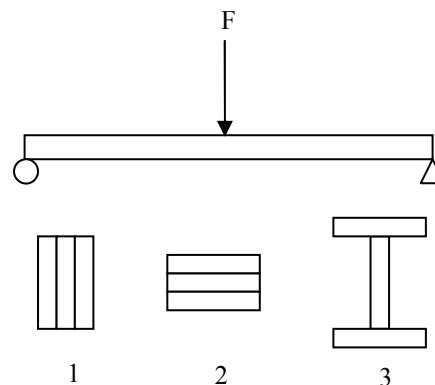


Fig. 5. Beam with cross-section options concept question

Figure 5 shows a figure for a pair of questions regarding the stress and deflection of a beam that is made of three joined planks. The top of the figure shows the beam loading, and the bottom shows the three possible configurations of the planks for the beam's cross section. The gist of what the paired questions ask for in this situation is to have the students rank order the amount of beam deflection for each possible cross section, with 'all the same' as one of the options, and then to do the same thing for beam stress.

When this question was used in a very small preliminary study, the students did a good job of properly ordering the relative amount of deflection for each configuration, but did not do a good job of ordering the stresses. 19 of 26 (73%) students got the relative deflections correctly ordered, but 14 of 26 (54%) students said that the beams would all have the same stress because they all have the same cross-sectional area, including 10 of the 19 (53%) who were able to order the deflections correctly [35]. In most instances of the pre-requisite Introduction to Materials Science and Engineering course, students are only introduced to direct stress, so it is not a surprise that many equate stress as being inversely proportional to area, but that roughly half of the one who recognized that the deflections would differ were unperturbed by the contradiction of the deflections being different while the stresses are the same is useful information for the instructor. These students may have even recalled that stress is directly proportional to strain in the linearly elastic region, but they were not able to apply that knowledge to the beam bending situation to realize that if the deflection (strain) differs so must the stress. It is another example of how relatively simple concept questions can be used to give instructors useful information regarding student thinking when put into a situation of vertical transfer.

IV. LESSONS AND CONCLUSIONS

All five of these questions or pairs of questions are examples of cases where students' thinking generally correlates well enough with answer selection for an instructor to be able to get good insight into a class simply by reviewing the answer distributions. The next step in the process, which is beyond the scope of this paper, is to find the activities that help students to get past their misconceptions and specific difficulties so that they develop appropriate and consistent mental models. Think-pair-share exercises are often helpful, but I have found in Statics that they are better when supplemented with physical explorations or computer animations that can also demonstrate the concepts in action. In addition, when discussing the answer distributions on a warm-up exercise, examination of why the incorrect answers that were popular are incorrect, and why they are attractive distractors, often seems to generate better class discussions than examining why the correct answer is correct.

There are no perfect solutions for helping all students to learn concepts like equilibrium and equivalence; the main point here is that instructors can ask students concept questions that give those instructors useful information about students' misconceptions and specific difficulties from answer distribution alone. There are a growing number of recommendations to use horizontal transfer assessment tools for pre-tests in order to be able to measure learning gains in a class from beginning to end. If measuring learning gains is the primary goal of giving

a pre-test, then this is good advice. However, using vertical transfer assessment tools, whether through pre-tests or some other method such as warm-up exercises, can provide instructors with information that is not available through the use of horizontal transfer assessment tools by showing instructors what misconceptions and specific difficulties students are exhibiting with the new material.

This paper has outlined five questions or paired questions that allow instructors to gain extra insight into student thinking from students' answer selections. Sometimes students strongly exhibit a single misconception or specific difficulty, as with the equivalence question described herein, and sometimes students might be prone to exhibiting more than one specific difficulty, as with the free body diagram question that was outlined. The important things are that the questions' distractors are set up to allow students to express their errors, and that the distractors are verified to confirm that students' explanations of their thinking match the intent of the distractor from the expert's perspective. If one or more of the distractors are a reliable indicator of student thinking, then the concept question or questions used can provide much more information than how often students selected a correct answer. Knowing that students' thinking on a concept is incorrect is far less useful than knowing the ways in which their thinking is incorrect.

The examples given in this paper are meant to just show the potential of what can be easily and reliably learned by well-structured, carefully selected, and thoughtfully used concept questions. This little set of questions is far from complete, and covers only a small part of engineering foundation courses. While some conceptual questions do not give much insight into student thinking, there are many that do or can with adjustments to their distractors. There is both plenty of room and much need to develop, test, and share questions that prove themselves to be useful for quickly assessing students' misconceptions and specific difficulties.

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Enterprise Architecture of Colombian Higher Education

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Abstract— Colombian Higher Education Enterprise Architecture is a framework for managing the system-of-systems lifecycle of Higher Education Programs. With this framework is possible to model scenarios about the government as a regulator of Higher Education services, the educational institutions as providers of higher education services and the different business and social sectors, and individual citizens as clients of higher education services. Under this perspective all the stakeholders can participate in the planning, development, transfer, use and control of all the products and services lifecycles of higher education in order to prioritize improvement alternatives and measure progress when it is moving towards excellence in training processes, research, innovation, development and knowledge transfer.

CHE²A is a supportive environment for the management of higher education as a public service, which hosts the vision of "Global Coalition Intelligent Network Services (-GIUNC -) to analyze and evaluate systematic, systemic and logistically, the characteristics of processes, outputs and outcomes and risks through key factors such as those proposed by the -GIUNC-itself, Registry of Qualification established by the Ministry of Education of Colombia or other similar factors established by national or international entities, from which, the stakeholders in the Higher Education services, interpret, evaluate, argue, propose, define, plan, implement and measure strategies, tactics and actions for improvement, innovation and development higher education programs.

CHE²A is a knowledge management system that is enriched by the experience of organizations and supports innovation in higher education toward a high performance service.

The approach set **CHE²A** does not advocate specific tools, methods or practices, but promotes a new way of thinking, to solve the great challenges of the interactions of technology, power, politics and economics made involves the general study design, complexity and systems engineering. Although these systems often exhibit behaviors systems of complex systems, however, not all complex problems fall within the scope of systems of systems.

This article presents the context, perspective and use of **CHE²A** through its models ontological, epistemological, methodological and regulatory that allow navigate the life cycles of products and services offered by higher education

institutions and all those entities benefiting from this results achieved.

Keywords—Enterprise Architecture; Agile Methods; Simulation; Serious Play; Maturity Models; Quality Assurance

I. INTRODUCTION

This paper presents a summary our processes of the research and development realized in the Laboratory of Integrated Organizational Systems (LASIO) using the framework "Enterprise Architecture with Agile Methods Model (ARTEMA)" for developing a Colombian Higher Education Enterprise Architecture prototype -CHE²A-, which it extends ours works of [7] [8] [9] [10] and the System Quality Assurance in Higher Education -SACES- used by the National Education Ministry of Colombia in recent years.

The Colombian Higher Education Enterprise Architecture prototype -CHE²A- is justified on framework for managing the Systems-of-Systems Lifecycle (SoSL) where we have established that a system should possess:

- An Enterprise Architecture [2][4][13][16][18] which represents the organizational and behavioral structure through integrated baselines of referential components and principles that guide their evolution.
- An Enterprise architecture [2] [18] which consists of building blocks organized in layers o views that encourage multidisciplinary work to engage and develop, with harmony, coherence and synchronization, institutional knowledge about continent and content around organization and behavior, which is observable by many holistic perspectives, for an efficient and flexible government through sustainable strategies, tactics and practices of continuing improvement, evolution and innovation.
- A sceneries views set [21] of organizational and functional capability models (executable architecture) that are composed of activities and these are in turn are decomposed operational architectures in which is possible to establish evaluation through simulations, virtually and physically, to analyze current capabilities or develop situational prognosis prior to the implementations and deployments of systems in order to verify, validate and communicate the relationship among complex structures of processes, stakeholders, rules, requirements and constraints, to improve design,

implementation, forecasting, deployments, and resourcing around systems, environment, technical, data and information about capabilities, services, products and outcomes.

- A set of principles [1] [2] [3] [5] [15] [17] to the learning and work collaborative (agile methods) to avoid the overhead and bureaucracy, solve problems, and promote participative adaptive of leadership, planning, management, development and transformation of the higher education.

This paper is organized as follows:

- **Processes Model of Leadership Organizational.** This section shows the building blocks that establish and locate the standards of structural, functional and operational practices with what is modeling the Colombian Higher Education Enterprise Architecture -CHE²A- ("what") associated to Administrative and Strategic Management, Tactical and Operative Administration ("how" through with lean-agile methods) associated with "where", "why", "when", "who", "how much" as reasons of feasibility and added value.
- **The Colombian Higher Education Enterprise Architecture Model.** This section describes the view of the Organizational Leadership Processes of Higher Education from the perspective of strategic, tactical and operational capabilities in three abstraction levels: High, Intermediate and detail, to particularize hierarchically capabilities. Additionally, there is a description of reference practices set to be used by the different institutions participants in the Colombian Higher Education System.
- **The Model Assessment of CHE²A.** This section describe the form of assessing compliance with standards defined in the CHE²A and its instances in order to monitoring and realizing continuous improvement associated with corrective (business continuity) and preventive actions (research, innovation and development) of calibration and adjustment in specifications (standards guides) and measuring instruments (smart metering).
- **Prototype Model for CHE²A.** This section shows the simplified tailoring of CHE²A as experimental reference of the organizational and behavioral practices in a educational component of a Higher Education Institution. This prototype has been developed within the CIDLIS and it represents a process lifecycle environment of research, teaching and learning about the courses taught in the E³T-UIS.
- **Conclusions.** This fragment recounts the retrospective assessment of the CHE²A research process regarding the lessons learned and future work to develop under this architecture.
- **Acknowledgment.** This part refers the gratitude to those stakeholders contributed in the development of this project.
- **References.** In last section it is referenced the bibliographic information underlying the approaches developed in this research.

II. PROCESSES MODEL OF LEADERSHIP ORGANIZATIONAL

The Processes Model of Leadership Organizational for develops CHE²A (Fig. 1) in its structure strategic, tactical and operational is organized into following steps:

Fig. 1. Process Model of Leadership Organizational

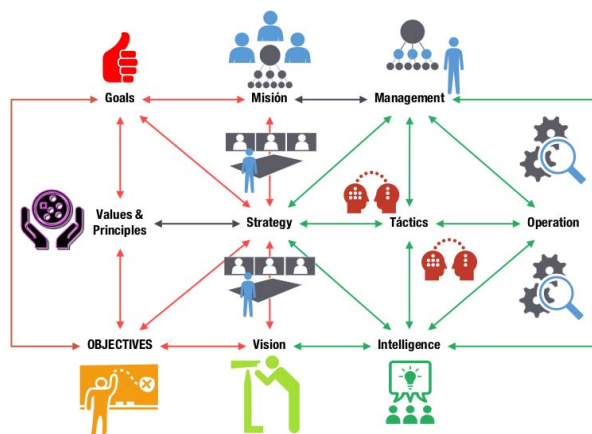


1. **Modeling.** In this step the experts model Higher Education sceneries through processes, capabilities and competences around Regulatory Institutions (Colombian State), Clients (Society and Sector environments) and Providers (Higher Education Institutions).
2. **Awareness (Consciousness).** In this second phase all experts agree together model and establish the SoS baseline:
 - a. Strategic thinking, capabilities, performance and regulatory standards for executing by the Regulatory Entities;
 - b. Goals, objectives, competences, politics, performance of managing human resources, innovation and development on the required knowledge and research needs of the different business lines of Clients; and,
 - c. The organizational objectives, commitment and social responsibility, and, development and environmental sustainability management on the services, research and knowledge transfer of higher education entities and regulatory institutions.

3. **Assessment.** In this third phase, it is realized the preparation, transfer, training and validation of instruments, products and services of the regulatory entity, clients and suppliers, that will be use during the assessment of Higher Education Ecosystem.

The process of monitoring and assessment of the evolution of the Higher Education Ecosystem (Fig. 2) require collect, analyze and evaluate compliance with the requirements of human resources, research, innovation and technological development, according with the strategic, tactical and operational goals and objectives about the management of educative products and services, committed between clients (sectoral environments) and providers (Higher Education Institutions) under the control of regulatory entity.

Fig. 2. Evaluation of Higher Education Environment



There are differences between the processes of monitoring and assessment about processes capability, events and risk situations in the scenarios of regulation, clients and suppliers. On clients, the analysis is done separately around processes and events. On the suppliers and the regulatory entities, the analysis is done mixed. This approach ensures transparency in the assessment. It should be reiterated that assessments meet simultaneous functions of regulation and improvement. The vision of the results of monitoring and assessment achieved sustains that:

- Client Entities judge and establish whether their products and value-added services are within their organizations and their clients. They judge and establish its needs and capabilities around the providers of Higher Education.
 - The Higher Education Institutions judge and establish whether human resources formed and the educational products and services generate value within their organizations, social networks, citizens, environment and industry.
 - The Regulatory judge and establish if the provides results of certification, accreditation, inspection and monitoring add value to the organization itself as a system-of-systems compounds by institutions of Higher Education, Business, Citizens and the state itself.
4. **Benchmarking.** From the result of assessment, it is possible to perform a comparative measurement between client organizations and higher education institutions

around the factors in the models of processes, capabilities, risks, inputs, outputs and outcomes. The comparative measurement environment could generate classifications around factors and provide new challenges and opportunities for improvement, innovation and development to match products and services, offered and received among all committed conglomerates.

5. **Performance.** Got Benchmarking, it is possible to establish action plans that lead the development of new strategic, tactical and operational for each type of participant in the Higher Education Ecosystem.

III. THE COLOMBIAN HIGHER EDUCATION ARCHITECTURE

"The Colombian Higher Education Architecture Model" (Fig. No. 3) is corresponding to the Process Model of Leadership Organizational with three abstraction levels: High, Intermediate and detail.

A. High Level of CHE²A

High Level of CHE²A consists of an essential element called Administrative Management, from which three building blocks emerge: Strategic, Tactical and Operational Administration. Each of the components is proposed as a means of skills (capacities) and capabilities to the different organizational perspectives for providing holistic common interpretations for those stakeholders in the higher education ecosystem. The model is deploying from the intelligence perspective for decision making supported by the direction and leadership through planning, monitoring and control of tactics actions around the educative architecture, providing logistics, manage resources and knowledge, and capture information, for and from, the operation, to improve, research, and develop, under continuous processes of optimization approach.

1) Administrative Management (Direction & Leadership).

The Administrative Management view include the capabilities of analytical thinking (creative thinking, decision making, learning, problem solving and systems thinking), behavioral characteristics (ethics, trustworthiness and management), body of knowledge about the products and services of the principles, practices, problems, solutions and organization of higher education programs, communication and interaction capacities and capabilities to support decision taking, facilitation, leadership and teamwork. This component is tactically supported by the tactical administration for implement strategies and operations, for transforming the current state of the mission towards the vision, achieving objectives and goals under the framework of organizational values and principles. All the capabilities described are inherited by all entities in the architecture model.

2) Tactical Administration (Institutional Management Knowledge).

The Tactical Administration view includes competences to Institutional Knowledge Management. This component manage the Educational Architecture to support, supply, monitor and control all the organizational activities and functional logistics around knowledge, communications, technology, economy, people and performance of the Administrative, Strategic, Operational, and itself. The Tactical

Administration view is nested in three levels of management: Establishment, Transfer and Monitoring of resources. It should be noted that all the components of CHE²A have the same lifecycle pattern: Feasibility, Initiation, Leadership and Decision Making, Monitoring and Control, and Clouse out. This pattern corresponds to agile methodology process which is characterized by a gradual and iterative delivery oriented by opportunity, courage, commitment, teamwork, problems solving, adaptive planning and continuous improvement

Fig. 3. Colombian Higher Education Architecture Model View

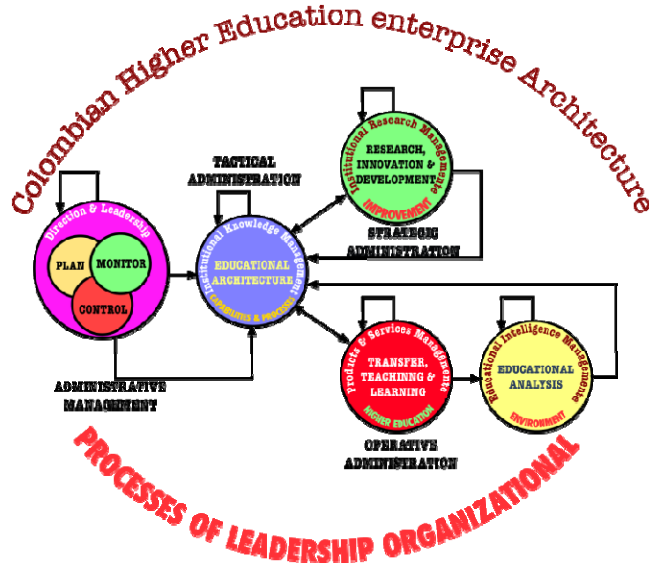
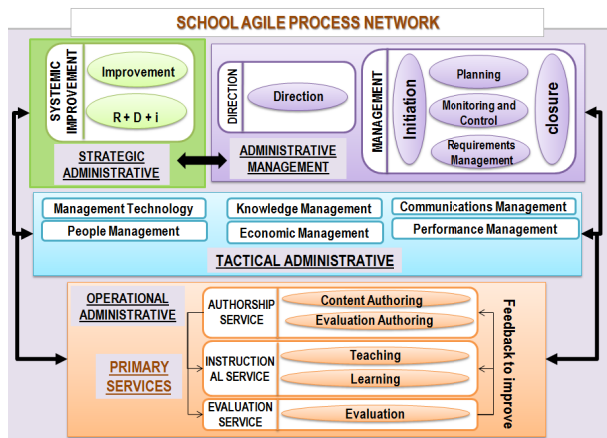


Fig. 4. Intermediate level of CHE²A



3) Strategic Administration (Research, Innovation & Development).

The Strategic Administration view include competences for improving the system as a whole, from the architecture to the environment and functional analysis studies, information on the specifications and the behavior of the processes developed by the organization. The performance of this component is supported and directed by Tactical Administration under the supervision and vision, leadership and direction of the Administration Management. The principal competence of this entity is the intelligence and educative Analysis (business analysis) for developing portfolios, plans, programs and

projects to produce goods and services to the Tactical Administration, who will integrate and deploy it. It is very important to note that the Strategic Administration supplies test and transfers all its products and services to the Tactical Administration, because this entity who manage the knowledge and the architecture (CHE²A) of research, innovation, improvement and development, around each of the architectural components carried out by the organization.

4) Operative Administration (Transfer, Teaching & Learning).

The Operative Administration view includes the capabilities corresponding with the bodies of knowledge of each of the educational programs offered. The Operational Administration develops the institutional mission that must be specified in all logistical architecture and the infrastructure and media resources, knowledge, and goods and services, with a focus on sustainable development provides to its environment. Its functionality depends on the Tactical Administration. The process follows the same mechanics of the other components already described but adapted hierarchically to all activities (features), operations and tasks of teaching and learning. It is important to reiterate again that the lifecycle of each process is associated with the already pattern of agile methods, emphasizing that the Operational Administration should be based on logistics provided by the Tactical Administration and also provide it, information from processes performance, and problems and incidents management that affect or may affect the continuity of the processes, to provide corrective and preventive actions for future improvement to be developed by the Strategic Administration.

B. Intermediate Level of CHE²A

The second level presents the view of breakdown of the capabilities associated with the Administrative Management and the Tactical, Strategic and Operational Administration (Fig. No. 4 and TABLE I). This level is the basis to support the actions of higher level about knowledge, capacities, skills, tools and techniques to fundament assessment of managers, analysts, researches, teachers, instructors, authors, mediators, students and other stakeholders associated with humans, knowledge, technology and infrastructure resources [6] [14] .

C. Detail level of CHE²A

This Detail level presents a capabilities breakdown view of the High (first) and Intermediate (second) level (Fig. No. 5) about specific areas of knowledge, capacities, skills, tools and techniques to fundament assessment of managers, analysts, researches, teachers, instructors, authors, mediators, students and other stakeholders associated with humans, knowledge, technology and infrastructure resources.

This level is considered variable because it must be tailored specifically to the alleged philosophical conditions within the autonomy of each of Higher Education Institutions. Under this interpretation the level includes the ontologies (superstructures, structures and infrastructure of higher education), the epistemology (Body-of-Knowledge) and methodology

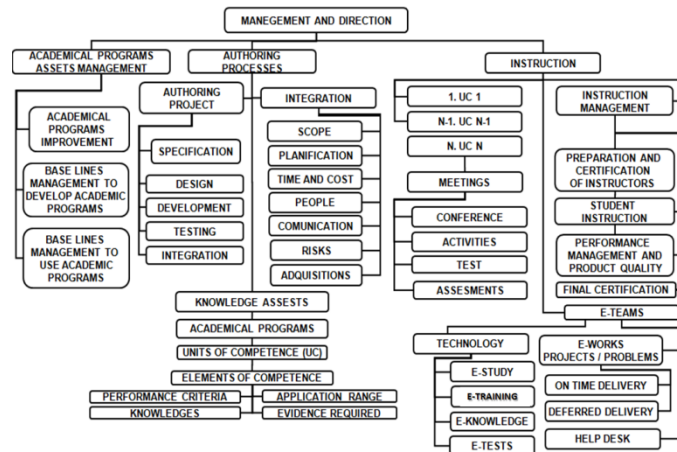
(capabilities, technologies, techniques, instruments, tools and skills) for using by all the stakeholders of each institution.

TABLE I. Intermediate level of CHE²A

Processes		
Capabilities	Capacities	Knowledge Competences (Maturity Level)
Administrative Management	Direction	1. Decision Analysis & Making (3) 2. Causes Analysis (5) 3. Educational Strategic (3)
	Management	4. Requirements Management (2) 5. Educational Planning (2) 6. Educational Monitoring/Control (2) 7. Risk Management (3) 8. Educational Quantification (4)
Operational Administration	Authoring	9. Requirements Definition (3) 10. Educational Design/Development (2) 11. Educational Verification (3) 12. Educational Validation (3)
	Instruction	13. Instruction Service Delivery (2) 14. Instruction Service Continuity (3) 15. Incident Resolution/Prevention (3)
	Evaluation	16. Evaluation (3)
Tactical Administration	Quality Assurance	17. Educative Architecture Enterprise (2) 18. Knowledge & Configuration Management (2) 19. Measurement and Analysis (2) 20. Educational Analysis (2) 21. Quality Assurance (2) 22. Training (3) 23. Communications Management (3) 24. Performance Measurement (4)
Strategic Administration	Systemic Improvement	25. Definition and Improvement (3) 26. Research, Development & Innovation (5)

As an example we describe how often we have developed this level in our experimental tests.

Fig. 5. Detail level of CHE²A



1) Detail Ontology level of CHE²A (Structure)

The Ontology of CHE²A follows the guidelines set for the two levels previous through an integrated administration management and tactical, strategic and operative administration that it is represented in "Management and Direction" [7] [8] [9] [10]. The components that emerge in this structure correspond to operative processes: Knowledge assets management: Authoring, Development and Maintenance:

- The Knowledge Asset Management Processes follows the guidelines to academics improve under Strategic Administration and baselines management following the guidelines developed by Tactical Administration.
- Authoring Processes, is covered by Strategic, Tactical and Operative Administration, for designing and making

teaching-learning modules and evaluations under the vision of competency-based formation using agile project management as a support tool to develop products and services of competence specifications, performance criteria, knowledge, applications and the establishment of evidence required to certify skills acquired; design and production of teaching-learning objects that are seen as technological applications of reusable components supported by human resources; verification, validation and integration of components; a integral improvement process for resources, content, practices and the same authoring. Authoring Processes also includes development, management and maintenance of knowledge, to make them consistent, permanent and relevant.

- Instruction and Evaluation Processes is established for following learning sequences through teamwork activities to solve problems through agile methods. The student projects are supported by a tutor, a coach and several assistants. These projects are charged with overseeing all activities of the students. Instruction Processes may include certification procedures and, eventually, be linked to each course; a fact that makes feasible the continuous monitoring practices of certified human resources and allows continuous improvement processes directly into formation development.

2) Detail Epistemology level of CHE²A (Performance)

Established the ontology [11] [12] the next step is validate and constitute criteria of truth to admit, raise and study cognitive phenomena that occur when observing how it is generated, builds, defines and institutionalize the knowledge and its own and emergent concepts, types of knowledge possible and the criteria that justify or invalidate, and the degree to which each criterion is true between the knower and the object known. In short, establishing and studying the conditions of production and validation of knowledge object as technological product applicable to the value chain of the educational process.

3) Detail Metodology level of CHE²A (Method).

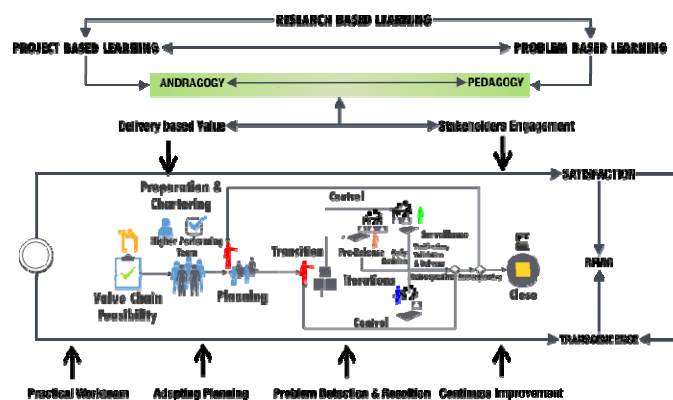
The methodological pattern is based on the scientific method for explaining phenomena; establish relationships between facts, and state guidelines grounded in principles and values that explain the phenomena and obtaining, with this knowledge, useful applications to the community.

By example, the CIDLIS² use the educative process pattern methodology which has three paradigms of learning (Fig. 6): Problems, Projects and Research [19][20], established under the principles of Andragogy (teaching techniques aimed at educating adults) and Pedagogy (teaching techniques geared toward education, as intrinsic phenomenon of the human species) developed to raise the continuous delivery of value supported by the commitment of all internal and external stakeholders that are associated with an higher education process. This process is clocked by stages. Each stage requires integrally inputs required to produce products and achieve a gradual iterative training in which knowledge and skills using proprietary techniques and tools for each phase of training.

Particularly in all phases of the teaching-learning activities covering:

- The intellectual domain (cognitive system) in which the learner receives direction and training
- Emotional and physical domain (emotional system) in which the learner, with the support of an educational coach and a facilitator, publicly confronts his learned achieved in the cognitive system.
- The practical domain (emotional system) in which the learner, with the support of educational assistants and facilitators, get experience, skill and maturity as a practitioner.
- The domain creative (expression system) in which the apprentice is delegate to perform own creations.
- The autonomous domain (Integrated system) in which the learner is leadership, free and critical, to make their knowledge practices.

Fig. 6. Example of Teaching & Learning Methodology of the Detail level

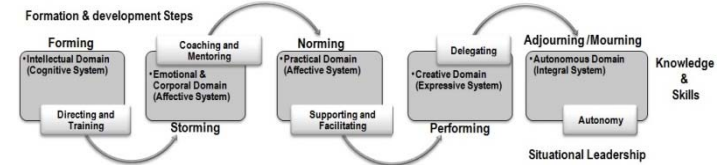


Others examples of methodological patterns used by the CIDLIS² are (Fig. 7): teamwork, adaptive planning (considering that educational outreach is variable in time), the detection and resolution of problems and continuous improvement, as elements which result in a work-oriented agile projects to realize practices and versioned deliveries supported in small iterative partial products that enable the gradual improvement of maturity and development of products, knowledge, and human and technological resources, necessary for the development of an educational process. The iterative cycle is set at multiple levels according to the Organizational Leadership Processes of CHE²A, following the specifications and requirements prioritized by value and opportunity for each of the required products to be delivered just in time to allow coexistence and synchronization processes related with products and authors, teachers, learners, administrators and other roles established in an educational process.

IV. THE MODEL ASSESSMENT OF CHE²A

The CHE²A and its implementation have two assessment tools (Fig. 8) the Integral Assessment Method of Interactions and Communications and The Integral Organizational Assessment Method.

Fig. 7. Example of Teams Developing Methodology of the Detail level



The Methods follows the principles of Standard CMMI[®] Appraisal Method for Process Improvement (SCAMPISM) [22] extending to aspects of cost, time and performance. The methods produce benefits around insight into an organization's capabilities by identifying the strengths and weaknesses of all current processes relative to CHE²A reference model to prioritize improvement plans, focus on improvements that are most beneficial to the organization given its current capabilities and risks processes level.

Both methods follow the same sequence of steps with roles and responsibilities assigned but with adaptation according to each assessment object; Plan and Prepare (Analyze Requirements, Develop Plan, Select and Prepare Team, Obtain and Initial inventory of Objective Evidence and Prepare for Appraisal Conduct), Conduct Appraisal (prepare participants, examine, document, verify and validate objective evidences, validate preliminary findings and generate results) and Report Results (deliver, package and archive results)

A. Integral Assessment Method of Interactions and Communications

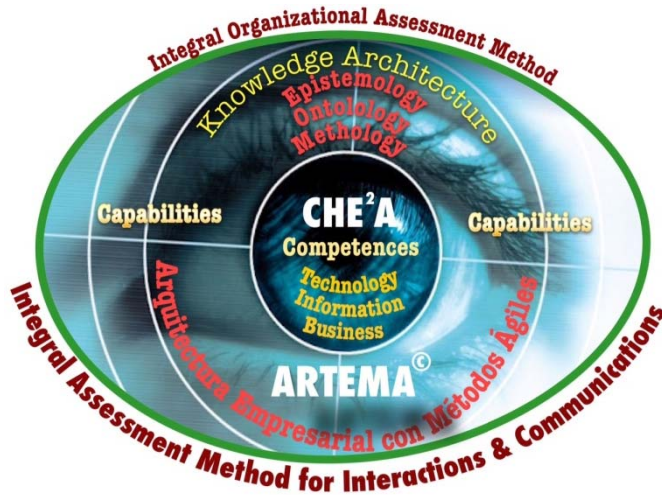
The first assessment method of CHE²A and its instances evaluates the characteristics of attitude and aptitude of interaction and communication capabilities to determine the quality and trustworthiness ethics of organizational and performance integrity respect to ontology, epistemology and methodology, capabilities and competencies of leadership, direction, administration, teaching, learning, facilitation, negotiation and teamwork. With this assessment becomes consciousness in matching CHE²A and reality environment to organizational and functional behavior to be aware for knowing and doing. This situation permits constructs intelligent measurement instruments (standards patterns of calibration and adjustment of specifications for measurement) to monitor and realize continuous improvement associated with corrective (business continuity) and preventive actions (research, innovation and development).

B. Integral Organizational Assessment Method

The second assessment method of CHE²A and its instances is supported in the validity of the results of the first assessment and evaluates the characteristics of attitude and aptitude of capabilities around the Educational Knowledge (principles and practices, environment, organizational and solutions of knowledge) to determine the quality, trustworthiness, suitability and ability to know, build, transfer, do, teach and learn how to work with knowledge in the different social and sectoral environments. With this assessment becomes consciousness in matching CHE²A and reality environment to organizational and functional behavior about knowledge. This situation can also constructs intelligent measurement

instruments to monitor and realize continuous improvement associated with corrective and preventive actions.

Fig. 8. CHE²A Assessment Methods



V. PROTOTYPE MODEL OF CHE²A

This section presents a prototype model of CHE²A. This modeling has required develop a vision of the current state of Colombian Higher Education in order to build a basic environment of analysis and validation.

A. The current state of Colombian Higher Education View.

The System of Higher Education in Colombia is comprised of three interrelated subsystems: Evaluation, Information and Development. With these systems the Higher Education Institutions are regulated by two major moments, one mandatory, when created, and other, voluntary when institutionally accredited under 10 quality factors (TABLE II).

TABLE II. Higher Quality Factors for Higher Education Institutions

Qualified Register Factors		
Id	Description	
1	Institutional Mission and Project	x
2	Students	x
3	Teachers	x
4	Academics processes	x
5	National e international Visibility	x
6	Research and Artistic Creation	x
7	Pertinence and Social Impact	x
8	Self-evaluation y Self-regulation	x
9	Institutional Welfare	x
10	Organization, Management & Administration	x
11	Academic Support Resources and Physics Infrastructure	x
12	Financial Resources	x

Similarly, academic programs of Higher Education are regulated in two stages, one mandatory, must fulfill 15 quality conditions (TABLE III) to be granted the Qualified Registry, and other, voluntary, getting demonstrate compliance with 10 factors high quality(TABLE IV).

The accreditation of institutions and programs are complementary. The first is oriented towards the institution as a whole; the second considers its integral parts or key components. With which, the Quality Assurance System is based on the National System of Higher Education that indirectly influences the curricular compositions and organizational structures under the support of competences according to the job performance information of graduates proportionate by the Labor Observatory about market needs.

With which, as a whole, the system are pretending create a self-regulating system with permanently seeks improvement processes.

TABLE No. III. Qualified Register Conditions

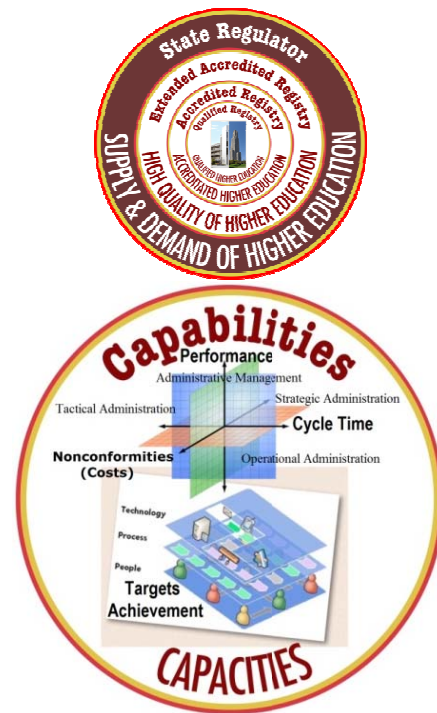
Id	Factor	
1	Name of Program	x
2	Justification	x
3	Curricular Content	x
4	Organization of Academic Activities	x
5	Research	x
6	Relationship with the External Sector	x
7	Teachers	x
8	Educational Media	x
9	Physical Infrastructure	x
10	Selection and Evaluation Mechanisms	x
11	Academically and Management Structure	x
12	Culture of the Self-evaluation	x
13	Program Graduates	x
14	University Welfare	x
15	Sufficient Financial Resources	x

In conclusion, while the Colombian state (Fig. 9) as regulator establishes general standards of regulation that induce curricular and organizational structures, it is necessary to define frameworks that provide comprehensive guidelines for the development of higher education, where the bodies of knowledge are determined as units of reusable composition (inputs, outputs, tools and techniques, and personal or organizational skills) for each of the capabilities offered in educational services.

TABLE IV. Accredited Register Factors in Colombian Higher Education

Id	Factor	
1	Mission, project and program	x
2	Students	x
3	Teachers	x
4	Academic Processes	x
5	Visibility	x
6	Research, Innovation & cultural	x
7	Institutional Welfare	x
8	Organization, administration & management	x
9	Impact in the middle	x
10	Physical & Financial Resources	x

Fig. 9. The current state of Higher Education in Colombia Versus CHE²A



B. Basic environment of analysis and validation.

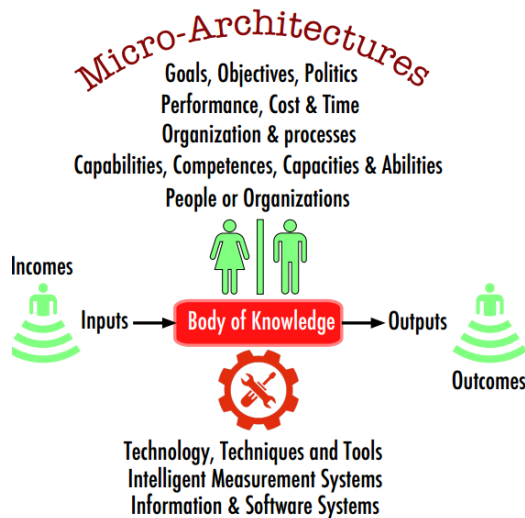
The basic architecture environment has been developed in the last two years about the undergraduate and graduate courses taught by CIDLIS at E3T-UIS. They supported in the school model Agile (Fig. 4 and Table I) were structured and integrated the CHE²A in High and Intermediate layers and the teaching-learning detail level was constituted by three components (micro-architectures) (Fig. 10 and 11); Bodies-of-Knowledge of Project management, Quality Engineering and Statistics for Engineers.

Assessed the results of the experimental period of use CHE²A (Table V), it appreciate that assessed the results of the experimental period implies that the culture of all stakeholders in higher education is still not prepared for the proposed changes, however, development and simulation and prototyping of architecture is useful for estimating and induce the development of a portfolio of projects associated with the entire higher education ecosystem, including the internal and external environments to higher education; administration, teachers, managers of infrastructure and knowledge, providers, alumni, state, productive sectors, and in general, all the community concerned.

Table V. Technical Data Sheet of experience with CHE²A

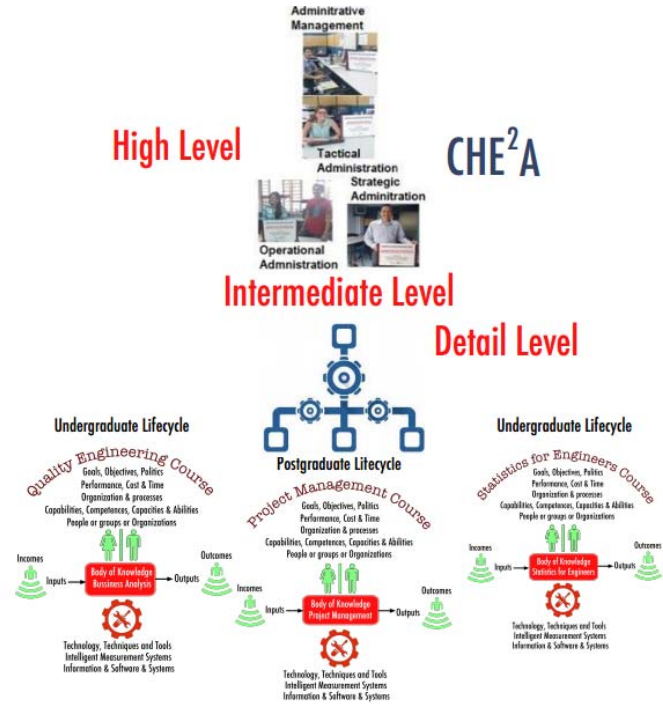
Resources	Quantity
Students	254
Teachers	3
Students approved	240
Students disapproved	14
Hours accompanied by teacher	704
Undergraduate courses	11
Postgraduate courses	6
Administrative Management	2
Tactic Administration	1
Strategic Administration	1
Operative Administration	1
Assistant Personal	9
Average grades in undergraduate courses (About 5)	3.5
Average grades in undergraduate in postgraduate courses	4.5

Fig. 10. CHE²A Knowledge Units



The instance of the CHE²A as pilot developed drove along the stakeholders to establish the results of leadership, management and administration, teamwork, value creation, engagement, problems identification and resolution, and continuous improvement.

Fig. 11. Examples of CHE²A Bodies-Of-Knowledge Micro-architectures



VI. CONCLUSIONS

The conclusions are presented from the organizational, performance and methodological perspective and future work.

Lessons learned from CHE²A and its implementations enhances the Teaching-Learning exercise to create a dynamic, agile and collaborative learning integrated with the environment, fact that motivates and creates value for all those involved in the educational process.

The achievements of CHE²A has been benefits, all the components and its instances has been translated into the creation of a discipline to internalize the processes and principles of performance and accountability, it must be sustained in models as CHE²A, always previous to any development, for doing actions reliable of leadership with all the teamwork and being whole integral organizations.

Future CHE²A argues to extend the model to the scenarios of simulation to work components as units on which their structures and behavior is not known, in order to perform intelligence to create collaborative environments supported by systems of systems.

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Evidence-Based Approaches for Engineering Global Preparedness Programming: Research to Inform Practice

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Abstract—Higher education has emphasized global education as a strategic goal over the past few decades, yet little empirical data has been collected to inform the decisions of global education. Engineering schools have integrated global experiences into programs with limited knowledge regarding the effectiveness of their program planning and capacity for supporting internationalization. Research is needed regarding strategies that support effective global programming and how outcomes of these strategies can be evaluated. Through three separate studies, this research addresses how engineering educators may implement, assess, and evaluate effective global engineering education programs. Using concept mapping, the first study will engage international engineering program facilitators to develop a framework that highlights effective global engineering education strategies and their evaluation. Data Envelopment Analysis will then be utilized to measure the relative effectiveness of global engineering education programming strategies using indices and outcomes identified in the framework. Using Latent Profile Analysis, the third study explores engineering global preparedness patterns among undergraduate engineering students as well as evaluates the relationships of engineering global preparedness with different student, institutional, and global programming variables. The anticipated results of this research are evidence-based global engineering programming strategies and systematic evaluation methods for international engineering program facilitators and educators.

Keywords—*global engineering education; engineering global preparedness; concept mapping; data envelopment analysis; latent profile analysis*

I. INTRODUCTION

Engineers in academics and industry are recognizing the importance of preparing the current and next generations of engineers to be successful in the new global economy [1]–[3]. National commissions and scholars have noted the impact of globalization and the implication for continued U.S. economic leadership [4]–[6]. To this end, engineering global preparedness has become an important educational outcome, with educators believing that success in a global context requires students to acquire specialized knowledge and develop new skills and attitudes. Engineering programs have increasingly emphasized global education programming as a

core piece of their strategic goals over the past few decades, investing substantial resources to increase participation in global experiences, both curricular and co-curricular, with the expectation that a student who participate in such experiences will become more globally prepared. Engineering schools integrate global perspectives and experiences into programs through a variety of offerings (both curricular and co-curricular) but are often operating with limited knowledge regarding the effectiveness of their program planning strategies and the organizational capacity for supporting the internationalization process. Most evidence as to how global programming impact engineering students is anecdotal, without much empirical evidence to guide educational practice [7], [8].

There is a lack of rigorous research regarding global engineering programming strategies and the fervor to globalize engineering programs has focused primarily on the development and less on evaluation [9]. Empirical research is needed regarding the strategic planning and outcomes evaluation of global engineering education programming strategies. Through three separate, but integrated, studies this proposed research addresses how engineering educators may implement, assess, and evaluate effective global engineering education programming (GEEP) strategies. The objectives of the three studies are as follows.

First, develop with international engineering program facilitators a conceptual framework via a logic model that identifies effective global engineering education programming strategies and outcomes. In doing this, we will establish essential inputs and outcomes for successful global engineering education programming, and distill feasible mechanisms for assessment and evaluation. A participatory, integrative mixed methods approach, called Concept Mapping [10], will be employed.

Second, based on the results of the conceptual framework, conduct a cross-institutional quantitative study of 30 engineering schools across the U.S. to analyze the relative efficiency of global engineering education programming strategies. Data Envelopment Analysis (DEA) [11] will be used to construct specific benchmarks for evaluating the performance of individual global engineering programs. This will be useful to engineering educators not only in measuring

efficiency of different program strategies, but also guiding them how that could be accomplished.

Third, build upon these findings by adopting a finite mixture models approach to discover undergraduate engineering students engineering global preparedness development patterns as well as evaluate the relationships of engineering global preparedness with student backgrounds, institutional constraints, and global programming strategies. Specifically, Latent Profile Analysis (LPA) [12] will be applied to a data set containing undergraduate engineering students' demographics, prior international experiences, and global preparedness. LPA has significant theoretical and practical advantages over traditional techniques when analyzing multidimensional data like global preparedness [12].

Figure 1 outlines the proposed research framework. To achieve these objectives, the following primary research questions are explored: (1) What are effective global engineering education programming strategies, and how can we empirically identify and assess the mechanisms for effectiveness within the engineering discipline?; and (2) How can we formulate evidence-based global engineering programming strategies that are robust to the diverse backgrounds and experiences of undergraduate engineering student populations and engineering programs?

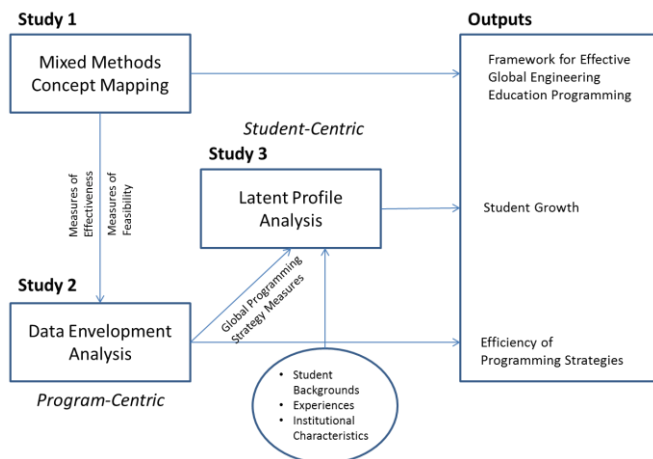


Fig. 1. Research Framework

II. RELATED WORK

A. The State of Global Engineering Education

Accreditation bodies, national engineering organizations, and government agencies have recognized the importance of global competence in today's globally interconnected world. The American Society for Engineering Education's (ASEE) Green Report (2010) has called for colleges to adapt curricula to incorporate "an appreciation of different cultures and business practices, and the understanding that the practice of engineering is now global"[13]. Engineering programs recognize the need to equip graduates with the right skills to stay globally competitive, and many schools have begun making efforts to incorporate global learning experiences into their program structure. Parkinson provides an overview of 24

exemplary programs [14], noting that a few have goals to increase their number of graduates with an international experience. Research, however, has indicated that international learning experiences are not necessarily predictive of students' engineering global preparedness. The beneficial effects of global engineering programming such as study abroad on engineering global preparedness may be a more popular narrative than an empirically grounded claim due to methodological shortcomings in prior research. A more comprehensive and integrated approach to enhance development of global preparedness in engineering students is necessary to meet the changing needs of society world-wide. As engineering programs continue to invest heavily in global education programming efforts, it is critical to determine whether these investments can be expected to produce their intended results and what strategies best produce these results.

B. Global Engineering Education Programming (GEEP) Framework

The Center for Internationalization and Global Engagement (CIGE) provides analyses of critical international education issues and supports the internationalization of higher education through a broad range of programs and services[15]. The Global Engineering Education Programming (GEEP) framework in Figure 2 is an adaptation of CIGE's Model for Comprehensive Internationalization, which is defined as a strategic, coordinated process that seeks to align and integrate international policies, programs, and initiatives, and positions colleges and universities as more globally oriented and internationally connected [15]. This framework will be used as a guide and leverage point for the construction and interpretation of the conceptual framework.

III. STUDY 1 - CONCEPT MAPPING OF GEEP STRATEGIES AND OUTCOMES

Concept mapping is a integrative, mixed methods approach for organizing the ideas of a group or organization, to bring together diverse groups of stakeholders and help them rapidly form a common framework that can be used for planning, evaluation, or both [10]. The approach integrates qualitative individual and group process with multivariate statistical analyses to help a group of individuals describe ideas on any topic of interest and represent these ideas visually through a series of related two-dimensional maps [16].

This methodology will be used for the development of both GEEP strategies (planning) and outcomes (evaluation). This concept mapping study will involve a group of 30+ stakeholders drawn from across key groups associated with current global engineering programming across the U.S. These participants will brainstorm planning strategies and outcome evaluation criteria, resulting in two sets of concept maps. These maps will be interpreted together to generate a conceptual framework for GEEP strategies. Study 1 will address the following research question: what are the key strategies when designing and implementing effective global engineering education programming, and how the effectiveness of these strategies be evaluated?

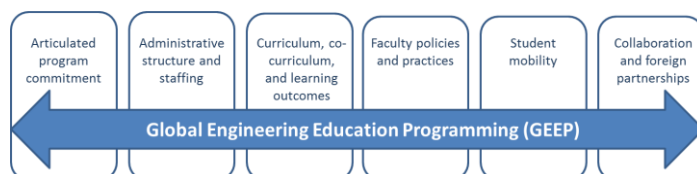


Fig. 2. Global Engineering Education Programming framework Adapted from Center for Internationalization and Global Engagement (CIGE) Model for Comprehensive Internationalization [15]

Stakeholders will first brainstorm a large set of statements relevant to GEEP strategies and outcome evaluation. Each stakeholder will sort the statements into piles based on perceived similarity, and rate each statement on 'Importance' and 'Feasibility'. Engineering program information on the type of school, size of engineering program, and other mitigating factors will be captured.

Multivariate analyses will be conducted that includes two-dimensional multidimensional scaling (MDS) of the unstructured sort data, hierarchical cluster analyses of the MDS coordinates, and then a computation of average importance and feasibility for each statement and cluster of statements. Finally, the group of stakeholder will interpret the maps through a structured interpretation process designed to help them understand the emergent strategies and outcomes; and label them in a substantively meaningful way [16].

The GEEP stakeholders interpret a series of maps that reflect item and cluster similarity and scale ratings, pattern matches (pairwise comparisons of cluster ratings across criteria such different stakeholder groups or rating variables, using a ladder graph representation), and go-zones (bivariate graphs of statement values for rating two variables within a cluster, divided into quadrants above and below the mean of each variable, showing a "go-zone" quadrant of statements that are above average on both variables). The stakeholder group will then discusses ways to utilize the final GEEP concept maps, pattern matches, and go-zones to enhance program planning and evaluation.

Using program theory [17], the resultant concept maps will be used to develop a model of how effective GEEP strategies work and how these strategies influence immediate outputs and through them, longer-term outcomes. Logic models are consistent with this emphasis, and typically show environmental factors, inputs, outputs, and outcomes for a program in a graphic form [18]. The logic model will be used to identify and develop GEEP outcome evaluation questions and a resulting GEEP evaluation instrument.

IV. STUDY 2 - BENCHMARKING GEEP AGAINST BEST-PRACTICE USING DATA ENVELOPMENT ANALYSIS

Data envelopment analysis (DEA) is a mathematical programming based approach for measuring the relative effectiveness of decision making units (DMUs) that have multiple inputs and outputs [19]. DEA can be viewed as a multiple-criteria evaluation methodology where DMUs are alternatives, and the inputs and outputs are two sets of performance criteria where inputs are to be minimized and outputs are to be maximized. The assumption here is that there is a conceptual or experiential relationship between the outputs

and inputs. The DEA linear program provides optimal weights on DMUs used as references to benchmark each DMU being evaluated to obtain an objectively identified efficient peer group [11]. In Study 2, the efficiency of global engineering programs in utilizing GEEP strategies (inputs identified in Study 1) will be measured. The inputs and outputs used in the proposed model will be the result of the conceptual framework and the results of the GEEP evaluation instrument designed in Study 1. The following research question is addressed: Can we systematically compare the effectiveness of different global engineering education programming strategies and how can we use this information to benchmark against best-practice? This study will be useful to engineering education policy makers not only in measuring the efficiency of different GEEP frameworks, but also in guiding them how that could be accomplished.

The inputs and outputs of the model will be the key strategies and outcomes identified in Study 1, and outlined in the conceptual framework and measured via the GEEP evaluation instrument. The Banker, Charnes, and Cooper (BCC) model of DEA is proposed to combat the perceived faulty assumption of constant returns to scale among global engineering programs. The BCC model takes into account the possibility that small global engineering programs may not be able to operate as efficiently larger ones, or in other words, variable returns to scale [20]. In addition to measuring the efficiency of each global engineering program, efficiency will be decomposed into the contributions of output factors. The efficiency measures will show the global engineering programs whose strategies have been utilized inefficiently and the decomposition will help determine future areas of improvement.

The weights obtained from the DEA linear program model have been used to represent the importance of the input and output factors, with the rationale that more favorable factors tend to have larger associated weights. However, weight restrictions are often imposed that constrains the weights of favorable factors to small values. To investigate the importance of a factor and its contribution to the efficiency score, a cluster analysis will be explored to distinguish the dissimilarity of the global engineering programs with respect to the efficiency contributions of the specified outputs/outcomes.

A further analytic step is to seek statistically the DEA efficiency scores by regressing the efficiency scores of each global engineering program with the controllable inputs of the BCC model described above. It is natural then to model them using a censored (tobit) regression, which is designed to estimate linear relationships between variables when there is either left or right censoring in the dependent variable. This follow-up methodology is being proposed as a way of exploring the associations between the DEA efficiency scores of global engineering programs and the GEEP strategies that are employed.

V. STUDY 3- LATENT PROFILE ANALYSIS AS A TOOL FOR UNDERSTANDING GLOBAL PREPAREDNESS PATTERNS

Of particular importance to global engineering research is engineering students' preparedness for global workforces (i.e.,

engineering global preparedness). To this end, the third study aims to profile undergraduate engineering students on different levels of engineering global preparedness as well as evaluate the relationships of engineering global preparedness with different student, institutional, and global GEEP strategy variables (discovered in Study 1). The following research questions are addressed: (1) Can we identify and examine different patterns of engineering global preparedness among undergraduate engineering students?; and (2) How do global engineering education programming strategies affect global preparedness development patterns, and how can we use this information to inform engineering practice regarding curricular and co-curricular globalization strategies?

These questions are addressed by employing Latent Profile Analysis (LPA), a type of latent variable mixture model, which has significant theoretical and practical advantages over traditional techniques when analyzing multidimensional data like global preparedness [12]. The goal of LPA is to identify clusters or patterns of observations that have similar values on latent indicators.

The purpose of study 3 is to identify the typical global preparedness profiles of undergraduate engineering students from 15+ universities across the U.S, resulting in a sample of roughly $N = 4,000$ students. Fifteen of the engineering programs involved in studies 1 and 2 will be the programs included in the LPA. Additionally, the LPA solutions obtained will be compared using different conceptualizations of global preparedness. LPA solutions obtained using a 2-, 3-, and 4-factor model of global preparedness will be explored to better understand if more complex conceptualizations were need to better differentiate students global preparedness patterns. Two primary steps will be used to accomplish the goals of Study 3. First, LPA will be used to classify engineering students into clusters with separate sets of analyses being conducted, one for each conceptualization of global preparedness. Second, hierarchical logit models will be constructed to examine the extent to which profile membership relates to student, institutional, and global programming variables. The extent to which profile membership relates to global experience patterns will be pursued to determine if solutions based on more complex conceptualizations of global preparedness can more accurately predict global experience participation and interest.

VI. CONCLUSIONS

The impetus behind the development of international engineering programming has been the perception that engineering has become a global profession [21]. As a result, engineering programs now have a responsibility to design effective and sustainable global preparedness development strategies for their engineering student populations and, in turn, evaluate the outcomes of these strategies. Results from the proposed research provide understanding regarding sustainable development of engineering global preparedness and broadens the knowledge base about the construction, implementation, and evaluation of global engineering education programming.

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Examining How International Experiences Promote Global Competency among Engineering Graduate Students

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Abstract— Employers worldwide are seeking engineers who possess a more complete professional skillset that could be useful in the constantly changing globalized economy. For this reason, engineers are expected to have leadership, communication, and teamwork skills, in addition to analytical skills. Furthermore, they are also expected to have attributes of global competency, which would help them thrive in the global workforce. A plethora of information and studies exist on undergraduate students and how institutions are helping students increase their global competency through methods such as international exchange and study abroad programs. Despite these efforts, there is little information on engineering doctoral students and methods for increasing their levels of global competency. Doctoral students are at the forefront of scientific and technological innovation and discoveries, so it is critical that they are trained to work effectively in diverse environments. This study comparatively examines the intercultural experiences of a) engineering Ph.D. students from the U.S. who traveled abroad, and b) international engineering Ph.D. students who traveled to the U.S. Findings indicate that students tended to prepare themselves for travel abroad in various ways, and that negative experiences of domestic students abroad are related to a mismatch between pre-travel expectations and actual experiences. International students more frequently mention cross-cultural differences, and those with greater levels of support tended to report easier adjustments. Findings can be applied toward helping U.S. and international academic institutions identify strategies to develop graduate students' global competency levels.

Keywords—doctoral students; global competency; study abroad; international experience.

I. INTRODUCTION

The world we live in is a vastly interconnected place. Each country is intertwined and dependent on other parts of the world. Countries will continue to become even more interconnected in the future, and this calls for universities to prepare their students to enter a globalized workforce through enhancing students' global competency levels. While an important concept, many different definitions of global competency have been proposed. One definition of global

competency is the ability to communicate effectively and appropriately in intercultural situations [1, pp. 247]. Based on this definition, global competency would depend on the individual's awareness, skills, and mindset in one's specific cultural setting. For example, specific aspects of global competency can include world knowledge, foreign language proficiency, cultural empathy, ability to work effectively with individuals from different cultures, and ability to practice one's profession in an international setting.

Historically, engineering degrees have been intensive programs in math, design, theory, and physics while classes for developing other skills that would lead to global competency have been viewed as tangential to the engineering curriculum [2]. This phenomenon also holds for engineering graduate studies, where programs commonly promote a high technical preparation while leaving aside other professional skills [3-5]. However, by the time they join the workforce, graduate students will be required to work effectively doing research or performing in industry within an internationalized framework. Some of the problems needing global collaboration have been listed in the National Academy of Engineering's Grand Challenges of Engineering, such as making solar energy economical, providing access to clean water, and engineering better medicines [6]. Therefore, increasing global competency in graduate engineering students is paramount to their success and the future of our society.

This study considers two groups of graduate engineering students: a) domestic U.S. students and, b) international students enrolled in U.S. institutions. We collected qualitative data from interviews including a variety of questions to investigate aspects of students' global competency development: understanding of other's world views, cultural self-awareness, adaptability and adjustment to new cultural environments, open-mindedness, second language proficiency, international experience, leadership, and other relevant information. The goal of this research is to gain more knowledge regarding the experiences of graduate students as they transition and work in a foreign country using a comparative framework between the two groups of students.

II. BACKGROUND

There is some history behind the birth of the need of global competence among engineers. Up until the last few decades, engineering education worldwide has dealt primarily with preparation to work in one's own country [7, pp. 433]. An increase in globalization and mobility in working engineers, as well as concerns with economic competitiveness and employability of engineers has required countries to reevaluate what competencies are needed for an engineer working in such diverse environments. In the United States during the 1990's, engineering education shifted accordingly to creating more flexible engineers to work internationally through establishing new accreditation criteria for engineering programs [7]. European nations have begun preparing their engineers to be mobile and transition to working throughout the entire European Union. Latin America has followed as well by placing more emphasis on global competency in engineers' education [7]. Therefore, the development of global competency is currently an essential quality of engineers.

Nowadays, global competency is a widely discussed topic, and because it has multiple aspects, multiple definitions have been put forth. Deardorff, for example, looked into how people think of and define global competency [1, pp. 242]. Participants in her study were asked to rate multiple definitions of global competency, and broad definitions were more widely accepted. The definition most highly favored was: "Knowledge of others; knowledge of self; skills to interpret and relate; skills to discover and/or to interact; valuing others' values, beliefs, and behaviors; and relativizing one's self. Linguistic competence plays a key role." Her study showed that although global competency is hard to define and is constantly changing, it is important to continue assessing students' global competency levels and the best way to do so is through a mixture of qualitative and quantitative measures [1]. This study uses a qualitative approach to analyze the development of global competence skills among engineering students.

There has been a lot of research on identifying the best strategies to promote global competence among engineering undergraduate students. Universities everywhere are finding ways to prepare their students for practicing in an international workforce, therefore they are interested on finding such strategies. Lohmann et al. [8, pp. 119] have discussed how engineering programs are finding ways to incorporate language preparation, coursework in global studies, and transnational design. In addition, many universities offer a co-major or dual major program in which students earn two bachelor degrees, one in engineering and the other in liberal arts or international studies. Other options include certificates in international engineering and many institutions also encourage international experiences, where the most common form for engineers is research or study abroad [8]. Downey et al. present more information on global competency in engineering students and show that international experience is one of the best ways to instill global competency [9, pp. 111]. International enrollment specifically pushes students out of their comfort zone and immerses them in another culture for a longer period of time. Other methods of increasing global competency are international projects, international work placement, international field trips, and integrated class experience.

Although there is still debate about which strategies are more efficient.

Within the analysis of students' experiences abroad, it has been shown that short-term periods of study abroad positively affect the development of intercultural sensitivity [10]. However, there is also evidence that longer periods of stay have more significant and enduring impact on students [11]. Also, Douglas and John-Rikkens have shown that the difference between a student's point-of-origin and the location of a study abroad program would have a positive effect on the students' development of worldmindedness, defined as "the extent to which individuals value the global perspective on various issues" [12]. Therefore, these factors have been already pointed out for consideration when students' decide the international endeavors they may undergo.

Even though the research on understanding the effects of students' experiences abroad is vast, it is mainly focused at the undergraduate level. However, the experiences of graduate students may differ from those of undergraduates, since graduate students tend to be older, have different academic expectations, are involved in research, and may have different worldviews and understandings. Therefore we should consider these differences when analyzing the development of global competency skills of graduate students.

It is important to start analyzing these effects on students at the graduate level since they will be also facing the challenge of joining a global workforce. Gearon [13] has pointed out that graduate students should seek having international experiences that would make them more competent professionals. He mention the efforts of different institutions supporting graduate students achieving this goal in the areas of medicine, law and engineering [13].

Furthermore, in engineering, the proportion of international graduate students tends to be larger than in the undergraduate population, therefore we must consider the potential differences in their experiences developing global competence due to their international status. Research has shown that international sojourners have usually lower adjustment rates than domestic U.S. students when relocating at U.S. universities [14], but to the best of our knowledge there is no literature on these differences at the graduate level.

Some studies have explored how the international experiences affect graduate students; however, these analyses have been mainly focused on international students in the U.S. [15-16]. For example, in the qualitative analysis performed by Jiang, Chinese engineering graduate students were interviewed to understand their intercultural learning process during their time attending U.S. graduate schools [16]. The results showed that even though the students were exposed to a high diversity of cultures and people, they did not to recognize any changes in their mindset in terms of their "values and beliefs, prejudices and stereotypes." The students reported that language barriers and cultural differences were their main challenges to engage in inter-cultural interactions [16]. They also reported detraction from looking for opportunities to interact with individuals outside of their comfort zone because of the presence of a strong peer-network of other Chinese students. In the academic aspect, students also reported to be challenged to adapt to the

independent learning style, and struggling with the lack of instructions or guidance [16]. Other studies have explored the experiences of Indian engineering graduate students in the U.S. in terms of their acculturation [17] and shifts in their own cultural expectations [18]. The analysis of the experiences of international graduate students in the U.S. has also include exploring the factors determining the students' levels of satisfaction with their academic programs and their social relationships [19]. Perruci and Hu reported that the level of contact with U.S. students, language skills and perceived levels of discrimination were strongly correlated with the student' level of academic satisfaction [19].

On the other hand, the analysis of the experiences of U.S. domestic graduate students abroad it is also very limited. Sciaky et al. [20] based on the claim that "graduate students who gain experience practicing science outside the U.S. will be better prepared to participate in [the] global scientific community" analyzed the experiences of about a dozen graduate students going abroad for research experiences and conclude that the challenges they faced were generally overcome and outnumbered by the perceived rewards.

Analyzing both groups of students: domestic U.S. students going abroad and international students in the U.S. would have value due to the different perspectives and challenges they hold. Therefore, further study is needed to show how global competency can be developed among engineering students at the graduate level considering both of these groups.

Thus, by examining comparatively international graduate engineering students attending U.S. institutions as well as domestic graduate engineering students in the U.S. we envision to contribute to the current body of knowledge that is more focused on the global competency gains of undergraduate engineering students. Finally, we aim to contribute identifying strategies to effectively increase these global competencies among all graduate engineering students. It is envisioned that these strategies will inform program administrators, graduate programs, and key stakeholders to make decisions aligned with preparing engineering graduate students for working in diverse environments.

III. METHODS

We conducted interviews to delve deep into students' global experiences. We administered these interviews to graduate engineering students at a large, research-intensive Midwestern university. The respondents vary in their engineering discipline. We interviewed four domestic U.S. graduate students who traveled abroad for conferences or research. For comparison, we interviewed eight international students who traveled to the Midwestern institution for graduate studies. After conducting the interviews they were transcribed by a private third party, we analyzed the transcripts using open-coding and thematic analysis in Dedoose software. We considered this method appropriate for the exploratory nature of this research.

IV. ANALYSIS AND RESULTS

A. Experiences of U.S. Domestic Students Abroad

We interviewed four domestic graduate engineering students, three men and one woman. Their lengths of stay varied between one to three weeks abroad for reasons such as an international conference or conducting research. The three research questions that were used to build the interview protocol, were the following:

- 1) *How do students prepare for their international experience?*
- 2) *How would they describe their experience?*
- 3) *How relevant are their experiences to their personal and professional network?*

In this section the evidence gathered from the analysis of the students' responses are summarized according to these research questions.

a) Preparation to go abroad

Besides the academic preparation (preparing a poster or a presentation), the students reported on preparing themselves through self-led online research about the things to avoid doing while in the host country. They expressed a concern on being respectful of the host culture. Students were not really interested in preparing for the language in the host country, since their stays were relatively short and all the people involved in the events they attended were able to speak English at a certain level. However, the student with the longest stay reported challenges to navigate the city due to these language limitations. They also reported doing some research about the touristic attractions in the host country since they considered these trips "*once in a lifetime*" opportunities.

b) Assessment of experiences

Students reported their experiences in terms of the differences they perceived between the U.S. and the country they were visiting. We classified these differences as neutral, positive, negative. The neutral differences were those where the students did not express positive or negative feelings attached to them. Their reflection on these differences can help them assess their own graduate experience compared to those students in the host country and reflect on the weight of their cultures into their work styles. The neutral differences students found by the students between the U.S. educational or research experience and that in the host country include:

- a) ***Cultural structures and the relevance of hierarchies***, for example, a student talking about the structures in the host country mentioned: "*the culture is very, very polite and you're very respectful of anyone who; a) is older than you, or b) has a position above you. So, it was really important like even just speaking to someone that you were very conscious of that and respectful.*" Acknowledging that this may be different from the style in the U.S. where students can often refer to professors

by their first name if that is the way they introduce themselves.

- b) **Work structures**, students perceived that graduate students in the host country worked longer than they usually do and that they are more dependent in supervision, and
- c) **Security levels**, students perceived that research institutions in the host country had higher security standards than those in U.S.

The identification of these differences can help establishing more efficient and successful research partnerships or work relationships in their future careers.

The positive experiences reported included academic growth due to the exposure to researchers from different places giving feedback to their work. Furthermore, they cited that their exposure to a different culture was something they enjoyed. As visitors they also got a good impression of the locals as they were always helpful towards tourists. It is envisioned that these positive experiences could help to set expected outcomes to plan the foreign forays for other students.

The few negative experiences they reported could be related to high expectations that the students were holding before going abroad. The student with the longest stay mentioned that the people in the host research laboratory did not have time for him, and that there was no specific project for him to work on. Another student reported how his expectations about the neatness of the host city were high; in consequence, seeing a relatively dirty and overpopulated city was something unexpected and disappointing. The exploration of these negative experiences helps noticing the relevance of setting realistic expectations before going abroad and can help on making recommendations to avoid the recurrence of similar episodes for future students.

c) Relevance of Their Experiences to Their Personal and Professional Networks

Students reported that they found it useful to meet different professors that may be helpful later in their career, as connections or potential employers. However, when questioned about other types of professional networks built, one student reported that he aimed to keep in touch with the people he met at the hosting institution but he did not succeed.

B. Experiences of International Students in the U.S.

We interviewed eight international graduate engineering students to obtain more in-depth information surrounding their global competency and experiences in the U.S. (six men and two women.) Students interviewed were from Colombia, Brazil, India, Pakistan, and China. The following three research questions were used to build the interview protocol for international students:

- 1) *What is the student's background and what were their experiences before moving to the U.S. to study?*
- 2) *What types of interaction do they have with U.S. citizens and U.S. culture?*

3) How has studying in the U.S. affected their future plans and career goals?

The interview transcripts were analyzed using thematic analysis. In this section, we present the main four themes emerging from the analysis. We also consider some suggested implications for the challenges to improve global competency among international students.

a) Stronger focus on differences than similarities

Interviewed international students consistently seemed to highlight cultural differences more often than similarities. Two interview questions asked them to compare their experiences in the US to their experiences at their home country, although did not explicitly use the word "differences." Only one question asked them to highlight their differences between their experiences as international students to other international students from different countries of origin. However, within this analysis, students mentioned differences between cultures ten times more than they commented on similarities. Students mentioned various differences between cultures as well as in their academic experiences.

Cultural differences that were mentioned when they compared their experience in the U.S. to that in their countries were:

- People in the U.S. seem more independent, having their own personal space and privacy, and a generally self-driven culture.
- The U.S. is more culturally diverse, especially in a university setting.
- There are higher levels of awareness about social issues pertaining to gender and race within the U.S.

Students also mentioned differences in academia, for example, some students mentioned that they like the academic system in the U.S. and that they have access to more resources through it. All over, most students mentioned they have more opportunities academically in the U.S.

It is important to recognize cross-cultural differences as these students have done, but this tendency of disregarding similarities between cultures may represent a limitation in developing global competency. One student reflected on the importance of recognizing cultural differences and trying to understand and learn from those differences mentioning: *"Listening and being aware of the differences is the first step in trying to establish a good process of adaptation and... it's a lot of listening instead of reacting and reflecting and acknowledging the differences. That helps me to adapt or adjust to new culture."*

Miville et al. [21], presented the construct of *universal-diverse orientation* (UDO) which reflects "an attitude of awareness and acceptance of both the similarities and differences among people." They developed a tool (the Miville-Guzman Universality-Diversity Scale, MGUDS) that has been extensively validated in different versions to measure global competence among different professional areas [22]. It has also been used to measure global competence among engineering students [23-25].

From the UDO definition, we can observe that acknowledging and appreciating similarities can be equally important than the appreciation of differences. Therefore, helping students start recognizing and valuing similarities between their culture and the culture in the host country would play a role in increasing their global competency and being ready to transition into the global workforce. Universities are advised to take action accordingly, and try to find ways to shape graduate engineering students' comfort with differences and enhance their appreciation of differences as well as their appreciation of similarities between cultures.

b) Relevance of family ties and support

Our interview protocol only contained one question mentioning family explicitly: "How did you prepare yourself to live in the U.S.? For example, mentally, legal/visa issues, talking with friends or family, financially/scholarships, etc." Although it was only prompted to be discussed once, participants talked about family ties throughout other portions of the interview. We may infer that those who mention their family more frequently have greater levels of support from their family, which helps them in the transition to moving to another country. For example, previous research on Latino families, that may be applicable to other types of families, shows that better family functioning and emotional support provided by family members leads to lower rates of depression and greater emotional adjustment in college students [26].

Family ties may lead to higher levels of global competency in different ways. Family trips and vacations may expose the students to the U.S. or other countries and inspire them to travel and live abroad later in life. Trips to the United States, or other English speaking countries, also give students a chance to practice and develop their English skills, which may give them more confidence that they can successfully live and study in the U.S. on their own. Furthermore, family may offer financial support that allows the student to study in another country. International students have greater fees to study at U.S. institutions, not to mention extra expenses due to travel. Having financial support is very helpful in assisting with the transition to another country. Although we acknowledge that families able to afford vacations abroad may be part of higher socioeconomic status in their country, a deeper analysis of the composition of graduate students in terms of their socioeconomic level and their dependence on other types of funding (e.g. scholarships, loans, etc.) could strengthen our conclusions on this type of family support.

Family offer a network of support for the student as they transition into another country and culture. A caring family may give the student the encouragement needed to make the move to another country. In addition, students can also turn to their family connections for advice after arrival in the host country. Furthermore, having family to turn to during times of distress makes the new atmosphere much more manageable. Having the support of family in the country of destination may be another factor influencing global competency. Many participants mention that they have family living in the United States, and that as graduate students they visit these family members. These trips within the U.S. increase their rate of cultural exchange.

Furthermore, some students have spouses living with them in the United States, which gives them another person to share this experience with and rely on. These findings are consistent with Poyrazli's, who showed that married international students would have higher levels of social support [27]. Having a spouse gives the student another person to go out and be involved in American culture with and attend outings and cultural events that the person may not have gone to alone. Having close family members' best interests in mind may make the person more willing to try new things and immerse themselves in the offerings of the new culture. In addition, university organizations can play a role in fostering these familial ties. One student mentioned his experience being paired up as an international student with a family in the U.S. for cultural immersion, having the opportunity to explore the culture through sharing different events such as Thanksgiving. This student's experience shows that students can get involved with other families aside from their own to increase their global competency and expose them to more cultural events. Family support may be a factor in higher levels of global competency and adaptation to the change of a new culture.

c) Networks of Support/Advice

A strong network of support and advice may lead to easier adjustment to a new culture. Cohen and Willis [28] found evidence of the use of social support (perceived as interpersonal psychological and material resources) as a buffer against stressful and potentially adverse situations. This was named the "buffering model" [28]; our results are somewhat aligned with this model. The amount of advice and mentorship the students received varied. Students mentioned many things that they got help with or needed advice on: paperwork and legal issues, housing choice, U.S. customs, and transportation, for example. The student expressing the highest number of difficulties while his graduate studies received little advice before their departure and also had less mentorship in the U.S. These findings are consistent with those of Poyrazli [27], who demonstrated that international students with higher levels of social support had less acculturative stress.

Most students received extensive advice before they arrived in the U.S. Many students received help with legal paperwork and their application to graduate school as an international student. These students received advice on how to survive here as well: safety, transportation such as bikes and cars, and where to live and what kind of apartments to rent. All of this preparation will make a student more adept at adjusting to the new culture. The positive impact of social support on cross-cultural adjustment was also studied by Adelman in the late 80's [29], when she analyzed how the informal networks of support positively impacted the cross-cultural adjustment of sojourners before departure and after their initial entry to the visiting country. In this context, a student mentioned that the support received from networks of friends helped them adjust socially: "*My friends and my colleagues have helped me figure out how to mingle with the American and become more a citizen of this country.*"

Many students in our sample were supported financially through their home institution or through some other type of funding. Having less worries about money in a foreign country

may make the transition easier for these students. Some students are already professors at their home institutions and are receiving financial support through these universities. Two students reported being funded through the Fulbright Program, which in addition to financial support gave them extensive preparation and advice on the transition to the U.S. One of them mentioned: *"They help you through the whole process. All the exams, all the tests...."* This positive impact of the Fulbright program is an indicator of its success in its intention to prepare global scholars that "advance international education and access to education worldwide" (www.fulbrightonline.org). Fulbright and other programs alike have played a significant role on promoting the global competency of engineering students in the U.S. through supporting and promoting studying abroad experiences [30].

Students also mentioned academic support, such as academic advisors. Many of these experiences are shared by the students with higher levels of global competency. The student reporting the most challenging financial difficulties in his time at graduate school expressed the need for someone to guide him by commenting: *"I think every student should have somebody who guides them. It's especially important for international people who come into this new environment. They're trying to adjust to this new setting and trying to understand what is going on. I wish I'd had a mentor."* Every student would benefit greatly from more mentorship and advice about the transition to living in another country, both before and during the transition.

d) Participation in U.S. culture/hobbies

From our analysis, we can infer that students that most frequently mentioned involvement in U.S. culture were those describing having better experiences. These results support literature reporting that international students' interactions with members of the host culture help them achieve better adjustment outcomes [31-32]. The student reporting the most frequent interaction with U.S. citizens and therefore U.S. culture, mentioned social activities such as hanging out with friends, cooking and hosting dinners for friends, going to the bars, and playing in a band.

Many students mentioned hanging out with friends, joining sports teams or collegiate clubs for example as part of their participation in U.S. culture. Interestingly, the two participants with the most negative experiences during their time at the U.S. reported having more solitary hobbies such as reading, doing research, bible study, or orchestra. One of these students commented on his opinion about not needing to interact with new people by saying: *"You don't need to approach others to officially like.... other cultures. If you just feel good, why do you need to change yourself?"* In general, students that did not interact with the U.S. culture did so because of lack of time, unease in such situations, language barriers, or lack of information on campus social events. Some research has been done to study the limitations of international graduate students on improving their intercultural learning process in the U.S. For example, Jiang [16] explored the experiences of Chinese graduate students in engineering programs in the U.S. and found that language barriers and cultural differences were their main challenges to engage in intercultural interactions, as well

as the existence of a strong peer-network of other Chinese students that helped them stay in their comfort zone [16]. These findings present universities with some suggestions on how they can engage international students. For example, universities can increase communication about campus events to engage international students.

Another finding from our research is that all of the participants have changed their hobbies since their arrival in the U.S. Some reasons cited for these changes were: moving to a different type of city (metropolitan area to the country), changes in weather patterns that force them to stay inside more. Students also reported increased levels of stress, either from moving to another country or from high requirements from their graduate program that forced them to take on easier and more relaxing hobbies. Students also mentioned changes in amounts of free time, however some reported more free time and others reported less free time. All of these changes in lifestyle have forced the students to find different hobbies in the U.S. that fit into their new schedules. How well students adjust to these differences may contribute to their levels of global competency.

Interestingly, every participant mentioned fitness, sports, and working out as a priority in their lifestyles. Participants mentioned a variety of hobbies such as swimming, martial arts, soccer, biking, working out, intramural sports, basketball, and attending and watching professional sports games. It has been documented that being active is a great way to relieve stress [33], and may be even more important for students adjusting to a new culture. One participant mentioned that her interaction with sports has helped her endure the culture shock. Furthermore, joining an intramural sports team may be a great way to start interacting with U.S. citizens. Since all of our participants mentioned fitness as a part of both their lives at home and in the U.S., it may be beneficial to create strategies considering this fact to promote the interaction of international and domestic U.S. students such as fitness clubs or sports leagues.

C. Comparing U.S. domestic and international graduate students experiences

It is important to relate the experiences of domestics abroad to that of international students in the U.S. For example, both groups of students frequently detailed differences between their country and their host country. Domestic U.S. students reported differences were analyzed to a greater depth, and we classified them as neutral, positive, or negative. This pattern was also seen in international students, however it was not reported in the scope of this paper. We suggest that both groups of students need help in drawing similarities between cultures which may help them with their adjustment. Another similarity we found is that both groups reported preparation before their trips. However, the domestic U.S. students often reported self-led preparation because of their relatively short length of stay.

On the contrary, international students preparing to live abroad for a longer period of time ranged from self-led to receiving extensive mentorship and advice before and during their move. Because the international students were preparing for a longer

stay, they often received more help. Also, the U.S. students did not prepare to speak the host country's language, whereas many of the international students coming to the U.S. reported studying and practicing English. We found that both groups would benefit from greater preparation and mentorship. Additionally, both groups reported making network connections or having academic opportunities in their travel experiences. It appears that the international students made more long-lasting connections, which can be explained by their longer lengths of stay. However, both groups reported overall academic benefits from their travels. This shows that international travel is indeed beneficial to students' academic growth and global competency development.

V. DISCUSSION

This work explored how the experiences of graduate engineering students influenced their development of global competency. This was performed through students' interviews. First, our analysis of domestic U.S. students going abroad explored how they prepared for it, how their experience was, and how relevant were these experiences for them. Students explored the culture in the host country before traveling to guide their behavior appropriately. They reported positive gains in their academic development and were highly reflective on the different structures in both culture and working styles between the U.S. and the host country. The negative experiences reported by students could be linked to unrealistic expectations they previously had.

Second, the analysis of international students in the U.S. gave evidence of different areas to consider for harnessing the acquisition of global competency. Students were more likely to talk about cultural differences than connect similarities; we consider that the reflection on similarities would improve the development of global competency and would enhance students' adaptation to the host country. Another result was that students with greater family ties as well as networks of support, both in the U.S. and their home countries, had greater levels of global competency. Parallel to this, there was a positive correlation between access to networks of support and levels of global competency. These networks can be really helpful for the demanding transition of living abroad. Furthermore, every participant in our study frequently mentioned sports or fitness as an integral part of their lives, even though their hobbies had changed from the time they lived in their home country.

There were no identifiable themes related to students' plans other than that most of the international students planned to return to their country of origin either after finishing their degree or after obtaining some professional experience in the U.S.

There are different limitations to this study that should be considered. First, we conducted the analyses with a relatively small sample of students from only two different engineering graduate programs. Second, our sample of international students was composed from students coming from only 5 different countries. Five interviewees were from South America, which could represent a bias towards the Latino experience in the U.S. and could represent lack of

generalizability to students coming to the U.S. from other countries. A more varied group of interviewees from different countries and more graduate programs could help to overcome these limitations.

VI. CONCLUSION

Our work can be summarized with three main findings. First, domestic students regularly prepared themselves for their experiences abroad through self-led preparation in order to be culturally appropriate. Furthermore, the few negative experiences they reported are connected to higher expectations formed before their trips. Therefore, better advising from mentors that have had experiences abroad would be useful to avoid having unsatisfied expectations.

International students studying in the U.S. frequently discussed cultural differences rather than similarities. These students tended to have low comfort with differences. These two traits may be a hindrance to building global competency. Universities are advised to help students in findings cross-cultural similarities and become more comfortable with differences. Additionally, international students with greater support from family, friends, and mentors had better adjustment outcomes. Universities are advised to help foster these relationships both before and during international students' traveling experiences.

VII. IMPLICATIONS AND FUTURE WORK

Our results about the experiences of domestic students abroad imply that it is important that sponsor organizations, as well as academic advisers and mentors, help students develop realistic expectation about their future experiences abroad. Academic advisors have usually been more exposed to international experiences, therefore could support students in this manner.

Our research shows that graduate engineering students are more likely to perceive cross-cultural differences rather than similarities. Our work also shows that students have low comfort with these differences. We suggest that universities take action accordingly and find ways to foster cross-cultural understanding and increase comfort with differences between graduate engineers. The evidence found about the relevance of family ties in the development of global competency would imply a possible strategy for universities to help students develop this trait. Cultural exchange programs that pair up international students with U.S. families have proved to be an efficient strategy to help speed up students' acculturation. Higher support to these type of programs would be suggested.

The development of different networks of support or advice would be an invaluable resource to adapting students in the U.S. Promoting structures of incoming advisors or student committees to help students before and after arrival could have a good impact on alleviating incoming students' burden. Our findings present universities with many suggestions on how they can engage international students in U.S. culture. For example, universities can increase communication about campus events to engage international students. Universities

can promote sports leagues as a place for cross-cultural engagement as well as a way to release stress that comes with the transition to another country.

Universities should enhance their graduate engineering students' international experiences in a way that those trips contribute to the development of global competency in a better way. Our studies show that students need to increase their appreciation of these diverse experiences and also their comfort with cultural differences.

Future endeavors on this research line will include longitudinal analyses of the development of global competency among graduate students, gathering data from different institutions, as well as different programs and among students going abroad to or coming to the U.S. from a wider variety of countries.

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A Semester-Long Study Abroad Model for Engineering Students

The Unified Project Approach

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Abstract— Study abroad programs have nearly doubled in the last ten years. Studies show that students who study abroad are better prepared for success in their respective fields of interest. This is no less true for engineering students. But engineering schools have been very slow accepting the challenge of providing study abroad opportunities to students, due perhaps to the rigidity of most engineering curricula which were developed in the last century. This trend is changing, however. The largest increase in students studying abroad are STEM students – in 2012/13 9% overall were from STEM disciplines and 2/3rd of these were engineering students. Many universities offer short-term study abroad programs for engineering students designed to be held during the summer. These short-term programs strive to accommodate those who cannot afford to delay their coursework. It can be suggested that semester-long programs provide greater cross-cultural benefits but providing a study abroad curriculum that fits the stringent engineering requirements can be difficult. The College of Engineering at The University of Oklahoma has developed an engineering study abroad program that offers key engineering courses chosen to fit a wide variety of discipline-specific engineering curricula. The key to success in any program is faculty involvement. In order to promote faculty involvement the course work is broken into concentrated four-week blocks taught by different engineering instructors, providing an opportunity for professors with active research programs to share their current expertise with the students in a foreign setting. In order to provide a cohesive educational experience, a Unified Project is developed that has components that relate to each course and which takes advantage of opportunities offered by the host country. This study model is expected to provide smooth transitions from one concentrated course to the next, while providing the students with the cross-disciplinary and cross-cultural experience that engineers will need to compete on a global marketplace.

Keywords—*Study Abroad, concentrated block study, unified project, Engineering Study Abroad*

I. INTRODUCTION

Undergraduate engineering students remain underrepresented in study abroad programs across the United States. This is a result of many factors, which often lead to the omission of a study abroad experience in engineering

programs. Major factors include the sequential nature of coursework, rigorous curricula, accreditation constraints, pressure to maintain high grade point averages, access to professional internships, and funding opportunities. Yet the refrain continues across the higher education community that our responsibility and charge is to graduate students with international awareness, cross-cultural skills and sensitivity. Indeed, future employers see this as a necessity under the paradigm of a global economy. This is clearly expressed by Ken Kohrs, former vice president of the Ford Motor Company, and quoted by Parkinson in [1]. Globalization is a key theme in all disciplines and engineering represents a key area where international cooperation may be the underpinning to technology access across the globe [2]. If modern stereotypes of engineers have any basis in reality, our engineering students would benefit greatly from the development of greater international awareness and cross-cultural skills.

II. PURPOSE OF PROGRAM DESIGN

A. Initial Program Alignment

The University of Oklahoma (OU) College of Engineering (CoE) has been engaged in promoting study abroad experiences for engineers for several years, with courses being offered in both summer programs and a full fall semester regimen. Study abroad for engineers is a growing effort amongst US universities [3,4] with many different approaches. In keeping with national trends, the most popular options among students are summer programs that do not disrupt the required course sequences that occur during the regular academic year [5]. But students and educators alike acknowledge that the truly transformative study abroad experiences occur in programs of significant duration, cultural immersion, and required adaptation [6]. Therefore, the most widely submitted study abroad requests among our students begin with an inquiry for a semester-long program that offers the right set of engineering courses that permit them to stay on track, yet provides the opportunity for a transformative global experience.

Toward this end, over the three fall semesters of 2012, 2013, and 2014, the CoE developed an engineering curriculum

approach at our flagship program in Arezzo, Italy, that fit within a myriad of academic issues or needs. The first issue was to offer engineering courses with broad appeal to attract greater student involvement. Engineering disciplines have become highly compartmentalized, making it difficult to offer a series of engineering courses that provide degree credits for engineering students from different disciplines. Careful consideration was given to selecting courses that were common to most engineering disciplines, such as Statics and Engineering Statistics. Other courses were selected for their popularity and flexibility in topic design. In particular, OU offers a course called Measurement and Automation that deals with data collection, sensor analysis, and measurement theory. Because computerized data collection and analysis are fundamental to all modern engineering disciplines, multiple small projects are easily constructed to which students can relate their studies. A fourth course offering provides an elective engineering credit in the area of technology history. The Disruptive and Innovative Technologies Ideation course examines the historical scientific context in which major technological shifts have occurred, and is well-suited for the cross-cultural environment of study abroad.

Another issue was the cost-effective deployment of faculty to lead the courses in Arezzo. There is a significant cost required to accommodate three or four professors for an entire semester in a foreign setting. A secondary constraint in this regard was the need to ensure ABET accreditation criteria were properly accounted for to ensure proper student credit toward their degree. It was essential to send faculty who have continually been vetted by the university's accreditation efforts. However, most engineering faculty have active research programs requiring significant time commitment. Indeed, typical engineering faculty work breakdown suggests that 40-50% of their time is allocated to research. Thus it is difficult for a professor with an active research program to commit to being out of the country for an entire 16-week semester. To alleviate this problem, a block course method was incorporated in which a single three-credit semester course in engineering was taught in a concentrated four-week block. This provided for a single housing solution for the engineering professors, while also alleviating the need for them to attain work/teaching visas required by Italian law. This model has reduced program costs for the CoE, but has also promoted involvement of faculty with active research areas. This is essential in promoting global engineering education environments because these faculty are most familiar with the current state of technology and can best relate the course work to both the local venue as well as broad intercultural engineering issues.

A final issue to address was the need to form a connection between the relevance of studying engineering subjects abroad with the international experience. Although engineering curricula are still fairly rigid in their requirements, ABET accreditation is changing the focus of assessment to include abilities such as *communication skills* and *teamwork* [7]. General education requirements are intended to help satisfy these less objective skill sets, and it is important to offer to the engineering students general education courses in areas of their interest, such as the history of science, engineering as a

business or the impact of technology. Because OU already had a study abroad program in Arezzo, it was an ideal environment in which to form a partnership between the humanities and engineering. Each engineering student is required to take a one-semester Italian class that introduces the practical aspects of the language, as well as a cultural analysis of the local environment. Because ABET accreditation concerns are not an issue in general education courses, this course is taught by local educators who are well-versed in Italian culture. Moreover, students are encouraged to take the Art History course offered each semester. Even when they choose not to officially enroll in this course, students are required to attend the field trips as a guided opportunity to explore other cultures, both current and historical. The engineering professors also attend the field trips and, after the Art History professor finishes a discussion, the engineering professor initiates a discussion on engineering elements of interest. So while the art history professor may discuss the artistic merits of a statue, the engineering professor may discuss why or how the statue is similar to a cantilever beam, or they may discuss the room itself. In this manner the engineering and liberal arts students learn that their worlds are interconnected and are much richer for it.

B. Modified Engineering Study Abroad Design

After establishing the program and acquiring feedback for the first semesters, several modifications are being implemented for the fall of 2015, and are the subject of this Work in Progress (WIP) paper. While the concept of block scheduling for engineering courses received positive feedback from both professors and students, one shortcoming that was identified was the need to provide a smoother transition between the concentrated areas of study. The initial test of the new structure is designed around the original four courses: Engineering Statics, Engineering Statistics, Measurement and Automation, and Disruptive and Innovative Technologies and Ideation. However, the structure of the model is the focus of this WIP and we expect it to be extendable to other course offerings. The future structure is detailed in the following paragraphs.

III. UNIFIED PROJECT APPROACH TO STUDY ABROAD

The intense four-week block schedule for engineering courses in the OU study abroad program can make the transition from one course to another rather abrupt. While the students enjoy getting to know each professor in a small classroom environment, which is extended through field trips and other community activities in which all study abroad participants take part, the discontinuity between courses is sometimes difficult for the students. To address this shortcoming, we have designed the engineering curriculum to provide a unique, full-semester project experience that unifies the disparate topics being taught. Synchronizing four different faculty members over several different engineering disciplines is made possible by a new emphasis on pre-departure organization both on a curricular and logistical level.

The *Unified Project* approach relies both on flexible course content and order of instruction. The project concept is intended to encompass several engineering disciplines because this is a hallmark of engineering projects that students will face

in the workplace. Indeed, many projects require a breadth of knowledge that should be reinforced during a student's college years, rather than after the fact once they face the situation as a practicing engineer on a project team. The courses taught and the material studied are detailed in order below.

A. Measurement and Automation

Analysis of data based on theoretical development requires some type of data set to be most effective. This is the premise of experiential learning. Toward this end, the concepts of measurement through data acquisition, data analysis, and control are studied first. This process leads to the acquisition of a set of data that can be studied in the Engineering Statics class. Necessarily, these data should be related to structures, so sensors common to structural analysis are studied. During this course students are exposed to the concepts of sensor types, bandwidth, sampling rates, dynamic range and resolution. The four-week block culminates in the acquisition of data related to a structure or sculpture of historical significance. This not only prepares the students with a data set for the following courses, but begins to associate the local culture with the engineering activities. In the fall 2015 semester we will acquire data on Michelangelo's *David*, a statue of some historical significance.

B. Statics

Statics is an engineering course required in several engineering disciplines, making it a useful course for a study abroad program. In an historical setting such as the OU Arezzo campus, much of the related material is architectural in nature. This environment provides a plethora of opportunities to study the theory of statics and examine extant examples to promote a practical understanding of what is traditionally merely classroom-only theory. The four-week block in Statics culminates in a practical application of lecture topics to the structural model data collected during the Measurement and Automation block. In the fall 2015 semester the data the students collected for Michelangelo's *David* will be used to compute the centroid and determine the weight of the statue. This will lead to calculations of gravity and lateral forces plus shear moments, culminating in a discussion on stress and the engineering limitations of Carrara marble.

C. Engineering Statistics

Engineering Statistics is a required course across most engineering curricula for good reason. Measurement is always subject to error, and the processes being measured generally have a random component. Although measurement and process error is briefly discussed in the Measurement and Automation block, particularly from the filtering aspect, the underlying statistical theory is not discussed. However, the data sets collected in the Measurement and Automation block are prime examples of the information corrupted by measurement error. This provides a rich data set to which statistical theories can be applied as they are developed in lecture. Also, the students have an understanding of data collection methods at this juncture, so the Statistics professor has an opportunity to collect other measurement sets for analysis.

A unique feature of study in Europe is the transportation infrastructure, particularly the train systems. American

students are much less familiar with this mode of travel which is extremely commonplace in Europe. Train schedules have profound statistical qualities based on usage patterns and this provides yet another opportunity for connecting the engineering theory, application, and local culture. This particular study is the quintessential study-abroad experience.

D. Disruptive and Innovative Technologies Ideation

The final four-week block is devoted to a course developed at the University of Oklahoma called Disruptive and Innovative Technologies and Ideation. This is an elective engineering course available to all engineering majors. This class studies the engineering principles of major technology shifts and their impact on society. Clearly, the Italian Renaissance created some significant technology shifts, and while the course is not restricted exclusively to Italian contributions, it provides the substrate to discuss some of the technology used earlier in the semester, and to analyze how the disruptive technologies around the world have affected Italian culture. This course provides engineers with an opportunity to expand their professional and ethical horizons in an intercultural environment that, it is expected, will create a deeper understanding of how technology and culture intersect. In the fall 2015 semester we will discuss how Michelangelo's *David* is an expression of art, but also an expression of Florentine engineering technology; and, when coupled with its originally intended setting of the Duomo of the Santa Maria del Fiore cathedral, it is an expression of power.

E. Semester Outline

Figure 1 shows the general progression of coursework through the semester. Each four-week block constitutes a 3-credit hour engineering course, meaning students can attain 12 credit hours designed to be applicable to each individual engineering degree. The classes meet for a total of ten hours each week, which is divided into three days. This ensures that the required contact hours are satisfied and allows time to develop theory and discuss application during each class. However, it also provides the students time to be involved in the other course offerings that are the cornerstone of expanding the engineer's cross-cultural literacy. Indeed, ensuring that the engineering students participate in the broader social context of study abroad is essential to their experience.

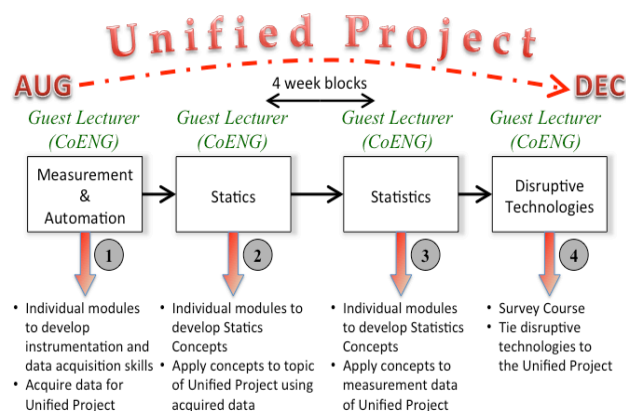


Figure 1 Engineering Course Progression for Unified Project

IV. CULTURAL EXTENSION IN ENGINEERING

It is a hallmark of US study abroad programs to integrate the student into the local or host culture and its history. Though the pervasiveness of this concept is fundamentally a representation of its importance, it should be noted that some students report that they did not feel integrated. OU engineering students are given ample opportunity to integrate via local language exchanges, engineering-based internships, volunteer activities, as well as via guest lecturers. Although engineers are often considered to be single-minded and unaware of more social, “right-brain” issues, understanding the relationship between art, culture, and technology is well within their grasp. The OU Arezzo campus offers an Art History course that studies some of the world’s classic artworks in the first person. This is a particularly effective time in history for engineers to study art, as many of the Renaissance artists studied math and science extensively, developing some fundamental concepts that are taught as fundamental ideas in art, and STEM, classes today. Perspectivism, optics, and the geometry associated with it were essential products of the Italian Renaissance. Moreover, the tools of science were artistic works themselves, and it is a seminal experience for the engineers to be exposed to these works of art and make that connection between culture and science.

V. CONCLUSION

The University of Oklahoma College of Engineering Study Abroad program in Arezzo, Italy, is a growing program that has a unique structure designed to expand the involvement of both engineering students and faculty. The concentrated block-study model provides the opportunity to engage a greater variety of professors who might not otherwise feel they can afford to spend an entire semester abroad. Our Unified Project model delivers a series of courses that have a

logical connection that enhances the semester-long studies that the students experience, while providing them with a solid set of engineering classes that can be counted toward their degree. This is essential to promote semester-long study abroad so that students do not have to worry that they will lose a semester in terms of graduating on time. The first offering of the Unified Project model will occur in Fall 2015. Assessment methods are being developed to measure the qualitative and quantitative results, and will be reported when available. We believe the growing program numbers are indicative of a successful program, and the Unified Project will provide that next step in the university’s goal of expanding study abroad opportunities to all undergraduates.

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Learning Philosophies: A Glimpse into Students' Approaches to Learning

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Abstract—A learning philosophy, as discussed in this paper, is a collection of beliefs about how one learns and approaches learning activities and tasks. Learning is often studied from the instructor's point of view, but learning from the student's perspective is not examined much. A baseline understanding of how students learning philosophies might be disclosed and interpreted are described by the nineteen student responses to an open-ended survey in an undergraduate elective course titled "Engineering in Global Context." The findings suggest implications for course and curriculum design in order to promote higher levels of thinking and to develop appropriate epistemological beliefs. Partially through the lenses of Bloom's Taxonomy and Schommer's Epistemological Dimensions, this paper offers a glimpse into students' conceptions about learning.

Keywords—Learning Philosophy, Bloom's Taxonomy, Epistemological Dimensions

I. INTRODUCTION AND LITERATURE REVIEW

Classrooms are steadily transitioning to being more student-focused than ever before. Course design and pedagogy have truly begun to engage students in active learning by incorporating the students' thoughts and opinions into classroom activities [1]. However, course design and pedagogy could be improved by better understanding what students are thinking about their learning. Do they like being actively engaged in discussions in class? How do they know they have mastered the material? Instructors have many ways to increase student engagement and to assess student learning, but both instructors and students would benefit from better understanding students' perspectives about their own learning.

An instructor likely has a teaching philosophy, or conceptions about teaching and how students learn. Often associated with a teaching statement, a teaching philosophy consists of an instructor's beliefs, attitudes, and perceptions about teaching. Much research has examined instructors' thoughts on student learning [1]–[3], instructors' thoughts on teaching philosophies [4], [5], and students' thoughts on teaching philosophies [6], but little if any research has examined students' thoughts on student learning.

A student's beliefs, attitudes, and perceptions about learning might be considered a learning philosophy. Similar to a teaching philosophy, a learning philosophy would describe how a student thinks about the act of learning, its purpose, and how one actually learns. As universities strive to produce

competent engineering graduates, what these graduates think about their approaches to learning and their thoughts about mastering the material is often not considered in the design of courses.

Adult learning theory can also help us make sense of the college student. It is common for students to develop into adult learners during the undergraduate years. Here, adult learner refers to someone "who (1) has an independent self-concept and who can direct his or her own learning, (2) has accumulated a reservoir of life experiences that is a rich resource for learning, (3) has learning needs closely related to changing social roles, (4) is problem-centered and interested in immediate application of knowledge, and (5) is motivated to learn by internal rather than external factors" [7, p. 5]. Adult learning theory can be even better understood by considering the states of development as Perry does.

Perry [8] examines the development of the dualistic thinker into the multiplicitic thinker. Often, undergraduates begin their university studies thinking dualistically about the nature of knowledge, believing there is always one correct answer and that knowledge is handed down only by authorities. Multiplicitic thinking, as Perry describes it, evolves through nine stages to where students become comfortable and reach a view that accepts knowledge as an ongoing, complex and evolving process [8].

Ideally, students graduate from college with an understanding of multiplicity of worldviews and an ability to engage in life-long learning. The ability to gauge and self-direct learning and understand what and how one should learn, and to know when something has been learned, are skills harbored as multiplicitic thinkers and lifelong learners. Studying students' learning philosophies might help us better understand how to guide students to achieve these goals.

In this study, we use Bloom's Taxonomy and Schommer's Epistemological Dimensions to understand what students said about their learning. Bloom's Taxonomy, which was revised by Anderson and Krathwohl [9], presents a hierarchy of cognitive thinking and the structure of knowledge. Instructors can use Bloom's Taxonomy to define learning objectives and the skills and abilities the course will provide [9]. The structure of these cognitive processes is organized from lower-level skills to higher-level skills: Remember, Understand, Apply, Analyze, Evaluate, and Create, respectively [10]. While assignments might make evident to the instructor the

level at which students are performing, students are likely unaware of how they are performing in relation to Bloom's Taxonomy.

Schommer [12] examined students' thoughts about the nature of knowledge, or their epistemological beliefs. Built upon Perry's Theory, these epistemological beliefs are generally thought of as "what individuals believe about the source, certainty, and organization of knowledge, as well as the control and the speed of learning" [11, p. 293]. Schommer identified the following four epistemological factors that might hinder college and university students as they work toward higher level thinking skills and abilities:

1. *Innate ability*: The ability to learn is determined at birth
2. *Quick learning*: Learning occurs in a short amount of time or not at all
3. *Simple knowledge*: Knowledge is best characterized as isolated facts
4. *Certain knowledge*: Knowledge is unchanging

Schommer found that students who exhibit these beliefs had poor comprehension skills. Holding on to these beliefs might hinder students from developing and gaining higher-level thinking skills and appropriate epistemological beliefs [12].

This study aims to examine students' thoughts and beliefs about their learning and study practices. As previous work has shown, examining an instructor's teaching philosophy can be very useful for addressing classroom improvement. However, the students' perspectives and beliefs about learning, or learning philosophies, have not been examined in much detail. We believe this information can be extremely useful to instructors and students alike in making courses more effective. This work contributes to the understanding of students across many learning spectrums (Bloom's, Schommer's, and Perry's). It also helps us better understand the transition to and development of adult learners. Furthermore, this work builds upon previous work by examining themes that fall beyond the two frameworks used.

Our findings, in addition to previous research, seem to suggest that students are initially comfortable as passive learners. Although students enjoy discussion in the lower-level engineering course described in this paper, they are not truly able to gauge and direct their own learning. We believe the lack of self-directed learning skills implies that educators and instructors need to purposefully include scaffolding for students to reflect on their learning and development into life-long learners, and in this case, successful professionals in engineering or other fields.

II. BACKGROUND

At Purdue University, ENGR 20100: Engineering in Global Context is a course that can satisfy a requirement for the Global Engineering Minor, can satisfy the general education requirements for undergraduates, or can be taken as an elective. ENGR 20100 was first offered in the Spring of

2014 and has been taught three times. The development of the course was informed by the Engineering Cultures content and model originally developed at Virginia Tech [13]. ENGR 20100 is the only course in Purdue's College of Engineering that explicitly considers the historical, social, and economic aspects of engineering. Student feedback has guided topic selection and course foci over the three course offerings. As a reading-, writing-, and discussion-based course, it differs from most typical engineering courses. Further information about challenges associated with getting official approval for the course can be found in a prior conference paper [14].

Below are the course description and course learning outcomes as defined in the syllabus, emphasis added to present verbs that correspond to Bloom's Taxonomy:

COURSE DESCRIPTION This course examines how engineering is intertwined with larger economic, social, cultural, and technological dynamics in an era of intensified globalization. Its major goals are to help you understand and appreciate what engineering is, how engineers are trained, what engineers do, and how engineering and society interact. The course approaches these themes through discussion of: the relation and interaction of engineering, science, technology, and society; the historical origins and development of engineering as a profession; diversity issues in engineering and other STEM fields; engineering in cross-national/cultural contexts; and contemporary challenges related to globalization, ethics, and sustainability. In summary, the course is designed to help students *understand* [Understand level of Bloom's Taxonomy] what it means to identify as, and/or work with, engineers. Recitation sections and/or independent projects provide further opportunities to expand your knowledge and improve your skills in relation to the major course topics and themes.

COURSE LEARNING OUTCOMES Students who successfully complete this course should have the ability to: 1. *Describe* [Understand] and *evaluate* [Evaluate] the specific kinds of knowledge and methods typically employed by engineers, including in comparison with other professional fields, 2. *Understand* [Understand] the historical development of engineering education and the engineering profession in the United States, 3. *Recognize* [Remember] how national differences are important in engineering work, including by *comparing* and *contrasting* [Apply] different national histories, cultures, and styles of engineering, 4. *Explain* [Understand] the significance of diversity in engineering education and professional practice, including by *evaluating* [Evaluate] competing perspectives on diversity in different historical and sociocultural contexts, 5. *Understand* [Understand] contemporary trends and issues related to globalization, ethics, social responsibility, and sustainability, and *interpret*

[Apply] their significance in relation to engineering education and practice, and 6. *Demonstrate* [Create] written communication capabilities at the level of “emerging” or higher (as defined by the Purdue Core Curriculum guidelines).

The course meets three times a week for 50 minutes, for which students are often assigned readings of 5 to 15 pages in length. There are frequent (approximately once per week) reading quizzes whose main purpose is to check for reading comprehension. There are six homework assignments (described below), a midterm exam and a final exam. The classroom is a mixture of lecture and discussion. A sample homework assignment, which is required to be at least 600 words, is presented below, emphasis added to again highlight verbs related to Bloom’s taxonomy:

This assignment begins with you reading Stuart Leslie’s article “Charles F. Kettering and the Copper-cooled Engine”, which highlights a struggle between two different engineering perspectives working to design and produce a copper-cooled engine for General Motors.

For this assignment, you will *apply* the “Engineering Problem Solving with People” framework to systematically *analyze* the two major perspectives in this case.

- After reading the article, write a one-paragraph *summary* of its content.
- Next, adopt Kettering’s perspective and in approximately one paragraph *describe* his location (organizational, geographical, etc.), knowledge (including skills, expertise, etc.), and desire (personal and professional goals).
- Now turn to the perspective of the manufacturing engineers and production staff, and in another paragraph *describe* their location, knowledge, and desire.
- Finally, in a concluding paragraph *develop* your own critical assessment of this case, including what you think were the biggest gaps in perspective between the two main stakeholder groups. Make sure you discuss how such issues might be remedied or addressed, and by whom.

With assignments that consider social and environmental implications, such as the one above, ENGR 20100 provides an appropriate context to explore student learning philosophies in engineering. As skills associated with reading and writing are particularly important in engineering fields, it is exciting to see how students develop and gain those skills through the voice of the students themselves. In this study, we examine the learning philosophies of students in ENGR 20100 as an effort to provide insight into their approaches to learning for the course.

III. METHODS

This work is guided by the following research question: **What are students’ learning philosophies in the context of ENGR 20100: Engineering in Global Context?**

We found the context of ENGR 20100 to be particularly appropriate for examining the learning philosophies of engineering students. In comparison to problem sets and note-taking, which are common course activities in engineering courses, the course activities in ENGR 20100 largely comprised of reading, writing, and discussion. The contrast naturally allowed for us to ask students to compare their study and learning approaches, highlighting the variation in cognitive levels and development between courses.

It is important to examine a course at this level and context since so much research is focused on freshman and senior engineering and design. The context of global engineering provides a fresh perspective and comparison for engineering students’ learning philosophies.

A. The Participants

The participants were the students enrolled in ENGR 20100 during the Spring 2015 semester. There were 25 students, of whom 19 took the survey and gave consent to allow the use their de-identified responses for this research project. The whole class consisted of seven females with a mixture of academic level ranging from freshmen to seniors. While most of the students were in engineering or computer science, a few students were in other disciplines, such as business and industrial management.

B. Tasks and Procedures

As part of the ENGR 20100 course grading, course surveys count for 5% of the final grade. Completing these surveys results in a binary completion grade: students were graded solely on whether they completed the survey, and not based on the content of their survey responses. The mid-course survey included two questions asking about how the course was going thus far, and for any recommendations for improvement. Additionally, the survey asked the following questions, the responses to which are the data for this study. As can be seen, student responses to these questions would provide useful insight for an instructor of any course. Some of the questions were inspired by Maryellen Weimer’s work [15].

1. How do you prepare for class sessions in this course?
2. Is how you prepare for this course similar to or different from how you prepare for other courses? Explain.
3. What do you do when you read the assigned texts for this course? (Take notes, formulate questions, skim, re-read, etc.)
4. How do you know if you’ve mastered the material for this course, other than a grade?

5. How do you know if you've mastered the material for other courses, other than a grade?
6. Think about the best course you ever had. What were some characteristics of the course that made it the best?
7. I learn best when... (complete this thought)
8. I feel most confident as a learner when... (complete this thought)
9. Classmates compromise my attempts to learn when... (complete this thought)

Qualitative data were collected from students in the form of open-ended survey responses so that we could see what students said about their learning in their own words. These questions ask students what they do with their study time in this course and what they think about themselves as learners. The data was collected following appropriate guidelines and approvals for human-subjects research.

C. Analysis

Student responses were analyzed using exploratory content analysis [16] to allow for themes to emerge naturally. Through discussion, the authors came to agreement about the emergent codes. These themes were then clustered using thematic analysis [16] to see what themes and concepts were common among the class as a whole. Next, the themes were deductively analyzed through the lens of the conceptual frameworks of Anderson and Krathwohl (Bloom's Taxonomy) and Schommer (Epistemological Dimensions). The researchers continued to meet and compare their results until a consensus on the coding framework was reached.

IV. RESULTS

Student responses were thematically clustered into three major themes. The first theme centers on items relating to Bloom's Taxonomy. The second theme relates to conceptions about learning according to Schommer's Epistemological Dimensions. And finally, a third theme clusters other noteworthy comments and remarks made by the students that do not fit into the two conceptual frameworks. Results related to each theme are presented in the sections that follow.

A. Bloom's Taxonomy: levels of thinking and mastery

Students were asked to think about their conceptions of mastery of material for the ENGR 20100 course as well as for other courses. Students largely described mastery in ENGR 20100 at the Remember and Understand levels in Bloom's Taxonomy. For example, in response to Question 4: "How do you know if you've mastered the material for this course, other than a grade," students responded:

"When I can discuss about a topic I know I understand it."

"If I have an understanding of the topic capable of teaching others."

"If I can contribute to Friday class discussions."

"I can tell based on how easily I can think of answers to questions presented by the instructors."

"If I can answer the questions on the power point correctly, then I assume that I understand the material."

"When I can remember the information I review in my head."

Only a few students went beyond the Remember and Understand levels of Bloom's Taxonomy. However, a couple students described mastery in ENGR 20100 as being able to connect and compare various course concepts, which is associated with the Apply level:

"If I can start back at engineering in England, Germany, and France, and tell the progression of thought and how it stemmed to the United States including where it is today (especially in a global perspective)."

"If I can pinpoint changes in my thought process regarding international engineering from now and the past."

Students' responses to Question 5, "How do you know if you've mastered the material in other courses, other than a grade", differed from their responses about the ENGR 20100 course. Here students generally defined mastery at the Apply level in Bloom's Taxonomy. For example, students described mastery in other courses, which are likely engineering science courses, as being able to apply knowledge with confidence and to real-world situations:

"If I can apply the knowledge outside of class with complete confidence."

"If I can solve problems similar to the problems given in a real world setting."

"For mathematical courses, I know I've mastered the course when I can apply what I've learned to a real-life situation."

One student described a still higher cognitive level of Bloom's Taxonomy as an indicator of mastery – Create:

"If I could solve problems or create problems without looking back at the textbook, I think I did master the material."

Similarly, responses to Question 8: "I feel most confident as a learner when... (continue this thought)", centered around

similar themes as the responses to Questions 4 and 5. The students described feeling confident when they were able to discuss, explain, and apply the material, and when they were able to get the correct answer. Some examples of these themes are:

“I am able to understand a concept and explain it to others clearly.”

“I understand the material and can apply it to other applications.”

“I am able to talk with others to discuss the material.”

“I feel most confident as a learner when I apply my current knowledge and I am correct or I am able to figure out what I did wrong and what I need to fix in order to get the problem right.”

Moving from levels of thinking to the content of what students are thinking gives us even more of an understanding of other components students’ learning philosophies include.

B. Schommer’s Epistemological Dimensions: Quick and accurate problem solving

Student responses also revealed evidence of two of the four dimensions described by Schommer, namely *quick learning* and *certain knowledge*.

Students described mastery in other courses as being able to apply knowledge to solve problems quickly and correctly. While effortlessly solving a problem is not equivalent to quick learning, the emphasis students put on easy problem solving is substantial. For example, in response to Question 5: “How do you know if you’ve mastered the material in other courses, other than a grade”, student responses included:

“I know I’ve mastered the material in a course if I use the information I learned in that course easily, as if it is now something that is a natural part of me and I do not need to think excessively about how to do it. For example, after Calc I, I can take simple integrals and derivatives quickly and without much hesitation.”

“I can work out problems of the same type of nature without having to really think about it.”

“If I can select any problem set from any point during the term and complete them with accuracy.”

“I can tell based on how easily I can discuss the material with peers.”

And additionally, in response to Question 8: “I feel most confident as a learner when... (continue this thought)”, one

student felt confidence when answering questions or following a lecture came with ease:

“I can answer all the questions a professor asks in class correctly and/or can follow the lecture very easily.”

In line with Schommer’s epistemological dimension of certain knowledge, one student also described how believing the instructor contributed to personal confidence as a learner. For example, this student reported feeling most confident as a learner when:

“I am sure that the person telling me something is telling the truth and that I can trust their knowledge.”

While examining student responses through the lenses of Bloom and Schommer, responses that did not fit into those frameworks still provide glimpses into what we can learn about student learning philosophies. The additional themes that resulted from our analysis are described next.

C. Other Themes

A number of student responses did not fit in line with either Bloom’s Taxonomy or Schommer’s Epistemological Dimensions, but nonetheless turned out to be interesting findings. These two themes were engagement with the readings and best course characteristics.

a) Engagement with readings: In ENGR 20100, students read articles and other publications in preparation for course sessions and for assignments. Question 3 asked students what they do when they read the assigned texts, even giving some suggestions such as take notes, formulate questions, skim, and re-read. The students described the activities of reading, re-reading, skimming, taking notes, and highlighting. Not one student described formulating questions, and no students suggested additional activities while reading. Some students offered reasons or explanations for their behavior. For example, some students skimmed long readings and others took notes on what they perceived to be important concepts:

“If the pages are not long, I would take notes for the points I think are important. Also for the assignment. If the reading is long, I would skim most of it.”

“I usually read the texts in their entirety. I will take notes if I think I will forget things.”

“When I read the assigned texts for this course I usually try and retain as much information as I can, but a lot of times that takes too long and I will just end up skim reading the texts.”

"I first read the assignment completely, then take notes on any insights I have so that I can remember them later. On the day of the discussion, I typically skim the assignment once more to ensure I can remember details."

Here, we are able to see what students are actually doing and thinking when they are assigned a reading. Next, while we know the instructor for a course plays an important role, we will see what students like about their best instructors and courses.

b) *Best course characteristics:* Question 6 asked students to consider the best course they have ever had and reflect on what characteristics of that course made it the best. The students responded about interest in the material; an engaging, clear, and organized professor; opportunities to practice what they were learning; and having an appropriate work load. For example, some responses that demonstrate each of the themes described above include:

"The instructor's explanation was clear, concise, and easy to follow. The instructor's handwriting on the blackboard was neat and clear. The class was very organized and [the instructor] supplements students with enough resources such as course slides, sample exams, and lecture notes. The topics covered were interesting and intellectually stimulating."

"Some characteristics include: professor/student interaction, enjoyable learning, relatable and interesting material."

The material was engaging and hands-on. Also, a lot of discussion and interaction between students and teachers made it feel like a comfortable environment."

"Characteristics include lots of time to practice during class and when the professor/TA has easy to access office hours."

One final theme examined the difference between learning goals and beliefs. It is important to recognize that while sometimes a learning goal heavily depends on the context, as will be described next.

c) *Learning goals vs. learning beliefs:* Some students expressed goals for ENGR 20100 that might not necessarily reflect their usual learning beliefs and goals. For example, in response to Question 6, "Is how you prepare for this course similar to or different from how you prepare for other courses? Explain," two student responses were:

"I prepare for this course very differently from my other courses. I took this class to fill a requirement and it is not one of the classes I'm interested in, so I

do not spend as much time working for this class as I do my core classes."

"Other courses are more relaxed in the way that I am a senior so I do not have to worry about doing the reading and can do it whenever I want."

Bloom's Taxonomy and Schommer's Epistemological Dimensions helped us make sense of a lot of student responses to questions about how they study and learn. Additionally, some responses that dealt with other aspects of learning conceptions were also explored to help us understand the idea of learning philosophies even more holistically. Possible interpretations and implications of the results can provide ways of implementing these findings into the classroom, and are discussed below.

V. DISCUSSION

The Bloom and Schommer frameworks provided useful ways to make sense of the data. However, the emergent thematic analysis that was conducted was beneficial to uncover other themes that emerged that did not fit in with the aforementioned frameworks. Since there has not been much work about students' learning and study practices, this work gives a preliminary understanding about students' perceptions.

The responses to Questions 4 and 5 about mastery revealed some interesting implications about the relative skill levels relating to reading and writing versus math, science, and engineering skills. In ENGR 20100, a reading- and writing-intensive course, students believed that they had mastered the material only if they had achieved the Understand level of Bloom's Taxonomy, whereas in presumably technical courses, students defined mastery as achieving the Apply level. One especially interesting point is that before students took the survey, they had completed two homework assignments that had required higher level thinking skills, including Evaluate and Create, but there was no evidence that students were aware of these higher level skills in their definition of what counted as mastery in the course.

The contrast between students achieving the Understand level in ENGR 20100 and the Apply level in technical courses on Bloom's Taxonomy might demonstrate to us as educators that engineering students largely perform at lower levels in more reading- and writing-based courses. If engineering students really perform at much lower levels in reading and writing tasks than problem solving tasks, there are significant implications for students to achieve the necessary and desired outcomes for graduation and advancing one's career.

Schommer's Epistemological Dimensions appeared only a few times within the students' responses in the form of quick leaning and certain knowledge. The fact that students still harbor these beliefs about the nature of knowledge demonstrate that they might not be moving towards more advanced and higher-level thinking. Again, if students are holding on to inaccurate beliefs about knowledge, there are useful implications for students moving forward and advancing, since developing a full and appropriate understanding of knowledge is necessary as engineers.

An explanation for why students' cognitive levels of mastery might be higher for other courses is likely due to practice – these students have been practicing technical problem solving and analysis in many of their courses. Additionally, students commonly believe that engineering does not require the skills of reading comprehension and effective writing. These beliefs may lead students to aim for lower levels of mastery for the ENGR 20100 course than for technical courses. Another possible explanation considers students who are purely taking this course to fulfill a requirement. These students may greatly value reading and writing but did not for this particular course.

The students also brought up how ENGR 20100 was “different” than other courses they usually take (namely technical courses), but then also discussed that they learn best in discussion-based courses. In general, many engineering courses are lecture-based with less discussion and other active learning. Since students in this study really valued discussion, we suggest that engineering students would benefit from the inclusion of discussion practices in their technical engineering courses.

The students' descriptions of good professors aligned well with what other research says about the characteristics of excellent instructors [17]. This consistency suggests that the participants in this study are similar to students in other studies. This similarity suggests that the findings in this paper regarding levels of thinking in reading and writing based courses are probably generalizable to similar courses at other universities. The questions used in this study would likely provide useful and insightful information to instructors, but might benefit from alterations as described below.

Although these findings and implications are interesting and can aid more student centered teaching, it is important to note some limitations of this study. The work would have been strengthened if students were given a more thorough understanding to the context of what was being studied. Focus groups and interviews could potentially have deepened our understanding of student conceptions about their learning. Furthermore, students' investment in this assignment was likely minimal. Students who are interested in self-reflection and considerations about their learning may have provided more thoughtful and complete interpretations about their learning. On the other hand, students who were taking this course purely to fill a requirement may not have had much interest in providing insightful responses to a course survey. More information about student demographics could have also provided deeper understanding about student motivation and how those are linked to student learning philosophies, although it is important to note that academic level and age do not necessarily map to higher levels of thinking or more accurate epistemological beliefs [7].

VI. IMPLICATIONS AND FUTURE WORK

Tools such as Bloom's Taxonomy and Schommer's Epistemological dimensions can illuminate areas of learning where students need further practice and skill development. Students reported to be performing at lower levels in a course that is largely reading- and writing-based as compared to their

technical courses, but the engineering profession requires higher levels of thinking for reading, writing, and communication to be successful. If these skills are addressed and improved, developing well-rounded competent engineers will become more realistic.

A student survey such as the one described in this paper can be extremely valuable to instructors and can potentially improve course alignment. Course alignment, in this case, means making sure there are clear connections between the content that is being taught, the way it is assessed, and the way it is taught (pedagogy). In line with adult learning theory, acknowledging student learning philosophies can help make courses more meaningful to the students. For example, one of the goals of this course is to support students as they develop as globally competent professionals working on cross-cultural teams. They were encouraged to discuss and analyze global situations through class discussion and homework assignments. Students were also often provided with the freedom to tailor their assignments to their particular interests. Seeing their comments about how they know they have mastered the material and that they like the discussions with their classmates reinforces that this goal is being met for some of the students.

This work might be enhanced if Bloom's and Schommer's concepts were integrated more into the survey itself. If students are asked to think in the terms of Bloom and Schommer, we might better understand their own interpretations of their learning philosophies through these frameworks. While the findings from this work might provide details about the various scales and levels of thinking, it would be interesting to make students more aware of these scales and levels so that they have the opportunity to better understand their development as adult learners.

Additionally, it would be valuable to understand what instructors and professors think of the learning philosophies of their students. Future work will include interviews with faculty that include a discussion about what was said in the survey responses and thoughts about how this new knowledge could be included in course design.

VII. CONCLUSION

By understanding students' learning philosophies through a research perspective, college students and instructors alike will begin to understand students' ways of thinking about their learning. When instructors understand the beliefs and practices used by students, they can adjust their teaching techniques to the benefit of the class. The survey questions utilized in this study can be used as a tool to gain insight into students' approaches to learning. Learning philosophies are an underexplored research area that needs further study at all levels of engineering education. This work provides one example of a specific instance in a particular context.

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A Bridge to Engineering:

A Personalized Precalculus (Bridge) Program

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Abstract—Mathematics continues to be a major hurdle for engineering students. The authors presented results of a pilot precalculus summer program at FIE 2014. In the current paper, we examined longitudinally the results of the institutionalized version of the precalculus summer program over four years. Students who scored less than 22 on the Mathematics Placement Exam could either a) participate in the personalized precalculus program (PPP) or b) take the fall precalculus course. The research question for this study was: How well did the students who took the PPP perform in the precalculus and engineering calculus course sequence compared with the students who did not participate in the PPP? The PPP included an online study plan with practice problems in common areas of difficulty in algebra and trigonometry and required online tutoring sessions for 30 hours over a six-week period for the first three years and the same number of hours over a three-week period for the fourth year. For this paper, we analyzed the trends over four years of the program to determine whether participants are progressing successfully through the engineering calculus sequence.

Keywords—calculus, engineering education, mathematics placement, summer program

I. INTRODUCTION

The gap between college acceptance and readiness remains. Yearly, almost 60% of eligible college freshmen discover they are not ready for university studies [1]. After enrolling, they realize it is necessary to enroll in remedial non-credit bearing courses in English or mathematics. In college remedial education programs, early successful intervention helps students, the institution, and society succeed all together [2].

Concern about the number of students requiring remediation has been evident for quite a few years, and the number of remedial courses that need to be offered, especially at the post-secondary level, has increased. Remedial courses

are an important and utilized component of higher education in the United States [3; 4; 5]. These courses have been offered in almost all U.S. two-year community colleges to students for writing, reading, and mathematics (below college algebra). Unfortunately, now four-year post-secondary institutions are also finding it necessary to offer a large number of remedial mathematics courses. Every year, over two million students enroll in remedial education courses in U.S. colleges and universities [6]. In the fall of 2000, 22% of freshmen entering American colleges were required to enroll in remedial mathematics courses [7]. Those numbers are increasing; 24% of students in four-year colleges and 38% of students in community colleges enrolled in remedial courses in 2006. Of all the remedial classes, mathematics had the largest enrollment [7]. In fall 2003, more than 65,000 students in Texas were enrolled in remedial mathematics courses [8].

Remedial courses are costing colleges more than they produce in revenues [9]. From 1995-2000, the number of freshmen registered in remedial courses remained the same; however, the number of courses they took grew from 28% to 35% [7]. Citizens are burdened by paying taxes twice for the same courses these students took in high school. One estimate of the total cost, including tuition, fees, and local taxes, for the 2000-2001 year was \$462 million [10].

In addition to the expenses incurred from remedial education tuition, there are also costs associated with families and the economy in general. During 2006, the U. S. lost \$2.3 billion in revenue due to the fact that “remedial reading students are more likely to drop out of college without a degree, thereby reducing their earning potential” [11]. Across the U.S., college graduates can expect to earn \$1.2 million more in average salary over a lifetime than a non-college graduate [8].

In addition to concerns about the costs associated with post-secondary remedial education, there is controversy surrounding the usefulness of remedial mathematics classes. While previous researchers have found the effectiveness of remedial programs in encouraging students to persist and succeed in credit-bearing courses [12; 13; 14], other researchers [15; 16; 17] have found that remedial courses can be a roadblock impeding students, or their supports are short-term and do not translate into successes in credit-bearing courses. Research results have demonstrated mixed results with remediated students as well. Another group of researchers have found that remediation can be detrimental to success; at the same time, others revealed there were adverse consequences in particular settings while there were positive effects in others [18; 19]. Students who start remedial work in one of the higher levels tend to perform like students who are not remediated [20; 21]. Students who need precalculus remediation in degree programs that require calculus generally graduate after four years at a rate of about 70%, compared to 80% for students who enroll straight into calculus [22].

Remedial mathematics courses have the highest rates of failure; thus, students are not succeeding in mathematics, which inhibits them from reaching their educational objectives [6]. Using data from the Beginning Postsecondary Students Longitudinal Study and the associated 2009 Postsecondary Education Transcript Study, a statistical analysis of factors contributing to STEM attrition was conducted. Findings showed that taking lighter credit loads in STEM courses in the first year and taking less challenging math courses in the first year increased retention in STEM fields [23]. An NSF STEP Grant [24] required students to attend a 3-contact-hour recitation session every day, in addition to the class lectures. These remedial techniques increased STEM retention in fields such as engineering. Unfortunately, if students needed to enroll in remedial mathematics before enrolling in mathematics courses required for their degree plans, their time to graduation took longer, and the probability of finishing their degree was less. In the U. S., about 20% of students who successfully finish a remedial program earn a four-year degree in a six-year time frame; at the same time, nearly 50% of regular students are expected to graduate in that same time frame. Whether or not a student dropped out was a predictor of their need for college remediation [8].

Engineering majors at Texas A&M University are required to be enrolled in Engineering Calculus I at the same time or before their first engineering course. Students who had to enroll in precalculus after they enrolled in the university were almost one semester behind in a demanding major program with few opportunities to achieve in the mathematics classes, thus preventing their admission into upper level engineering classes. Reference [25] has acknowledged that employing remedial technology programs can bolster student learning and can serve as a positive influence on instructors' skills when working with students. Instructional technology programs including WeBWork [26], math and engineering supplemental tutorial sessions [27], and an online homework system – MasteringEngineering [28] – have been used to eliminate the learning gaps of students. These programs demonstrated positive results in bolstering mathematics skills and the self-confidence of students in beginning engineering classes.

The current study is based on a previous study [29] in which participants were enrolled in a bridge program for 30 hours with a tutor and an on-line course that lasted three weeks. After the program students were allowed to retake the placement test with the hope that they would now score a 22 or above and be eligible for Engineering Calculus. By the end of the program, mean student scores on the placement exam increased by 8 points and the standard deviation was reduced by 50%, negatively skewing the distribution.

II. PROGRAM DESCRIPTION

Reference [30] noted that “self-perceptions of competence begin to decline in Grade 7 or earlier” and show up more in mathematics. Reference [31] found that only some students are able to control and direct their own studying. Some students need assistance developing study skills. Without help, these students end up only “employ[ing] task-specific strategies such as preparing for tests” [32]. Reference [30] found that “learning environments that are intellectually challenging and supportive of individual progress and mastery” and that students “who feel self-efficacious about learning or performing a task competently are apt to participate more readily, work harder, persist longer when they encounter difficulties, and achieve at higher levels”.

The Personalized Precalculus Program (PPP) project is about mathematics remediation, retention, and keeping students on their academic track. The purpose is to remediate students needing precalculus help for Engineering Calculus I before their first semester in college.

The typical student is admitted during his/her senior year. If the student declares a STEM major, he/she is required to take the online Mathematics Placement Exam (MPE), a 33 question precalculus examination that is a good predictor of Engineering Calculus I success [33]. Currently, students with a score of 22 or higher are automatically admitted to Engineering Calculus I. Students with scores in the 14-21 range are given the opportunity to take the PPP. Students below this score must take precalculus or college algebra. This affects about 4,200 students during a typical fall term, of which more than 800 are destined for precalculus.

There are numerous other reasons why placing students in precalculus is undesirable. 1) Many (if not most) students forced to take this course enter it believing they already know the material, and it is true they have probably seen most of it. This creates a negative attitude toward learning. 2) Students have a low success rate (~51%). 3) Students forced to take the course suffer (in their own minds) something of a stigma at not being allowed to take Calculus I, and sometimes resentment builds. 4) Often precalculus students' classmates say the course has little value, reinforcing some of the factors above. 5) In most STEM majors, students taking a precalculus course are locked out of their normal program and can be delayed in graduation for as much as a year.

There are two other large groups of students of about 300 each that are at risk, and both are Calculus I bound. The first of these will eventually earn a D or F (or W) in the course. Often these students are lost to their STEM aspirations or must repeat Calculus I. The second are those that will eventually earn a C.

Aside from those dropping from STEM at this point, this group continues to Calculus II, but their grade point average is typically 1.3 on a four point scale. Thus, more STEM majors are lost.

The PPP course materials have been placed on WebAssign, a commercial assessment and course management tool. The student pays \$150 to take the course, almost enough to make the program self-sustaining. It is completely online. The materials consist of videos of math topics, a complete precalculus text, and a variety of quizzes the student must take to advance in the program. So, for purposes here, imagine the PPP to be an essentially complete precalculus course, where participants are required to complete various components. The program is personalized in that students are not necessarily required to complete all of the materials in the course. The test they take at the beginning of the course identifies which of the four main areas they need to complete. Experience over several years has shown that students are generally deficient in all the same areas originally identified to be included in the program. Within each of the areas, they take quizzes. If they do not score at least 70%, they are expected to continue practicing the algorithmic problems in that topical area. This feature personalizes the program throughout the students' time in the course. A bar that turns from red to yellow to green indicates their progress through the material. The mathematical components such as trigonometry are exactly those for which the typical calculus student has the greatest trouble.

The operations of the PPP are complex. In the next paragraphs, the main components are sketched out, including tutoring, format, and recruiting. Enrolled students are divided into cohorts of at most twenty. They are assigned a tutor and live, online meeting times with the tutor. Tutors are carefully selected for qualities related to teaching calculus to beginning students and for their excellence at truly communicating with students. The communications factor is extremely important, as the online environment can promote passivity. Therefore, tutors must be able to engage students in the learning process. A fully online program without a tutor would likely not succeed, as most students are essentially unable to learn mathematics independently, videos, applets, and other assists notwithstanding. Indeed, it has been shown a large percentage of entering students lack useful direction with specific study methods, which includes self-study [34]. In fact, had they been able to learn well from the textbook alone [35], they would have been able to attain the cut score to enroll in engineering calculus. The online system contains algorithmic problems, providing an almost endless supply of practice problems with immediate feedback on the answer [36]. Videos of similar types of problems are available to support them when they continue to have difficulty with the problems. Additionally, students have access to the tutor in the online sessions and through email. The tutor not only explains problems with which students are having difficulty, but also provides an opportunity for engaging in "practices of negotiation and interpretation" that enables students to transfer the use of mathematics knowledge to different situations [29].

As for the PPP duration, the course format has been changed somewhat over the five years of its operation. Originally, it was viewed and taught as a six-week course,

meeting three times per week. This format was somewhat unsuccessful in retention though good in results. Beginning in 2014, the sessions have been condensed to about three weeks to improve retention. The number of student-tutor contact hours have remained essentially the same, however. This has proved far more successful in PPP retention, though success results are still under study.

Students completing the program are encouraged to take the MPE once again, with the vast majority now placing into Calculus I. The first question to ask is how well do these students perform? In fact, those placing into Calculus I complete the course at the same rate as those in their MPE grade-class. Previous analyses proved such students succeed at a substantially lower rate if they are placed into calculus without the PPP intervention [37; 38].

The perennial problem with the PPP program has been recruiting students to enroll. All recruiting is done by email with an online enrollment site. Note the program is completely voluntary. This cannot be changed. It is online when the student is still at home; it is taken during the summer when many students work at various jobs. For a couple of years the enrollment remained at less than one hundred. However, in our most recent application (2014), more than 250 students enrolled. This is evidence of student perceived value of the program, of student's understanding they may need help in mathematics, of the encouragement of college advisers to students, and to the reasonable costs for this service.

III. PURPOSE AND RESEARCH QUESTIONS

The mathematics sequence for engineering students is critical to their success and enrollment in upper level engineering courses. In a prior paper we reported the results of student success in Engineering Calculus I in one academic year at the beginning of the program [37]. The summer program described was designed to improve students' algebra and precalculus skills before retaking the MPE so that they could begin on track for their engineering courses. As the program has evolved through institutional changes in student advising, additional support resources, different tutors, and different groups of students over four years, modified research questions needed to be asked.

The research question for this study was: How well did the students who took the PPP perform in the precalculus and engineering calculus sequence courses compared with the students who did not participate in the PPP?

IV. METHODOLOGY

Before enrolling in mathematics courses at Texas A&M University, students were required to take the MPE. An opportunity to participate in the PPP was offered to students who scored below 22, with the hope that they could improve their MPE scores enough to enroll in Engineering Calculus I their first semester and begin on track with the engineering course sequence. The 23,237 students who enrolled in Precalculus, Engineering Calculus I, II, and/or III during the fall or spring semesters from Fall 2010 through Fall 2014 were study participants.

Random assignment for the study was not possible because it would require offering some students the opportunity to begin on track in their engineering studies while denying the opportunity to other students who did not meet the cut score on the MPE by requiring them to take Precalculus in the fall. The best research design possible was to compare performance of those who enrolled in the PPP with similar students who did not enroll.

In this study, we examined not only the results from the first semester of calculus, but also subsequent courses in the engineering calculus sequence. The question under consideration was whether PPP participants continue to be at least as successful through the sequence as non-PPP participants. Data analyses consisted of recommended methods [39; 40; 41; 42]. The recommendation for data analysis is to report findings in a way that promotes meta-analytic thinking so that conclusions can be drawn across studies [43; 44]. Therefore, in addition to correlational analyses across subgroups, non-sample size dependent estimates of importance were used. Data were analyzed using 95% confidence intervals and Cohen's d effect size estimates. Data confirmation follow-up was scheduled for the semester following post-secondary matriculation. Confidence intervals represent the results by providing a measure of variation around the point estimate, which provides a clear picture of accuracy of that estimate. Narrower bars indicate greater precision, which is heavily influenced by sample size.

V. RESULTS

There was a valuable and powerful influence of PPP on grade when considering the first mathematics class. The mean grades were nearly identical and were not statistically significantly different. The effect size Cohen's d was nearly zero, meaning that the PPP students were just as likely to succeed in Engineering Calculus I as those students not needing remediation. However, the effect dropped off marginally in the second course (151) and fell precipitously in the two subsequent courses. When considering that, even for the initially qualified students, the average score (1.97) was below passing, but for the PPP group the average grade (1.2) was markedly low. The residual effect of PPP was not helpful in improving performance of PPP students in mathematics courses beyond Engineering Calculus I.

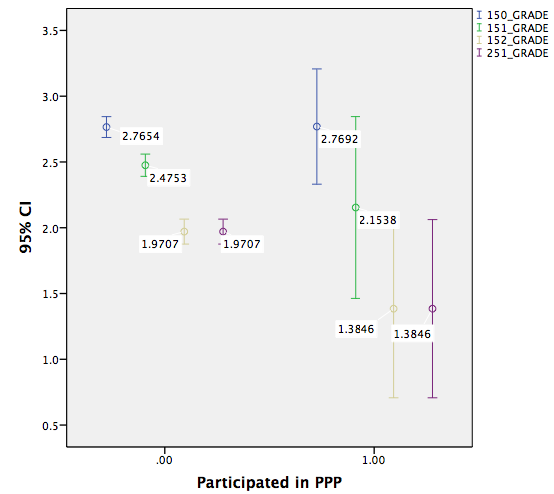


Fig. 1. Comparison of Academic Performance by Participation/Non-Participation in PPP

We examined how PPP impacted female performance and likely persistence in a 4-course sequence. It was evident that the mean female score started out relatively equal to males and became relatively constant with earning a passing grade and, on average, there was a likelihood of persevering because the average score met the 2.0 cutoff for matriculation into a subsequent class. The average female score exceeded that of males. While the mean difference between males and females was small, the male mean was below the 2.0 cutoff for matriculation into the subsequent mathematics class. Note that in Figure 2 the 0 represents females, and 1 represents males.

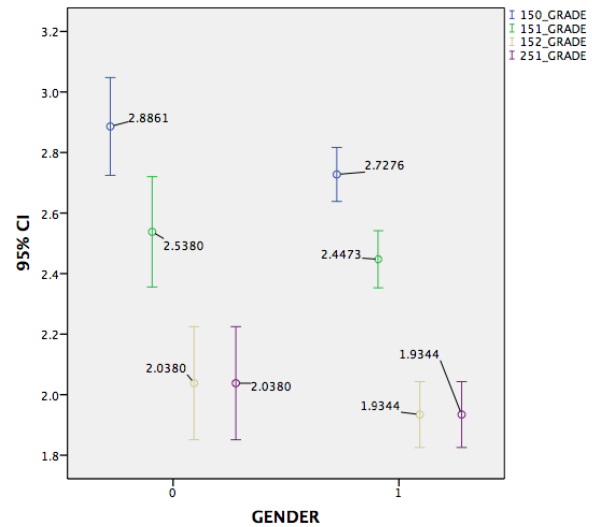


Fig. 2. Performance by Gender Across Courses for PPP Participants

VI. CONCLUSIONS

There are several reasons for offering a program like the PPP: leveling the playing field for those students with less adequate prior knowledge from high school; keeping students with weaker math backgrounds on track for graduation in a calculus engineering sequence; and improving the performance of at-risk students in their calculus sequence. Any pre-college program can contribute to leveling the playing field, if only by

allowing students more time to adjust to the differences college life offers and providing them a glimpse of the expectations in college courses. Many students were able to save time and money and begin calculus on track during their first semester. However, overall, PPP students taking Engineering Calculus I in their first semester did not perform as well in terms of grades as those taking it second semester. One of the reasons for this result could be the adjustment from high school. All students have some adjustment pains, and the “weaker” PPP students may well have performed better in the spring because they decoupled the stress of first semester college and the stress of a rigorous course like Engineering Calculus I. Other differences are not likely in our case: many of the same teachers teach Calculus I both fall and spring semesters. Before the final exam, the course has three common exams constructed by faculty teaching the course, leading to very similar faculty expectations from semester to semester. This finding aligns with research on the effect of study skills on student performance and with the previous study over the results from the program in 2011 alone [43].

Like most programs, the PPP has undergone changes over time. In the original offering, only students scoring above a minimum threshold (MPE score of 16) were allowed to participate. This minimum score was eliminated in subsequent years. Students were able to circumvent the registration system and register for Engineering Calculus I even if their MPE score fell below the minimum cut score on the MPE. After the first two years, students were blocked from registering for calculus I if they did not meet the minimum cut score on the MPE. A few students could still have bypassed the registration block if they were able to convince advisors that their scores were not representative of their *real* knowledge. Finally, in 2014, the PPP was reduced from a six-week program to a three-week program. The jury is still out on this change. A comparative analysis of the six-week and the three-week PPP will begin following the 2015 offering. Additionally, because students who perform marginally well in the first course are at high risk for failure in subsequent courses in the engineering calculus sequence, bridge programs for continued support throughout the sequence have been initiated. Studies about the effects of those programs are in progress.

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First in the Family:

A Comparison of First-Generation and Non-First-Generation Engineering College Students

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Abstract—This study investigates first-generation and non-first-generation engineering undergraduates' math/science identities, subject-related interests, and career plans. First-generation students are an understudied, but growing population. Understanding how these self-beliefs and background factors affect students' engineering choice can help widen pathways into engineering which continues to be defined as “pale and male.” Additionally, identity has predictive value for practical outcomes like engineering choice in college. The data for this study comes from the nationally representative Sustainability and Gender in Engineering (SaGE) survey completed by 6,772 college students who enrolled in first-year English courses at 2- and 4-year colleges across the U.S. Data were analyzed using t-test and chi-square tests for linear and dichotomous outcomes respectively. Our results show differences in first-generation students' identities, interests, performance/ competence beliefs, and family support for science. These differences can serve as a stepping stone towards understanding the trajectories of first-generation college students in engineering. By understanding underrepresented students' identities, performance, and backgrounds, specific strategies can be developed to support these students in our engineering programs.

Keywords—*first-generation college student; identity; career plans; family support*

I. INTRODUCTION

The President's Council of Advisors on Science and Technology have stated that there is a significant need for recruiting and retaining more engineering students [1]. However, a longitudinal study of students' academic records at several large engineering institutions showed that students who matriculate into engineering have higher persistent rates than those in other areas of study, highlighting that the deficiency of engineers is not due to retention but recruitment. In large part, first-generation students attend 2-year institutions and transfer into 4-year engineering programs at higher rates than non-first-generation students [2], [3]. Engineering has lower migration rates into the discipline after the first year than other fields; students who do not matriculate into engineering in their first semester have a lower chance of going into the field later on in their academic careers [4]. Combined, these trends differentially impact first-generation students than their peers who are not first-generation.

The changing demographics of the United States, in terms of college enrollment, demonstrate an upward trend in the enrollment of first-generation college students in higher education. Although there are few recruitment or outreach efforts directly targeting this growing population of first-generation college students interested in engineering, this demographic offers a significant contribution to the nation's engineering workforce [5]. Additionally, students from diverse backgrounds can improve the quality of solutions for engineering problems through alternative perspectives [6]. This argument for increased diversity in engineering appeals to the improvement of engineering outcomes. An additional need for diversity in engineering takes a social justice perspective, that access to engineering and the social and economic capital that an engineering career offers, as well as the solutions generated, should be representative of the U.S. population [7]. With an increasing number of first-generation college students entering universities, and the need for more engineers [8], this population has the potential to improve the variety of who is represented in engineering and offer unique perspectives to help solve important engineering challenges.

While first-generation students have potential to increase the size of the engineering workforce, they face many educational obstacles. The experiences and challenges that first-generation students face in the higher education system demands further research attention. The U.S. Department of Education classifies first-generation college students as those who came from families where neither parent obtained a four-year college degree [9]. These students are disproportionately Latinos and African-American students and have greater missed opportunities in the quality of their mathematics education [10], [11]. In the 2007-2008 academic year, the National Center for Education Statistics reported the following percentages of college students whose parents had a high school diploma or less: 25 percent of White parents, 32.2 percent of Asian parents, 35.6 percent of Native American parents, 45 percent of African-American parents, and 48.5 percent Latin American parents [12]. Previous studies found that poor classroom and academic climate, low academic achievement, difficulty with conceptual understanding, low self-efficacy, inadequate high school preparation, lack of interest, alternative career goals, and minority status increased students' chances of leaving engineering [13]. These trends make first-generation students a high risk population for attrition in engineering.

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The educational system in America has been regarded as an “engine of social mobility that provides equal opportunities to all deserving students, irrespective of their previous background, upbringing, or life circumstances” [14, p. 1178]. However, sociologists have argued against this belief of upward social mobility through open opportunities for education [14]. In fact, the higher education culture in America creates “social reproduction,” which constructs, retains, and recreates inequalities amongst groups based on access and equity patterns that limit participation of minority groups. Social class inequalities are created by institutions of higher education through their middle- and upper-class cultural norms of independence, which do not take into consideration students who come from working-class backgrounds, typically possessing norms of cultural interdependence [14]. First-generation students are likely to face this cultural disconnect in higher education due to their lack of social capital. Social capital as defined by Bourdieu is “the sum of the resources, actual or virtual, that accrue to an individual or a group by virtue of possessing a durable network of more or less institutionalized relationships of mutual acquaintance and recognition” [15, p. 2]. In large, social capital not only encompasses income and socioeconomic status, but also inequalities of resources in the public education system [16]. These factors differentially affect first-generation students based on family structure. Students from first-generation families have lower parental education level than their peers that often defines their own socioeconomic status. Lower socioeconomic status families typically have less access to quality schools and teachers based on the locations in which they live. Additionally, the community values of first-generation students are not always directed towards the pursuit of a higher education. All of these factors, as well as community values, have an influence on students’ academic achievement [16].

National studies have reported academic under preparation for first-generation college students who are typically falling behind their non-first-generation peers [14], [17], [18]. Certain privileges accessible to non-first-generation college students, such as parents with first-hand knowledge of the college process and procedures, study skills, and mentors in the college system are not present for first-generation college students [17], [19]. Previous research studies have reported that first-generation college students typically come from lower socioeconomic status household, are less prepared academically, have lower high school and college GPAs and lower SAT scores, have not participated in honor programs, have a part-time student enrollment status, have dependents, have geographical constraints with regards to college choice, and have greater drop-out rates when compared to non-first-generation students [7], [9], [11], [13], [15]. Additionally, first-generation college students often come from high schools with low college enrollment rates, have peers who are not college-bound, and have a lower understanding of what college is about, and possess less knowledge about the expectations of students in college and how to prepare for their first term compared to their peers [22]. The cultural mismatch first-generation students face in the higher education system is an unseen disadvantage that can hinder their performance, thus systemically reproducing differences in academic achievement and maintaining existing social hierarchy [14]. All of these factors naturally disadvantage this group’s ability to see engineering as a possible career in college.

Family encouragement and interest have proven to foster academic achievement for students, even after controlling for socioeconomic status. Parents can enhance their student’s interest in mathematics and science by helping their student see the importance of these courses, as well as emphasizing their importance in future careers [23]. Interest in mathematics and science as possible careers declines for many students at an early age. However, a recent study found that parental encouragement was more affective in increasing test scores than having parents who attending parent/teacher conferences or having at home resources (i.e. books, magazines, video games) [23]. These findings illustrate the importance of having family members that support students’ STEM interests.

While there is significant research highlighting average differences between first-generation students and their peers on background factors, there has been a dearth of research on how first-generation students’ attitudes and self-beliefs impact choice of major. The aim of this study is to examine differences between mathematics identity, self-perceptions of mathematics performance, and STEM-related interest for first-generation and non-first-generation college students in engineering and how this may influence career plans. Math was chosen as an area of interest because connections between math and choice of engineering have been found for STEM students [24], [25]. Math and science academic ability were also found to be significant predictors of admission and retention in engineering, while college student’s self-confidence in math and science has been found to be a strong predictor of short-term and long-term persistence in engineering. However, a significant percentage of first year students are entering engineering with weak mathematics preparation [26]. For these reasons, understanding first-generation students’ attitudes and self-beliefs can be an important part in understanding how to recruit and retain this population in engineering.

II. THEORETICAL FRAMEWORK

Identity has been researched in a wide range of theoretical perspectives and contexts including psychology, sociology, anthropology [27]. In recent years, identity has been used as an analytical tool for studying issues around theory and practice in education [28]. People have multiple identities that are connected to their performances in society. Role identity is an authoring of one’s self in a particular context (e.g. in an engineering discipline) and how this concept remains changes over time [29]. As a student’s identification with a particular field or subject grows, a student can begin to develop agency to make positive changes in their world based on who they see themselves to be. An individual’s agency along with societal structures, which may also constrain an individual’s possibilities [30], interact to develop students’ authoring of themselves and the impacts they can make in their world.

This research is focused on students’ role identities as a “math person” or a “science person.” The theoretical framework, used in this work, is constructed of three dimensions of students’ self-beliefs that are central to their development: students’ perceptions of their own performance/competence, beliefs that they are recognized by others, and their perceived interest in math or science. The performance and competence dimensions are not independent of each other [31]; students who believe that the

can do well on course assessments (i.e. performance) respond similarly to items measuring their beliefs about being able to learn content knowledge (i.e. competence) as measured by confirmatory factor analysis [25]. A longitudinal study conducted by Cass et al. [32] found these dimensions of mathematics interest, performance/competence and recognition significantly predict choice of engineering career, irrespective of SAT/ACT math scores and background factors (i.e. parental education as a proxy for socioeconomic status). Students with a high level of self-perceived academic competence tend to persist at higher rates, have a greater chance of adopting mastery and/or performance approach goals, understand the material at a deeper level, and have better study skills [33]. Interest in the subject matter plays a key role in choosing engineering; students should have an understanding of the field of engineering in order to be attracted to it and have opportunities to develop their identity around engineering. The recognition factor of identity is related to the individual's beliefs that are recognized externally by professors, other students, and parents as an engineering student. This conceptual framework has been previously researched to identify students' physics and mathematics identity [25], [29], [31], [32], [34].

In addition to a role identity framework, students' career outcome expectations from Social Cognitive Career Theory (SCCT) were examined. SCCT has been widely used to investigate choice of engineering as a career. This theory is based on a social cognitive approach originally introduced by Bandura [35]. SCCT is founded on the triadic reciprocal relationship between personal and physical attributes, external environmental factors, and over behavior included in social cognitive theory. This model, first proposed by Lent, Brown, and Hackett [36], features three interlocking models including interest development, choice of career, and performance (described by self-efficacy) developed from previous work by the authors as well as a meta-analysis of current vocational career models and research. Outcome expectations, job aspects students' want in their future careers (e.g. making money, supervising others, etc.), are impacted by students learning experiences and self-efficacy and have an effect on interests, career goals, and choice actions related to students' career decisions. These aspects can tie identity theory via interests and performance/competence beliefs with career choice by understanding how first-generation student differ in what they hope to gain in their future careers.

III. RESEARCH QUESTION

Utilizing these frameworks, we worked to address the following research questions:

How are first-generation college students different when compared to non-first-generation college students on: 1) family support and background factors; 2) math and science identity; and 3) career intentions?

IV. METHODS

The data analyzed in this study comes from the nationally representative Sustainability and Gender in Engineering or SaGE (engineering.purdue.edu/ENE/Research/SaGE_survey_God

[win 2014](#)) survey completed by 6,772 college students (55% female) who were enrolled in first-year English courses at 50 different 2 and 4-year colleges across the U.S during the fall semester of 2011. The colleges and universities were drawn from a stratified random sample taken from the National Center for Education Statistics (NCES). The development of this survey has been extensively addressed in previous studies [25], [29], [37] and thus will be briefly explained in this paper. The development of the SaGE survey was organized into three main sections: 1) a literature review to identify factors that may influence increased enrollment in engineering, 2) an extraction of items from previous national studies (FICSS, PRiSE, and FICS-Math) and, 3) open-ended responses from 83 high school science teachers across the nation via a survey administered on-line. The final survey consisted of 47 questions (i.e. anchored scale, multiple choice, and categorical responses) regarding students' career goals, high school science and math experiences, science enrollment and achievement as well as demographic information. This survey has been used in other studies to identify factors that influence students' attitudes towards engineering careers using the construct of mathematics and physics identity [25], [37], [38], as well as to investigate the association between engineering and sustainability-related topics in students' experiences [39]. To compare differences between first-generation students and their peers, pairwise comparisons were conducted for each of the research question topics. The data were analyzed using t-test and chi-square tests for anchored and dichotomous outcomes, respectively. Effect sizes were calculated by Cohen's d and Cramer's v for t-test and chi-square comparisons, respectively. All statistical analyses were conducted using the R programming language statistical software system [40].

V. RESULTS AND DISCUSSION

Students who reported their male and female guardian or parent had completed a "bachelor's degree" or "master's degree or higher" were coded as non-first-generation students (4,206), and students who reported both male and female guardian or parent with "less than a high school diploma," "high school diploma/GED," or "some college or associate/trade degree" were coded as first-generation students (1,057) as consistent with the U.S. Department of Education's classification. Students who indicated "don't know" for both parents were eliminated from the study (1,509). First, the student demographics for first-generation and non-first-generation students were examined via descriptive statistics to understand the students encompassed in the groups. Latino/a students comprised a significantly larger portion of the first-generation students (30% versus 12%, $v = 2.68$) and Caucasian students comprised a significantly larger percentage of the non-first-generation students (84% versus 53%, $v = 1.43$) when compared using chi-square contingency table tests. This finding confirms the same trends as national reports that the first-generation population is a majority of students from Latino origins [41], [42].

A group comparison, using Welch's t-test, was conducted to find differences in academic performance of first-generation and non-first-generation students prior to college using an academic performance index, which is a scaled measure from 0 to 1 of students' prior high school course taking, level of course, and standardized tests scores [39], [43]. Non-first-generation students had a significantly higher academic performance average (55%) than first-generation students with an effect size of $d = 1.87$ ($p < 0.001$). This data set demonstrates the lack of academic preparation first-generation college students have received, which is consistent with previous research findings reporting lower academic achievement when compared to non-first-generation students [14], [17], [18]. This difference in students' academic performance begs the question of whether instructors and administrators need to

focus more on supporting this population before the transition from high school to college. As well, research indicates students come from low socioeconomic status and are more likely to be from underrepresented groups. When asked if English was the primary language spoken at home, the data also revealed first-generation students were less likely to solely speak English at home ($p < 0.001$) with an effect size of $v = 2.07$.

Students were asked to rate the importance of the following outcome expectations for their future career satisfaction anchored from 0 ("not at all important") to 4 ("very important" – see Table II). First-generation students demonstrated significantly higher interest than their peers in "applying math and science" in their future career, as well as interest of "developing new knowledge and skills." First-generation students also reported, on average, higher interest in careers related to mathematics and engineering compared

TABLE I. FUTURE CAREER INTERESTS AND EXPECTATIONS

Statement	Average for First-Generation	Average for Non-first-generation	Significance [§]	Effect Size (d)
Outcome Expectations for Future Career (0-"Not all important"; 4-"Very important")				
Q1a: making money	3.42	3.28	***	0.68
Q1d: supervising others	2.24	2.13	**	0.17
Q1e: having job security and opportunity	3.58	3.53	*	0.10
Q1g: inventing/designing things	1.88	1.79	*	0.10
Q1h: developing new knowledge and skills	3.17	3.02	***	0.46
Q1j: having an easy job	1.98	1.76	***	0.74
Q1n: doing hands-on work	3.07	2.95	**	0.31
Q1o: applying math and science	2.10	1.96	***	0.25
Career Interest (0-"Not at all likely"; 4-"Extremely likely")				
Q26: Science Interest	2.01	2.14	**	0.30
Q27: Math Interest	1.99	1.88	*	0.14
Q3g-n: Engineering career interest	1.30	1.18	*	0.14
Q3a: Choosing a career in mathematics	1.09	0.97	*	0.17
Q3b: Choosing a career as math/science teacher	0.82	0.69	***	0.25
Q3e: Choosing a career in physics	0.74	0.64	**	0.17

[§]The level of statistical significance is coded in this column: * represents a statistical significance less than 0.05 but greater than or equal to 0.01, ** represents a statistical significance less than 0.01 but greater than or equal to 0.001, and *** represents a statistical significance less than 0.001

TABLE II. FAMILY SUPPORT OF MATH AND SCIENCE

Statement	% of First-Generation	% of Non-first-generation	Significance [§]	Effect Size (v)
Family Interest & Support (0-Not marked; 1-Marked)				
Q35Math_c: my family helped me with my schoolwork in this topic (math)	36%	49%	***	0.78
Q35Math_d: my family arranged for tutoring in this topic (math)	20%	26%	***	0.18
Q35Math_e: this topic (math) was a series of courses that I had to pass	50%	55%	**	0.12
Q35Math_f: this topic (math) was not a family interest	38%	33%	***	0.16
Q35Sci_c: my family helped me with my schoolwork in this topic (science)	20%	32%	***	0.90
Q35Sci_d: my family arranged for tutoring in this topic (science)	10%	12%	*	0.06
Q35Sci_e: this topic (science) was a series of courses that I had to pass	46%	50%	*	0.07
Q35Sci_f: this topic (science) was not a family interest	43%	34%	***	0.38

[§]The level of statistical significance is coded in this column: * represents a statistical significance less than 0.05 but greater than or equal to 0.01, ** represents a statistical significance less than 0.01 but greater than or equal to 0.001, and *** represents a statistical significance less than 0.001

to a higher science interest for non-first-generation college students.

Contrary to some previous literature indicating that fewer Latino and African American students were interested in mathematics careers [23], these results offer encouragement for finding ways to recruit more and diverse students in engineering. But, they also highlight potential challenges for first-generation students, their instructors, and administration in supporting these students academically in engineering programs. While recruitment strategies based on these attitudes and interests offer opportunities to persuade first-generation students to choose engineering in college, specific strategies to help these students navigate their engineering education and be successful in their programs are needed. We must not only recruit talented students with diverse backgrounds into engineering, but also promote their success and retain them in engineering careers. To maintain America's global competitiveness, we need innovative engineers capable of solving large, complex, global problems [44], [45]. These much needed future engineers will have to come from new sources of talent, including the growing population of first-generation students in higher education. There is a significant need for not just more engineers [46], [47], but a more diverse workforce of engineers which can lead to greater innovation [6].

Research studies have also suggested that STEM-interested students with low socioeconomic status choose engineering more often than science [29], [48]. In one study, students with lower socioeconomic status were also more likely to have taken Calculus in high school and had, on average, higher SAT math scores [48]. These students may focus on mathematics because they were encouraged by their school's guidance counselors who recommend a solid career in engineering for students talented in STEM [48]. This option may be more often prescribed because students with a degree in engineering can regularly earn more than their peers in entry-level positions with only a bachelor's degree. Often, careers in science or mathematics require additional education for graduates to be successful.

First-generation students reported a higher interest in "having an easy job," than non-first-generation students. Since first-generation students in this study reported demonstrating a significantly higher interest in applying math and science to their future career, we initially questioned first-generation students' understanding of the mathematics and engineering fields. While this may be one reason for both the desire to apply math and science and have an easy job were reported by these students, other explanations exist. These students may have a different perception about the concept of "having an easy job" as being less physically labor intensive. For many first-generation students, their parents are manual laborers or agricultural workers. Having "an easy job" may equate to working in an air-conditioned building, making higher amounts of money, and using their intellect and education as the basis for their employment. Future qualitative work can explore these student perceptions about career expectations. . While studies suggest that students with at least one engineering parent, have greater chances of choosing an engineering major [26], [49]–[51], first-generation students who do not have parents that are in the engineering field, may be persuaded to pursue careers that offer significant economic capital and require higher academic training than

the ones their parents possess. First-generation students may find a connection between engineering and a manual job their parent may hold. For example, in some of our previous work, one first-generation student spoke about his parent's job as the reason he wanted to enter the military and major in electrical engineering. This student's father was a veteran, but worked in appliance repairs. The student made the connection between his father's job and an engineering discipline so that he could "following in his father's footsteps" while pursuing an advanced degree [49].

Additionally, engineering students with lower socioeconomic status are less likely to be encouraged by their science teachers than their peers [48]. On average, non-first-generation students reported having a greater interest in science with an effect size of $d = 0.30$ ($p < 0.01$) than first-generation students. A study claims that "well-rounded" students, those who typically have a higher socioeconomic status, tend to have greater family encouragement towards science [48], our findings also validate this claim.

Our analysis suggests that first-generation students show a slightly greater interest in "having job security and opportunity" ($p < 0.05$). This finding may be consistent with their higher interest in careers in engineering and math. One study reported that students may be more likely to persist towards earning an engineering degree, regardless of any "negative views about certain aspects of engineering education," if they strongly believe an engineering degree will improve career security [26, p. 366].

Chi-square tests were conducted to analyze group differences in family interest in and support of science and mathematics (see Table II). Although first-generation students had high levels of interest in mathematics and mathematics related fields, these students reported lower levels of family support in mathematics. The lack of support in math and science, for first-generation students, may also account for the highly significant difference in reporting that these topics were "not a family interest." Having non-college educated parents equates to lacking social and/or cultural capital, which can undermined access to resources (i.e. math/science tutors) given to first-generation students. At the same time, this lack can lead to less informed decisions about the need to excel in the mathematics and science fields [52]. Research has demonstrated that parental beliefs and expectations can promote academic achievement in mathematics for students [23], [53]. A prior study reported that students whose parents met with mathematics teachers, counselors or attended training workshops on how to support student's mathematics skills made greater gains in mathematics than those who did not [53]. This kind of parental involvement in students' academics may be a challenge for first-generation students with parents that primarily speak a language other than English in the home. Students may be experiencing a difficult time translating mathematics terminologies to their parents, thus making it more challenging for the parents to provide support. Layered on top of the complexity of non-English speaking families are different cultural understandings the role of school in students' lives and how parents interact with this institution [54]. For some immigrant families, parents may not expect to have a lot of interaction with the teacher because that is not a common practice in their home country. The difficulty is often not only linguistic (schools regularly employ translators) but can also include working conditions (e.g.

multiple jobs) which do not allow parents to participate as readily in school activities. As well, some parents also have little schooling themselves, which creates a disconnect in understanding the role teachers in the American school system play in their children's lives. Some parents were even said to be "sensitive about the issue and aware of their own limitations in the eyes of their children" [54, p. 151]. However, this ethnographic study points out that life circumstances had prohibited these immigrant parents from receiving a formal education rather than explicit decisions not to pursue additional education opportunities [54]. Additionally, parents might not be aware of alternative ways of helping their student, such as tutoring services or online resources, to name a few. Parents may also be working long hours or have work schedules that conflict with their students' homework time. So, there are complex dynamics at play that can vary significantly and require different types of interventions. Efforts to support this population will require educators to actively engage with these students, as well as provide resources for parents to become involved in their student's academics.

The reported lack of family support towards math and science may hinder first-generation students' perceptions of themselves as math and science people. One of the most important subconstructs of identity theory is feeling recognized by others as the type of person who can fulfill a particular role (e.g. science person, math person, engineer, etc.). We found no significant differences in students' self-beliefs of performance/competence in math and science or feeling recognized by others in those areas. While differences in interest were found, with higher interest in math for first-generation students and higher interest in science for non-first-generation students, interest is only one subconstruct of identity. Other work has shown that believing that other see them as a "math person" or "science person" (e.g. recognition) is the most important factor for identity development [24], [25]. In order to begin to understand first-generation student's math identity, further research is required to uncover how this math interest is developed and who, if anyone, recognizes students.

These results are, overall, consistent with findings from several previous qualitative studies on first-generation students. However, these results offer insight into how students see themselves as math and science people (identity) and how they differed in expectations for career from their peers. First-generation students are similar in many ways to their peers. While non-significant results were not reported in this study, other identity subconstructs in math and science recognition and performance/competence beliefs were not any different between the two groups compared.

In utilizing a cross-sectional study design, the data gathered have some strengths: large statistical power, national representativeness in the sample, and the ability to test hypotheses surrounding events that were introduced to students naturally rather than through an intervention. This study design also has certain weaknesses, notably including the inability to draw causal conclusions. Rather, results are correlational in nature. The results do indicate substantial correlations between student responses and students' choice of major, but further work is necessary to indicate a causal direction to these relationships. For example, first-generation students may be interested in STEM-related careers because they see it as a way to "apply math and science" as an

outcome expectation, or they may want to "apply math and science" because they have chosen a STEM-related career that does so. The direction of the effect cannot be determined from the data collected in this study.

VI. CONCLUSION

These results show significant differences in first-generation students' career outcome expectations, interest in math and science, career interests, and family backgrounds as compared to their peers. These differences have some implications for high school guidance counselors, college instructors, and engineering education researchers. When advising students for entry into college, ensuring that first-generation students have an understanding of the expectations and types of careers that they could possibly pursue in engineering could improve the match between students' interests and career outcome expectations. This approach could also improve retention of these talented and diverse students within engineering programs. In designing curricula or pedagogy, mapping how engineering meets desired outcome expectations (inventing/designing things through the engineering design process, developing new knowledge and skills, and doing hands on work in classroom environments through CAD drawing, prototyping, gathering data, etc.) could improve students' desires to continue in engineering. This work also highlights the needs for educators and schools to partner with first-generation students' parents to provide the support and resources that these families need. Finally, this research highlights areas of research in how first-generation students are prepared to enter college, how they choose engineering, and what factors can help support identity development in this group of students. Our future work will begin to explore these areas through mixed methods research.

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Effects of Pre-College Engineering Participation on First-Year Engineering Outcomes

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Abstract— With the increased acceptance and inclusion of engineering as an area of study at the K-12 and the proliferation of outreach activities intended to increase students' interest in pursuing degrees and careers in engineering, first-year engineering students are increasingly arriving in university engineering programs with significant prior exposure to engineering content and practices. In this study, using a combination of a survey and follow-up transcript analysis, we explored the relationship between students' participation in pre-college engineering activities and their academic performance in their first year of studying engineering at a large research university. We found no significant relationships between either the type of pre-college engineering activity or the level of participation and students' grades in their first-year engineering classes. We did identify several trends in the data that suggest other areas of study, as well as changes to the data we request from students regarding their pre-college experiences.

Keywords—pre-college engineering, first-year engineering, K-12, persistence

I. INTRODUCTION

Pre-college engineering is growing. This growth is evident in the proliferation of pre-college engineering programs and activities, the inclusion of engineering knowledge and practices in state and national educational standards, and a growing acceptance of engineering as part of the K-12 curriculum. Popular programs such as the Project Lead The Way curriculum and FIRST Robotics competitions attract large numbers of students each year. Engineering is featured prominently in the *Next Generation Science Standards* [1], which guide the development of state science standards that in turn influence what students are expected to learn in the K-12 classroom. Engineering is already included in the educational standards of many states, although the implementation of engineering and level of integration in the K-12 curriculum varies significantly between states [2], [3]. As the acceptance of pre-college engineering programs continue to grow, increasing numbers of young people will be exposed to engineering ideas and practices.

The pre-college study of engineering presents numerous benefits. These include increased awareness of engineering and the work of engineers, a valuable context for the promotion and growth of mathematics and scientific knowledge and applications, the development of engineering habits of mind

and thinking modalities that can help solve problems encountered in everyday life, increased technological literacy, and interest in pursuing engineering as a career [4]. Although limited in their ability to establish causal relationships, many studies have shown that exposure to pre-college engineering activities in formal and informal educational settings can influence students' decisions to pursue a degree and career in engineering [5]. However, relatively little is known about the relationship between pre-college exposure and students' subsequent academic performance in an engineering degree program. The present study seeks to address this gap and explore the connection between pre-college engineering programs and students' first-year of studying engineering at a large public research university.

II. BACKGROUND

Students who have participated in pre-college engineering programs tend to perceive lasting benefits of participation in their university engineering studies. These perceived benefits include increased technical knowledge and abilities, increased comfort with engineering design, and improved professional skills such as the ability to work on a team or communicate technical ideas [6], [7].

Prior quantitative research on the effects of pre-college engineering is limited, and tends to focus on either Project Lead The Way (PLTW) or FIRST Robotics (FIRST), the two largest pre-college engineering programs in the country. PLTW is a series of elementary, middle and high school classes, with a variety of courses focused on different engineering disciplines available at the high school level. FIRST Robotics is a series of robotics design and build competitions, with different events targeted at elementary, middle, and high school programs and generally implemented as an extra-curricular activity.

With over 6,500 schools in all 50 states offering one or more of its courses, PLTW is the largest provider of pre-college engineering curricula in the United States [8]. Research on the effects of participation in PLTW courses are mixed, with most studies showing a positive relationship between participation in the program and students' decisions to pursue further study in STEM fields and increased achievement in their chosen degree programs compared to students that have not participated [9]. A large study utilizing propensity score

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matching to compare students that have participated in PLTW to students who have not found that the PLTW students scored higher on statewide mathematics assessments, were more likely to be college-ready, and more likely to pursue higher education [10]. Another large study found that PLTW participants were more likely to enroll in STEM degree programs, but did not measure students' performance in those programs. Studies that have looked at persistence of PLTW students have found no significant difference in persistence [11]. Overall, existing research on PLTW suggests positive effects on high school performance, but do not establish a strong relationship between participation and college performance [5].

Studies of FIRST Robotics are more limited, and show a high rate of interest in and tendency to pursue engineering degrees, but with little information on students' performance or persistence in their chosen degree programs. Evaluations of the outcomes of participation in FIRST Robotics competitions [12]–[14] found that students were more likely to pursue degrees and continue on to careers in STEM fields than students who had not participated in the program. Other research has shown that participants in FIRST robotics teams who were involved with specific aspects of the competition such as design, building, or documentation aspects of the competition were more likely to pursue STEM majors than team members who had not participated in those aspects of the competition [15]. A small sample of FIRST alumni who went on to serve as mentors for FIRST robotics teams attributed numerous benefits to having participated in the program such as increased technical skills and competence and knowing how to work on teams [7]. To summarize, while several studies have shown students participating in FIRST programs were more likely to pursue further study in engineering or other STEM fields, relatively little is known about how the students fared in their degree programs or if a relationship exists between participation and success in undergraduate engineering.

Other related studies connect pre-college engineering experiences to positive outcomes for students studying engineering. Participation in technology or engineering classes or interest in an engineering-related hobby such as computer programming or robotics can have a positive effect on university engineering students' self-efficacy, which may lead to increased achievement [16]. Engineering-focused high schools can also increase students' self-efficacy and interest in pursuing further study in engineering [17]. However, none of these studies explore differences in grades between pre-college engineering participants and non-participants.

Given the lack of research on university engineering program success and its relationship to pre-college engineering participation, this study seeks to answer the following research questions: 1) Is there a relationship between participation in different types of pre-college engineering programs (formal classes, extracurricular activities, enrichment programs, etc.) and students' academic achievement in their first-year of engineering studies? 2) Do students who have participated in a greater number of pre-college engineering activities have higher academic achievement in their first year of engineering studies?

III. METHOD

To explore these questions we developed a survey [18] and administered it to students in four sections of the First-Year engineering course at Purdue University. At the same time, we obtained consent from a portion of the students completing the survey to access their academic records to explore the connection between pre-college engineering participation and students' grades in the two classes that comprise the first-year engineering program, along with their grades in their first two calculus classes. The original survey link was sent to 470 students, with 411 students completing the survey. Of those respondents, 301 were domestic students, and of those students 230 consented to allowing access to their academic records. We administered the survey in Fall of 2013, and in Fall of 2014 retrieved the academic records of the students and connected this information to their original survey responses.

In this study, we examined the relationship between pre-college engineering participation and four courses in the first-year engineering sequence. Engineering 1 is taught in sections of 120 students, with students working in consistent teams of 4 students through the semester studying engineering design, analysis, ethics, diversity, and developing professional skills. Engineering 2 continues the study of design via a curriculum organized around learning MATLAB. The Calculus 1 and 2 courses are taught through the mathematics department, and have curricula consistent with the offerings of these courses at most universities.

To analyze the data, we conducted independent samples T-tests using SPSS to compare differences in mean grades in the aforementioned engineering and calculus courses. We conducted two sets of analyses. The first focused on exploring differences between students who had participated in various types of pre-college engineering programs compared to students that had not participated in those programs. The types of programs we compared were classes in elementary, middle, and high school, extracurricular activities, summer camps, university-sponsored pre-college engineering programs, and an "Other" category for students who had experiences that they felt were connected to engineering but did not fit in any of the provided categories. The second analysis also used independent samples T-tests to compare the mean grades of students differentiated by the number of pre-college engineering activities that they reported.

IV. RESULTS

Tables 1 and 2 show demographic information for the participants in this study, and suggest that the sample is representative of the overall demographics of First-Year Engineering at the University.

TABLE 1: GENDER OF DOMESTIC RESPONDENTS (N=226)

Gender	Count	Percent
Female	58	26%
Male	168	74%

TABLE 2: RACE/ETHNICITY OF DOMESTIC RESPONDENTS (N=225)

Race	Count	Percent	Percent of First-Year Engineering Students
White	177	79%	80%
Asian	28	12%	7%
Hispanic/Latino	13	6%	5%
Multiple/Other	4	2%	Not tracked
Black/African American	3	1%	3%

Table 3 shows the number of students interested in the various engineering disciplines available at the University, sorted by the average number of activities reported by the respondents. Significant variation exists in the number of reported pre-college engineering activities, ranging from around three activities for students interested in electrical or computer engineering to 1 activity for students indicating interest in Agricultural, Biological, Biomedical, or Industrial Engineering.

TABLE 3: MAJOR AND AVERAGE NUMBER OF PRE-COLLEGE ENGINEERING ACTIVITIES (N=226)

Major (number of respondents)	Average number of activities
Computer Engineering (15)	3.1
Electrical Engineering (14)	2.9
Interdisciplinary / Multidisciplinary Engineering (5)	2.4
Mechanical Engineering (64)	2.3
Nuclear Engineering (8)	2.1
Aeronautical and Astronautical Engineering (31)	2.0
Chemical Engineering (26)	1.9
Undecided (7)	1.7

TABLE 4: DIFFERENCES IN MEAN FIRST-YEAR COURSE GRADES BY CONTEXT OF PRE-COLLEGE ENGINEERING PARTICIPATION

Course Mean Grades and Sample Sizes						
Context		%	ENGR 1	ENGR 2	Math 1	Math 2
Elementary School	Y	4.4	3.50 (10)	3.00 (10)	3.00 (9)	2.30 (10)
	N	95.6	3.67 (219)	3.11 (200)	2.78 (199)	2.57 (198)
Middle School	Y	18.3	3.62 (42)	3.15 (40)	2.92 (37)	2.50 (41)
	N	81.7	3.67 (187)	3.09 (170)	2.76 (171)	2.57 (167)
High School	Y	66.8	3.65 (153)	3.14 (142)	2.84 (141)	2.57 (139)
	N	33.2	3.67 (76)	3.03 (68)	2.66 (67)	2.55 (69)
Extracurricular	Y	32.3	3.57 (74)	3.04 (69)	2.79 (69)	2.47 (69)
	N	67.7	3.70 (155)	3.13 (141)	2.78 (139)	2.60 (139)
Summer Camp	Y	17.5	3.55 (40)	3.23 (35)	2.59 (38)	2.60 (36)
	N	82.5	3.68 (189)	3.08 (175)	2.83 (170)	2.55 (172)
University Program	Y	14.8	3.65 (34)	3.07 (28)	2.63 (29)	2.53 (29)
	N	85.2	3.66 (195)	3.11 (182)	2.81 (179)	2.57 (179)
Other	Y	16.6	3.58 (38)	3.14 (35)	2.63 (31)	2.74 (36)
	N	83.4	3.68 (191)	3.10 (175)	2.81 (177)	2.52 (172)

Mean (Sample Size) no differences significant

TABLE 5: DIFFERENCES IN MEAN FIRST-YEAR COURSE GRADES BY AMOUNT OF PRE-COLLEGE ENGINEERING PARTICIPATION

Course Mean Grades and Sample Sizes					
Participation		ENGR 1	ENGR 2	Math 1	Math 2
1 or more activities	Y	3.65 (178)	3.10 (163)	2.79 (160)	2.55 (164)
	N	3.69 (51)	3.11 (47)	2.76 (48)	2.60 (44)
2 or more activities	Y	3.60 (118)	3.16 (108)	2.82 (106)	2.57 (108)
	N	3.72 (111)	3.05 (102)	2.75 (102)	2.55 (100)
3 or more activities	Y	3.61 (70)	3.22 (65)	2.70 (63)	2.50 (66)
	N	3.68 (159)	3.06 (145)	2.82 (145)	2.59 (142)
4 or more activities	Y	3.59 (39)	3.25 (36)	2.63 (34)	2.38 (38)
	N	3.67 (190)	3.07 (174)	2.82 (174)	2.60 (170)

Mean (Sample Size) no differences significant

Civil Engineering (13)	1.7
Environmental and Ecological Engineering (5)	1.6
Materials Engineering (7)	1.6
Agricultural Engineering (4)	1.0
Biological and Food Process Engineering (2)	1.0
Biomedical Engineering (13)	1.0
Industrial Engineering (12)	0.8

Table 4 shows comparisons of the mean final course grades in the respondents' first-year engineering courses and first two semesters of calculus, separated by the context of pre-college engineering participation. Significant variation exists in the level of participation in each of the contexts, ranging from 66.8% of respondents indicating that had done engineering activities in a high school class to only 4.4% of the sample indicating exposure to engineering in an elementary school class. Note that many of the respondents will be included in multiple comparisons, as they have had exposure to engineering in multiple contexts. All of the mean course grades were comparable between each of the engineering contexts, and this combined with the relatively small sample sizes for several of the contexts led to no significant differences in the means as measured using an independent samples T-test.

Table 5 shows comparisons of the mean final course grades in the respondents' first-year engineering courses and first two semesters of calculus, separated by number of pre-college engineering activities. Similar to the engineering contexts, we did not find any significant differences in the means between the groups using an independent samples T-test.

In addition to the results shown in the tables, we conducted a one-way between groups analysis of variance to explore the effect of pre-college engineering participation on course outcomes in the first two engineering courses and math courses included in the first-year engineering curriculum. Participants were divided into groups according to their level of participation (Group 0: 0 activities; Group 1: 1 activity; Group 2: 2 activities; Group 3: 3 activities; Group 4: 4 or more activities). We did not find any statistically significant differences in any of the final course grades for any of these groups.

V. DISCUSSION

Although the differences are not significant, students with increased pre-college engineering participation tended to have higher grades in Engineering 2. This may be indicative of the relationship between prior programming experience and increased performance in this programming-focused class, and suggests that future surveys should more strongly focus on identifying the content of the students' pre-college engineering experiences, as this may have a more measurable effect on course outcomes.

Students who participated in significant numbers of pre-college engineering activities also tended to have lower grades in their math course, although again these results are not statistically significant. This may suggest that although these students were highly engaged in their engineering activities, they may have been less focused on their studies in general. This is not necessarily bad, as it suggests that pre-college engineering activities may have some success in recruiting students into engineering who might otherwise be deterred by lower grades in their math and science courses. This suggests a need for a future study that includes more information on students' pre-college academic performance to explore this hypothesis.

VI. CONCLUSION

The results of this study suggest that minimal relationships exist between students' participation in various types of pre-college engineering programs and activities, and their academic performance in their first-year of engineering studies. The results also suggest that we need to make changes to the survey instrument to explore students' exposure to various types of engineering content as opposed to the types of activities that they participated in.

As the students described in this paper complete their second years of study and decide to continue towards the completion of their engineering degree programs or leave engineering to pursue a different degree, we will be able to explore the relationship between pre-college engineering programs and persistence in undergraduate engineering.

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Early Identification of At-Risk Students in a Lower-Level Engineering Gatekeeper Course

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Abstract— Engineering Mechanics (Statics) is a challenging sophomore course and an essential prerequisite for many branches of engineering. Unfortunately, the Statics course often becomes a gatekeeper course for numerous engineering students. This paper focuses on the process and the tools developed for effective identification of at-risk students in the Statics course. Effective early identification of at-risk students allows for timely interventions and for the informed use of teaching resources. In this paper, the authors describe the methods employed to effectively identify at-risk student and accurately assess students' mastery of prerequisite material. Moreover, the authors describe herein the interventions employed to improve student success. It is argued that the described activities have increased and will continue to increase student engagement in learning and their persistence to pass the Statics course. Preliminary assessment results show promising accomplishments in addressing knowledge and student retention and engagement.

I. INTRODUCTION

Investigations of students' academic preparedness [1]–[2], study practices [3], and engagement with their own learning process have been useful in identifying students at risk. At-risk student in this paper is used to describe students who are considered to have a higher probability of failing specific lower level STEM gatekeeper courses. Drawing from the literature, the identification of at-risk students in lower-level engineering courses in this project is based on assessment of student prerequisite knowledge retention, student past performance, and student self-efficacy. This section describes some of the most common ways to identify students at risk and the importance of early educational interventions.

A. Early Identification of At-Risk Students Based on Prerequisite Knowledge Retention

STEM curricula are structured in such a way that students are required to satisfactorily complete the prerequisite courses before progressing in their degree program. It has been well established that the assessment of students' prior knowledge and understanding of prerequisite concepts is an effective tool to establish the appropriate level at which to begin instruction in a specific course [4]. In many cases, STEM programs rely only on students passing the prerequisite courses for admission into the advanced courses. However, issues with

knowledge retention of prerequisite material are commonly observed and reported in the literature [5]. Thus, diagnostic testing has become more widespread in colleges and universities [6].

Identification of at-risk students based on prerequisite knowledge is especially relevant for lower-level engineering students. In fact, Efimba et al. [7] concluded that prerequisite knowledge is a more important factor in determining student's success in a sophomore engineering course for underclassmen than for upperclassmen (i.e. the achievement of underclassmen was directly related to prerequisite knowledge). The study suggested that upperclassmen are more likely to work to compensate for deficiencies in prerequisite knowledge and that underclassmen are more likely to need additional measures to enhance their achievement. Stated by Mills et al. [8], a newly implemented Civil Engineering curriculum was mainly focused on project-based and problem-based learning. The authors show the effectiveness of the new curriculum to be the best way to satisfy industry needs, without sacrificing knowledge of engineering fundamentals. They concluded that the engineering industry and academics are more familiar with concepts of projects in professional practices than with concepts of problem-based learning.

B. Early Identification of At-Risk Based on Past Performance

Even though knowledge retention may be a valid concern, a student's past performance record provides an early indication of whether she/he is at-risk. For example, Levin and Wyckoff [8] determined that an effective freshman year model to identify the best predictors of retention is using grades in Physics I, Calculus I and Chemistry I; and in a sophomore year model, the best predictors of retention were grades in Calculus II, Physics I and Physics II. Zhang [10] found out that high school GPA and math SAT scores were positively correlated with engineering graduation rates for all universities for which data were available. Interestingly, verbal SAT scores correlated negatively with odds of graduation, the consistency of this outcome for seven out of eight universities makes this observation even more notable. Several other studies [11]–[16] have identified at-risk students in engineering programs based on the students' high school

GPA, SAT and ACT scores, college GPA, and passing grades in the freshman engineering courses, among other predictors.

Some of the previous studies, however, usually presume students are completing prerequisite coursework at the institution and do not necessarily consider the impact should they be transferred from early-college programs or two-year institutions. Preliminary work was previously conducted by the authors to determine if there were definitive correlations between success in Statics and performance in prerequisite courses. The results were highly inconsistent. This was attributed to the fact that at The University of Texas-Pan American (UTPA) students can transfer in or receive credit for Calculus I and Physics I – the prerequisites for Statics – through various means that introduce high variance in the results. Some of the options include the credit for high scores on either the Advanced Placement (AP) or International Baccalaureate (IB) Exams. Other means are far less consistent, however. Students can transfer credit from the regional two-year institutions, which have dual enrollment agreements with school districts to offer early-college programs directly at the high schools sometimes employing existing high school educators credentialed to offer courses for college credit. Assessments and curriculum for these courses are not standardized. Though UTPA does collect data regarding whether course credit was attained by exam or transfer credit, with regards to the transfer credit in particular, it cannot parse where or how the course was administered.

Some studies have suggested combining student past performance with retention of prerequisite knowledge and/or ongoing performance in the course to identify at-risk students. For example, Huang [18] indicated that in engineering dynamics, a sophomore-level course, many students perform poorly because they lack solid mathematical skills and good understanding of concepts and principles. The most useful predictor variables in dynamics were the cumulative GPA, three prerequisite course grades, and the first exam score in the course, allowing sufficient time for the instructor to implement educational interventions during the rest of the course [18]. Furthermore, to better assess student prior domain knowledge, a pretest prior to the start of the dynamics course and homework grades were suggested to be included in future studies as predictor variables [18]. Other programs have significantly invested in technology to track students beyond the traditional online homework system. For example, Steif and Dollar [19] developed a learning dashboard (LD) computer system in Statics as part of the Carnegie Mellon Open Learning Initiative to allow instructors to track on-line learning activities and to estimate needed skills and concepts for students to master Statics. Another study has been performed to identify how organization of a student's solution to problems in Statics relates to correctness of the work and can be used as indicator of at-risk students [20], [21].

C. Early Identification of At-Risk Based on Self-Efficacy

The majority of the reviewed studies focused on early identification of at-risk students based on prerequisite knowledge and/or past student performance; however, there is recognition in the literature of other missing factors.

Besterfield-Sacre et al. [22] mentioned that students' attitudes are important in the perception students have about engineering and their self-assessed abilities; however, educators have focused more on assessing the mastery of content knowledge and skills. The perception of engineering, motivation, confidence, competency, retention, and persistence is affected by these attitudes [22]. Many students need a reality check to conceptualize their own responsibility and what is required of them to obtain an engineering degree; some students lack certain skills and level of maturity (e.g. time management, how to talk to professors and ask for help) that instructors might take for granted [22]–[24].

Albert Bandura [24], [26] defines self-efficacy as “people's beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives.” Increasing a person's self-efficacy for a specific challenge will have a direct impact on achievement [27]. Also, Denzine [27] mentioned that engineering education researchers are focusing on the topic of achievement motivation. Developing motivated, self-directed, or self-regulated, students allows for self-regulatory learning with the benefit being students self-monitor thoughts, feelings, and behavior to achieve the goal. Zajacova [28] conducted a study on first-semester freshman students to demonstrate the relationship between academic self-efficacy and stress and its effects on students' grades and persistence; suggesting that that self-efficacy is a better predictor of success than stress. Instructors and mentors can help students modify their learning strategies to lead to college and lifelong positive benefits [28]. It is suggested that instructors must consider providing frequent feedback to students to develop self-regulating behavior and help them to understand their learning process. Self-efficacy develops with experience and time and it is not a fixed personality characteristic. College students should have a learning goal orientation, which is a malleable state, rather than a performance goal orientation, in order to have positive effects on learning, motivation and achievement [24].

The identification of at-risk students based on past performance has been combined and/or compared with assessment of different aspects of student self-efficacy. For example, the Pittsburgh Freshman Engineering Attitudes Survey (PFEAS) has been used to measure incoming freshmen attitudes during registration and SAT score was used to measure initial preparedness [28]. The PFEAS was used to measure students' attitudes toward an engineering career and their self-assessment about confidence in study habits and communications skills. The most important predictor factors that were identified included preparation (SAT), academic ability (high school rank), and confidence in study habits (PFEAS) [28]. Allen et al. [30] analyzed the effects of academic performance, motivation and social behavior on the third-year retention, transfer and dropout from college. If the reason for students to drop out is clarified and studied, they believe that the intervention programs and supplemental instruction can serve students better.

D. Importance of Early Educational Interventions

Successful early interventions increase student learning and decrease student attrition and frustration. In fact, the literature suggests that by improving the performance during the first term of students at risk, the chance of successful completion of the engineering programs increases [31]. For example, the provision of supplemental instruction for at-risk students has been found to be effective in improving the grades of such students [32]. However, the success of some teaching/learning methods, such as problem-based learning, depends on student's self-efficacy and team collaboration [33]. Blat [34] indicated that supplemental instruction (SI) focuses on high-risk courses ($> 30\%$ students failing) not on high-risk students, and that SI is not a remedial program. SI is recommended to promote and facilitate collaborative learning, with specially qualified and trained peer leads that do not work problems for students but teach students how to learn.

There is evidence that early educational interventions are especially important for lower-level students. For example, Knight [35] determined that engineering students who take a first-year engineering projects course are significantly more likely to be retained at the third, fifth, and seventh semesters than their peers who do not take the course. This is accredited to the impact of active hands-on pedagogy, developing student learning communities, early experiences of the human side of engineering, self-directed acquisition of knowledge, mentoring, and the success orientation of the course. Thompson mentioned that many newcomer students simply do not know how to look at themselves as learners, think about how they learn, set goals, actively apply strategies, and monitor themselves as they make progress [36]. The degree of self-regulation required at the college level is frequently not what students are used to. Instructors must do more than prepare lectures, they must address students' processing skills.

There is evidence that the process of selection, implementation, and fine-tuning of early educational interventions is not trivial. For example, a study determined the effectiveness of 4-hour as opposed to 3-hour version of a traditional Statics course [37]. The additional hour involved a mandatory problem session. After controlling for factors such as SAT Math scores, Calculus I grades, and Chemistry I grades, to identify at-risk students, it was found that the performance difference on the final exam between those who took the 3- and 4-hour sections of the course was statistically insignificant implying that the additional hour was not effective. Another study [38] demonstrated the effect of small group learning on success of undergraduate students in science, mathematics, engineering and technology courses.

E. Statics: Lower-Level Engineering Gatekeeper

Fig. 1 indicates the main topics that are associated with student learning outcomes in the Statics course in our department, shown in the order covered in class. One of the main difficulties students face in Statics is retention and integration of knowledge in all these topics to develop adaptive expertise skills to apply the learned concepts and

procedures to solve a variety of engineering mechanics problems.

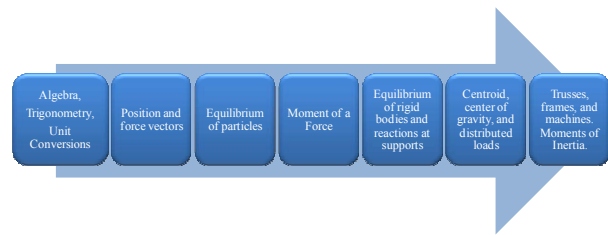


Fig. 1. Main topics studies in Statics.

As baseline information, the passing and failing rates of students that took Statics taught by the same instructor in the regular semesters from the Fall 2006 to Spring 2011 semesters are as follows. Students that passed the course got A, B, or C grades and the average passing rate during such time was 60.7%. Students that dropped were about 14.3%; therefore, about 25% of students got D or F grades. With a different instructor, the average passing rate remained at about 60% until the Fall 2013 semester (before early educational interventions). However, the students who dropped the course increased up to $\sim 25\%$. Students drop the course due to different circumstances along the semester: deficiency in algebra and trigonometry, too much work, too many courses, missing homeworks and classes, and lack of commitment to be persistent and overcome frustrating experiences.

II. AT RISK STUDENT EARLY IDENTIFICATION

This section describes the methods selected to identify students at risk (based on prerequisite knowledge, past performance, and self-efficacy) in this study and the early interventions to be studied [Fig. 2].

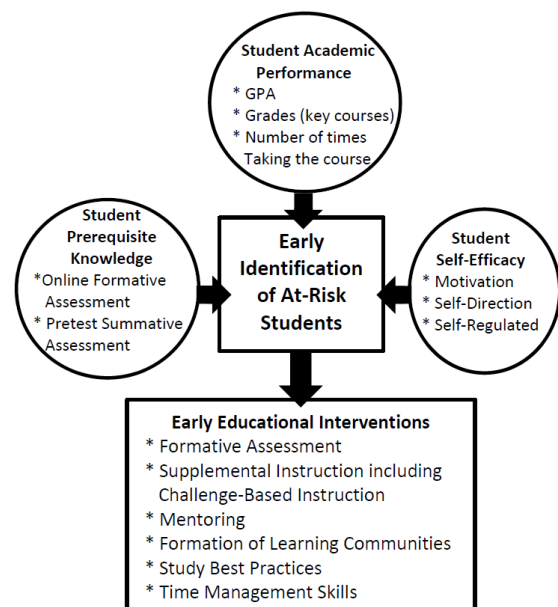


Fig. 2. Early Identification of At-Risk Students and Intervention.

The use of frequent online formative assessments is being promoted in gatekeeper courses to keep students actively learning outside of the classroom, solving problems to master the material, and abreast of their current knowledge mastery. Assessments were prepared in Statics for students to review prerequisite material at the beginning of the course. Figs. 3-4 show sample online questions, prepared with Respondus and implemented on Blackboard, about algebra, trigonometry, calculus, and physics. The online assessments provide students with quick feedback to test and improve their knowledge in prerequisite topics as well as in new concepts studied in the course. An important goal of these online assessments is to encourage students to study out of the class time and apply the concepts they are learning to reinforce knowledge retention and at the same time to emphasize the importance of such knowledge. It is estimated that the perception and the interest of the students about what they are learning improves through these online assessments. In fact, students have shown increased engagement in learning and perseverance to pass the class because the majority try multiple attempts in order to improve the online assessment grades and to practice more problems. Online assessments are graded automatically and provide immediate feedback to the students. In each question, students get random values from a range previously determined by the instructor; therefore, it is usually the case that different students do not get the same values. Also, not all students get exactly the same questions. However, preparing online assessments is a complex task that requires developing, testing, and implementing the assessments, ideally involving relevant real-life applications to make a positive impact on the students' understanding of concepts.

Fig. 4 shows an example question used in the online assessments that are given to the students at the beginning of the semester to review prerequisite topics. Notice that this example shows the feedback students receive when answering either correct or incorrectly. As the online assessments are improved, it is expected that the feedback becomes more elaborated so that students might be directed to study specific sections of the textbook, to study information from a web page, to watch a video, or other remedial action. Reviewing these topics is an essential step at the beginning of the Statics course. Fig. 4 illustrates a question about Physics to review for the pretest in which students need to determine the horizontal and vertical components of a force vector. These online formative assessments present multiple advantages, including the randomly generated parameters that allow assigning different system conditions to each student.

One important fact that might become a drawback of online assessments in comparison to written homework assignments or in class or recitation session assessments is that the students' complete work is not revised by a grader. Therefore, the required steps in the procedure to solve online problems, such as drawing complete free body diagrams and finding the equilibrium equations are not directly being evaluated; instead, it is expected that students attend the instructor's office hours or mentoring sessions (when

available) to get help to answer any online assessment questions. In such case, it is important to allow students to perform the assignments in multiple attempts to obtain the best possible grade, to ask questions before the next attempt, and to practice solving more problems. Consequently, it is important that the students take ownership of their learning process by asking questions and being persistent to complete the online assignments.

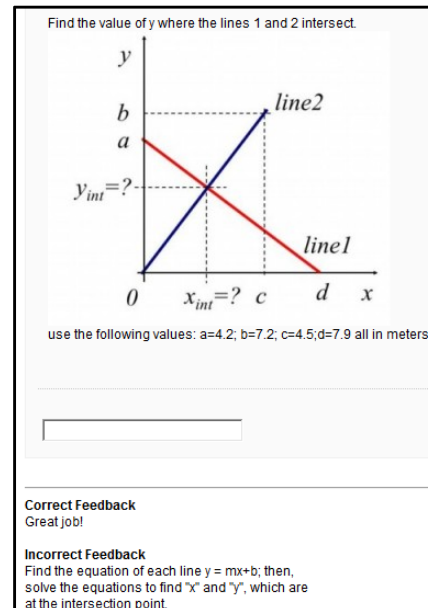


Fig. 3. Online question example to review prerequisite Trigonometry material.

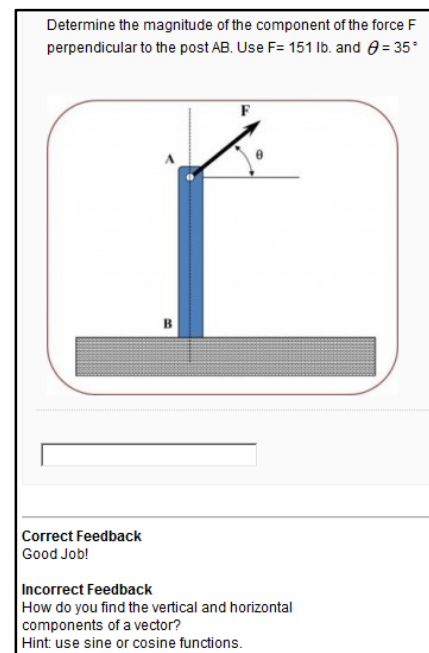


Fig. 4. Online question example to review prerequisite Physics material.

III. SAMPLE INTERVENTIONS

The first step in the intervention was to develop online assessments for students to review prerequisite material. After

that, a pretest was prepared to identify strengths and deficiencies of students at the beginning of the course. The next intervention step was to identify the best study practices to use as guidelines for students to be successful in the gatekeeper courses. Supplementary instruction in the form of mentoring sessions was also provided to help students solve homework. Online formative assessments were developed to engage and help students to persistently study to retain and integrate knowledge and apply it to solve problems throughout the semester. Another intervention in the gatekeeper courses consists of developing challenges with real world context problems to motivate students to learn the material and acquire adaptive expertise. Consequently, it is expected that by combining best study practice guidelines, online assessments, real world context challenges, and peer-led mentoring sessions, student performance and passing rates in the gatekeeper courses will be improved.

Expectations and Guidelines for Students to be engaged in the Gatekeeper Courses: In collaboration with the Center of Excellence in STEM Education at UTPA, a website is being designed to help faculty and students to achieve academic excellence. The instructors of gatekeeper courses are encouraged to make students aware of the purpose and importance of the following course materials, resources, and best student practices:

- Considerations to prepare and to explain the syllabus;
- Importance of note taking and record keeping;
- Time management tips;
- Taking full advantage of office hours;
- Solving homework and solution format;
- Benefits of attending mentoring sessions and mentors' benefits;
- Advantages and disadvantages of team work and study groups; and
- Creating and implementing challenges and promoting adaptive expertise

Identifying At-Risk Students at the Beginning of the Course: Several tools were developed and implemented to identify at-risk students at the beginning of the gatekeeper courses. It is estimated that supplementary instruction, such as mentoring, could benefit at-risk students that are willing to work hard, study, ask questions, and dedicate time to learn and master the material in the course.

As shown in Fig. 2, the specific factors that were taken into account to identify at-risk students are:

- Grades on first assignments to prepare for pre-test;
- Pre-test grades;
- GPA and performance in pre-requisite courses;
- Class repetition due to failure or drop; and
- Survey to determine motivational, socio-economic, and demographic factors.

The purposes of students preparing for the pre-test and taking the pre-test are to make them aware of the need to retain previously acquired knowledge; another purpose is to identify those students that might be at-risk at the beginning of

the courses due to insufficient mastery of prerequisite knowledge. So far, it has been determined that, when well designed, there is a correlation among the results of a pretest and the final grades in the Statics course. Hence, it is important that the instructors of gatekeeper courses develop activities to engage students to review and study prerequisite material because it could be a determinant factor in the success or failure of the students in the course. As the courses progress, most students usually assume that new concepts are not very difficult to understand because they can follow the instructor's explanation in the lectures. However, difficulties arise for some students when making decisions needed to adapt and apply the acquired knowledge to solve different or more complicated problems.

Implementation Process: In order to prepare the students for the pretest (i.e. prerequisite material evaluation), the developed online formative assessments were assigned to students the first day of classes. The pretest, which has been refined for a number of years, is usually administered during the third class of the semester (i.e. second week). Besides having questions about prerequisite material, the pretest contains questions about students' previous academic performance (e.g. GPA, grades in pre-requisite courses, number of times taking the courses) to help identify at-risk students. At the same time, students completed an online survey to determine student self-efficacy and motivation and to try to capture socio-economic and demographic factors. Based on student pretest performance (e.g. pretest grade <70) and these other factors, students at risk were identified and were asked to attend mentoring sessions led by trained upper level students to discuss and clarify any doubts about class, homework, or projects.

IV. PRELIMINARY RESULTS

The project began in Fall 2013 with development and refinement of the previously described instruments. The results in Statics in the Fall 2014 semester about the online assessment developed to review prerequisite material is presented in Table 1. It was determined that 44 out of 45 students completed the online assessment at least one time. During the first attempt, the average grade was 44; 41 students attempted to solve the assessment a second time and the average grade was about 57%; 33 students attempted to solve it a third time and the average was about 69%; 18 and 13 students attempted it for a 4th and a 5th time, respectively. The average number of attempts the students tried on the first online assessment was 2.5. This shows that the formative online assessments engage students and make them persistent to study and try to obtain better grades. The overall average, considering the final grade as the highest grade of all five possible attempts of this assessment, was 80.8%.

Table 1. Results of the first online assessment.

	Grade on HW1	Attempt #1	Attempt #2	Attempt #3	Attempt #4	Attempt #5	Attempt #6
Number of Students	44	44	41	33	18	13	5
Average grade (%)	80.8	44.0	56.9	68.8	70.5	76.9	76.0

The results showed that there is a strong correlation among the results of a pretest and the final grades in the Statics course. Previous to this study, the authors found out that the implementation of prerequisite assessment instruments without allowing students to review the material did not provide useful information about at-risk students or predicted success in the course. Therefore, it is important that the instructors of gatekeeper courses develop activities to engage students to review and study prerequisite material before assessing them in such topics. Fig. 6 shows that a student who failed the course (final grade < 70) would have scored roughly lower than a 68 on the pre-test. In other words, a score of 68 on the pretest would, on average, lead to a final grade of 70, and with 95% confidence, it is estimated that the final grade would be between 65 and 75. A similar result was obtained between the pretest and the results on the exam 1 in Statics.

Even though these preliminary results need to continue being verified in future semesters and different courses, it is expected that well-designed pre-tests and prerequisite assessments could be accurate predictors of student performance in the course. The pre-test results not only provide important information to the instructor, about the students' preparation and knowledge of prerequisite material, but they also reinforce students' understanding of the need to review and further master prerequisite material in order to be properly prepared for the new course.

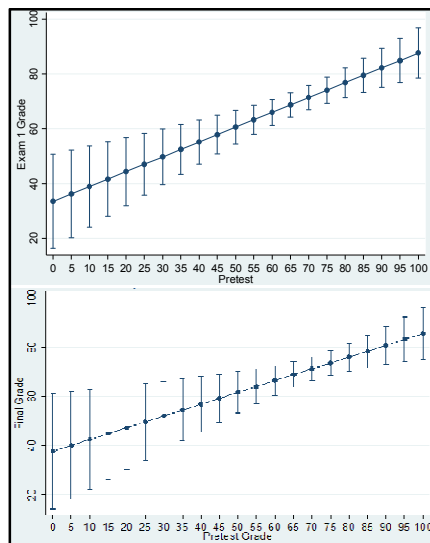


Fig. 5. Correlation between pre-test and Exam 1 (top) and final course grade (bottom) [Fall 2014]

Figs. 7 and 8 shows the correlation of the final course grade and the results in exam 1, the students' GPA, and grades in prerequisite courses (Calculus I and Physics). However, a

model was obtained after a series of diagnostic tests (e.g., normality), with no major violations of the procedure assumptions, so a basic ordinary least squares regression model was used. From the model results, the only significant predictor of final grade was the pretest. The GPA was significant originally, but, when pre-test was included as an input factor, it became no longer so ($P > |t| = 0.6$). We believe this is because a vast majority of variation in GPA outcomes is determined by non-mathematical classes (e.g. English, Sociology, Political Science, History, etc.) students encounter in the general curriculum and the fact that the GPA includes only UTPA coursework. Hence, key prerequisite courses are not included into the calculation of the GPA if credit is transferred from another institution.

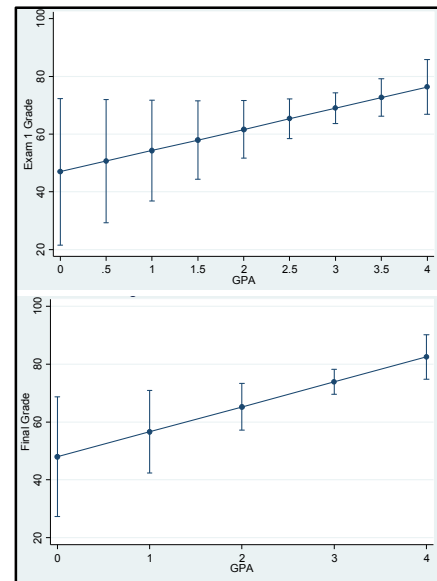


Fig. 6. Correlation between GPA and exam 1 (top) and final grade (bottom) [Fall 2014].

The pre-test was a strong predictor of final course grade, however ($P > |t| = 0.05$). The pre-test is a direct measure of math/engineering fluency so it is therefore the more reliable predictor of course outcome. With the help of the grant's evaluator, a consent form and a socioeconomic, motivational, and demographics survey, both approved by IRB, were prepared and implemented in the courses. Student self-efficacy and motivation was estimated at the beginning of the semester by an online survey performed by the Center for Survey Research at our institution. The survey inquiry students about their interest in learning engineering, getting good grades, career advantages, discoveries, enjoyment of learning, and scoring high on test and course grades. Fig. 9 shows that students that score 38/50 or less on the motivation survey are at-risk of getting a final grade in the course that is less than 60%. The data are suggesting that any student scoring a 40/50 or below on the pretest motivation scale should be flagged for intervention.

In terms of demographic factors, the instruments showed that 93% of the students were underrepresented Hispanics and that 19% were female. About 40% of the female and male

students were identified as at-risk and attended mentoring sessions. The results showed that the mentorship program has a positive effect, especially for students with GPAs greater than 2.5. Female students have a slight declining performance from pretest to final grade. Fig. 10 shows the relationship between pretest-final grade improvement (i.e. the difference between the final grade score and the pretest score) and mentorship with GPA controls during the Spring 2015. It is important to mention that a number of students who were not identified as at risk requested permission to attend the mentorship program.

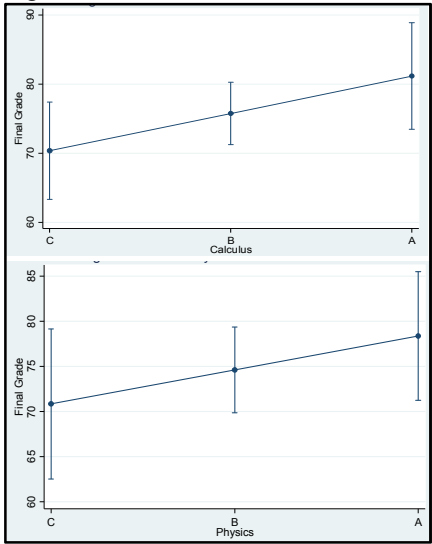


Fig. 7. Correlation between prerequisite course grades (Calculus top and Physics bottom) and Statics final grade [Fall 2014].

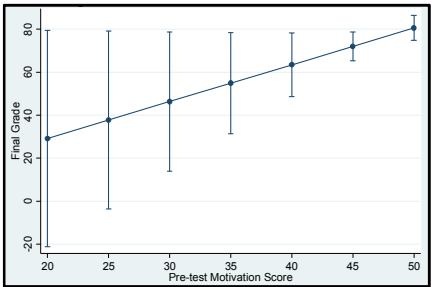


Fig. 8. Correlation between motivational survey and final grade [Fall 2014].

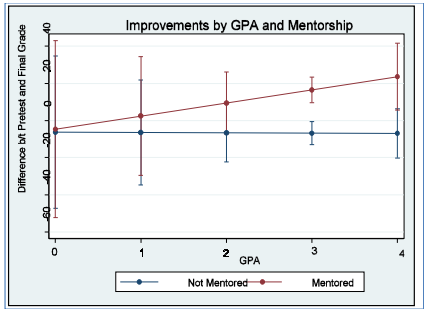


Fig. 10. Difference between Statics Pretest and final grade [Spring 2015].

Finally, the Statics course passing rate in the Spring 2014 (56 students with an online review average of 68 and a pretest average of 70), Fall 2014 (45 students with an online review

average of 80 and a pretest average of 83) and Spring 2015 (63 students with an online review of 70 and a pretest average of 70) were 75%, 71% and 61% respectively (including students who dropped the class). The authors expect that the results depend on, among other things, the number of students in the course and prior preparation as determined by the online assessments and pretest average. In the aforementioned semesters, interventions, including peer mentoring, had a significantly increase (~10%) in the number of student receiving a final grade of A or B.

V. CONCLUSIONS

This paper focused on the process and the tools developed for effective identification of at risk student in the Statics and other gatekeeper courses. In this study, early identification of at-risk students led to interventions with supplementary instruction activities, such as mentoring sessions, challenges, online assessments, attendance of office hours, and awareness of best study practices. Based on lessons learned, the semester started with a review of important prerequisite material needed to succeed in the course. A review of trigonometry, algebra, calculus and physics concepts was performed during the first lecture. Following the review, online assessments were used to provide instant feedback to students about areas of weaknesses where additional review is needed. An in-class pre-test is then implemented to assess the same prerequisite topics but with slightly different contexts to determine whether or not the students actually understood and mastered the prerequisite concepts. Identification of students at risk is then based on student prerequisite knowledge (e.g. pretest results, pretest online assessment), student past performance (e.g. GPA, the number of times taking the course, and grades in the prerequisite courses), and/or student self-efficacy. Among other things, a direct correlation was found between the results in the pretest and the student final grade in the course. The mentoring sessions were recommended to all students in the course; but, they became mandatory for at risk students.

In addition, the developed early at-risk identification system allowed the instructors to determine the preparation of the students at the beginning of the semester to tailor the instruction during the semester. It is argued that the described activities have increased and will continue to increase student engagement in learning and their persistence to pass the Statics course. Preliminary assessment results show promising accomplishments in addressing knowledge and student retention and engagement.

For at-risk students, the results of the interventions not always generate expected positive results. Some students have difficult schedules and/or poor time management skills; they do not complete the online homework, put no effort to attend office hours or mentoring sessions, and end up struggling and no passing the course. Different strategies are being implemented to motivate students. The instructors continue creating or adapting more online assessments and challenges to integrate knowledge. In each gatekeeper course, there has to be a plan for mentoring activities and training of mentors.

Future work in this project consists of completing the evaluation of results in Statics, Electrical Circuits I, Statistics, Computer Science I, Calculus I, and Chemistry I and adapting, developing, and implementing the materials required to perform the proposed interventions in the corresponding gatekeeper courses. This project is ongoing and it is in the middle of the second year of a total of five years. In the future, it will be important to complete and analyze the results of the pretest, surveys, and concept inventory required to identify at-risk students in several gatekeeper courses.

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Engineering Curriculum Readiness: Implementing an Analytical and Communication Skills Building Course for the Technical Disciplines

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Abstract— Many domestic and international students arrive at college lacking the skills needed for academic careers in engineering or engineering technology. To support academic progress and develop essential skills, TECH 101, Engineering Technology Fundamentals, was proposed, approved, and funded by the School of Engineering and Technology at a large urban public university. The course offered students the preparatory skill development needed to begin an engineering or engineering technology major. TECH 101 facilitated a completely different approach, utilizing a very rare collaboration. Course design and implementation were championed by an experienced engineering technology instructor and a uniquely qualified faculty member whose background includes both transition to college expertise as well as second language acquisition. Drawing the two diverse skill-sets together resulted in context-based activities closely integrated with hands-on technical work, as well as development of a technical vocabulary and English language skills. A small group of learners participated in the initial course offering in the fall of 2014. This Work In Progress paper will explore the unique technical and preparatory course components that promote the support of underprepared domestic and international students.

Keywords—retention, remediation, engineering education

I. INTRODUCTION

In 2005, a joint report from the National Science Foundation and the National Academy of Engineering [1] framed the priorities for improvement in academic institutions involved in engineering education. The group warned that, in order to meet the demands for engineering graduates, remedial coursework must be available and well-crafted. In addition, the report encouraged educators to incorporate engineering concepts into developmental education. However, the dearth of scholarly research associated with discipline-specific remedial educational experiences in engineering and engineering technology seems to document that few institutions heard this decade-old warning.

At some colleges and universities, especially less-selective institutions, many students arrive on campus lacking the academic and personal skills required for success in engineering or engineering technology programs. The typical support solution for these deficiencies is to require enrollment in developmental mathematics and English courses, guided by

placement tests [2]. As a result, the academic pathway toward enrollment in discipline-specific courses may be a long one. Student attrition during the remedial period may be substantial [3].

Vincent Tinto, the student retention theorist, has asserted that student access without support is not opportunity [4]. This perspective may lead educators to conclude that admitted students should receive highly engaging and academically appropriate support services that could promote growth, persistence, and achievement. Utilizing research results [5] associated with persistence factors identified in student populations in engineering technology served by urban public institutions, discipline-specific developmental coursework seemed to be appropriate approach to promote academic success. Important conclusions from the literature shaped the intervention, including personal goals centered around both degree attainment and discipline understanding, academic collaboration (as opposed to social connections), strong faculty relationships, and adaptability surrounding the student's academic role. All of these factors collectively can be generalized by a sense of belonging and a sense of purpose.

Donna Riley, in a March, 2015 *Prism* article stated, "Four-year institutions must no longer cherry-pick students able to withstand engineering's 'rigors'." [6] The prominent National Science Foundation-affiliated author strongly advocated for a "resource-rich" environment that includes substantial academic support. In addition Riley held the provocative position that "there is no situation from which one can 'never' become an engineer." Riley's stance strongly supports the notion of intertwining remedial content embedded in discipline-specific material and activities.

With a desire to support underprepared learners admitted to an urban public university, two faculty members identified and designed the delivery of a discipline-integrated support course to engineering and engineering technology learners, as a supplement to additional developmental mathematics and English coursework.

II. COURSE OBJECTIVES AND DESIGN

TECH 101 was created to cultivate fundamental analytical and communication skills for students who were unable to meet the pre-requisites for the first technical course in the engineering technology curriculum, TECH 105, Engineering Technology Fundamentals. TECH 105 requires students are ready for freshman composition and pre-college algebra. Many learners were international students or who may have graduated from an underperforming high school. As a result, participants in the first TECH 101 generally lacked a basic knowledge of mathematics or the ability to communicate effectively in English, either written or spoken, or both. In addition, engineering learners could utilize TECH 101 in order to maintain full-time enrollment while enhancing technical skills and progressing toward technical courses required in the curriculum.

While academic skill building was inherent in the course design, objectives related to the exploration of the role of a college student associated with the common practices, codes, values, and interactions associated with the collegiate culture, were integral to the successful delivery of TECH 101. The instructors hoped to cultivate the positive attributes of resilience and adaptability in TECH 101 learners. Factors associated with persistence were tightly woven into the discipline-specific material.

Course objectives were designed to align with the expectations of coursework in TECH 105. In collaboration with the freshman engineering technology instructors, the following course objectives were identified:

After completion of the course, the student should be able to:

- Create graphical representations of data
- Describe and define common metric prefixes
- Demonstrate basic unit conversion applications
- Identify and apply the scientific method to the investigative process
- Communicate the results of a scientific experiment using a generally accepted lab report format
- Create written technical reports using WORD software
- Create fundamental spreadsheets and use them to solve basic problems
- Use spreadsheet software to create graphs and charts
- Develop an effective technical vocabulary
- Describe and apply the concepts of effective teamwork
- Demonstrate an ability to meet deadlines and instructor expectations.

To promote successful completion of the course objectives, several key course components were identified including the use of weekly vocabulary words, a question of the day, a student presentation, written examinations, and laboratory reports.

A. Question of the Day

The question of the day technique utilized a scientific prompt drawn from the *Science Teacher's Activity-a-Day* [7] and the *Science Question of the Day* [8]. This process fostered group collaboration and brainstorming to determine a solution to the prompt. The course instructor guided the investigation by careful evaluation of each word in the question. The questions were often tied to the fundamental concepts associated with the laboratory experience planned for the week. The students' effort in arriving at a solution to the question of the day served as preparation for the vocabulary and scientific theory needed for the weekly topic and hands-on experiences.

B. Vocabulary Words

Each week, five words were provided to the students, typically associated with the technical concept under examination. For example, during the lesson associated with observations and the scientific method, vocabulary words included observation, bias, appearance, quality, and quantity. Flash cards were utilized to reinforce understanding, with time spent explaining how flash cards should be incorporated into study techniques. The students utilized multiple online dictionaries to evaluate the various entries for the word and assorted meanings, utilizing context to be able to determine the appropriate definition, and choosing the most succinct definition; which allowed them to practice their summarizing skills as well as using contextual clues to define new words.

Vocabulary words served as models to explore the concepts of context, homophones, and online translator tools. Learners were guided through the examination of dictionary entries to identify the particular meaning most likely to be associated with TECH 101 content. An example of this process was undertaken for the term "mass," utilized in the density content area, a challenging term for some international students. An online dictionary was consulted and the various meanings explored. The definition as a Christian service was discussed as well as the dictionary labels such as "related to medicine." Students were guided to evaluate and select the appropriate meaning.

C. Reflective Discussion

Throughout the course, open discussion between both instructor and learners as well as among students was highly encouraged. In the beginning of the course, it was explicitly explained that this was a safe space for questions and for practicing English. A supportive environment among peers was encouraged and fostered, which lead to students being very open to class discussions and supporting each other when questions arose. Diminishing the power distance between students and professor was a vital step in promoting role understanding, behavioral expectations, and overall course success.

Discussions were always conducted with the instructor seated with the students facilitating, but not leading, the communication. Often, the students would rely heavily on the instructor to answer questions, expecting immediate answers instead of working out a solution individually or collectively. Once this was noted, the instructor would set up a hands-on

activity, facilitate the necessary discussion, and then excuse herself for a period of time. The students were left to work together and solve problems without the intervention of the instructor. This proved very successful. The students became excellent problem solvers on their own, and became proud of their work and new-found abilities.

D. Laboratory Reports

Formal and written laboratory reports developed skills associated with summarizing, communicating technical terms in English, and conveying data. The requirement demanded significant attention to detail, comprehension of faculty expectations, and ability to meet deadlines. Throughout the semester, assignments increased in depth and complexity, building on previous understandings.

The instructor was surprised at the significant deficit in computer literacy. Course laboratory reports offered students task-specific activities to promote fundamental skill building including keyboarding, work processing commands and techniques, access to online data storage, and functions within course management software. Careful emphasis to cultivate computer literacy was an essential course outcome in order to promote success in future courses.

III. HANDS-ON ACTIVITIES

Hands on activities were crucial. Experiences were drawn from a variety of resources including The Sourcebook for Teaching Science [9], resources at the Discover Engineering website [10], and Engineering World Health [11]. Some of the experiential learning projects are described in this section.

A. Density of a Tootsie Roll

In the pre-work for this experience, the vocabulary words of the day explored the terms in the density equation. The question of the day dealt with how and why density should be calculated and the students practiced using and understanding the formula. As part of the lab, the students used the formula $D=M/V$ to calculate the density of different sized Tootsie Rolls. They made a hypothesis about whether the size would affect the density and then used scientific language to explain their results. The students also used very simple unit conversions with the scales. Learners were introduced to tools to help convert and understand the difference between English and Metric Units, as the international students were unfamiliar with English Units.

B. Paper Airplane

This experience was completed at the beginning of the semester and primarily focused on clear communication skills and attention to detail, but was integrated with engineering design. Students were tasked with designing a paper airplane that would fly the farthest of any in the class. They were then asked to write instructions for the instructor to create a paper airplane exactly like the one they created. A competition took place to see whose plan flew the farthest and then to see if the instructor's version was identical to the original. A final discussion after the laboratory helped the students understand

the need for clear word choices. In addition, learners postulated how their instructions could have been improved. The need for engineers to possess excellent written communication skills was also discussed.

The written instructions and a summary of the findings were the written deliverables for this activity.

C. Tower Project

This lab engaged students in engineering design, formal written communication skills, and a basic understand of the potential social impacts associated with the discipline of engineering. The discussion for this lab was comprised of research the construction of towers around the world and the race to build the tallest building. A visit to the website for the Burj Khalifa building [12] sparked interesting discussion, as the international students were very familiar with this building in Dubai.

Once students were familiarized with the positive and negative social impact of engineering design, specifically the design of the tallest building in the world, they began their own design of 'towers'. The students were each given a box of toothpicks and unlimited mini marshmallows. They were tasked with building the tallest tower, the minimum height had to be 12 inches, and it had to withstand a breeze of a fan. They concluded this experience with a written report.

D. Robot Arm

Students were given a box of various office supplies and were tasked with building a robot arm that would pick up a cup holding paper clips and empty this cup into another cup roughly one foot away. This experience included little discussion and preparation as a way to help the students hone their design and teamwork skills. The vocabulary words for the week were centered around team work.

Students were given the basic instructions for this lab and were left alone for approximately 15 minutes to begin their design process. After that time, they were shown a short video of students who had previously completed this project and were allowed more time to work on their design. Learners met the objective and concluded the class with a discussion about their work together and how teamwork might be challenging in a professional engineering environment. Students completed a written laboratory report as homework.

E. Estimating

Somewhat surprisingly, this experience was noted as a favorite by the class members. The objective of this lab was to explore the importance of estimating within the engineering discipline, and to practice using basic tools of measurement. Discussions began with brainstorming how and why engineers should have well-honed estimating skills. The lab work required a variety of estimating skills, including estimating weight, length, height, and number of objects. Students completed a worksheet where they estimated several objects such as number of objects in a jar, the temperature of the classroom, the width of the classroom, the height of their instructor, etc. Next learners took actual measurements of these items. Finally, students wrote a reflection describing

what they learned as well as why estimating skills are important for engineers. The following class, the instructor offered some suggestions on how to best complete the estimates required for the activity.

IV. OBSERVATIONS

The students in Tech 101 were all studying different engineering technology disciplines, which created a wonderfully diverse environment for discussions and teamwork. Students were extremely conscientious and engaged in the learning process, which resulted in fruitful discussions and thoughtful responses in their written lab reports and reflections.

The greatest challenge for learners in this course was the successful completion of the written report. The first lab report of the semester was completed step-by-step as a class; with each student submitting his individual report. Each week, students were tasked with completing more of their lab report on their own.

The students experienced difficulty when asked, at the end of the semester, to name all parts of the lab report. Upon reflection, this course should have included an entire class period devoted to the written report, the importance of understanding its different sections, and how to produce a quality product. Because this is an important fundamental skill for engineering students, special consideration should be given to this skill in a remedial setting.

The course activities promoted a deeper understanding of the role of a college student (in the United States), especially the responsibilities, expectations, and the keys to success in the engineering and engineering technology disciplines.

Four students began the course, one student withdrew from the university. Of the three remaining students, all are still enrolled in their majors and successfully completing TECH 105.

V. CONCLUSIONS

Upon completion of TECH 101, students were asked their opinions and concerns both in a formal, anonymous course evaluation and as part of a class discussion. All students in the class agreed that they found the course beneficial and taught at a speed compatible with their learning, even if they had been hesitant to enroll initially. Throughout the course, the improvement in confidence of the students was noticeable, as was the production and success in course assignments.

A familiarity with the jargon and tools used in an engineering classroom supports and encourages the underprepared student, especially those who are studying in a

foreign language. This course provides those skills in a nurturing setting where students can test their new-found skills in authentic, discipline-specific environments, which is a best practice for second language development.

In future semesters, the instructors will fine-tune the course content, with special emphasis to maintain relevancy to the current student population. The Tech 101 pilot demonstrates that discipline-specific developmental coursework fosters both technical fluency as well as college-student role understandings in a highly satisfactory way. Learners enjoyed the hands-on activities and responded to the escalating instructor expectations. Initial findings suggest that TECH 101 supports student success once learners begin engineering or engineering technology curricular coursework.

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Getting Past the First Year: Retaining Engineering Majors

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Abstract—Peer Led Team Learning (PLTL) is a nationally recognized curriculum enhancement strategy adopted in various forms by over 150 universities and colleges across the United States. Consistent with the outcomes and the vision of ABET Engineering Criteria 2000 and the National Academy of Engineering Engineer 2020, PLTL prepares students to work in teams; apply knowledge of mathematics, science, and engineering to solve problems; communicate effectively; engage in life-long learning; and develop leadership skills. Published PLTL program data have shown that using peer leaders in small group workshop settings boosts performance in critical first-year courses including core math, science and engineering courses. The PLTL model promotes the growth of critical workplace skills for students and peer leaders such as working in teams, listening, critical thinking and leadership. This paper will present the basics of the PLTL instructional model, including sample materials developed for engineering workshops. Consideration of the practicalities of the six critical components will be discussed: integration of the workshop component into the course structure, involvement of the teaching faculty, training and supervision of the peer leaders, creation of challenging materials, and provision of appropriate institutional resources.

Keywords—first year; engineering; retention; peer-led team learning

I. INTRODUCTION

In the United States, engineering programs suffer high rates of attrition. Among students who start as freshmen in engineering, only 57% complete baccalaureate degrees in engineering [1]. Attrition from other STEM disciplines is also high: “less than 40% of US students who enter universities with an interest in STEM, and just 20% of STEM-interested underrepresented minority students, finish with a STEM degree” [2]. The importance of promoting greater success among would-be engineers has been a long-standing concern in numerous reports issued by governmental agencies or appointed task forces, especially with the recent call to graduate “10,000 more engineers a year and 100,000 new teachers with majors in STEM” [3]. According to a study commissioned by the Association of American Colleges and Universities (AACU), Liberal Education and America's

Promise (LEAP), and other organizations [4], employers need employees who know how to communicate across diverse cultures and can work in teams of diverse groups, are knowledgeable about science and technology, are able to reason analytically, write clearly, and demonstrate creativity and innovation. These practices promote flexibility in working on multi-disciplinary solutions to complex problems.

Despite these calls to action, the U.S. has a “leaky pipeline” in engineering. Universities have implemented various efforts to improve retention and increase recruitment in the engineering fields. Numerous studies have identified reasons for attrition from engineering, such as excessive coursework and diminished interest [5], poor teaching and advising [6], and lack of confidence in mathematics and science skills [7]. To meet accreditation requirements, undergraduate engineering programs include a substantial number of mathematics and science courses, typically concentrated in the first two years of studies. “The math-science death march,” a phrase coined by Goldberg [8], refers to calculus, chemistry, and physics courses frequently required prior to taking engineering courses, as well as the slew of engineering science courses in the second and third years of engineering programs.

Although academic performance might be a factor for some first-year students, persisters and nonpersisters earned similar grades[9]. Most attrition from engineering occurs at the end of the first year, but attrition during the second year is still significant. Even for students who survive first-year courses, second-year core engineering courses can present barriers to persisting. These core courses, in the first and second years, provide excellent opportunities for the application of peer-led team learning.

II. THE PEER-LED TEAM LEARNING MODEL

Peer-led Team Learning is a “curricular structure” [10] developed in the early 1990s originally to improve college students’ pass rates in chemistry courses. In addition to the traditional lectures by faculty, a course includes a weekly

scheduled workshop, led by a peer leader, a student who has previously completed the course successfully. The PLTL model is characterized by six “critical components” which were developed through extensive evaluations of workshop programs that worked best when all six components were present [11]. These six critical components are:

- 1) Peer-Led Workshops are integral to the course.
- 2) Instructors are involved in the selection of materials, training, and supervision of peer leaders, and they monitor the progress of workshops.
- 3) Peer leaders are selected, trained, and supervised to be skilled in group work as facilitators.
- 4) Workshop materials are appropriately challenging, directly related to course methods of assessment, and designed for small group work.
- 5) Workshops are scheduled and held once a week for two hours, contain six to eight students per group, in space suitable for small-group activities.
- 6) The Peer-Led Team Learning program is supported by the department and the institution with funds, course status, and other support so that the program has the opportunity to be adopted across courses and disciplines.

PLTL workshops provide students with a collaborative learning environment, mentoring relationships, and effective learning strategies which encourages student retention in STEM majors. Beyond supporting student learning, PLTL helps undergraduate students develop as leaders. The peer leaders, trained as facilitators of learning, serve as role models and guides to the academic culture.

Where peer-led workshop strategies have been implemented, data on student performance have shown significant improvement in the pass rates. These improvements have averaged 12-15% increase of ABC grades, fewer withdrawals, and other measures of student performance in the first-year courses that are requisites for engineering majors. These results are demonstrated, for example, in general chemistry at Washington University [12]; University of Puerto Rico [13]; University of Texas at El Paso [14], and Kennesaw State University [15]; organic chemistry at Portland State University [16] and University of Rochester [17]; biology [18]; and pre-calculus at New York City College of Technology, CUNY [19]. Computer science as a discipline, in an effort to attract more students, especially those not yet well-represented, has used PLTL as a best practice by two consortia: one focused on recruiting more women, led by the University of Wisconsin, Madison [20]; and one focused on Hispanic students at eight Hispanic-Serving Institutions [21].

Examples of the incorporation of PLTL in engineering courses are not yet prevalent. At the University of Rochester, use of workshops for several years in an electrical and computer Engineering (ECE) course intended for mechanical engineering and optics majors, joins the long list of STEM and social science courses that incorporate peer-led workshops at

this private research-intensive university. Those non-ECE majors must complete a course in circuits, and data over five years found a positive correlation between final course grade and workshop attendance [22]. At Northwestern University, all engineering students in their first year must complete a four-quarter sequence, Engineering Analysis, which “integrates math, science and computer programming with engineering applications” [23]. Attendance at optional peer-led workshops correlated with successful completion of the required four-course sequence. Findings indicate that a workshop program using undergraduate leaders is an appropriate model for increasing students’ academic success in freshmen undergraduate engineering courses.

A. General Chemistry at the University of Texas at El Paso

At the University of Texas at El Paso, 33% of students taking first-semester general chemistry intend to be engineering majors. PLTL Workshop provides an innovative strategy for enhancing and increasing 1) student success in courses, 2) retention at the university, 3) successful completion of and timeliness to graduation. Because of the gatekeeper nature of the first semester general chemistry course (CHEM 1305), the PLTL program at the University of Texas at El Paso has led to a dramatic increase in the number of science and engineering students successfully progressing into STEM majors. Since this Peer-Led Team Learning Workshop Program was implemented in the year 2000, the Program has significantly improved the passing rate in CHEM 1305 by almost 20%.

An added benefit of the UTEP PLTL program is the development of professional skills: Over the past fifteen years, Peer Leaders have been first authors for almost two dozen publications and first authors on more than 110 posters and oral presentations made to international, national, and regional audiences. These experiences dramatically benefit the careers of the Peer Leaders and provide meaningful work experience enhancing professional skills and significantly contributing to the career objectives for the Leaders involved. Fig. 1 shows the number of students passing general chemistry.

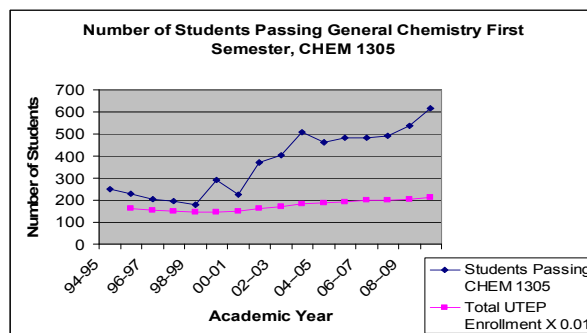


Fig. 1. Number of Students Passing General Chemistry I (CHEM 1305) at the University of Texas, El Paso, 1994-2009.

B. Introduction to Electrical and Computer Engineering, at the University of Illinois at Urbana-Champaign

The Department of Electrical and Computer Engineering at the University of Illinois at Urbana-Champaign offers two majors and one minor: bachelor of science in computer engineering, bachelor of science in electrical engineering, and a minor in electrical and computer engineering. Beginning in the fall of 2007, PLTL was implemented in ECE 110, Introduction to Electrical and Computer Engineering. ECE 110 is a large course with 300 to 400 students per semester that is required for first-year students majoring in electrical and computer engineering, and for students majoring in general engineering. Students should have completed or be concurrently registered in a first semester calculus course. ECE 110 introduces selected topics in circuits, electronics, and digital systems: topics that are often taught in second-year engineering courses at other universities. ECE 110 was developed in the early 1990s to give first-year students an engineering design experience [24].

The PLTL workshops were implemented as optional 90-minute sessions “supervised study sessions,” in specific time periods on Sunday afternoons and evenings. Students who elected to participate in the PLTL workshops were randomly assigned to learning teams in one of their available time periods. The peer leaders or “team leaders,” as identified by the Urbana-Champaign program, comprised graduate teaching assistants and undergraduate “graders” already assigned to ECE 110, and unpaid undergraduate volunteers; more than half of the leaders were volunteers. New team leaders attended a two-hour training session at the beginning of each semester, and most attended thirty-minute weekly meetings throughout the remainder of the semester. Team leaders were responsible for administrative duties, such as sending e-mail messages to their teams, and recording student attendance.

Workshops were held in classrooms, with two teams working at separate chalkboards in each classroom. Whenever possible, an experienced leader led one team and a new leader led the other team in the same classroom; this arrangement enabled the new leader to obtain help from the experienced leader. During each weekly workshop, each learning team collaborated to solve four to eight difficult problems selected from ECE 110 examinations given in previous semesters (see sample problem in Fig. 2). These problems were more challenging than routine homework problems: their solutions sometimes required understanding of basic concepts, analysis of complex situations, and the creative application of knowledge to unusual situations. The problems included circuit design and logic design problems that had multiple solutions.

Students who regularly attended PLTL workshops earned higher scores on the final examination than did other students [25]. Further, regular attendees enjoyed social benefits such as making new friends, networked support structures, and increased confidence with their school environment.

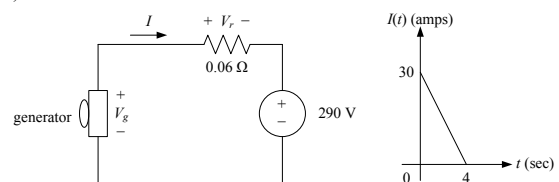
Johnson and Loui [26, 27] analyzed the experiences of fourteen peer leaders who kept weekly reflective journals: each

leader wrote a journal entry after each PLTL workshop. Initially the leaders worried about their own limitations. As the semester progressed, the leaders faced operational challenges and tried to encourage cooperation within their teams. The leaders adjusted their teaching methods, and they began to appreciate intellectual diversity. By the end of the semester, they reported increased self-confidence and interest in teaching in the future.

ECE 110 was completely redesigned in 2014 and became a 3-credit course; the current enrollment is more than 400 per semester. Workshops are still offered on weekend afternoons and evenings; most students live nearby or on campus so weekend workshops fit into their schedules. One of the ECE 110 instructors takes responsibility for preparing all problems used in the workshops in each semester. This instructor supervises the graduate teaching assistant who coordinates the peer leaders, to ensure that everyone understands these materials and the rationale for the selection of the problems. The College of Engineering currently provides space for the workshops in the engineering library. The Department of Electrical and Computer Engineering provides funding for the undergraduate graders who serve as peer leaders. It has allocated funds from internal grants to develop a new workshop-style discussion section in the fall of 2015 that targets students from underrepresented groups, including students from rural high schools.

Fall 2008, ECE 110 Problem 2. Written by Michael C. Loui.

The kinetic energy of a Toyota Prius car is 53 kilojoules (kJ) when it travels at 20 miles per hour (mph). The car’s regenerative braking system has a generator that converts the kinetic energy into electricity, which recharges the battery. We model the battery as a 290 V ideal voltage source and a $0.06\ \Omega$ resistor. Starting from a speed of 20 mph, the brakes are applied at time $t = 0$, and the current $I(t)$ from the generator decreases linearly from 30 A to 0 A at time $t = 4$ seconds (sec).



- Write a KVL equation that relates V_r and V_g .
- Determine the value of V_g when I reaches 0. **Explain your reasoning.**
- Determine the average SRS power P_{avg} for the 290 V voltage source between 0 and 4 seconds. **Show your work.**
- Determine the total amount of energy returned to the voltage source and the efficiency of the regenerating system in this case.

Fig. 2. Sample problem for peer-led workshop in ECE 110, at the University of Illinois at Urbana-Champaign, written by Michael Loui (2008).

C. *Statics, at New York City College of Technology, City University of New York (CUNY)*

The Department of Construction Management and Civil Engineering Technology (CMCE) of New York City College of Technology (City Tech) at CUNY offers associate degree programs in Construction Management Technology (CM) and Civil Engineering Technology (CE). All freshmen students in CMCE are required to complete Statics as a prerequisite to their design courses. Students should have completed college algebra and trigonometry and be concurrently registered in a first-semester physics course. The statics course provides an introduction to the concepts of force, equilibrium, section properties, load pattern distribution and equilibrium. About 60 to 90 students enroll in statics each semester.

PLTL was implemented in Statics in spring 2012 in an effort to increase student performance and decrease withdrawal rates. PLTL workshops in Statics are one hour in length and take place outside of the classroom. Workshop attendance contributes to the students' grade; students who are not able to attend can complete a supplementary assignment. Peer Leaders complete a one-credit course in Peer Leader Training in their first semester; in addition, all Peer Leaders are expected to attend weekly leadership seminars, which form the basis of a community of practice [28]. The workshop modules are designed to be reflective of the lecture topic but are at a more challenging level than the examples done in class.

Prior to the implementation of PLTL, the average percent of students passing with a C or better was about 50%. This percentage has increased steadily from 52% in spring 2012 to 79.5% in fall 2014 and the withdrawal rate has decreased from 33% in spring 2012 to 16.5% in fall 2014.

PLTL workshops provide civil engineering technology students with a collaborative learning environment, mentoring relationships, and effective learning strategies. The program has been successful for both participating students as well as for the peer leaders. Since 2012, of the 12 peer leaders for statics, 11 have been retained in the engineering program. Peer leaders have presented at the Peer-Led Team Learning International Society conferences (pltlis.org), as well as at regional conferences.

From 2012 through spring 2015, PLTL was incorporated in some but not all sections; starting fall 2015, a one-hour workshop component will be integrated in all sections of statics. The CMCE department has been instrumental in supporting curriculum change and securing funding to pay the Peer Leaders. Sections are taught by full-time as well as adjunct faculty, therefore the level of involvement varies with the type of faculty assigned to the course. City Tech peer leaders undergo training during their first semester. Fig. 3 shows student performance in statics and Fig. 4 is a problem developed for statics workshop.

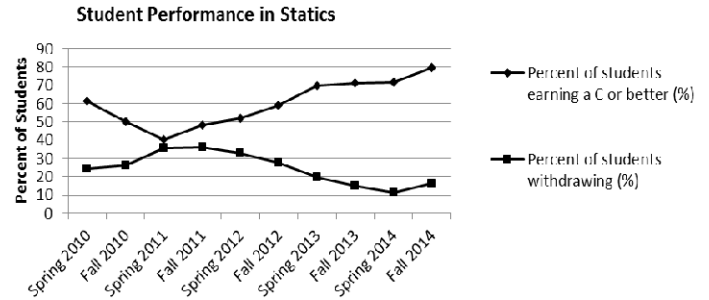
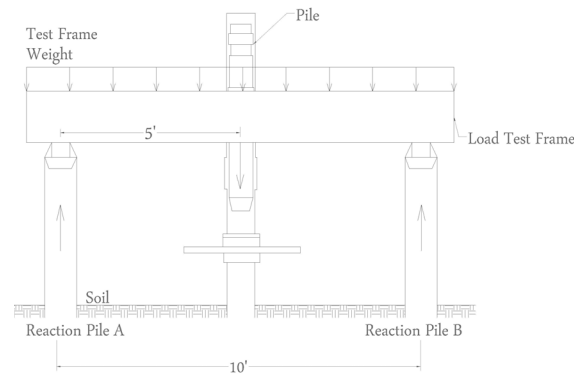


Fig. 3. Student performance in Statics.

Fall 2015 CMCE 1115 Workshop Problem. Written by M.Villatoro and R. Mason.

Given: A load test is required on Pile X, this load test will indicate whether the pile can hold 1000 lbs of load in compression. The load test frame is setup as follows.

Required: Determine the reaction force created in Piles A and B due to the 1000 lbs force on Pile X.



Given: The 5 ft wall is supported on a W12x26 girder spanning 16 ft between 2 supports. The line load produces by the wall is 2 kips per linear ft.

Required: Determine the reactions at the two temporary support blocks. Be sure to include the weight of the girder.

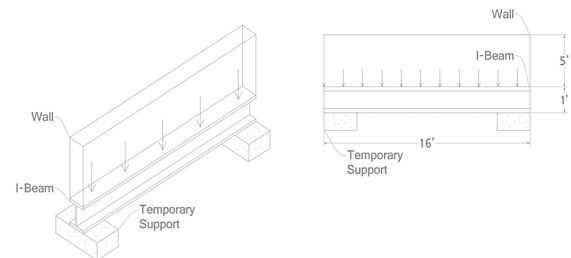


Fig. 4. Sample problem for peer-led workshop in CMCE 1115, at NYC College of Technology, written by M.Villatoro and R. Mason.

III. DISCUSSION

PLTL has proven successful in applications for STEM courses in universities across the nation. Students in STEM courses perform better with the incorporation of peer-led workshops; implementations in engineering and technology courses help students succeed as have implementations in science and mathematics courses. The three case studies presented provide a summary of the PLTL application, and the data indicating the improvement of student performance and withdrawal rates. Each application incorporates the six critical components at varying levels. The ability to incorporate all six critical components effectively is a function of various elements including institutional support, uniformity across sections, and time required for supervision and preparation. The adherence to the PLTL model's critical components helps campus programs gain from others' experiences with continual trends in improving grades, persistence, and retention. Where the administration does not support faculty's efforts, the PLTL program will not become embedded in helping students learn through discussion, and collaborative problem-solving.

PLTL introduces students to working as a team, developing communication skills, and working with diverse learners, preparing students to be successful engineers in accordance with Engineer 2020 [29] and ABET EC 2000 [30]. The Engineer of 2020 urges the engineering profession to recognize what engineers can build for the future through a wide range of leadership roles in industry, government, and academia--not just through technical jobs. Some of the desired attributes developed through PLTL include analytical skills, creativity, practical ingenuity, flexibility, leadership, and lifelong learning.

IV. CONCLUSION

Arendale [31] notes that, "the highest level of student outcomes occurs when a comprehensive learning system is integrated throughout the course learning experience." PLTL is an effective learning system which provides new experiential learning dimensions, not only for students, but also for the peer leaders, who gain leadership and other skills. PLTL provides students with the learning tools and supportive environment critical to the success of students.

As PLTL is introduced to more engineering and technology courses, studies investigating how it can develop students' teamwork and communication skills, to satisfy ABET Criterion 3, could be conducted. What aspects of the PLTL model are essential in achieving these outcomes? How can the incorporation of peer-led workshops be designed to promote these attributes?

The many studies conducted on student performance with PLTL have shown improvements in retention, whether in the sciences, mathematics, and engineering courses. What is the logic model, or mechanism, by which PLTL promotes retention? Working with Tinto's theory of academic and social integration [32], peer-led workshops may offer alternative mechanisms to learning communities. What conditions of

peer-led workshops foster improved retention in groups that are underrepresented in engineering?

Unlike homework problems in science courses, problems in engineering courses can also involve design. These design problems are difficult for beginning students because they have multiple solutions and require judgment in making tradeoffs. Can the experience of solving design problems through PLTL in first- and second-year engineering courses prepare students for month-long and semester-long design projects in subsequent courses? PLTL is an excellent platform in which to apply design problem exercises.

The implementation of Peer-Led Team Learning in engineering courses is in a nascent stage. Its continued adoption will support students' learning in the first year courses in mathematics, science, and engineering, thus forestalling the "death march" in those courses, and fostering the necessary critical thinking [33] needed in engineering. PLTL can be key to improving retention in the engineering majors, and be vital to responding to the needs of the nation's workforce.

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Are They Simply Interested? An Exploration of Engineering Students' Most Favorite Classes

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Abstract— This work in progress explores how instructional strategies and technology use were related to engineering students' affinity toward a class. Instructional strategies, such as contextual problem-based learning and teamwork, can increase student interest in a topic. Additionally using different technological tools affects student interest and learning. However, instructors can be challenged to encourage and maintain student interest, which makes this study worthwhile to pursue. To our knowledge, there is a dearth of engineering education research exploring the relationship between instructional technology, instructional strategies, and engineering students' course favoritism. This study aims to fill this gap by identifying effective instructional strategies and the use of educational technology that helped make a class engineering students' favorite.

Keywords—*instructional strategies; educational technology; student interest; course favoritism*

I. INTRODUCTION

It is reasonable to speculate that students learn more and are more motivated to learn in their favorite classes. Therefore, to identify and implement effective instructional strategies that help increase student favoritism for a class is a worthwhile goal. If students are more motivated to complete coursework, they learn or perform better [1, 2]. In searching the literature, we did not find any research study that specifically explored the relationship between instructional strategies and engineering students' favorite classes. Some instructional strategies identified in general, such as problem-based learning [3] and teamwork [4], make classes more motivating or interesting. However, to our knowledge, there is no set of specific instructional strategies that are proven to be effective in increasing student favoritism for a course.

Generating and maintaining student interest in the class or topic is a critical component of favorite classes. Interest refers to "focused attention and/or engagement with particular events and objects" [5, p. 169] so we can actively process the important and relevant information. Generating and maintaining student interest can contribute to creating optimal

learning environments [5], which we argue should be considered when developing and implementing learning activities. Student interest in learning can be promoted via effective instructional approaches [5] and the use of educational technology [6]. There is a lack of research on motivational effects of instructional strategies and the use of educational technology on students' affinity toward a class. Likewise, few studies explore effective instructional strategies and the use of educational technology in engineering students' most favorite classes. Our study aims to fill this gap by identifying effective instructional strategies and the use of educational technology that helped make a class engineering students' favorite. We asked the following research question: What kind of instructional strategies and technology were used in engineering students' most and least favorite classes? We aimed to identify the instructional approaches and tools used in engineering students' most and least favorite classes.

II. LITERATURE REVIEW

A. Instructional Strategies

Some specific course instructional strategies may motivate student learning and engagement. For example, problem-based learning (PBL) can motivate students in applying what they have learned to solve real world problems [7]. Through PBL, instructors can encourage students to seek out new information and generate new knowledge based upon their prior knowledge. Students engaged in problem-solving demonstrate greater focus and attention to learning as well as engage in deeper cognitive processing [3]. Problem-solving also provides engineering students with hands-on activities, which helps develop and sustain interest [8].

Similarly, service learning that combines instruction/learning with meaningful community service helps prepare students professionally [9]. Service-learning provides students hands-on opportunities to gain skills and knowledge that may otherwise not be obtainable in their classes. Through service-learning, students are motivated to gain effective communication and project management skills [10].

Additionally, group projects or teamwork can develop student interest in subject content through the need for autonomy, competence, and social relatedness [11]. In group projects, students engage and interact with others, which allows interest to be modeled and remodeled, such as one develops an interest because of one's peers [4]. Friendly competition within a team or between teams can also promote interest in some subject topics. A meta-analysis of college students studying STEM subjects found small group work has a significant positive effect on academic achievement and motivation [12].

A study by Dartmouth University reported that engineering alumni's favorite classes involved problem-solving, service-learning or teamwork [13]. The participants also reported enjoying transferring theory to practice through solving real-world problems in their favorite classes.

In addition to specific instructional strategies that can help develop student interest in subject matter, there are some general approaches that can build student interest in learning. Krajcik and Mamlok-Naaman [14] suggest organizing instruction around a driving question rather than topics. This practice emphasizes the relevance of the material (driving questions) to real life. Using driving questions to organize instruction helps pull relevant information together, which facilitates application of learning [14].

Likewise, learner centered teaching approaches increase student interest in instructional material. Ellis, Rudnitsky and Scordilis [15] found that learner centered instruction in teaching introductory engineering mechanics could help students become more committed in the field of engineering.

B. The Use of Educational Technology

As educational technology becomes an essential element in teaching and learning, students' interest and motivation can be affected by the use of technology in their classes. Appropriate use of technology in the classroom can increase student interest [6] and can enhance students' learning [16]. For example, visualizations and simulations not only help generate students' interest but also allow students to better use evidence and data during their scientific inquiries [17]. Technology, especially technology-based student-centered learning, has the potential to optimize student learning [18].

Technology can be used to support learner autonomy, i.e. taking charge of one's own learning [19], and to encourage more active and deeper learning [20]. For example, providing technology-supported instruction in the form of motivational emails and links to supplementary instructional materials (such as videos) increased student motivation to learn [21]. Students who received supplementary motivational instruction perceived that they could take charge of their own learning and displayed more self-directed learning than students who did not receive supplementary motivational instruction. Similarly, educational games were found to be effective for learning and motivation in the context of learning computer concepts [22]. Educational technology may enhance student learning and attainment for learning, providing resources and learning platforms (such as Blackboard and Coursera) for independent learning and team collaboration [23]. Despite the promise of technology tools to engage and motivate, it is important to note that they are just

tools, a means to accomplish an end goal. Therefore, educators need to focus on the learning processes (such as collaborative learning) instead of the tools [24].

III. METHOD

We created a survey containing a combination of selected and free-response items which we invited engineering students to complete. The survey included items asking the participants' to share their most and least favorite classes and justifications for their ranking of the courses, the major instructional approaches used in the courses, and the technology used in the courses. The survey also included demographic questions and Likert-scale questions asking students to rate the usefulness of the instructional strategies and use of technology in their most and least favorite classes. An invitation to participate in the online survey was sent to more than 500 undergraduate students in the College of Engineering at a Western university. Ninety-five students (73 men, 22 women) completed the survey. Participants included undergraduate engineering students from various engineering program areas such as mechanical and biomedical engineering, electrical engineering, materials science engineering, civil engineering, computer science (in the college of engineering), and construction management (in the college of engineering). The average age of the survey respondents was 25, 12 respondents were freshman, 26 were sophomores, and 26 and 27 were juniors and seniors respectively.

IV. RESULTS

Research Question: What kind of instructional strategies and technology were used in engineering students' most and least favorite classes?

According to the survey results, a variety of instructional strategies were adopted in students' most favorite classes including lecture (100%), live demonstration (65%), individual problem solving (63%), group problem solving (58%), full class discussion (54%), group discussion (49%), and laboratory experiments (35%) (see Table I). Only one most favorite class had adopted all seven of the above instructional strategies. The majority of participants believed the instructional approaches adopted in their most favorite class helped their learning. Similarly, a variety of instructional strategies were adopted in students' least favorite classes. However, it seemed that more least favorite classes had adopted less interactive (discussions) and less hands-on (labs) approaches.

Results showed that a variety of technology tools were used in students' most favorite classes including PowerPoint presentations (100%), video/simulation during class (71%), online homework system such as Masteringphysics.com and Webassign.com (48%), clickers (classroom response system 23%), relevant videos used outside of class (46%), Blackboard discussions or online discussion forums (23%), mobile devices (e.g. iPad, tablet computer, smart phone 17%), Blackboard quiz/test (17%), and recorded lectures provided by course instructors (17%) (see Table II). Only two most favorite classes

did not use any other technology except for PowerPoint presentations. In the most favorite courses, more participants believed the use of technology outside of the classroom was helpful for their learning compared to those in the least favorite courses. However, more than half of the participants held a neutral attitude (neither helpful nor harmful for their learning) towards the use of technology in their most favorite class.

Most participants' most favorite classes incorporated several instructional strategies (see Table I). Similarly, most participants' most favorite classes included several technological tools (see Table II). Results also showed that a variety of technology tools were used in students' least favorite classes (see Table II). However, the percentages of the use of technology in students' least favorite classes were less than those of the most favorite classes. The Ns in Table I and II stand for the actual number of responses for that particular item choice.

TABLE I. INSTRUCTIONAL STRATEGIES IN THE MOST AND LEAST FAVORITE CLASSES

Instructional strategies	Most Favorite (%) N=71	Least Favorite (%) N=62
Lecture	100	90
Live demo	65	15
Individual problem solving	63	3
Group problem solving	58	23
Full class discussion	54	23
Group discussion	49	16
Lab experiments	35	10

TABLE II. TECHNOLOGY ADOPTED IN THE MOST AND LEAST FAVORITE CLASSES

Technology/ tools used	Most Favorite (%) N=52	Least Favorite (%) N=62
PowerPoint presentations	100	53
Video/simulation used in class	71	27
Online homework system	48	42
Other relevant videos used outside of class	46	16
Clickers	23	21
Blackboard discussion	23	16
Mobile devices (e.g. iPad, tablets, smart phone)	17	11
Blackboard quiz/test	17	23
Recorded lectures	17	6

In the most favorite classes, 97% of students (36 out of 37 responses) considered the instructional approach helped their learning, and only one responded the instructional approach was neither helpful nor harmful. About 32% of participants (22/69) considered the use of technology in class helped their learning, and 68% participants (47/69) considered the use of

technology neither helped nor harmed their learning. In the least favorite classes, 73% students (24 out of 33 responses) considered that the instructional approach harmed their learning; only 2 responded the instructional approach helped their learning; and 7/33 participants considered neither helpful nor harmful. Only 3% of participants (3/87) considered the use of technology (including both in and outside the class) in their least favorite course helped their learning, while 13% participants (11/87) considered the use of technology harmed their learning; and 84% participants (73/87) considered the use of technology neither helped nor harmed their learning.

VI. DISCUSSION AND CONCLUSION

In our study we explored instructional strategies and the use of technology in engineering students' most and least favorite classes. Most participants considered the instructional approaches in their most favorite class helpful. Specifically, problem solving, hands-on activities, demonstrations, and discussions were found to be positively linked to most students' favorite classes. Instructional approaches are closely related to learner satisfaction and supportive course instructors, which are critical to generate and or sustain students' interest in the course. However, few students considered technology use helpful in their most favorite classes, which means the use of technology in those most favorite classes did not necessarily motivate the students to learn. Therefore, effective use of technology in engineering classrooms needs to be improved.

Although instructors play an important role in implementing the instructional strategies and technology tools, our study did not consider the impact of instructor in student's most favorite and least favorite classes. From the overall differences between participants' responses to the same instructional strategies and technology tools in both most and least favorite classes, we could see a clear trend with respect to our findings (see Table I and II).

Our study has some limitations. First, the survey relied on self-report data, which may be subject to bias of participants when recalling their most and least favorite courses. Second, the relatively low sample size may limit the generalization of the study. Future studies on exploring the relationships between instructional strategies and the use of technology with engineering students' favorite and least favorite classes from different types of institutions are needed. Nevertheless, the findings of the study can provide some practical guidelines on supporting students' interest via effective instructional strategies and use of technology (part of the instructional strategies). Future studies on how instructional strategies and the use of technology have the potential to help instructors learn how they can generate interest in those academically unmotivated students as well as sustain interest in students who are initially motivated. Different instructors could implement the same instructional strategy differently. For example, some instructors explain and discuss their PowerPoint slides while others just read their slides. Future studies may need to include the impact of instructors in such studies.

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Is this “transfer shock”?

Examining the perceptions of engineering students who articulate within the Irish higher education context

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Abstract—“Transfer shock” is a well-known phenomenon during the process of articulation, when students move from short-cycle applied programs to more academic longer-cycle study programs. In the US context this problematic transition has been observed in students transferring from community colleges into the traditional university system. In Ireland’s binary higher education structure, one set of institutions, known as Institutes of Technology (IoTs) allow for this transition to take place entirely within individual institutions. This paper is part of an ongoing investigation into one such IoT, where engineering students who achieve high grades at the end of 3-year (so-called Level 7) “ordinary degree” programs frequently transfer into the 3rd year of 4-year Level 8 “honors degree” programs, with surprisingly successful outcomes. One surprise derives from the fact that the students who enter Level 7 engineering programs are deemed at the outset to be academically less able, particularly in mathematics, than those who go directly into Level 8 programs from secondary school. Relatively little work has been done on this transition to date. In the 3rd and 4th year of many honors engineering programs within this institution it is not unusual to have 30-50% of the students coming from an ordinary degree background, the majority from within the institution itself – with others transferring from other IoTs in Ireland. Previous research has shown that students from this background initially struggle in the 3rd year of the honors degree program when compared with students who have proceeded directly through the honors program, before going on to successfully graduate. Can this be attributed to ‘transfer shock’; even though most of these students are continuing in an institution and with faculty that they are already familiar with? In order to examine this phenomenon we interview students from several engineering disciplines at various points in this transition. We explore the perceptions of the students regarding this transition and, based on the information coming from the interviews, we conduct a large scale survey to be administered to articulating students across engineering programs in the institution. The preliminary results of this survey are also presented here.

I. Introduction

For several decades many higher education systems across the world have been attempting to respond to the increasing demand for graduates. One method has been to encourage articulation, which is the transfer of students at the end of short-cycle applied programs into more academic degree programs at universities. In the US context this process sees students moving from community colleges [1], while in the UK students may complete a foundation degree [2] or a Higher National certificate or diploma [3] at a further education college before transferring to a university. Articulation can give students from non-traditional backgrounds, who may be economically disadvantaged; or from the first generation of their family to enter higher education; and mature students, the opportunity to gain an honors degree through this indirect route. However, the process is not without difficulty and many students who undertake this route drop out before attaining their goal or experience problems in coming to terms with the new institutional culture they encounter. This set of problems has been referred to as “transfer shock” and studies in the US and the UK have sought to analyze its effect [4], [5]. The phenomenon typically results in a dip in grades for a period after transition to university [6], [7], [8], and is thought to be attributed to the adjustment to the new “institutional habitus, including staff attitudes and relationships (community), teaching and learning strategies (curriculum) and social spaces (campus)” [9]. One solution suggested by Greenbank is to offer both short-cycle applied and honors degree programs in the same institutions [2]. This is where the Irish higher education system may have an advantage.

Ireland’s higher education system is said to be binary. On one side are the seven traditional universities, the oldest being Trinity College Dublin which was founded in 1592. On the other side are 13 Institutes of Technology (IoTs), set up originally as regional technical colleges to support the training and educational needs of their local areas. Then there is the Dublin Institute of Technology (DIT), which straddles both

Keywords—*articulation; transfer shock; engineering students*

sides of this divide¹. It grew from a group of technical colleges, founded in the late 19th and early 20th centuries to deal with vocational training and education, into a fully independent institution, established in 1993. Today DIT is a member of the European Universities Association and has degree-awarding powers up to doctorate level. Its so-called “ladder system” (see Table 1 below) allows a student to begin by completing an apprenticeship or short-cycle applied certificate program (known as Level 6 in the National Qualifications Authority of Ireland’s framework (NFQ) of levels in the Irish education system [10]) right through to a doctorate at Level 10 – all within the same institution. This, surely, is the ideal place in which to examine whether transfer shock can be avoided during the process of articulation.

Table 1 Explanation of NFQ Levels [10]

NFQ Level	Explanation
Level 6	Advanced Certificate
Level 7	Ordinary Degree
Level 8	Honors Degree
Level 9	Masters Degree
Level 10	Doctoral Degree

A research group of faculty who teach students of various engineering disciplines at DIT has been examining the experience of articulation from 3-year engineering technology programs (at Level 7) into the 3rd year of 4-year Level 8 degree programs. This research has shown that some articulating students do indeed struggle, particularly in mathematics, when they move from Level 7 to Level 8 but that the majority recovers sufficiently to graduate with, on average, a grade higher than students who came directly through the four years of Level 8 programs [11]. This paper sets out to explore students’ own perceptions of their transition, their awareness of experiencing transfer shock, or otherwise, their motivations, difficulties and successes. Following on from the analysis of interviews with a group of currently articulating students, a survey has been created and administered to a larger group from the same engineering disciplines. Both the interview and survey analysis will propose an answer to the question of whether these students perceive transfer shock as something that has affected them during their transition into an honors degree program.

II. Background to the study

The traditional route into a level 8 degree program in engineering in Ireland requires students at the end of their second-level schooling to achieve high proficiency in mathematics, as the professional body for engineers, Engineers Ireland, stipulates a minimum of grade C at higher

level in the State Leaving Certificate examination. The numbers taking the higher level mathematics have never exceeded 25% of the examination cohort and this has greatly restricted potential entrants to level 8 engineering programs. One solution provided by DIT and other IoTs has been to provide less theoretical programs requiring a lower level of mathematics on entry – these are the 3-year Level 7 degrees, known as Bachelor of Engineering Technology, from which many students go on to articulate into the 3rd year of Level 8 programs at DIT. Recent research into the expectations of students starting out in a Level 7 program in mechanical engineering in 2013 shows that at least 73% of them intend to transfer to a Level 8 program after graduation [11]. This is very different to the expectations of, for example, Scottish students in equivalent programs, only 13% of whom had decided at the start of their studies that they would want to articulate later [5].

Despite their proven weakness in mathematics, students articulating from Level 7 and graduating in 2009 and 2010 have been shown to have averaged a mark of 62% while, surprisingly, their direct entry colleagues with high mathematics competence at the outset achieved an average mark of only 53% [11]. This was in spite of research showing that, within the first semester after articulating, many former Level 7 students had had difficulties passing their first math modules in the honors program [12]. In order to be allowed to articulate, these students had been required to attain an average of 60% in their final grades at Level 7. They then appeared to allow their marks to dip for a semester or year after transferring to Level 8 before outshining their direct entry colleagues in the final year towards obtaining their honors degree.

Students who graduated from 2011 onwards have not been required to attain such a high grade at Level 7 in order to be permitted to articulate. Since then the average mark on entry to the 3rd year of the Level 8 degree program has been reducing year on year so that in 2013 the average mark of entrants was 51%. Perhaps not surprisingly in this case, the grade advantage of former Level 7 students on graduation from Level 8 has also reduced – now their final marks are on a par with their direct entry colleagues [13]. This is not to forget that such students, coming into DIT with weak mathematics skills and completing their level 7 programs with mediocre results, are nonetheless graduating with similar grades to those who entered with high math competence directly into the 4-year Level 8 program, admittedly by taking one year longer to do so.

The dip in results that has been observed immediately following transfer into Level 8 programs, as discussed above, mirrors the phenomenon of transfer shock seen in students moving from one institution to another. However, these students are not moving to an unfamiliar institution. In fact, in many cases they encounter the same faculty members teaching similar modules in the same environment as before they

¹ This binary division ignores private colleges and specialized education and art colleges, for example.

articulated. As was seen earlier, many of those who start out at Level 7 fully intend to transfer to the Level 8 program as soon as they are permitted to do so – so where does the difficulty lie? The only way to discover the answer to this question was to ask the students themselves.

III. Methodology

This section of the paper outlines the methodology applied to answer the research question as to whether articulating engineering students perceive “transfer shock” as something that has affected them during their transition from a Level 7 program into a Level 8 program. Included are the details and justification of the research method used; the profile of the participants; the research protocol, ethical considerations and how the results were obtained and analyzed.

A. Research Method and participant profile

This study utilized a number of methods, namely a qualitative approach in the form of one-to-one interviews conducted by faculty members, some of whom lecture on Level 7 and/or Level 8 engineering programs, and follow-up quantitative research by means of an anonymous online survey. Given the complex nature of “transfer shock” the qualitative approach was applied first to gather insights on the “how” and “why” of student experiences in order to enable common themes to be identified. The quantitative approach was to investigate whether these identified themes or issues could be generalized to the larger articulating engineering population. As it was thought the information may be sensitive, the online survey was anonymous and only general profiling data was gathered from participating students as outlined in the next sub-section. This approach is similar to that taken by Greenbank [2] and Winter and Dismore [9].

Students enrolled in the 2014/2015 academic year from both 3rd year and 4th year stages of Level 8 programs were considered. While previous research had concentrated on mechanical engineering students [11], this study gave an opportunity to include civil, structural and manufacturing & design engineering students. The total cohort available was 105 students across all four disciplines. Students were asked to volunteer to participate in the face-to-face interviews with three students selected from each category, and where possible, across the range of academic performance. Overall, 13 student volunteers were separately interviewed – a breakdown of their profile is shown in *Fig. 1*. For the online survey, 41 students took part giving a response rate of 39%. The breakdown in *Fig. 2* shows more 3rd year than 4th year participants in contrast to the qualitative study.

A review of recent literature on the difficulties encountered by articulating students identified four main problem areas, [2], [4] [5], [6], [8] and [9]. These can be categorized as: community (both inter-student and student-faculty member relationships); curriculum (work load and learning styles); culture (expectations set by faculty members, class attendance,

assignment submission guidelines and class interaction) and campus. The last category was not a factor in this study given that all those interviewed came from the same institution and did not have to deal with a new campus environment.

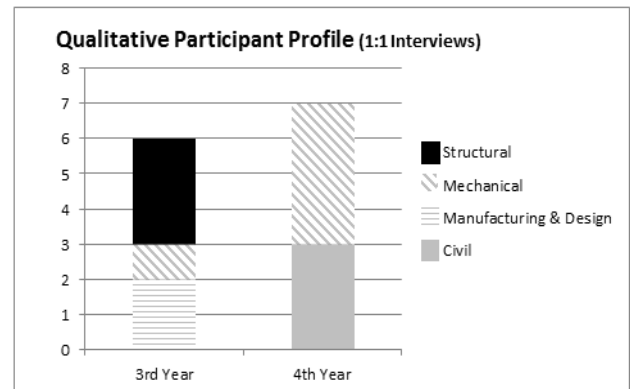


Fig. 1. Qualitative Participant Profile in 1:1 interviews

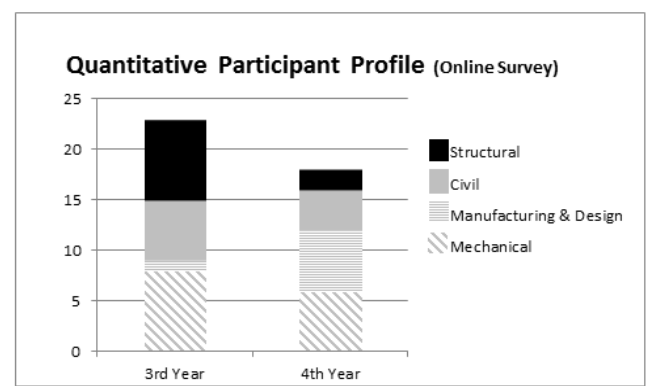


Fig. 2. Quantitative Participant Profile of online survey

B. Approach to conducting the research and analyzing results

The categories were used as a guide during the semi-structured interviews to ensure students considered all aspects of their transition. Faculty did not interview any student from their own discipline and the recorded interviews lasted on average 15-20 minutes. Prior to the commencement of the interview students were asked to read an information sheet outlining the parameters of the study and they also signed consent forms. It was clearly stated that they could conclude the interview at any stage.

A detailed review and analysis of the transcripts of the interviews identified themes that formed the basis for the online survey. Focus was put on the categories of culture, community and curriculum as well as specific terms such as “grades dipping” in an attempt to find evidence to support previous research that had shown particular difficulties in the first semester after transferring into Level 8 [11]. Howieson’s research on articulating students in Scotland [5], which involved a large questionnaire of approximately 50 questions, also provided a useful source for the final online version,

which was chosen for ease of development and administration of the survey responses. There were 10 questions in total, with initial questions designed to gather information on student profile and their own expected performance for the end of this academic year. Most questions were structured using a Likert 5-point scale with a comment section provided for respondents to explain or justify their selection. A final open-ended question required students to sum up their overall transition experience. All students currently studying on Level 8 programs in civil, structural, mechanical and manufacturing & design engineering received an email requesting those who entered through a Level 7 program to participate in the anonymous online survey. The quantitative data received from the survey was exported and a graphical analysis was completed. The comments provided to support the selection made by the students was examined in order to help understand their responses more thoroughly.

iv. Results

This section presents briefly the qualitative and quantitative data from the research conducted through the face-to-face interviews and the online anonymous survey. Analysis and discussion of these findings will be presented later.

A. Qualitative Results

Five main themes were identified from the interviews: a dip in grades; the expectations of faculty; class integration; study behavior and challenges related to the content of the Level 8 programs. The students' perception of whether their performance dropped as measured by the grades they attained in the first year of transition was mixed overall, with some having experienced a drop in grades while others claimed no effect or even increasing grades at Level 8. The content of the program was perceived to be delivered at a faster pace and more in-depth theoretical aspects were explored. In relation to the expectations of faculty, one key finding was that students perceived more self-directed learning was expected and that a higher quality and depth of analysis was required for Level 8 success. There was little "hand-holding" observed as compared with Level 7 programs. Effective peer-learning and an overall positive interaction between Level 7 articulating students and the existing Level 8 cohort was noted. With regard to study behavior, students indicated that an adjustment was required to balance the workload, giving less time for ongoing study and more time needed for continuous assignments because of the greater workload in Level 8 programs. On the other hand, transitioning students felt they had benefited from their experience of having already completed a final year project at Level 7 and that this increased their ability to plan assignments and projects on the honors program.

B. Quantitative Results

From the online survey, 38% of students stated that articulating was very easy or easy, but the majority (62%, Fig. 3) found it either somewhat challenging or difficult. Many

commented on the fact that some repetition of module content enabled a smooth transition, while comments made in relation to the increased workload evidenced a more challenging aspect of the transition process. The academic performance of the articulating students was mixed, with 57% stating they were successful or very successful with another 30% stating they were somewhat successful. Only 14% felt they were unsuccessful, explaining that they were mentally exhausted or experiencing a lack of motivation (see Fig. 4). Eighty percent of participants responded to the question regarding specific difficulties with module content, with a quarter not finding that any specific content was challenging. Modules that were mentioned as challenging were mathematically based. A higher volume and level of theory was highlighted as a problematic aspect of transition but there was an even spread over other modules based on individual abilities, preferences or learning styles.

Many students perceived no or only minor differences (57%, Fig. 5) with respect to the teaching styles of faculty between Level 7 and Level 8. Students supported their opinions by commenting that they felt more self-learning was expected and in Level 8 a hands-off approach was more evident. Also, it was mentioned that fewer practical "worked through" examples were given at Level 8 with a greater focus on theoretical knowledge proving somewhat more of a challenge to understand. The majority of students found that they had to change their study habits a lot or at least to some degree (62%, Fig. 6) to deal with the Level 8 workload. Predominantly, their comments suggested that there was less time available for study due to projects and group assignments. More personal focus and interest in the program was indicated by some whilst others, now in their 4th year of the Level 8 program and 5th year overall, just wanted to pass and get finished at this stage. Due to their heavy workload, end of semester study rather than consistent study throughout the semester was the main observation here.

A Cronbach Alpha test was carried out to determine the level of internal consistency of responses between the student perceptions of transfer challenge and successful transfer based on their academic performance. The calculated Cronbach alpha value was 0.495. This value indicates that there is a low level of consistency which is evident in some responses. For example, some students considered that the transfer was easy, but were unsuccessful with regard to academic performance.

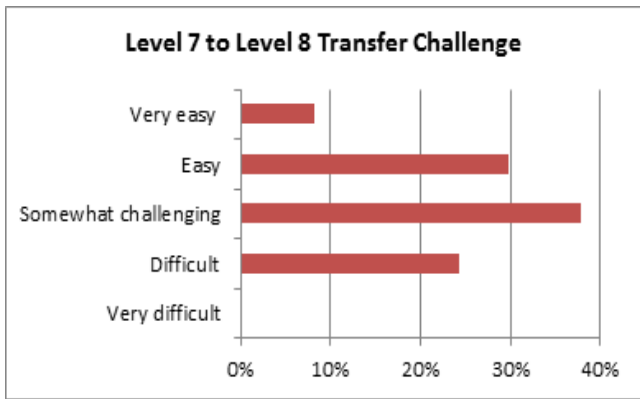


Fig. 3. Students' perception of the challenge in articulating

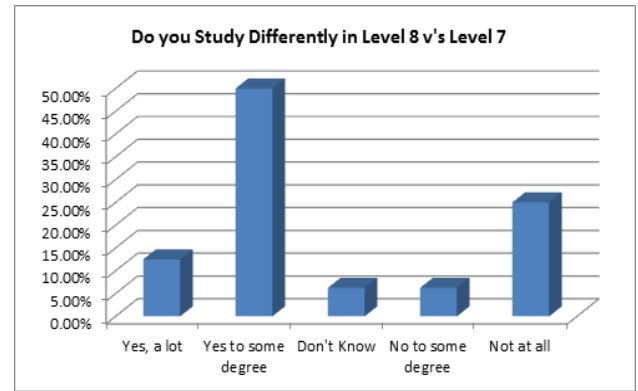


Fig. 6. Students' perception of the difference in their study behavior

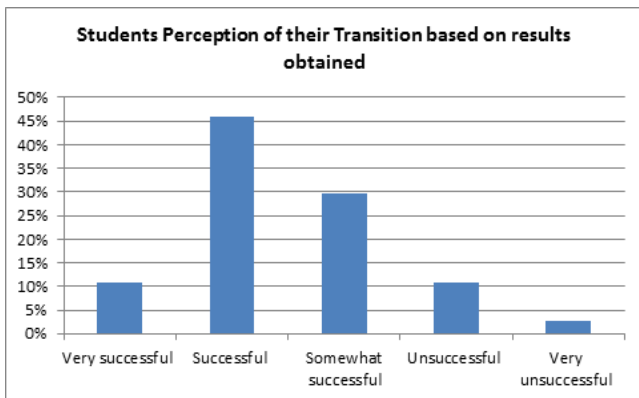


Fig. 4. Students' perception of how well they transitioned based on their academic performance

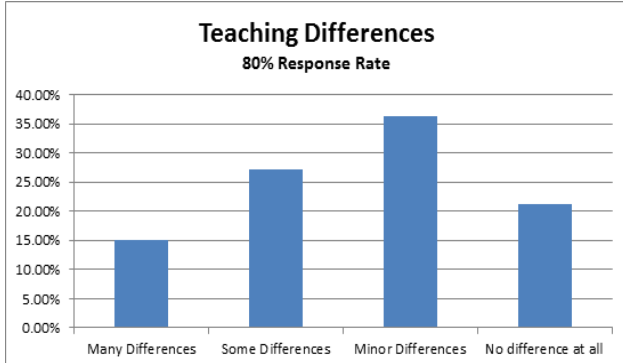


Fig. 5. Students' perception of the difference in teaching styles by faculty members

v. Analysis and discussion

This paper set out to answer the question: do articulating students perceive transfer shock as something that has affected them? This question was analyzed using quantitative and qualitative data and was examined under several themes which now provide a useful framework for discussion of the results. The themes were derived from students' comments collated during interviews with faculty. It is worth observing, however, that these themes fit well with those already identified in research by Winter and Dismore [9] – which are: community, curriculum and culture.

A. Dips in grades

Thirty percent of the interviewees stated that they were somewhat successful in articulating, while only 14% felt they were unsuccessful. Fifty seven percent said they were successful. Since this study involved both 3rd and 4th year students, the findings of this study could be assumed to compare favorably with results from previous studies, [12] and [13], which show that, while identifying initial difficulties in transferring, these appear to be resolved at the end of year 4, when articulating students are on a par with direct entry colleagues in terms of average grades. When grades did not dip the reasons given included the intensity of effort required to complete the Level 7 programs and the level of difficulty at Level 8 not being significantly greater than in Level 7. In contrast, reasons given for grades dipping included a lack of motivation and that the “difficulty was so high”.

B. Faculty expectations

While 57% of respondents perceived only minor differences or some differences in the teaching styles of faculty, comments collated from the interviews show faculty expectations are perceived by some students to be quite different at Level 8. The following quotes emphasize the need for self-directed learning:

- “You have to do a lot more research yourself.”
- “Even the likes of printed out notes, that was left up to yourself.”
- “Left to your own devices.”

Other comments emphasized the faster pace and higher intensity of the requirements of the Level 8 program:

- “It’s just tough to keep up with everything.”
- “There was a significant increase in the workload.”
- “We are expected to up our game.”
- “Maths moved at a slightly quicker pace.”

C. Class integration

Comments made during interviews indicated that students consider integration of former Level 7 and Level 8 students to pose no problems. Comments include “there is not a huge difference between the way they do things and the way I do.” While initially “we would sit on either side of the room”, in semester 2 one student observed “more mixing going on”. Several students perceived the mix to be advantageous to both articulating and traditional Level 8 students, commenting that they “spur us on” and “some of the stuff I would have done in Level 7 and they wouldn’t have touched on, I’d help them with that, and other students would help us with stuff we hadn’t done.” Hence, the positive experience and advantages of peer learning are evident.

D. Study behavior

The majority of students found that they had to change their study habits a lot or at least to some degree (62%) in order to deal with the Level 8 workload. Predominantly, their comments suggested that there was less time available for study due to projects and group assignments. Additional comments collected during interviews indicate again that students feel the Level 7 experience has given them an advantage over their Level 8 colleagues because “we have done a final year project before, we have a good idea of what is needed” and “from the first final year we did, we were slow off the mark, we won’t let that happen again.” Some overlap with the theme of faculty expectations is evident here, with one student commenting “you are being asked to think about

what you are doing ... and see if you can come up with new ideas.”

E. Challenges related to content

Eighty percent of participants responded to the question regarding specific module content challenges, with a quarter not finding that any specific content was challenging. More than 50% of respondents said the transfer to Level 8 was either somewhat challenging or difficult. Some modules (with high theoretical and mathematical content) were highlighted by some as posing difficulties – “it’s a lot more in depth”. Further, the importance of regular attendance at lectures was highlighted – “even if you have covered it before, you have to be in the vicinity to pick things up again”, while other students commented on the amount of repetition between Level 7 modules and their corresponding Level 8 modules. Some saw this as an advantage, especially in the more theoretical modules – “that kinda eased the transition”, while others complained. It was noted that this problem is specific to some engineering disciplines and not to others.

A recurring challenge highlighted by respondents was the volume of assignment work required. Answers included comments like “it’s tough to keep going” and “a significant increase in workload”, “the biggest challenge is to try to get them all done on time”. One student recommended that “people in Level 7 need to be notified more about how difficult Level 8 is”. Another student, however, commented that the “pace increased slightly”.

IV. Conclusions

Previous research at DIT [11] has shown that some articulating students do struggle when they move from Level 7 to Level 8. Other recent research [12] shows that, while students initially struggle with their math modules, their final average marks are on a par with their direct entry colleagues [13]. The purpose of this paper has been to explore students’ own perceptions of their transition, in particular their awareness of experiencing transfer shock or not, their motivations, difficulties and successes. The question this study set out to answer was: do articulating students perceive transfer shock as something that has affected them?

Whilst 38% of students in the online survey stated that articulating was very easy or easy, 62% found it somewhat challenging (38%) or difficult (24%). This provides the clearest indicator of transfer shock. Analysis of the interviews shows that a significant proportion of students do perceive challenges and significant changes in transferring from Level 7 to Level 8 – which concurs with previous studies. The difficulties identified by students correspond to the themes such as faculty expectations, study behavior and content challenges. Integration of former Level 7 and Level 8 students is seen by many interviewees as advantageous, with one

cohort being able to help the other, thereby demonstrating the positive experience of peer learning.

Another indicator of transfer shock is that of academic achievement or dips in grades. The academic performance of the articulating students was mixed, with 57% stating they were either successful or very successful and another 30% stating they were somewhat successful, whilst only 14% felt they were unsuccessful. This divergence in student perception of academic performance could be explained by the fact that the cohort studied as part of this paper includes both 3rd year and 4th year students. It is our contention that the 4th year students have either recovered from the challenges faced in transferring or, indeed, have forgotten that they ever experienced challenges in the first place. This view is supported by findings from a parallel study [13] which shows that the final marks of articulating students are on a par with their direct entry colleagues. The Cronbach Alpha test performed on the internal consistency of responses could indicate the presence of transfer shock also.

Finally, while adjusting to a new campus cannot be considered a factor in contributing to transfer shock in this study, since students articulate within the same campus, it might well ease the articulation process, as suggested by Greenbank [2]. This is validated by analyzing the comments captured by students who responded (38%) that they found the transfer between level 7 and level 8 as 'very easy' or 'easy'.

Further research into articulation of DIT engineering students is planned. Areas to be focused on will include:

- The practice of peer learning between articulating and direct entry students.
- The extent to which faculty expectations differ between Level 7 and Level 8 programs.
- Has Ireland set the correct drivers for its Level 8 engineering programs?

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WhatsApp with Learning Preferences?

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Abstract—Systems Analysis and Design is a second year subject offered as two modules. It forms part of the Information Technology course at the North-West University's Vaal Triangle Campus. As part of an initiative to create varied opportunities for students to learn, the lecturer creates instant messaging groups on WhatsApp; a forum created to allow communication between peers. It is designed to allow students not having access to Internet away from campus, access to peers while preparing for formative and summative assessment.

Felder and Silverman developed five dimensions of learning preferences, each with two sections. Their research built on the research of Kolb, Meyers-Briggs and Jung. The dimensions include: perception where learning takes place in an intuitive way or by sensing; input which may be visual or verbal; organizing which may be inductive or deductive; processing where students learn through active participation or on their own through reflection; and understanding in a sequential or global way.

The WhatsApp environment was included in students learning repertoire to allow for differences in learning preferences and to enable students to get answers to questions while away from campus. With WhatsApp being a social media platform, we may assume that students who learn actively will be more inclined to use it. Since text is used to communicate, we may suspect that verbal learners will also benefit. Pictures can be sent, which may assist visual learners. In this way, it may be argued that most learning preferences can be addressed in a conversation group.

Are these assumptions true? Does instant messaging address most learning preferences? This paper will attempt to identify students from the different learning preferences by analyzing the WhatsApp conversations among them. Other questions that will be answered from this research include: How good is student participation – how many students prefer not to be part of a conversation group for learning, and how many would stay, but only to read conversations between peers?

Keywords— *learning preferences, WhatsApp groups, Systems Analysis and Design*

I. INTRODUCTION AND CONTEXT

Systems Analysis and Design (SA&D) is offered as a second year subject in the Information Technology course offered at the Vaal Triangle Campus (VTC) of the North-West University (NWU). It is offered over a year as two modules.

Students are diverse; black, white, Indian, colored, foreigners; male and female make up the classes that grew from 50 students in 2011 to 125 in 2014. Many students are

from disadvantaged backgrounds, magnifying the importance of using resources to its full capacity.

Students find the subject difficult for various reasons, including the fact that the subject is not as structured as mathematics and programming (in which they normally excel), but fuzzy; it includes a lot of material to be made sense of and the lecturer expects them to work in groups while it is the first time they are exposed to closely working with and relying on their peers. To help all students to participate to their full capacity, many resources are utilized and made available to students. These include eFundi, a Learning Management System (LMS) with all resources and information uploaded in one place. Since 2014 study guides were replaced by SmartGuides, which are downloadable to any device and are used to guide students through every study unit. Videos on difficult concepts support the text book. Various formative assessment opportunities exist to create formative feedback opportunities and allow students to build a solid participation mark. A group project teaches students to work in groups to support one another and learn from one another.

Since students consistently find the preparation for semester tests the most difficult and stressful activity, the compilation of instant messaging (IM) groups were introduced to allow students to communicate with one another and get feedback from peers or the lecturer – immediately. When the initiative was introduced, Blackberry Messenger (BBM), MXiT (a South African development) and WhatsApp were used to ensure that all students have access, but since the middle of 2013 only WhatsApp is used, since most students have access to it. It was found that group sizes should be fairly big to ensure active communication on a variety of topics. Here the developments in IM implementations assisted its use for our purpose – when the project started in 2012, the three IM applications used (BBM, MXiT, WhatsApp) allowed between 15 and 25 people per group, this was extended with subsequent upgrades of WhatsApp to 50 in 2013 and 100 in 2015. Bigger groups generate lots of communication, streamed 24/7 as students work on different schedules. This did create problems for some students who left the groups when the discussions got momentum. Since the early days some time is taken to make group members aware that posts need to be made with care and that one may silence a conversation while focusing on studies or sleeping – current applications allows it.

In the subsequent sections the following topics will be addressed, namely the formulation of the problem, a background on learning preferences, a discussion of the research project, the learning preferences identified from the WhatsApp conversations and finally, the concluding remarks.

II. PROBLEM FORMULATION

An obvious potential advantage of the use of IM in learning is that factors that normally hinder collaboration and group work are minimized when using this technology. Irrespective of geographical distances, students are able to interact with their lecturers and classmates, both synchronously and asynchronously.

The disadvantages of online discussions emerged through a study by reference [1] who reported that some participants preferred a face-to-face format to the more limited social interaction of an online learning environment. Reference [2] again, found the limited flow in dialogue and the absence facial expressions and gestures that occur in face-to-face contact, limited the impact of discussions. It was also found that some students were intimidated by having to put their thoughts in writing [3].

To counteract some of the disadvantages mentioned reference [10] reports that the use of emoticons, for example “:D” or “😊” to show emotion, small verbalizations like “lol” (which means “laugh out loud”) or “yea” are used to sustain conversational flow and also to demonstrate understanding. This enables the student to build rapport and establish common ground.

To what extent do WhatsApp conversations, as a teaching and learning tool, support the different learning preferences?

During the first semester of 2012, IM platforms (BlackBerry Messaging (BBM), WhatsApp and MXit) were introduced to support students’ learning. Students were asked to indicate the platform they already use to socialize, so platforms were utilized based on their popularity among the students. Initially IM was used to make concepts covered in SA&D available to students – on their cell phones. It was thought that this would allow students to familiarize themselves with concepts anywhere, anytime. This experiment was not received well by students and they suggested that it would be better if the platforms could rather be used to support them in preparing for semester tests and examinations.

The suggestion was implemented during the latter part of the same semester, using the same platforms. Groups were formed according to the restrictions of each platform, and the number of students using each platform. The lecturer created groups from information supplied by students on a voluntary basis. Students were invited to join at any time and they could delete the conversation at any time. For this reason figures supplied in Table I below are only estimations – numbers changed on a continuous basis as students were added and removed themselves. In addition to the voluntary basis on which the interaction worked, technology is not stable, cell phones break, they get stolen and, especially in the early days upgrades left one with a virgin IM tool – all groups and conversations were lost.

Students were prepared that they were supposed to help one another, although the lecturer would clarify issues when she felt students go astray.

During the first semester of 2013, it was noticed that MXit lost its popularity among the students (only one student used it)

and although BBM was still popular, all students using it also used WhatsApp. This situation called for the decision to only use WhatsApp – which allowed groups of up to 50 students at that time. This decision was supported by the fact that MXit made use of advertisements to supply an income stream – a model that can distract attention from the work at hand. On the other hand, BBM allowed students to choose their own names – which made it difficult for the lecturer to identify the person talking. BBM was also only supported by a BlackBerry phone in the initial years. The lecturer felt that WhatsApp was accessible by all smartphones, it focused on conversations only, it supported the sending of pictures to support conversations and it was easy to identify students.

TABLE I. CLASSES AND STUDENTS USING IM IN SA&D

<i>Year</i>	<i>Class size</i>	<i>WhatsApp</i>	<i>BBM</i>	<i>MXiT</i>
2011, S1	50			
2011, S2	44			
2012, S1	82	23 (2 groups)	19 (1 group)	23 (1 group)
2012, S2	70	20 (2 groups)	15 (1 group)	18 (1 group)
2013, S1	110	45 (1 group)	18 (1 group)	1 student
2013, S2	86	42 (1 group)		
2014, S1	126	93 (3 groups)		
2014, S2	78	64 (2 groups)		

In addition to the groups listed in Table I, a new group was formed after the first examination was written at the end of each semester. The NWU allows for a second opportunity examination for students not able to write the first examination, or failing it.

In the next section learning preferences are scrutinized to set the scheme for evaluation the students’ learning preferences on the IM platform.

III. LEARNING PREFERENCES

Reference [4] studied students in the engineering field and identified five learning dimensions, each having two focuses. This information is reflected in Table II that follows on the next page.

The answers to five choices may define a student’s learning preference [4]:

1) The type of information the student preferentially perceive is either sensory which includes sights, sounds, physical sensations; or intuitive which includes possibilities, insights, hunches.

2) The sensory channel through which external information is effectively perceived may be visual, including pictures, diagrams and demonstrations; or verbal, including words and sounds.

3) The organization of information with which the student is most comfortable is either inductive, where facts and observations are given, underlying principles are inferred; or deductive where principles are given, consequences and applications are deduced.

4) The student’s preference regarding processing of information, which may be actively through engagement in

physical activity or discussion; or reflectively through introspection.

5) The student's progression towards understanding, which may be sequentially, occurring in continual steps; or globally, occurring in large jumps, holistically.

TABLE II. LEARNING PREFERENCES ADOPTED FROM REFERENCE [4]

<i>Dimension</i>	<i>Focus</i>	<i>Description</i>
Perception	Intuitive	Uses existing knowledge framework to scaffold new concepts and find relationships, little attention to detail.
	Sensing	Experiment with new concepts, like to do examples to learn, build on facts.
Input	Visual	See new concepts in pictures, diagrams, demonstrations, graphics. Color attracts them.
	Verbal	Learn through words, whether written or verbal, hearing and explaining to others enhances remembering.
Organization	Inductive	Reasoning progresses from particulars to generalities.
	Deductive	Reasoning progresses from principles to consequences.
Processing	Active	Summarize new concepts, participate in discussions with peers; or explain to peers.
	Reflective	Needs time alone to think about new concepts. Learn on their own.
Understanding	Sequential	Linear lessons offered in short successive sessions, increasing in difficulty.
	Global	First sees the bigger picture, then the detail and its relationships. Relates new concepts to current knowledge and understanding.

The index of learning styles, developed by references [5, 6], addresses only the last four categories in its questions, namely input, organization, processing and understanding.

Reference [7] stresses the fact that no learning preference is preferred to another. They are simply different. Each has its own strengths and weaknesses. Lecturers should equip students with the skills associated with each preference.

With the above statement in mind, it is also true that for a professional person to function effectively in a work environment; requires working well in all learning preference modes [8].

It is the opinion of the researcher that is especially true in SA&D, because of the fact that the discipline requires people skills and technical ability and requires of the professional to draw from a variety of tools to be able to do the job well. It is therefore also important to develop a well-rounded young professional with regards to learning preferences.

IV. RESEARCH PROJECT

Interpretive research is a research paradigm that allows a researcher to understand the research environment [9]. This research project has the goal to understand through determining whether IM conversations allow students along the learning preference spectrum to use it as a learning tool.

WhatsApp history is downloadable through electronic mail. It lists conversations, indicating the person talking, the time and the date. For the purpose of this paper students are protected and their identities are not made known. Pictures that were sent are not shown on the history. This conversation data was analyzed to decide which learning preference a student likely prefers. Snippets of conversations are used to illustrate and motivate this.

For the purpose of this paper, the communication in the WhatsApp group created for the second opportunity examination of the first semester of 2013, are used for analysis purposes. The group was fairly small – it consisted of 18 students, but was made up of a group of students motivated to pass the subject module.

The second opportunity examination group was created on 2 July 2013, the examination was scheduled for the afternoon of 5 July 2013 and the group dismantled on 14 July 2015. It included almost 400 conversation lines.

The basic structure included the following:

- The **formation** of the group by the lecturer. The group is named and a group photo that may be changed by any participant is uploaded. The students are prepared regarding the purpose of the group. Missing members are named to enlist the help of the members in getting them on board.
- Six **topics** were discussed, of which the longest covered almost 135 conversation lines. They included the following:
 - Topic 1: Expectation management.
 - Topic 2: Gantt charts.
 - Topic 3: Object-oriented analysis.
 - Topic 4: Use-cases.
 - Topic 5: Cross life-cycle activities.
 - Topic 6: Entity relationship diagrams.
- **Administrative issues** were addressed during these topic conversations. Administrative issues addressed, included the following; arranging a face-to-face examination preparation session and clarifying the purpose of the second examination.
- Establishing the **scope** of the paper. Although the scope of the paper includes all the subject module outcomes, allowing students to speculate on the chances of a question being asked may help them to enter the examination being more confident.
- **Unwind** from the pressure of the examination, directly after the examination. Four members left the group immediately after the examination was written. The rest stayed on to talk about the experience writing the examination and to keep tabs on the assessment progress. Most students left the group after their marks were made available.

These categories may be compared to the work done by reference [10], where four conversation types were identified, namely:

- 1) A shared understanding and the construction of meaning, where peers talk only for the purpose of establishing common ground.
- 2) Displays of intimacy and making fun for the purpose of building relationships.
- 3) Labor division in the creation of artifacts (or answers) – something that was not found regularly in this research.
- 4) Sharing of feelings regarding work completed, their lecturer(s) and peers.

It may be noted that the first two points were almost absent in the SA&D conversations. This may be because of the fact that these students worked together in groups and knew one another quite well when the group was formed.

Labor division (point 3) did occur during the discussion of topic 2, although it was initiated by the lecturer.

The fourth point also occurred after the examination was written when students speculated on their chances of passing.

In addition to the four conversation types mentioned by reference [10], discussion of the topics mentioned occurred, which was very encouraging.

The WhatsApp group had 15 members. This supported the claim that the students were motivated to do what was necessary to pass the module. Only 9 students actively participated in the discussions. The other 6 students only “listened in” and did not say anything. It is hoped that these students learnt while reading even though they were not participating.

Of the 9 students who interacted, 4 students participated by using the forum only to solve administrative problems. It is hoped that these students were set at ease and could therefore focus on their studies. One student only participated while the scope was discussed.

The WhatsApp conversations included the discussion of 6 topics among the lecturer and 4 students who made meaningful contributions. From the analyses, deductions can be made to determine whether IM as a teaching and learning tool accommodates most learning preferences.

V. LEARNING PREFERENCES IDENTIFIED IN WHATSAPP CONVERSATIONS

Referring to Table II in Section III and Section III in general, the four dimensions used to determine learning preferences, namely input, organization, processing and understanding, builds on one another, where the input represents the way learners prefer to view new information; organization refers to how they would integrate this new information with what they already know; processing refers to how they prefer to interrogate the new information to convert it to knowledge and understanding refers to how they would likely look at the world – using a bird’s eye view or seeing details as important.

Keeping this building block categorization in mind, the data of the four students who participated in a meaningful conversation about the material to be examined was analyzed. Tables III, IV, V and VI show the evidence as compiled by the researcher.

TABLE III. LEARNING PREFERENCES STUDENT A

<i>Student A</i>	<i>Classification</i>		<i>Example from conversations</i>
Input	Visual	Verbal	Topic 2: (<i>advised another student to watch a video on the topic</i>) “Theres a video on how to do gantt and pert diagrams. Check it out it will help u.”
Organization	Inductive	Deductive	Topic 2: (<i>figuring out the critical path</i>) “Subtract the others from the critical path, since its the longest, we dnt want negatives.”
Processing	Active	Reflective	Active participation during the topic 2 discussion.
Understanding	Sequential	Global	Topic 2: (<i>attention to detail</i>) “I also think the nodes shud b there even thou we dnt write anything on them”

From her conversations, student A is perceived as a *visual* learner who watches the videos provided, she derives at conclusions regarding what she sees (*inductive*) to help her organize the information. She is an *active* learner who likes to interact with others while processing information. Although her understanding is difficult to assess, her attention to detail categorizes her as a *sequential* learner.

TABLE IV. LEARNING PREFERENCES STUDENT B

<i>Student B</i>	<i>Classification</i>		<i>Example from conversations</i>
Input	Visual	Verbal	Topic 3: “Mense, could yal please explain the inheritance relationship ... hw to draw the second part of it”
Organization	Inductive	Deductive	Topic 2: (<i>figuring out what a dummy path is</i>) “Yah ... bt wt mkes the path to b a dummy path???”
Processing	Active	Reflective	Active participation during the topic 1, 2 and 3 discussions.
Understanding	Sequential	Global	Topic 2: “Ka gantt u draw bars not lines ... ke pert dt uses lines to connect paths ... a path ka gantt is represented by a bar ...”

From her conversations, student B is perceived as a *verbal* learner, since she only uses only words to communicate; she makes deductions from the examples discussed (*inductive*). She is an *active* learner who likes to interact with others while

processing information. Her understanding is assessed as *sequential*, since it is clear that she gives attention to detail.

TABLE V. LEARNING PREFERENCES STUDENT C

<i>Student C</i>	<i>Classification</i>		<i>Example from conversations</i>
Input	Visual	Verbal	Topic 2: Uploaded a picture.
Organization	Inductive	Deductive	Topic 2: (<i>loads Gantt example, then interrogates it</i>) "In my Gantt chart how do I represent two paths that connects to one point, like Mam say path E 2 B, C?"
Processing	Active	Reflective	Topic 2: (<i>after an explanation by another student</i>) "Yes I agree with u, ohk let me try figure it out..thank neh"
Understanding	Sequential	Global	Topic 2: (<i>attention to detail</i>) "I am not sure I get u, on node activity diagram I do get I can connect the parts, but in my Gantt chart I have to shade the days my project will take place, so I am puzzled on how we do dat in Gantt Chart."

From her conversations, student C is perceived as a *visual* learner who likes to draw conclusions from the examples discussed (*inductive*) to help her organize the information. She is a *reflective* learner who prefers to spend time on her own to process information. Although her understanding is difficult to assess, her attention to detail categorizes her as a *sequential* learner.

TABLE VI. LEARNING PREFERENCES STUDENT D

<i>Student D</i>	<i>Classification</i>		<i>Example from conversations</i>
Input	Visual	Verbal	Topic 5: (<i>another student asked where to find information on cross-life cycle activities</i>) "It's on chapter 3's slides."
Organization	Inductive	Deductive	No evidence.
Processing	Active	Reflective	No evidence.
Understanding	Sequential	Global	Topic 5: (<i>another student asked where to find information on cross-life cycle activities</i>) "It's on chapter 3's slides."

From his limited interaction, student D is perceived as a verbal learner. He gives no indication of his preferences regarding organization and processing of new information. The fact that he knows exactly where the information his peer is requesting is to be found, categorizes him as a sequential learner.

VI. CONCLUSION

For the purpose of this paper a fairly small group of students were selected. They were part of a WhatsApp IM group preparing for a second opportunity examination. Their conversations were analyzed to determine their learning styles as displayed in their conversations.

From the analysis of the conversations an IM application like WhatsApp may be categorized as a useful tool to assist students in their preparation for assessment. Table VII attempts to use a heat map approach to indicate how useful WhatsApp may be as a tool to accommodate learning preferences when preparing for assessments.

TABLE VII. IM'S CAPACITY TO ACCOMMODATE LEARNING PREFERENCES

Does IMs accommodate learning preferences?		
<i>Dimension</i>	<i>Focus</i>	<i>Motivation</i>
Input	Visual	Since WhatsApp allows for the distribution of pictures, visual learning is supported.
	Verbal	Verbal explanations work well on WhatsApp.
Organization	Inductive	On WhatsApp it is easy to list examples and progress from particulars to generalities.
	Deductive	WhatsApp is not a teaching tool and therefore deductive reasoning will rarely happen..
Processing	Active	Any person may start a conversation, get inputs and discuss topics.
	Reflective	A cell phone can be put on silent or ignored.
Understanding	Sequential	The fact that more than one conversation may take place at the same time may confuse a person who understands sequentially.
	Global	Distribution of pictures like mind-maps may assist. Unfortunately little evidence could be found as proof of understanding.
Heat map clarification		
Not well-suited		Fairly well-suited
		Well-suited

In the conversations analyzed, little evidence was found of students' understanding and deductions had to be made. It may be that students prefer not to converse their progress towards understanding or that they progress towards understanding on their own, while studying and making sense of what was discussed on the IM platform.

Future research may include the following:

- To focus on a larger group of students with a bigger cohort participating actively. Such a study may include a larger variety of differences in learning preferences – with the accompanying proof in terms of conversations.
- The research may also be expanded to include teaching styles to match learning preferences. This may help students struggling to progress because of a mismatch with the lecturer's preferred teaching style.
- The delivery of a well-rounded young professional upon graduation may include the development of individual students' non-prominent learning preferences.

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The Puerto Rico CubeSat Project to Attract STEM Students Into the Area of Aerospace Engineering

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Abstract – The purpose of this paper is to present an interdisciplinary research project in order to attract engineering students to the area of aerospace systems. The Puerto Rico NASA Space Grant (PRSGC) is a joint program between the University of Puerto Rico-Mayagüez (UPRM), the Inter American University of Puerto Rico-Bayamon (UIPRB) and other educational institutions. The desired impact of the project is to promote interdisciplinary research in the area of aerospace systems with the collaboration of graduate and undergraduate students from electrical, mechanical and computer engineering departments. As an example of the progress obtained through interdisciplinary research, this paper will focus on the Electronic Power Supply (EPS) developed of a CubeSat by both the UPRM and the UIPRB. CubeSats are miniature satellites designed for space science explorations. Due to their low cost and reduced size, not only have they earned an eminent position in the field of space exploration but they have also become a reliable tool for space education. The multidisciplinary process consists of the design, simulation, and construction of each the CubeSats EPS. This collaboration has helped create ties between UPRM and the UIPRB.

Index Terms – *CubeSat, aerospace, interdisciplinary research, study programs, electrical power supply*

I. INTRODUCTION

It is evident that research and development has become an essential part of a large number of engineering universities for its significant contributions to society [1]. Despite the global impact research conveys, it is mostly a closed group effort. Specific groups (companies, organizations, universities, departments, etc.) work towards achieving a single objective in order to create a positive impact. Engineering research should no longer be constrained to single agencies; interdisciplinary efforts should aid in accomplishing global objectives. Recently universities have adopted interdisciplinary approaches, collaborating with other institutes in order to expand ideas and improve teaching methods [2]. As part of the PRSGC, engineering departments from different universities in Puerto Rico have merged together in order to design and construct Puerto Rico's first functioning CubeSat. This project is considered to be interdisciplinary due to its use of the diverse aspects performed by the different fields of engineering. The PRSGC is composed of the UPRM, the UIPRB as well as other educational institutes in Puerto Rico. Fig. 1 illustrates a diagram of the different universities, agencies and departments that are collaborating in this project.

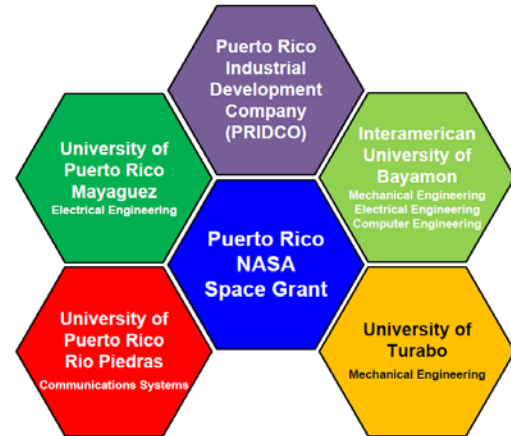


Fig 1: The collaborators in the NASA Space Grant Consortium. Certain projects focus on the collaboration between different educational institutions in Puerto Rico.

The PRSGC is an opportunity to encourage collaboration between different universities in Puerto Rico while at the same time promoting a higher degree of learning. The PRSGC focuses on enhancing Puerto Rico's research, education and workforce in the fields of Science, Technology, Engineering and Mathematics (STEM). With this in mind, the participating universities are encouraged to collaborate in different projects in an interdisciplinary manner. For this reason UPRM along with the UIPRB are collaborating in aerospace related projects to create a platform for students to work on. Some of these aerospace related projects involve unmanned aerial vehicles and small satellites. One of the steps taken to strengthen the aerospace program of both the UPRM and UIPRB is to combine both their curriculums. As an example of the progress obtained through interdisciplinary research, this paper will focus on the results obtained through the collaboration of the UPRM and the UIPRB.

This article is organized in the following manner: section II describes the academic background of the UPRM and UIPRB as well as their collaboration. Section III gives a general description of the selected aerospace project. Section IV describes the projects methodology and expectations from each engineering field. Section V describes the educational impact the project had on students. Finally section VI presents the conclusions obtained.

II. ACADEMIC BACKGROUND AND COLLABORATIONS

The UPRM is a public university located in the municipality of Mayagüez, Puerto Rico established in 1911. UPRM offers 52 bachelor's programs, 28 master's programs and 5 doctoral programs. Moreover, it has been accredited by the Middle States Commission on Higher Education (MSCHE) since 1946 and by the Accreditation Board of Engineering and Technology (ABET), ranking among the top 10 U.S. universities in the field of engineering. The Electrical and Computer Engineering (ECE) Program currently has nearly 1,100 students which represents nearly 10% of the whole UPRM's student population and more that 20% of the UPRM College of Engineering' student population. Also, the ECE Department's research and graduate programs involve 14 laboratories, groups and centers, more than 40 graduate-level courses, 49 faculty members with PhD degrees, 2 adjunct professors, nearly 1,100 undergraduate students and over 60 graduated students. At present, the ECE Department offers BS and MS degrees in ECE and a PhD in computer informatics science and engineering.

The ECE Department offers several areas of specialization that could be applied to aerospace systems: control systems (e.g. trajectory optimization), electronics (e.g. IC for energy harvesting), power electronics (e.g. high density power supplies for satellites), computing systems (e.g. cyber security), and communications (e.g. wireless communications). Also, collaborations between the Mechanical Engineering (ME) Department and the ECE Department have resulted in a minor in Aerospace Engineering. Table I shows examples of the foundation courses offered by the ME Department. Table II shows examples of ECE and ME elective courses that are offered as part of the aerospace program.

TABLE I: UPRM AEROSPACE FOUNDATION COURSES

Field	Course	Description
Mechanical Engineering	INME 4709	Aircraft Performance
	INME 4717	Introduction to Aircraft Structural Analysis

TABLE II: UPRM AEROSPACE ELECTIVE COURSES

Field	Course	Description
Mechanical Engineering	INME 4705	Applied Aerodynamics
	INME 5717	Aircraft Structural Analysis and Design
	INME 5707	Gas Turbine System Operation
Computer Engineering	ICOM 5015	Artificial Intelligence
	ICOM 5018	Network Security and Cryptography
	ICOM 4009	Software Engineering
	ICOM 5217	Microprocessor Interfacing
	INEL 4308	Networking and Routing Fundamentals
	INEL 4207	Digital Electronics
Electrical Engineering	INEL 4416	Power Electronics
	INEL 5309	Digital Signal Processing
	INEL 5505	Linear System Analysis
	INEL 5605	Antenna Theory and Design

The UIPRB is a private university located in Bayamon, Puerto Rico, established in 1956. With an enrollment of about 5,000 students, UIPRB offers undergraduate programs with emphasis on technology, engineering, aviation, computer and science. Its BS programs in Industrial, Electrical and Mechanical engineering are also accredited by ABET. Its ME program is designed to train students to develop the knowledge and abilities needed to function as an efficient professional in the fields of energy and aerospace by providing students with the opportunity to hone in on the necessary skills required to become successful in the aerospace industry.

One of the UIPRBs largest contributions is their research facilities, which are designed for aerospace testing; ground station laboratory for communications systems, thermal analysis laboratory equipped with thermal oven and a vacuum designed for testing space conditions. The university also possesses a control systems and electronics laboratory as well as a clean room. Table III illustrates the UIPRBs aerospace programs and courses.

TABLE III: UIPR-BAYAMON AEROSPACE PROGRAM

Program	Course	Description
Minor Aerospace Engineering	MECN 3974	Aerospace Experience I
	MECN 3973	Aerospace Experience II
	MECN 3975	Space Mission Analysis and Design
	MECN 4301	Aerospace Materials
	MECN 3545	Gas Turbines and Propulsion systems
	MECN 3350	Aircraft Design and Performance
Master of Science in Mechanical Engineering with concentration in Aerospace	MECN 6210	System Engineering
	MECN 6220	Advance Structure Engineering
	MECN 6230	Aerospace Dynamic
	MECN 6300	Advance Control System
	MECN 6260	Advance Mechanical Vibration

The UIPRBs curriculum and facilities in combination with the UPRMs courses is the key to developing successful projects in the field of aerospace. Undergraduate courses from the UIPRB such as; MECN 3974 and MECN 3973 provide UPRM students with the fundamental in the field of aerospace. Graduate design courses like MECN 6230 are also incorporated into lectures in order to gives students a better understanding of aerospace dynamics.

For the fall semester of 2014, the ECE Department of UPRM provided the graduate courses of INEL 6085 and INEL 6066. These courses were used to introduce the concept of aerospace applications into the curriculum and shared with faculty and students from UIPRB. Both of these courses incorporated the subjects of solar energy and power supply design, two topics that are essential for the aerospace applications. The final projects for these courses were also related to aerospace and were presented to students and faculty from both universities. For the spring semester of 2015, a new course, INEL 6995, was created and added to the graduate curriculum for the sole purpose of continuing this interdisciplinary collaboration between universities.

III. THE CUBESAT PROJECT

A CubeSat is a miniature satellite originally designed for space science exploration. Conceived as an educational tool, they have managed to challenge traditional satellite standards and are recognized for their potential utility by space and research agencies around the world [3]. The design and construction of a satellite is a multidisciplinary effort, involving aspects of all fields of engineering [4]. It is not expected that a single group should design and construct the entire CubeSat. For this task to be achieved it is essential to involve several groups, from different institutes and disciplines [5], [6]. These CubeSat projects are primarily led by universities and non-US space groups. In most cases government agencies have sponsored the development of these projects through organizations such as; NASA, National Science Foundation, and the Department of Energy [7].

CubeSats are mainly composed of several units; an on-board computer, control and communication systems, among other measurement devices. In order for these units to operate it is essential that their power is supplied by an EPS. The interconnection between the EPS and other subsystems is the key in developing a well-functioning CubeSat [8]. The UPRM, in collaboration with UIPRB are tasked with designing the EPS for the Space Plasma Ionic Charge Analyzer (SPICA) CubeSat. This is achieved by joining together the electrical, mechanical and computer engineering departments. The wide variety of courses and facilities from both universities will help students develop an EPS prototype for the CubeSat. Fig. 2 shows a Computer Aided Design (CAD) 3D model of a standard U2 CubeSat design, illustrating some of the most vital parts of the EPS developed by students.

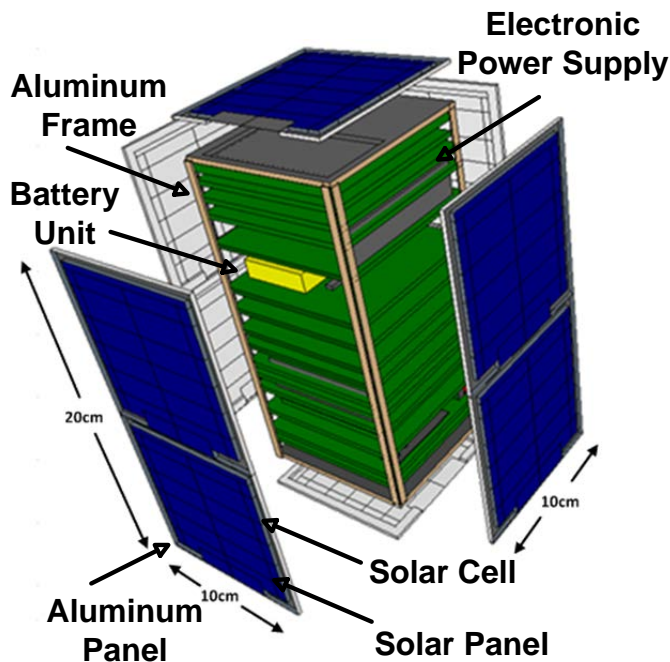


Fig 2: Standard 2U CubeSat diagram. CubeSats are small scale satellites composed of several subsystems. They are designed to provide easy access to space science education and space science exploration.

IV. PROJECT METHODOLOGY

Through the PRSGC, graduate and undergraduate students from UPRM and UIPRB collaborate in the project. This project organization is based on similar Cubesat schemes from other successful institutes that have managed to create an impact in their communities [9], [10], [11]. This university uses a project group structure composed of three groups; Project Management Group, Supervisor Group, as well as several other Project Groups. The supervisor group is composed of the supervisors of the different project groups tasked with providing guidance to each group. These groups are overseen by a steering committee composed of each member of the project groups and the professor acting as project manager.

A similar project organization is adapted for this project joining together faculty, industrial affiliates and students. Faculty members are involved in supervising the overall development of the project. They provide students with course work, articles and related material that may guide them in the right direction. Faculty members are aware that their participation in the project must not interfere in the student's leadership development. In addition, graduate advisors can become a part of the mentoring process. These advisors can range from professors to industrial affiliates. The team is organized in order place students in charge of the project. The team leaders or Systems Engineering Group, composed primarily of graduate students, are in charge of managing and keeping a constant flow of information between all engineering groups. They are also the bridge between students and advisors. Fig. 3 illustrates the organization of the team established by both the UPRM and UIPRB.

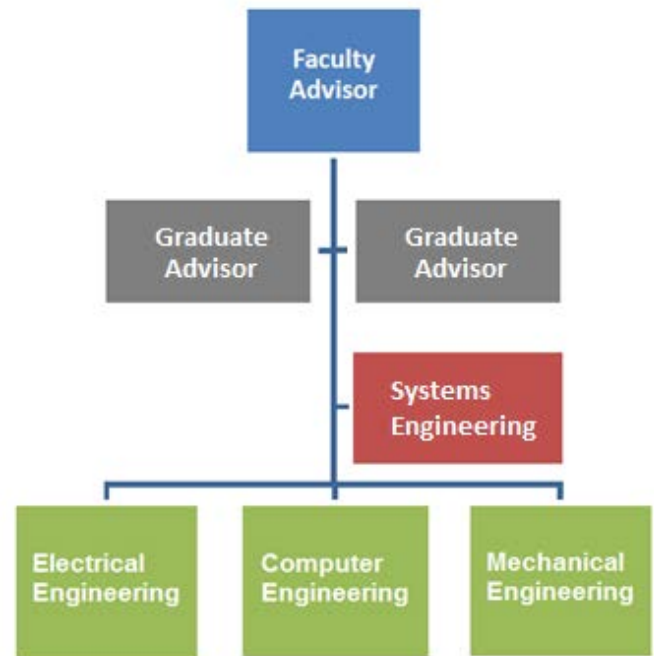


Fig 3: Team organization. Team includes faculty advisors, graduate advisors as well as the integration of each engineering discipline. The group is organized in a manner that students have the responsibility of leading the project.

Four teams are formed, each team consisting of students from both the UPRM and UIPRB. Each group specializes in a specific engineering field; electrical, computer and mechanical engineering. An additional group consists of one student member from each engineering field. Teams are student managed and are assisted by mentors and supported by industry specialists [12], [13]. This teaching method requires teams to work together, for the duration of several semesters, in order to learn the necessary skills required to complete their tasks [14]. Each one of these teams is expected to have a basic set of skills that play an essential part in the project with the purpose of teaching students new skills. However there are some basic abilities that students should possess in order to understand how to tackle obstacles that may occur during the course of the project.

A. Systems Engineering Group

The systems engineering group are the student team leaders of the project. They consist of one student representative from each engineering department. These students are the leaders of their respective engineering groups and are expected to be experts in their field. Their responsibilities are not limited to their engineering knowledge; they must also possess strong communication skills, leadership abilities and powerful project management skills. The main objective of this group is to promote interdisciplinary research among other groups. This group is also the bridge between the engineering groups and the faculty advisor. They must present results as well as the progress of the project.

B. Electrical Engineering

Electrical engineering students are required to have a solid background in circuit design and analysis. It is essential that the group possesses basic circuit analysis knowledge in order to understand the electrical characteristics of the topologies proposed for the EPS. An intense literary review of conference articles, journals and transactions help identify acceptable circuit designs. Once a series of circuit topologies are selected, students design, build and test them in order to identify which are more suitable based on the desired application.

C. Computer Engineering

The students from the computer engineering team are expected to have enough background in order to program microcontrollers (MCUs) and to be able to implement different types of algorithms. These students are prepared to attack any computational problems that may occur. Students are also expected to be familiar with software that can aid other groups by using simulation software or computer aided Printed Circuit Board (PCB) design tools.

D. Mechanical Engineering

Mechanical engineering students are suggested to have taken courses contained in the aerospace programs offered by the ME Department of UPRM and UIPRB. These students must be able to design small parts, structural hardware and other components required by the CubeSat infrastructure. These students are also expected to have basic skills related to CAD, and computer aided manufacturing (CAM) software, as well as computer numerical controlled (CNC) tools for milling machines.

Each group is assigned a certain task in order to identify what goals must be completed at the end of each semester. Table IV shows the organized teams and their respective responsibilities.

TABLE IV: TEAM AND TASK DISTRIBUTION

Field	Task	Description
Electrical Engineering	Design	The design process consists of selecting the suitable circuit topologies for the EPS. Once the design for the EPS is completed, electrical engineering students work alongside the computer engineering group in order to design the PCB layout using CAD tools.
	Construct	Students must construct a final EPS prototype that complies with the CubeSat weight and size limitations established by the mechanical engineering group.
	Test	The testing process involves characterizing the solar panels as well as validating the functionality of the EPS.
Computer Engineering	Design	This task requires basic programming knowledge of MCU in order to design the control system responsible for performing the MPPT and any additional control functions.
	Construct	The construction process consists of building a simulation for the entire EPS system including the CubeSats solar power array. This group also aids the electrical engineering group with PCB design software and the mechanical engineering group with CNC design tools.
	Test	Testing requires students to assure that the MCU is executing the correct algorithms for the control system as well as the MPPT.
Mechanical Engineering	Design	This task requires the design of small parts, structural hardware and other components required for the CubeSats infrastructure.
	Construct	The construction process requires the mechanical engineering students to work together with the electrical and computer engineering groups in order to manufacture the PCB for the EPS using CNC machine tools.
	Test	The testing process involves thermal and vibration testing in order to assure that the EPS can withstand deployments as well as the harsh conditions of space.

Although groups focus on their own tasks, students are encouraged to assist each other in order to promote interdisciplinary research. This in combination with the time shared in the laboratories helps create an exchange of information between the different engineering disciplines that promotes an interdisciplinary research environment [15], [16]. Because of the interdisciplinary aspect of the research project, there is a great number of professional skills learned between the students that is not learned in traditional classrooms. This skills help build the bridge between the learning and the social environment of the academia. Teams are encouraged to prepare presentations, reports and articles as well as attend conferences and workshops in order to teach them how to present their work to experts, professionals, and colleagues [17].

V. BROADER EDUCATIONAL IMPACT AND RESULTS

A beneficial impact obtained from this project is the experience students earn from working with relevant software in the field of engineering: MATLAB, Simulink, Multisim and LabView among others. These different software tools help simulate stress and space conditions that cannot be easily verified with theoretical calculations. In the ECE department of the UPRM, power electronics is generally applied to the subjects of motor control and renewable energy. This project has broadened the field of power electronics applications in the area of aerospace. A variety of DC/DC converters topologies, microcontrollers (MSP430, ArduinoUno, Propeller, Parallax, etc.) and MPPT techniques have been explored in order to meet the CubeSats specific needs. Another added incentive from this project is improving the students' hands-on skills and laboratory capabilities. Students learn how to design and print circuit boards. Fig. 4 illustrates a PCB design made with the Eagle software for the final version of the CubeSats EPS.

This project has provided student the experience of focusing on a variety of tasks while also allowing them to coordinate work between various groups from other departments and in the UPRM and the UIPRB [18]. It has motivated undergraduate students in the mechanical, electrical and computer engineering and computer science programs to embrace a multidisciplinary approach to engineering. Currently there are 42 students working directly on the CubeSat project. Notice the improvement in the design of the EPS. The initial prototype, although functional, is bulky and exceeds the CubeSats size limitations. In a period of half a year, the students have taken the design and transformed it into a robust, that complies with both size and weight limitations. The constructed CubeSat EPS prototypes developed over the course of the project are shown in fig. 5.

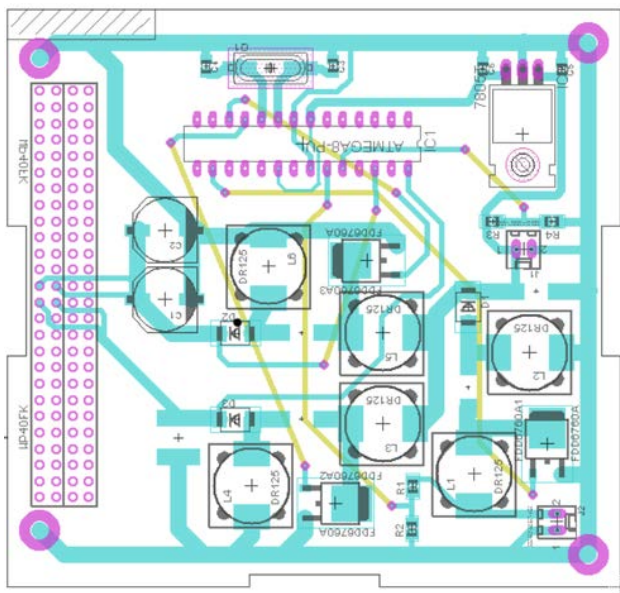
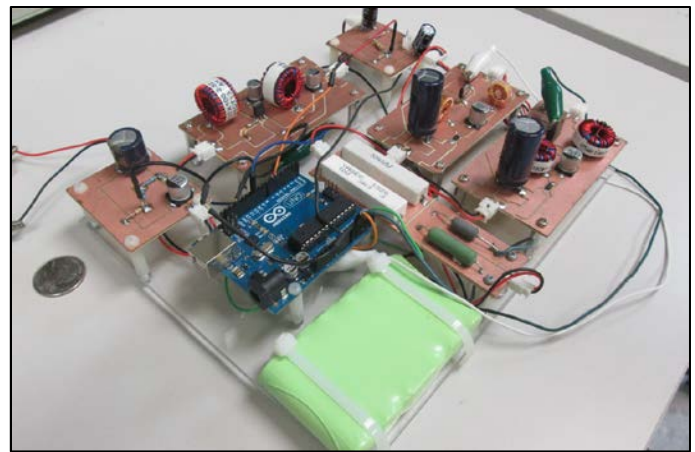
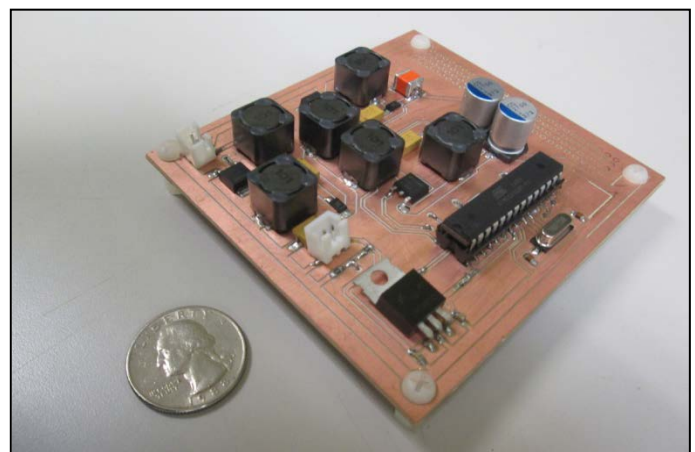


Fig 4: The 9cm x 9cm PCB design of the CubeSats EPS, developed by the computer engineering team of the UPRM. The project gives students the opportunity to learn new design software that is not traditionally taught in courses.



(a)



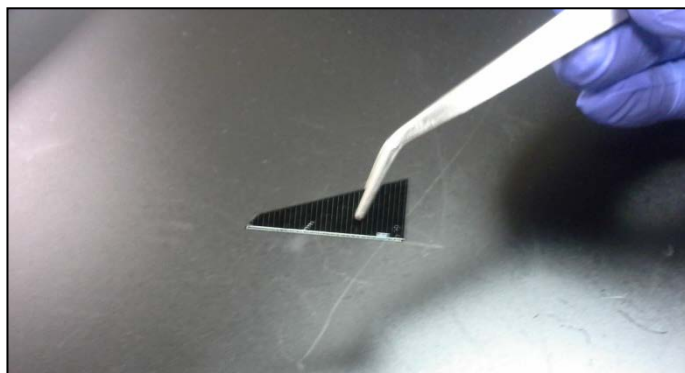
(b)

Fig 5: The developed CubeSat EPS Prototypes. (a) The initial EPS prototype developed for the first semester 2013-2014 with no weight or size limitations. (b) The second EPS prototype developed for the second semester 2013-2014 designed with the CubeSats restrictions.

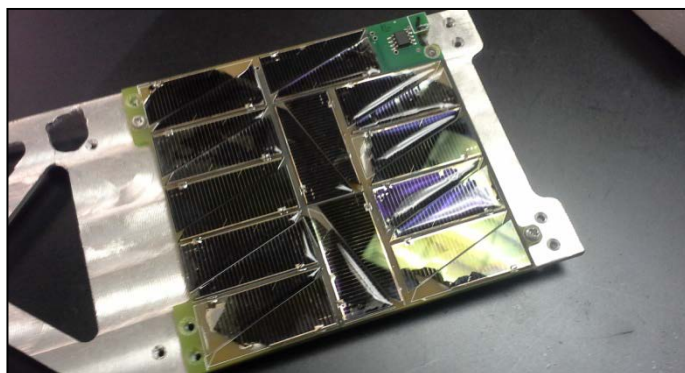
Once the PCB is designed, it is manufactured using a CNC milling machine which traces the circuit paths on a copper clad. Electrical components as well as connectors are carefully soldered unto the PCB. The end result is a 9cm x 9cm EPS capable of charging the CubeSats battery as well as supplying the required voltages to the measurement devices. Notice how the EPS complies with the CubeSats weight and size limitations established by the mechanical engineering team.

The final product is tested with the use of a solar array simulator that aids in emulating the CubeSats solar panels. Although the construction of the EPS is a task assigned to the electrical engineering team, computer engineering students provide support by integrating the microprocessor unto the PCB. This included adding capacitors as well as the selection of voltage regulators (to supply power to the MCU) and adding a crystal oscillator. This is an example of how the electrical and computer engineering teams collaborated in order to achieve a common objective. This PCB design and construction approach has been adopted by other power electronics projects in UPRM and UIPRB [19].

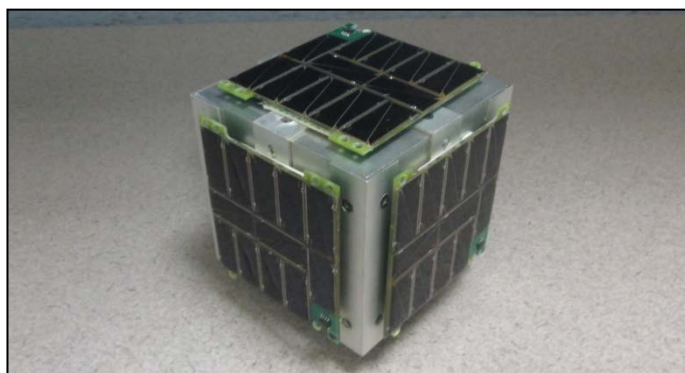
In order to power the CubeSat, solar panels are located on each one of its sides. Mechanical engineering students designed and manufactured several solar panels, using triangular advanced, improved triple-junction Gallium Arsenide (GaAs) solar cells. These solar panels supply power to the loads while charging the battery of the CubeSat. Each solar panel consists of 24 GaAs solar cells. When the series and parallel connections are made between the solar cells, the result is a 9cm x 9cm solar panel. Fig. 6 illustrates the GaAs solar cells, solar panels that have undergone and the developed CubeSat casing which houses the EPS.



(a)



(b)



(c)

Fig 6: The GaAs solar panels. (a) The triangular advanced triple-junction GaAs Solar cell. (b) The solar panels constructed by the mechanical engineering students of the UIPRB. (c) The developed CubeSat casing with solar panels attached.

Once the solar panels were constructed, the electrical and mechanical engineering teams were tasked with their characterization. Based on the parameters obtained by the electrical engineering team, the computer engineering group simulated the solar panels in order to obtain their I-V and P-V curves. This is another example of how, the mechanical, electrical and computer engineering students all collaborate with each other in order to complete their task of constructing a GaAs solar panel model.

Finally, the solar panels were electrically connected to the input of the EPS and the control system was programmed unto the MCU. With the connections in place, the EPS system was inserted into the CubeSats housing and the solar panels were mounted unto the sides of the frame. This is another example of interdisciplinary research between the mechanical, electrical and computer engineering departments.

VI. CONCLUSION

An interdisciplinary CubeSat project between the UPRM and the UIPRB is discussed in this paper. The desired impact of this project is to establish collaborations between the engineering departments from different universities of Puerto Rico. In order to do this, the universities have selected a specific area of interest. Aerospace is an emerging topic in Puerto Rico that engulfs several fields of engineering. Cubesats in particular, are an interdisciplinary project that involves different aspects of all the fields of engineering. The UPRM and UIPRB are tasked with developing the CubeSats EPS. Students from electrical, computer and mechanical engineering from both the UPRM and UIPRB exchange course material in order to strengthen their universities curriculums.

This collaboration has influenced a growth in aerospace technologies in universities in Puerto Rico and has helped create ties between UPRM and the UIPRB as well as with agencies like NASA and PRIDCO. The efforts of all the universities participating in this project have proven that interdisciplinary research can have a great impact on students, while at the same time influencing institutions into adopting new courses and teaching methods. In general the learned resources could not only be applied to this project but to any other project, including topics outside of the aerospace and power electronics field.

It is expected that undergraduate students interested in pursuing a master's degree will base their thesis on this project. This will help prologue the participation of students in the project, while at the same time providing an additional incentive. The majority of students that have worked in CubeSat related projects in the past have been employed by companies such as: Texas Instruments, Honewell, Infotech aerospace services, Florida Turbine, Lockheed Martin and NASA. Students have also had the opportunity of participating in summer internships at high raking institutions and laboratories such as: Michigan State University, Ohio State University, University of Minnesota and Argonne National Laboratories.

ACKNOWLEDGMENT

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Informing Change: Course Content Analysis and Organization

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Abstract—This paper introduces a novel, supportive tool for engineering educators while making course adaptations. As pointed out in the 2013 FIE workshop “An Online Revolution in Learning and Teaching,” online learning is likely to impact every department and teacher in some manner. Other innovations impacting engineering educators include active learning, peer instruction, problem-based learning, and just-in-time teaching. When implementing change, educators are expected to present existing course materials in alternative formats. One resultant difficulty is visualizing, understanding, and judging the impact of various alternatives. Learning materials organization is often limited by delivery methods such as learning management systems that present material linearly. This project uses text analysis and graph transformation techniques to produce various alternatives allowing educators to envision ways changes can be effectively implemented in their courses. We demonstrate how temporal and topical relations between individual learning items can be extracted from existing courses and used to produce a graph that is an effective representation of the course. From this, graph transformations produce alternative organizations of course material allowing various solutions for educators to consider while redesigning their courses. This form of automated brainstorming stimulates out-of-the-box thinking, often producing options previously not considered.

I. INTRODUCTION

In an effort to meet the changing landscape of education many departments and universities are offering more online courses – a move that is likely to impact every department in some way [9]. This will require more instructors create on-line courses. Other innovations in instructional strategies are also widely impacting engineering educators [2] including peer instruction, flipped classrooms, problem-based learning, just-in-time teaching, and a variety of active learning strategies. Implementing any of these strategies requires changes to existing courses. Sometimes an educator is so familiar with the current course organization that it becomes a stumbling block for visualizing alternative options.

When anticipating change it is valuable to see how existing learning materials can be organized and used in new ways. The purpose of the ENABLE project is to provide assistance in making informed changes. ENABLE is not an acronym, rather a name that reflects the purpose to enable the implementation of quality educational strategies. The two major contributions of the current ENABLE system are that it:

- gathers information about the existing course and creates a graphical representation of the relations between the learning items, and

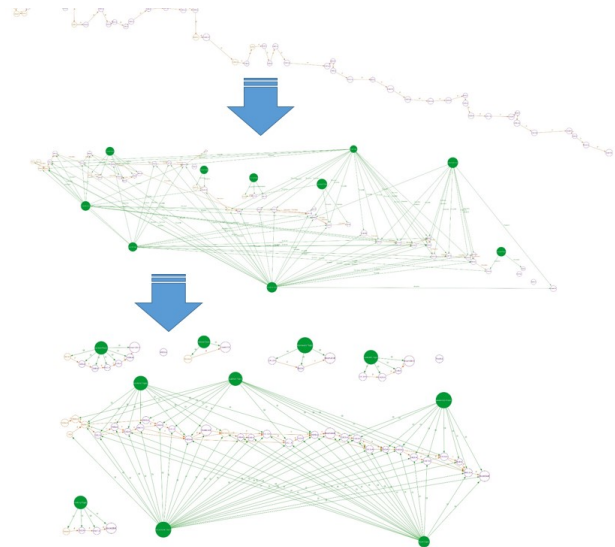


Fig. 1. CS0, Foundations of Computer Science Original Course Organization (upper). CS0, Initial Course Graph Relations (middle). CS0, Transformed Course Organization (lower).

- uses text analysis and graph transformation techniques to present alternative arrangements of the learning items.

As an example, consider the data from a sample CS0 course, Foundations of Computer Science, taught at Utah State University. The information about the learning items for this course was gathered from Canvas (a standard learning management system) and a graph was produced representing the current organization of the course; see Figure 1 (upper). This shows all the learning items for the course laid out in order across the days of the semester. Figure 1 (middle) shows the initial course graph constructed directly from the learning materials, and visually exhibiting the relations of interest: *precedes*, *occurs in*, and *includes*. The orange nodes (small, no fill color) represent the learning items. The orange edges between the learning item nodes are the *precedes* relations. The green nodes (larger with solid fill color) represent the topics. The green edges go between the topic nodes and the learning item nodes and represent the *occurs in* relations. The unit relations are expressed visually by locating nodes *included* in a unit near the same vertical location. Figure 1 (lower) shows the class material after text analysis and graph transformation by the ENABLE system. Note that this is one possible reorganization of the course. In

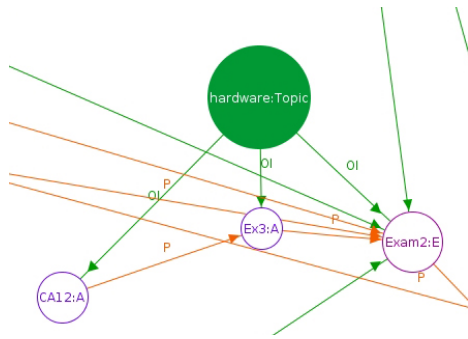


Fig. 2. Close up of small section of graph from Figure 1 (middle).

this transformation the learning items are organized by topic. Only the topically related *precedes* relations are included which allows a more clear separation of learning items by topic. The *occurs in* relations are all represented. In this particular transformation *includes* relations are not expressed. Due to the size of these graphs it is difficult to see the details clearly in this small of an image but the changes are significant enough that you get a sense of the differences the transformations make. Figure 2 shows a small section of the graph and allows the details to be more visible. This image shows a single topic node (solid circle) and three learning items (circles with no fill color). The learning item to the far right is an exam and the relations coming into this exam consist of four *occurs in* relations and three *precedes* relations. This is an ideal situation to apply the split exams transform that is discussed in section IV, Transforming the Graph.

II. DISCOVERY OF RELATIONS IN COURSE MATERIAL

Many types of relations exist between the learning items, but here we focus on three basic ones: temporal, topical, and unit coherence. These describe the chronological order, similarity of topics, and presentation organization of the learning items, respectively.

A. Identifying Temporal Relations

Temporal relations express the relation in time between learning items. The word *precedes* is used to express this relation. A learning item (Item A) *precedes* another learning item (Item B) when the due date of Item A is before the due date of Item B. These relations are transitive such that if Item A precedes Item B and Item B precedes Item C, then Item A precedes Item C. When all these relations are included on a directed graph the learning item at location k in the sequence has $k - 1$ in-edges and $n - k$ out-edges, where n is the number of learning items. These graphs are too cluttered to be informative. See Figure 3 (upper).

A simpler view of the temporal relations displays only the *precedes* relations that come immediately before a given node. This graph displays an edge from a node to the node it immediately precedes in time. This reduces the number of edges to $n-1$ and makes a much more readable graph. Since these relations are transitive, no connection is lost.

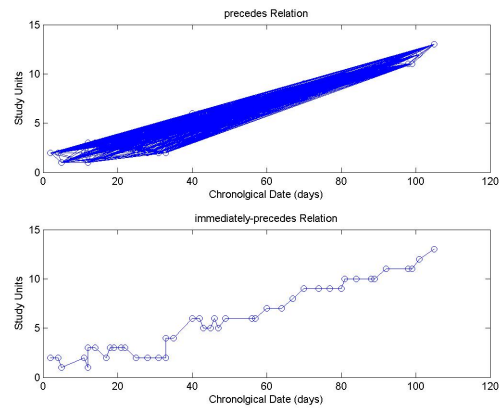


Fig. 3. Detailed Graph of *precedes* Relations (upper). Graph of immediately *precedes* Relation (lower).

See Figure 3 (lower). These figures are the graphs produced for the CS0 course.

The meaning of the *precedes* relation is limited. Learning items connected in this way are not necessarily related by topic or grouped in the same unit. Note that *precedes* does not mean it is a prerequisite. This relation expresses nothing more than how learning items are laid out in time in the original course.

By itself, the temporal relation seems trivial, and yet it is the predominant relation presented to students. An educator who has designed and implemented a course is aware of other relations between the learning items such as how they are grouped together to create a unit of learning, how they are related by a single topic or a group of topics, and prerequisite recommendations. Although the educator may consider these other relations more significant, the learning management systems currently available use the temporal relation as the dominant organizational aspect when presenting learning materials. Even when the module tool is used in Canvas to group learning items together into units, the student view presents learning items in a linear format based solely on temporal relations in the assignments page, the gradebook, and the syllabus.

When combined with topical and unit relations the temporal relations add some information. For example, if there are two assignments that cover the same topic and one precedes the other it is likely that there is a non-commutative relation between the two learning items and it is important that the first is completed before the other.

Not all items in Canvas have due dates. In the sample CS0 course, 8 out of 49 learning items do not have due dates associated with them. These undated learning items include lecture notes, videos, and frequently asked questions. It is likely these items are informational materials that are most beneficial when preceding other items in the same unit or other items of the same topic. As topics extend across a larger time period than units, associating the undated learning items with other items in the unit is preferred. These learning items are dated two days before the first dated item in their unit.

B. Topical Relations

To identify the topical relations the text of each learning item is gathered. Canvas provides a title and a text description of each learning item. These become the basis of the text. This text is analyzed to see if there is a link to a file. Canvas has a specific way of referencing files that have been uploaded making it possible to use text parsing and regular expressions to identify these references. Once a filename is found, the file extension is considered. Currently ENABLE adds .txt and .pdf files to the text description. Pdf files are converted to text before being added. Canvas has a category of items identified as quizzes. These contain questions in addition to the text description. For these types of learning items, the questions are added to the text description.

ENABLE uses a .txt file to store a series of topic lists. These lists contain topic words, word groups, and variations. Each line in the file represents a single topic. Individual topic variations are separated by a comma. The original list of topics for the sample CS0 course includes:

- <content>
- <html, structure>
- <attribute, attributes>
- <tag, tags>
- <element, elements>
- <publishing, host, publish, published>
- <careers, career, careers in cs, cs careers>
- <darpa>
- <history, cs history>
- <css, style>
- <hardware, system>
- <javascript, script>
- <functions, function>
- <textboxes, textbox>
- <using the web, use the web>.

The use of a list of topic variations allows different versions of the same word such as **publishing**, **publish**, and **published** to be counted as a single topic. Stemming algorithms [11] may be used to accomplish this same grouping. However, this list of topic variations allows entirely different words to be associated with the same topic. For example, the word **host** is included in the list with **publishing**. This allows the instructor a great deal of flexibility in associating a variety of words or word phrases with a single topic.

Using these lists of topic words, a term frequency vector is created for each learning item document. Term frequency (*tf*) is a count of how many times a term occurs in the learning item document [7]. The document in this case is the description of the learning item. This description includes any text available in Canvas or uploaded by the instructor. The frequency count of terms found in a topic list are combined to produce a single *tf* count for each topic.

When computing *tf* for all the terms in a corpus of documents, this process produces high-dimensional, sparse vectors [8]. Techniques such as the application of singular value decomposition (SVD) to a topic similarity matrix (i.e., spectral graph analysis) may allow the reduction of

dimension to make computationally intensive text analysis more efficient [3]. In the CS0 example here, the limited number of specific terms found in the topic lists produced *tf* vectors for which no dimensional reduction was possible.

This raw count of how many times a term occurs in a document can be more informative if it is weighted. The weighting approach used by ENABLE is *tf-idf*. *tf-idf* starts with the *tf* and then multiplies it by the inverse of the document frequency. The document frequency (*df*) of a term is the count of how many of the documents in the corpus contain that specific term. If the *df* is high, the term is very common so the fact that it shows up in a document is not as significant as a term that is less common. When the *df* is low, the occurrence of the term in a document is more significant. By multiplying *tf* by the inverse document frequency (*idf*) the resulting value results from a weighting based on the relative frequency of the term in the corpus. The ENABLE system computes *tf-idf* using log weighting of the *tf* count and log inverse frequency weighting on the document counts [7].

$$tfidf_{t,d} = (1 + \log(tf_{t,d})) \log\left(\frac{N}{df_t}\right)$$

A Pearson correlation was done between the *tf-idf* values of the topics. For each correlation that was greater than 0.8, the topics were considered for combining. In the sample CS0 course there was a correlation between the *HTML*, *attribute*, *element*, and *tag* topic lists. Combining these was obvious once the correlation pointed them out. These are all parts of the HTML language. The other topics that were highly correlated were *JavaScript*, *functions*, and *textboxes*. Although functions is a topic that exists outside of JavaScript, in the context of this course, functions are only discussed or used in JavaScript. This correlation made the instructor aware that their broader view of the computer science curriculum was reflected in this separation of topics and would best be adapted to fit the content of this specific course. This provided the instructor a fresh perspective informed by feedback from ENABLE.

This illustrates one of the many benefits of gaining another perspective when considering changes to current courses. This process of identifying correlations between topics provided new insights into possible changes to the topic lists. These insights were not recognized when the original topic lists were made. This process led to the reduction of topics from the original fifteen to the following ten:

- <content>
- <html, structure, attribute, attributes, element, elements, tag, tags>
- <publishing, host, publish, published>
- <careers, career, careers in cs,cs careers>
- <darpa>
- <history, cs history>
- <css, style>
- <hardware, system>
- <javascript, script, functions, function, textboxes, textbox>
- <using the web, use the web>.

C. Unit Relations

Units are a set of learning items that are grouped together. Unit relations come directly from the modules tool in Canvas. This tool allows an instructor to group learning items into units. Many different groupings are used. Some instructors group the material based on a textbook such as a unit for each chapter. Others use it to organize temporally such as one unit for each week in the course. Another approach is to organize by specific topic coverage. Current grouping in these modules reflects groupings that are in some way meaningful to the instructor. The unit grouping of learning items is used as the y-value in Figure 1 (upper and middle) and Figure 3. This visually shows how learning items are related by unit.

III. CREATING THE INITIAL GRAPH

A. Temporal Relations

When graphing the temporal relations the *precedes* relation is used. Nodes represent learning items and edges are the relations between them. This is a directed graph with the arrow of the edge on the node with the later due date, expressing that one node precedes the other node in time. To make the graphs more readable, these edges are labeled with *P*.

B. Topical Relations

To graph the topical relations, a bipartite graph is used with one set of nodes representing the topics and the other set of nodes representing the learning items. This is a directed graph with the arrow of the edge on the learning item nodes expressing that the topic *occurs in* the learning item. For readability, these edges are labeled *OI*.

C. Unit Relations

The unit relations represent a grouping of the current organization. This is represented as a bipartite graph with one set of nodes representing the units and the other set of nodes representing the learning items. This is a directed graph with the arrow of the edge on the learning item nodes expressing that the unit *includes* the learning item.

D. Combining the Graphs

The temporal and topical relations go well together since the temporal relations are entirely in the set of learning items. This combined graph includes all the topic nodes and learning item nodes with both the *precedes* and the *occurs in* edges included.

The unit relations are loosely expressed by using the unit value to compute the vertical location of the nodes in the starting graph. This provides a visual representation of how the learning items are grouped into units but does not include any edges that connect items in a unit. Figure 1 (middle) shows the graph structure produced for the learning materials in sample CS0 course when these relations are combined.

IV. TRANSFORMING THE GRAPH

Because ENABLE identifies alternative course structures that maintain the relations between learning items it becomes necessary to transform the graph while still keeping the meaningful relations intact. Graph grammars and graph transformation systems provide a means for doing this. There is much research and many successful applications based on the research in this area [4]. One of the application areas of graph transformation systems is model transformations. This area of model transformation has become important to the field of software engineering [1]. The models used in software engineering have enough similarities to the graphical representation of learning materials to allow model transformation as the graph transformation technique used by ENABLE. These similarities include typed nodes, node attributes, and edges that represent different types of relations.

For graph transformation, ENABLE uses AGG, a development environment for attributed graph transformation [6]. It is based on an algebraic approach to graph transformations. The implementation of this approach closely follows the formal, theoretical foundation of algebraic graph transformation and so provides validation support [5] and sound behavior concerning graph transformation [10]. AGG has non-deterministic rule and match selection but provides control of this with rule layers.

A. Defining Semantic Rules

Once the initial course graph is available, it becomes possible to begin a conversion process from a linear (chronological) style class organization to a more non-deterministic, multi-path organization of the learning items more suitable to online delivery. It is now necessary to determine the types of desirable transforms and their meanings. We begin with the consideration of how to eliminate unnecessary *precedes* relations.

We define a restraint as an unnecessary constraint between two items. Thus, restraints are removed in order to open up more possibilities for the relations between learning items. When removing restraints it is important to maintain the integrity of the course representation.

1) *T1: Topic-based precedes Elimination Rule:* The major restraint is the *precedes* relation. It restricts any change in the order of learning items. However, many of the *precedes* relations are not necessary and can be removed without changing the necessary relations. The first step is to remove unnecessary *precedes* relations. As discussed earlier, *precedes* relations by themselves have little meaning. The fact that one learning item comes before another provides only limited information. Now that the temporal and topical relations have been combined into a single graph the system can identify *precedes* relations that have no topical connections and can be removed.

If *A precedes B* and *B precedes C* and there are no common topics that occur in both *A* and *B*, the *precedes* relation from *A* to *B* can be removed. When removing this relation it is important to keep the relation that *A precedes C* and *B precedes C*. Note, however, that the net number of

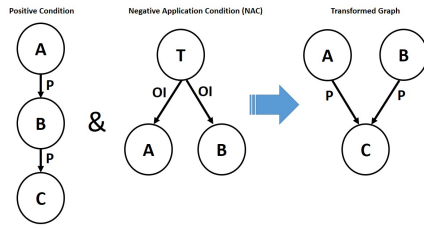


Fig. 4. Graph Transformation to Eliminate Unnecessary *precedes*.

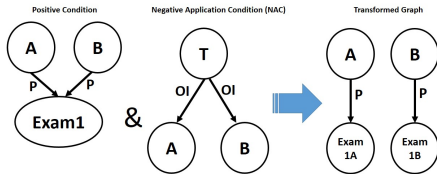


Fig. 5. Graph Transformation to Split Unrelated Exam Elements.

precedes relations is reduced by 1 as there was an implied $P(A,C)$ before the application of $T1$.

More formally, this can be stated as:

$$\text{if } P(A,B) \wedge P(B,C) \wedge \neg T \ni (OI(T,A) \wedge OI(T,B)) \\ \text{then remove } P(A,B) \text{ and add } P(A,C)$$

We call this the *Topic-based precedes Breaking rule (T1)*. Figure 4 shows a graphical representation of this transform.

2) *T2: Topic-based Exam Splitting Rule*: One result of building course organization based on temporal relations is illustrated by exams. Commonly, an exam is written to assess the material that has been covered over a specific period of time. For example, since the last exam or since the beginning of the semester. This time-based connection is not required for assessment. Therefore it is possible to divide the material assessed in an exam by topic. Separating the temporal grouping inherent in exams provides additional possibilities for change. The split exams rule is applied after the remove *precedes* rule has been applied. Enforcing this rule application order prevents any exams being split when preceding learning items are topically related. AGG allows the user to specify which rule layer a specific rule is in. It enforces rule ordering by applying all the rules in one layer before applying rules in the next layer. This, then, is another example of a restraint: when exams tie learning items together that are not related in any other way.

If A *precedes* Exam 1 and B *precedes* Exam 1 and there are no common topics that occur in both A and B , then Exam 1 can be split into two exams, Exam 1A and Exam 1B such that A *precedes* Exam 1A and B *precedes* Exam 1B, and A and B are independent of Exam 1B and Exam 1A, respectively. See Figure 5. This transform must be applied after $T1$.

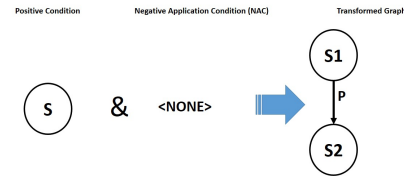


Fig. 6. Learning Item Split Due to Too Much Material.

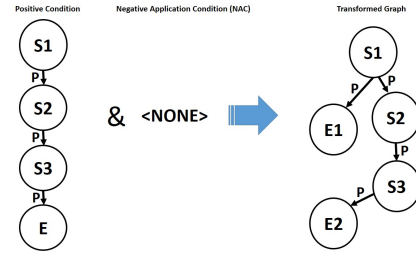


Fig. 7. Pressure Reducing Exam Split Transform.

Currently ENABLE applies both these semantic rules using graph transformations. There are additional meaningful transformations to be explored in the future work of this project, but we give them here to show the power of the approach.

3) *T3: Material Splitting Transform*: It may be determined from analysis of student success on homework problems and exams that there is too much material in some learning items. This leads to the transform shown in Figure 6.

4) *T4: Reduced Pressure Splitting Transform*: Another way to reduce the cognitive load for an exam is to split an exam temporally. This leads to the transform shown in Figure 7.

5) *T5: Change of Topic Detection Transform*: In a standard classroom setting, a sequence of material on one subject will eventually give way to a change of topic and a new set of materials. We believe that this can be detected in the initial course graph due to the overlap pattern of related topics among the learning items. For example, a learning item that sits at the end of a sequence of topic-related items, and at the start of a distinct topic-related set of items, is most likely a transition item. This leads to the transform shown in Figure 8.

B. Applying Semantic Rules to the Graph

In AGG, transformations are defined by a rule with three parts (as described in the transformations given above):

- LHS (Left Hand Side): specify the pattern to find in the graph.
- NAC (Negative Application Condition): identify any restrictions to be imposed on the transformation. This part shows results that are not allowed. If the transformation would produce this result, the transformation is not applied.

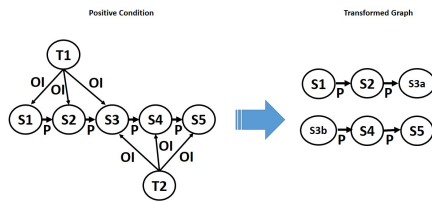


Fig. 8. Topic Change Item Split Transform.

- RHS (Right Hand Side): demonstrate what the pattern in the graph is to be after the transformation is applied.

These transformations embody the semantic rules listed above.

C. Applying T1: Topic-based precedes Elimination Rule

After the topic-based *precedes* elimination rule was first applied to the sample CS0 course, the instructor reviewed the resulting graph. Several unexpected findings were encountered.

1) *Learning Items with No Topical Relations*: There were five learning items that had no topic relations. Upon examination, two of the items were truly not related to any topic, an assignment in which students were to submit which team they wanted to be on, and the teacher evaluation. Both items were left unchanged with no topical relations.

The other three clearly were related to a specific topic but none of the terms in the topic list were found in the description. This could be remedied by using ENABLE's file upload tool that provides a way to add additional text to the description of a learning item. This also caused the instructor to consider the value of more frequently using the topic terms explicitly in the textual presentation of the learning items.

2) *Learning Items with Meaningless Topical Relations*: There were six topical relations that connected learning items to topics mistakenly. In five of these learning items, the topic words occurred but were being used in a more general way. For example, one of the topics is **content**. This is specifically related to selecting content when creating a web site. However, the word **content** was used in its more general way in three of the learning items. In the other case the instructions included a restriction to not use JavaScript which was a future topic. These relations were manually removed.

D. Applying T2: Topic-based Exam Splitting Rule

The first time the topic-based exam splitting rule was applied there were fewer exam splits than expected. Upon closer review it was discovered that the exam asked questions about a topic without using a topic word explicitly. This seemed pedagogically sound. For example, one question about computer science history was "Why was the invention of the integrated circuit important?" Although this question does not use the term **history**, it is clearly assessing the student's familiarity with the computer science history covered in the course. These missing meaningful relations can

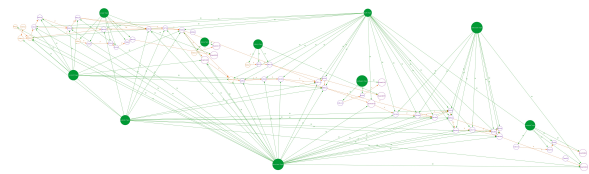


Fig. 9. Course Graph After the Application of Transforms T1 and T2.

be included by adding text that includes the missing topic words to the description using ENABLE's file upload tool. This adds the text to the ENABLE system without altering the exam itself.

There was one case where the review of the exam exposed the possibility of adding a word to the topic list. The word **occupation** was used in the exam that covered careers in computer science. This word was also used in other learning items about the topic. It was determined that adding this word to the topic list would add clarity. Adding the term to the topic list resolved this missing relation.

E. The Resulting Graph

Figure 9 shows the result of the application of the transforms T1 and T2. The revised graph affords much greater leeway in the organization, presentation, and order of selection of material for the instructor and the student.

V. ALTERNATIVE ARRANGEMENTS

Once the T1 and T2 transforms have been applied, many of the original organizational limitations have been removed. This opens the way for alternative arrangements of the learning items.

A. Separating by Topics

The graph in Figure 10 shows the learning items organized by topic. This arrangement separates the learning items in several distinct topic groups. The large group in the middle reflects the interrelated nature of several topics. This provides a visualization of how topics are related and how they might be rearranged. There is no visualization of *includes* relations.

B. Adding Unit Clustering

The graph in Figure 11 is clustered by units. The similarity between the graph arranged by topic and this one indicates that the units in the original organization grouped learning items into units by topic. Order of the units is not restricted. There are *precedes* relations between the the five units in center of the graph. In the first and second grouping there are edges going in both directions.

C. Informing Change

There is information in these graphs that can be visually retrieved. Consider the following:

- How many topics occur in a specific assignment? This question can be answered by looking at how many *topic* edges come into an assignment. In the sample course, only one topic *occurs in* each of HW3, HW4, and HW7

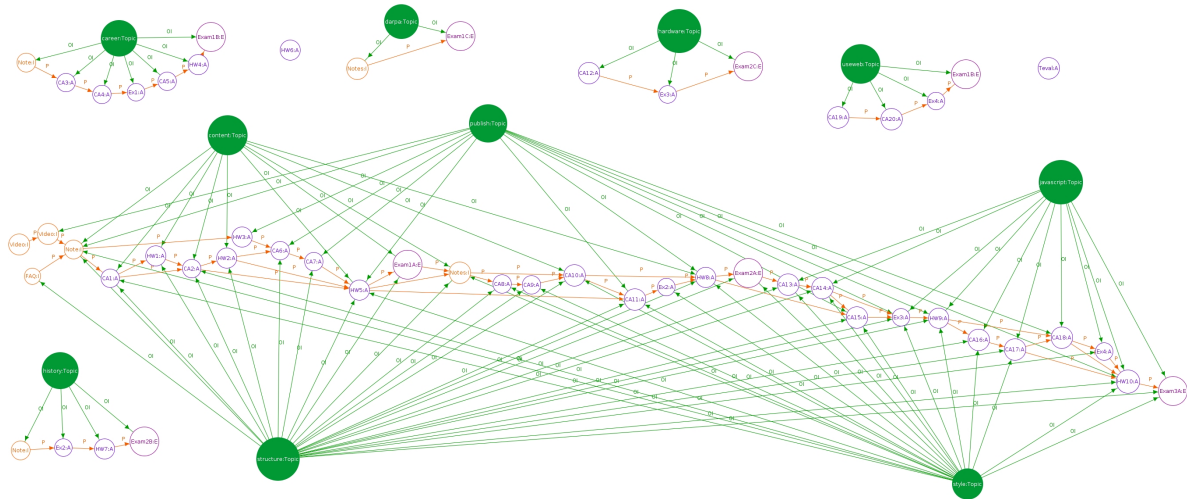


Fig. 10. Course Graph Arranging Learning Items by Topic

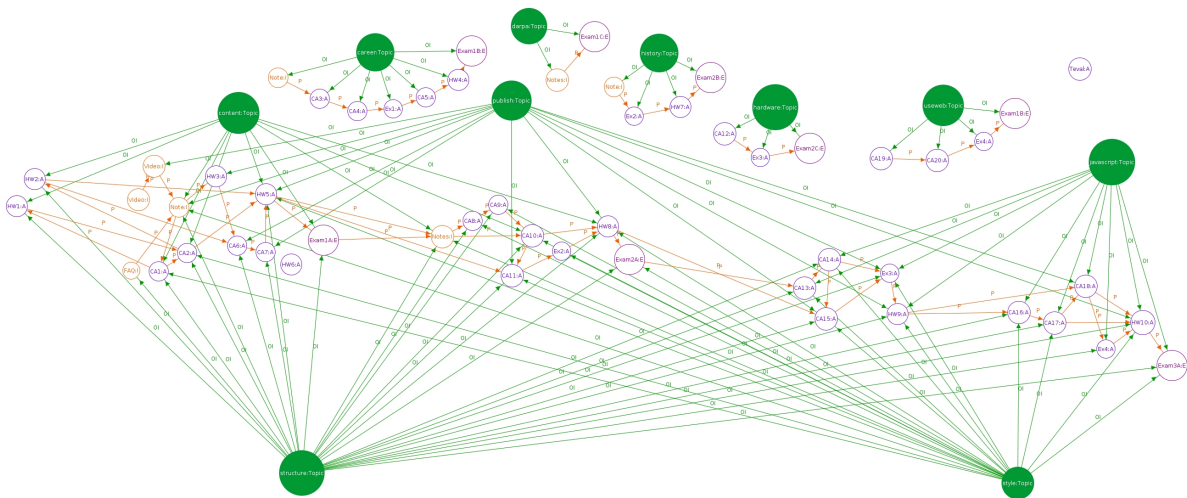


Fig. 11. Course Graph Arranging Learning Items with Clustering by Units.

while four topics *occur in* in each of HW5, HW8, HW9, and HW10.

- What units can be rearranged without interfering with *precedes* relations? The answer to this question can be found by looking at the *precedes* edges between unit clusters. For those units with no *precedes* edges between them the order can be changed without disrupting the temporal order restrictions expressed by these edges.

Having access to this kind of visual information has the potential to provide meaningful insights very quickly.

VI. CONCLUSIONS AND FUTURE WORK

We have developed an automated system that constructs an initial course organization graph based on information provided by Canvas, a standard Learning Management System (LMS). A variety of types of material are represented in the nodes of the graph and initially only their chronology is known. A detailed analysis of the materials based on the text

contained within each learning item allows a more informed representation which captures the topic relations among the items. A set of graph transformations is then defined which convert the (basically) linear structure of the course to a graph structure which makes evident the dependencies and independencies of the learning items. A specific test case, CS0, was transformed in this way to demonstrate the power of the method.

A. Validation of Results

The system is able to exactly reproduce the temporal *precedes* relations of all dated learning items. For those learning items that do not have a due date, a date is used that is related to the earliest date in the unit in which the undated item is included. It is also possible to extract and identify the Unit or *includes* relations in all cases where the modules tool in Canvas is used. No testing was done with courses that did not use the modules tool. It is anticipated

that input from the instructor would be required to identify unit relations if they are not identified in the LMS. Topical *occurs in* relations are produced from the text. In the example course the automated assignment of *occurs in* relations was correct in 472 of the 490 topic to learning item combinations. In eight cases none of the topic word variations was found in the learning item but they were in fact related to the topic. For nine combinations a topic word was encountered in the description but the learning item was not related to the topic. In one case the topic word was used to instruct the students to not use the topic on this specific assignment. These discrepancies were corrected with input from the instructor. Involving the instructor in the analysis process is one of the strengths of the ENABLE system. It not only improves the validity of the results but also improves the possibility of increasing the instructor's potential for understanding the possibilities for change.

Currently ENABLE produces eight different course maps based on the relations between learning items. Each of these graphs can be rearranged by the instructor to produce many organizations. The course maps have been designed to minimize the congestion of learning items and relations. The system does not, however, guarantee a minimum number of edge crossings. There is congestion of undated learning items as they are all positioned temporally at the beginning of a unit. This is a problem in one of the 13 units in the sample course. Another congested area is produced when exams are split. The due date and unit assignments are the same for each of the split exams. This locates them close together. These congested areas are easy to resolve by dragging the nodes to new locations. When the nodes are moved the connecting edges automatically move with them keeping the visual representation of relations intact.

B. Informing Change

This process of analysis and transformation provides insight for the instructor about a variety of ways the course materials can be organized. As the instructor sees existing course materials presented in a variety of ways their perception of the possibilities for making innovative changes like using peer instruction, flipping the classroom, adding blended learning, implementing more active learning, etc. is increased. This increase in possibilities facilitates change.

Information about the existing course is provided by each step in this process. The ENABLE system gathers existing information from what is available about the course in the LMS and represents it in a visual way. This sheds light on what students currently have available through their access to the learning materials in the LMS. The most significant finding was how entrenched the *precedes* relation is in the presentation of course material. This relation often adds little meaning to how learning items are related and yet it is the predominant organization strategy used when displaying information to students. When comparing the visual representation of that organization, see Figure 1 (upper) to the alternative organizations produced by ENABLE, see Figures 10 and 11, it is clear that there is significant room

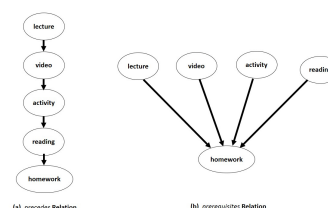


Fig. 12. *precedes* vs. *prerequisite* Relations.

for improvement in how the educational community presents learning material to students. Although this first phase was designed to inform instructors about the many organization options available when making changes, the feeling of the authors is that the effort to develop a graphical, non-linear representation of a course could have significant impact on how the students perceive and interact with course materials.

C. Future Work

During the course of this work, we determined that even though the *precedes* relations have been restricted to those that have common topic relations, they still express limited information. We believe that a more informative relation is the *prerequisite* relation that expresses a recommendation that one learning item be completed before another learning item. The *precedes* relation limits the connections between learning items and does not allow flexibility in ordering. It is easy to identify cases when this representation is too limited to express how the learning items are actually related. For example, there may be several learning items that are designed to prepare a student to complete a particular homework assignment such as a lecture, a class activity, a video, and a reading assignment. Using *precedes* relations, a graphical representation would look similar to that shown in Figure 12. Representing it this way indicates a specific ordering between the learning items when in fact this ordering is not required.

In the future we hope to transform learning outcomes by (1) facilitating deep student learning in science and engineering by providing the student feedback resulting from behavior models based on monitoring paths taken through the online course graph and linking that to performance in the class; and (2) providing effective tools for the instructor to monitor the effectiveness of the course material and its organization. The innovative use of a Bayesian inference network, a technology currently applied in many intelligent systems, will be developed and applied in a real-world learning environment to create a predictive computational model for individual learners and educators. By identifying operational student learning processes it may be possible to detect how knowledge gaps are a consequence of less successful learning strategies and tactics. Developing learning strategies can be challenging, thus an effective learning environment to support this must be designed and developed. As a next step we propose to integrate a Bayesian inference network within the ENABLE system to provide synthesized data about learners' activities, behaviors, and performance.

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Automatically augmenting learning material with practical questions to increase its relevance

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Abstract— Relevance of a concept being taught to the real world is believed to contribute to an increase in the intrinsic motivation and engagement of a learner. Such relevance is often found lacking in learning material such as textbooks. Practical issues and problems one could face while learning or implementing new concepts are a means of establishing such relevance. In this paper, we propose a method to automatically augment learning material with practical questions about the concept being learnt. We use questions and answers from StackOverflow, a leading social Questions and Answers (Q&A) website to augment an electronic textbook interface, thus connecting the concepts being taught to the real world. For achieving this automatically, we first mine the textbook content to locate words and phrases which are likely to be the most important concepts on each page of the textbook. We then select only those words and phrases which appear as ‘tags’ in StackOverflow, typically defined by users while asking and answering questions. Using permutations of these tags as queries, we query the StackOverflow database to obtain relevant questions and answers to augment any given page. We present an interface to augment textbooks with such questions using the aforementioned method. We also present the results of a student survey examining the effectiveness of the augmentation in establishing relevance to their learning.

Keywords— Computer Science Education; e-learning; Relevance; Questions; StackOverflow; Augmentation

I. INTRODUCTION

Keller [1] defined *relevance* as a learner perception of whether the course instruction and content satisfies personal needs and/or career goals of learners. Studies show that establishing the relevance of what is being learnt to learners’ personal goals and experiences increases learner motivation [2-4]. One of the ten principles of good teaching derived by Kember and McNaught [5] after a study of 62 award-winning teachers was establishing relevance of the learning content to the learner. Another study by Ballantyne et al. [6] on 44 award-winning teachers reported that exemplary teachers often linked theory with practice in order to establish relevance. A good teacher can often make an important contribution in establishing relevance thereby increasing learner motivation. However, students often study on their own and may not get ready help from teachers. Also, not all teachers are good at establishing relevance of the learning material to the learner’s world.

Even though computer science has a pervasive presence in our lives with its diverse applications, computer science textbooks often primarily focus on its theoretical aspects. Large portions of computer science textbooks are dedicated to teaching theory and mathematical foundations of underlying concepts. Practical examples do appear, but they typically do not appear alongside the theory being taught. Due to this, a learner may miss the relevance of what is being learnt while learning from such textbooks. Kember et al. [7] found that a common cause reported by learners for lack of motivation was “purely abstract teaching, confined to theory”. As a result, a learner can get demotivated from such lack of relevance in learning material used for self-study.

Can relevance be established while learning from such material? Agrawal et al. [8] proposed augmentation of textbooks with content obtained from the internet to increase the effectiveness of textbooks. Gandhi et al. [9] proposed a design for augmentation of learning material such as textbooks and e-books in order to aid personalization. They mined content from the internet to populate ‘layers’ of relevant information for the concepts being taught. In their proposed electronic book interface, they placed such information besides the learning content so that it could be accessed as required by the learner.

Starkey [10] proposed integrating radiographic medical images when radiology students learnt pathology using preserved specimen. The augmentation helped establish the relevance of the pathology concepts to learners’ future vocation and led to a “positive impact on the learning experience”. In case of computer science, such relevance can be established through exposing undergraduate learners to real-life situations encountered by programmers, software developers and graduate students, which are the roles that they are likely to take up in future. We believe that such situations are often represented as questions and answers on social Questions and Answers (Q&A) websites such as StackOverflow [11].

In this paper, we propose ‘augmenting’ learning material such as electronic textbooks with practical questions and answers posed by real users in order to establish relevance of the learning material to real life. In specific, we use questions and answers posted at a popular social Q&A website called StackOverflow.

In specific, our contributions are:

- 1) We propose augmenting learning material such as e-textbooks with Q&A to establish relevance while learning,
- 2) We propose algorithms to automatically retrieve and recommend Q&A most appropriate to a given page of learning material, and
- 3) We present the results of a survey conducted with 48 undergraduate students to assess the effectiveness of the augmentation in establishing relevance.

II. STACKOVERFLOW AS A SOURCE OF PRACTICAL KNOWLEDGE

StackOverflow [11] is a free social Q&A for professional and enthusiast programmers with over 9 million questions asked and / or answered by over 4 million users. Users post questions about programming concepts on StackOverflow and other users answer these questions. The answers deemed best by many users get more number of votes thus automatically filtering bad quality answers or spam. Furthermore, users gain a reputation score as they consistently answer questions thus increasing the credibility of their answers [12]. Typical questions are related to practical application of programming and technology such as technology implementation, how-to procedures, concept explanation, code debugging and troubleshooting, review, and advice [13]. Users typically tag the questions with the concepts they are related to, thus allowing easy search [14]. The site receives over 6 million views per day from software professionals and students all over the world [15]. In fact, John Bishke, the education entrepreneur, termed sites such as StackOverflow as the “new Computer Science Departments”, where people went to learn and employers went to find more about potential employees [16].

Surakka [17] reported that subjects such as data structures, algorithms, procedural programming, object-oriented programming, software architecture and software engineering were rated to be the most important computer science skills by combining multiple studies with software developers, graduate students and teachers. StackOverflow has an abundance of Q&A related to these concepts. For example, Table I shows the number of questions in StackOverflow tagged using main concepts in data structures, an important skill for computer programmers [18].

StackOverflow has been used as a source of knowledge for assisting experienced as well as novice programmers. In two separate studies, Ponzanelli et al. [19] and Bacchelli et al. [20] proposed augmenting an integrated development environment (IDE) typically used for programming with StackOverflow

TABLE I. NUMBER OF QUESTIONS IN STACKOVERFLOW FOR IMPORTANT CONCEPTS IN DATA STRUCTURES

Concept	Number of questions tagged
Arrays	13,000+
Linked Lists	7,300+
Trees	7,700+
Stacks	4,900+
Queue	4,500+

Q&A. This allowed programmers to instantly view Q&A related to the program they were writing. Pai et al. [21] proposed automatically recommending StackOverflow expert users as mentors to novice programmers.

In this paper, we use the Q&A in StackOverflow as a means of relating the concept being learnt by learners to questions posed to real practitioners thereby establishing its relevance.

III. AUGMENTATION OF LEARNING MATERIAL WITH Q&A

We used the concept of textbook augmentation described by Gandhi et al. [9] to establish relevance during self-study. In order to demonstrate the concept, we used 14 pages describing 3 common topics chosen from 3 different textbooks as the base learning material used for augmentation. The topics were *multithreading* (a basic programming concept) [22], *database normalization* (a practical database concept) [23] and *Dijkstra's algorithm* (a theoretical concept) [24]. As a test prototype, we provided a web interface to the PDF versions of these pages with navigation controls. On the right side of the page, we provided a Q&A pane with links to questions from StackOverflow for the concepts being taught on the page. The prototype interface was web-based [25] and could be accessed

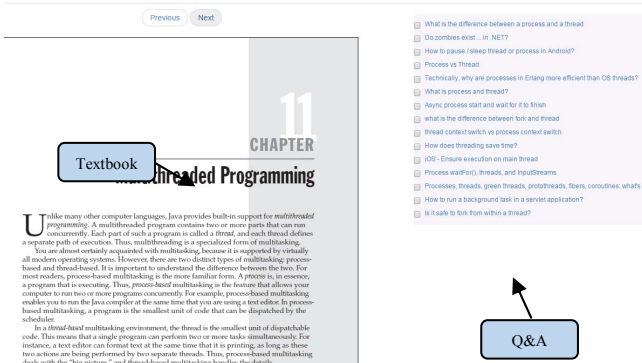


Fig. 1. Interface for augmenting textbooks with Q&A

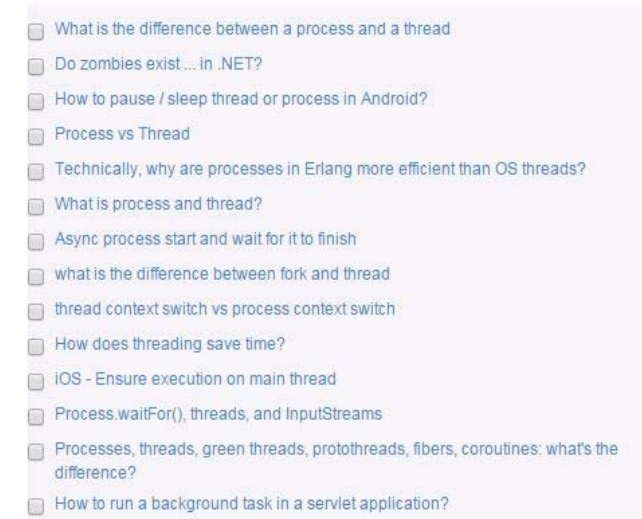


Fig. 2. Details of the Q&A pane automatically recommended for the topic *multithreading*

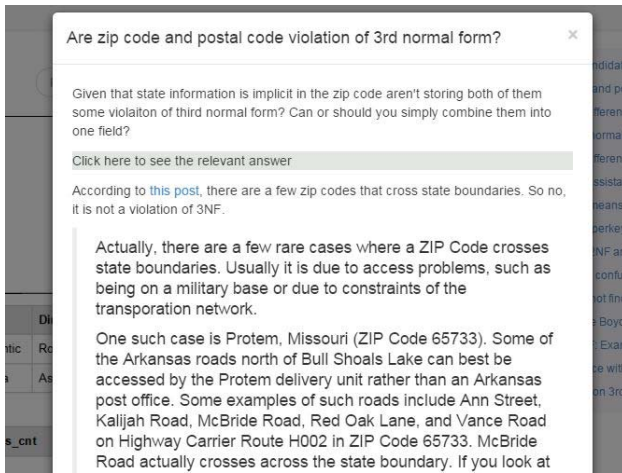


Fig. 3. Details of the Q&A popup window

in a browser as shown in Fig. 1. The details of the Q&A pane are shown in Fig. 2. Clicking on a question opened a popup window with the entire question. The answer was hidden to begin with for arousing learner curiosity. Clicking on the bar below the question revealed the top answer for that question in StackOverflow as shown in Fig. 3. The learner could also vote for a question she found relevant by clicking on the *like* icon.

IV. AUTOMATICALLY RECOMMENDING Q&A

Though we described the interface using limited learning material consisting of 14 pages, we devised an algorithm to automatically recommend Q&A and augment every page of any given computer science learning material available as electronic text. The algorithm consisted of the following two steps:

A. Find important concepts from each page

Since different learning materials can have different formats, we could not rely on formatting features such as headings and emphasis to extract keywords. Instead, we used a natural language processing approach prescribed by Liu et al. [26] for finding important phrases from the learning material.

As a first step, we extracted the text from the PDF files using PDFBox [27]. Then, we built a word graph for the given learning material. For this, we selected all unique single words and removed the most commonly occurring words such as *the*, *and*, *a*, *for* (also known as *stop-words*). We found what part of speech each word was using the Stanford part-of-speech tagger [28] and selected only adjectives and nouns. We created the word graph by connecting a pair of words with an edge if they co-occurred in a sentence. We then modeled the topics in the learning material using a technique called Latent Dirichlet Allocation (LDA) [29]. LDA represents documents as mixtures of topics and predicts the probability of words being associated with a particular topic. Using LDA by considering each page of the learning material as a document, we found the probability of a topic occurring in a document if a certain word occurred in the document.

Then using the word graph and the topic probabilities, we computed a Topical PageRank (TPR) score for each word, which indicated the importance of each word to different topics. This formulation used the PageRank algorithm [30] proposed by Page et al. which ranks a vertex in a graph higher if there are other vertices connecting to it. We computed the TPR by running PageRank on the word graph for each topic separately, while providing a bias towards the words contained in that topic.

The above exercise gave us a list of keywords (such as *multithreading* and *tree*) and their TRP score, but we also needed to find keyphrases containing more than one word (such as *binary tree* and *shortest path*). For finding such keyphrases, we adopted the approach prescribed by Agrawal et al. [8]. Using this, we first split the learning material in sentences and tagged every word with its part of speech. We used the following regular expression patterns to extract keyphrases (Note that *JJ* stands for adjective, *NN* for noun and *IN* for preposition):

1. $\{<JJ.*>*<NN.>+<IN><JJ.*>*<NN.>\}$
e.g. *depth of tree*
2. $\{<JJ.*>*<NN.*>+\}$
e.g. *random sampling, linked list*
3. $\{<NN.*>+\}$
e.g. *quicksort algorithm*

We then added the TPR scores for each keyword contained in each keyphrase to assign a total score to the keyphrase.

B. Query StackOverflow using these concepts to get Q&A for recommendation

First we created a search index for the entire StackOverflow repository containing 27 GB of data made available by StackOverflow [31]. We did not use the web service provided by StackOverflow for querying to provide flexibility, increase performance and avoid web traffic.

For each page of the learning material, we selected the top 10 keywords and keyphrases according to their TPR score. We then formulated queries using a mathematical combination of at most 6 words and at least 2 words from the top 10 list. This resulted in over 800 queries per page. Though only a few of these combinations yielded search results, they covered all possible combinations of keywords thus increasing the chances of retrieving appropriate Q&A. We combined the search results obtained for all the queries to obtain a unique set of Q&A as candidates for augmentation.

StackOverflow provides a mechanism for voting Q&A in positive (*upvote*) and negative (*downvote*) directions. The difference in the upvotes and downvotes is often regarded as the score for the question [32]. We used the same metric to rank the candidate Q&A and selected the top 15 questions for augmenting the page.

V. OBSERVATIONS ON RECOMMENDED Q&A

We found that for the aforementioned test learning material of 14 pages, 111 Q&A were automatically recommended by our algorithm. No related questions were found for 4 of the pages. This was because these pages either contained examples or lacked keywords important for the concept being taught. We manually analyzed the recommended Q&A and made the following observations:

1) *Questions catering to Bloom's taxonomy*: We found that the questions catered to lower-order as well as higher-order thinking skills prescribed by the revised Bloom's taxonomy [33]. For example, recommended questions such as *what is the difference between a process and a thread*, *can trivial superkey be considered as candidate key* and *what data structures to use for Dijkstra's algorithm in Erlang* were related to lower-order thinking skills such as *understand* and *apply*. Recommended questions such as *is it safe to fork within a thread*, *finding highest normal form of a relation of database* and *how to optimize Dijkstra algorithm for a single shortest path between 2 nodes* were examples of higher-order thinking skills such as *analyze* and *evaluate*.

2) *Interesting questions*: We found some of the recommended questions to be interesting and unexpected. Example of these were *how waterproof is a Swiss cheese*, *are zip code and postal code violation of 3rd normal form* and *do zombies exist... in .NET*. We believe that such interesting content can be useful towards arousing curiosity and increasing engagement in learners.

3) *Questions useful for job interviews*: We found that some of the recommended questions were questions often asked in job interviews. Examples of these were *how to find the distance between two nodes using BFS* and *what is the difference between fork and thread*.

4) *High quality answers*: While we found a rich variety of questions, we also found high quality answers to most of the questions. In many cases, they were interesting as well as accurate. We believe that this quality of curation is largely a result of the StackOverflow voting mechanism being used by a large number of active users.

5) *Almost no unrelated questions*: We found only one question which was unrelated to the learning material. This indicated that our automated recommendation algorithm worked well on the given learning material without needing any manual curation.

VI. EXPERIMENTAL STUDY USING THE AUGMENTED INTERFACE

In order to examine the efficacy of the proposed interface in establishing relevance of the learning content using StackOverflow Q&A, we conducted a classroom experiment with 48 undergraduate (senior, junior and sophomore) students of computer science. We asked the students to spend 15 minutes in learning from the aforementioned 14-page learning material augmented with Q&A. We then asked them to fill out a survey consisting of 12 questions assessing *relevance* and *preference* on a 5-point Likert scale (1 – *Strongly disagree*, 2 –

Disagree, 3 – *Neutral*, 4 – *Agree*, 5 – *Strongly agree*). The questions assessing relevance consisted of 8 statements such as *Learning with such accompanying Q&A will help me in my job interviews* and *In future I am likely to face such questions while doing my job*. The questions assessing preference consisted of 3 statements such as *The accompanying Q&A made my learning more interesting* and *I will prefer learning with such accompanying Q&A*. The last question *When am I most likely to use such a learning interface with accompanying Q&A* allowed multiple selection from 7 learning situations such as *In class*, *Exam preparation* and *Job interview preparation*.

We also recorded the learner activity during the experiment by recording the time that they spent on each accessed question and questions flagged as relevant by them.

A. Results of the survey

We found that a reverse coded question from the preference assessment was misinterpreted by some respondents, and therefore we had to discard it. Also, we found that 3 respondents had given the same rating to every question. So we discarded their responses from further analysis thus considering 45 responses for further analysis.

We found acceptable consistency in responses for relevance (Cronbach $\alpha = 0.72$) as well as for preference (Cronbach $\alpha = 0.8$). Fig. 4 shows the mean of responses for all the survey questions. We further grouped the responses together into two

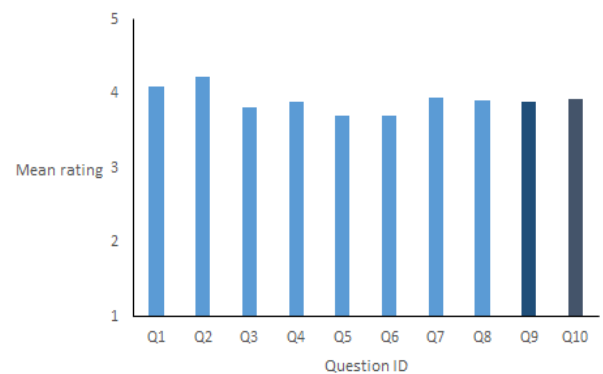


Fig. 4. Mean rating for survey questions for relevance (blue bars) and preference (dark blue bars)

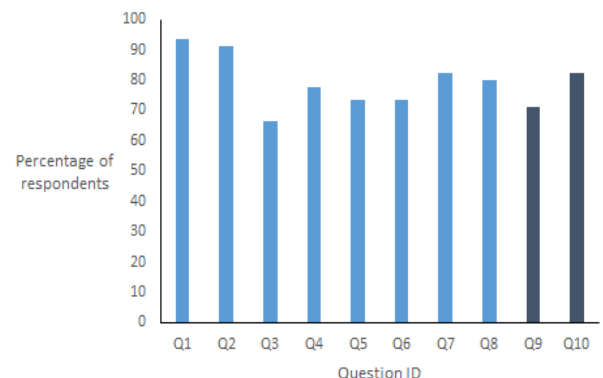


Fig. 5. Percentage of respondents agreeing to Q&A augmentation being relevant (blue bars) and to them preferring such augmentation (dark blue bars)

TABLE II. SPEARMAN'S RHO CORRELATION AMONG RESPONSES⁺

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Q1										
Q2	0.48**									
Q3	0.45**	0.32								
Q4	0.32	0.26	0.11							
Q5	0.23	0.42*	0.33	0.36						
Q6	0.06	-0.05	0.23	0.11	0.07					
Q7	0.21	0.29	0.17	0.03	0.07	0.18				
Q8	0.09	0.30	0.23	0.07	0.17	0.06	0.42*			
Q9	0.35	0.24	0.26	0.32	0.29	0.13	0.23	0.18		
Q10	0.54**	0.23	0.44*	0.39*	0.47**	0.06	0.18	0.18	0.61**	

⁺ The *relevance* questions are related to – Q1: Examinations, Q2: Job interviews, Q3: Job, Q4: Past experience, Q5: Future work content, Q6: Level of knowledge, Q7: Outcome, Q8: Freedom to choose. The preference questions are related to – Q9: Interest, Q10: Preference.

** $p < 0.001$, * $p < 0.01$.

categories, viz., Agree (corresponding to Strongly agree and Agree responses) and Disagree (corresponding to Strongly disagree, Disagree and Neutral responses). We grouped Neutral under Disagree to account for a possible central tendency bias wherein respondents tend to pick the neutral option in case they leaned towards disagreement. Fig. 5 shows the percentage of respondents agreeing to the Q&A being of relevance to them as blue bars, and that agreeing to prefer augmentation of their learning interface with Q&A as dark blue bars. In summary, we reported that 79% percent respondent agreed to the interface being relevant to them and 76% respondents agreed to them preferring the augmented interface for self-studying.

Table II shows the Spearman's rho correlation among the responses. The statistically significant correlations are denoted by two stars ($p < 0.001$) and one star ($p < 0.01$). We found moderate correlations between preference and Q&A being relevant to examinations ($\rho = 0.54$, $p < 0.001$), to future job content ($\rho = 0.44$, $p < 0.01$), to past experience ($\rho = 0.39$, $p < 0.01$) and to future job expectations ($\rho = 0.47$, $p < 0.001$). We also found a statistically significant moderate correlation between the aggregated relevance response and the aggregated preference response ($\rho = 0.49$, $p < 0.001$).

B. Analysis of usage patterns

We analyzed the learner activity in terms of the time they spent on accessing Q&A on each page as well as the Q&A they

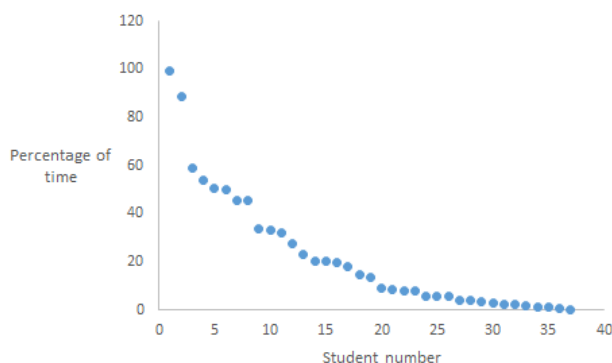


Fig. 6. Percentage of learning time spent by learners on accessing Q&A

TABLE III. TOP Q&A IN TERMS OF TIME SPENT BY STUDENTS

Question	Time, min	Bloom's skill type
What is the difference between a process and a thread	13.8	Understand
Process vs. Thread	8.6	Understand
Do zombies exist ... in .NET?	8.0	Analyze
How does threading save time?	5.3	Analyze
How to pause / sleep thread or process in Android?	4.8	Apply
The best shortest path algorithm	4.6	Apply
How waterproof is a Swiss cheese?	4.2	Evaluate
Are zip code and postal code violation of 3rd normal form?	3.9	Analyze
Superkey, candidate key & primary key	3.8	Understand
What is the difference between fork and thread	3.8	Understand

^ indicates a higher order thinking skill as per Bloom's taxonomy

found relevant. We removed 2 outliers from the time data which corresponded to students leaving keeping the popup window open. We found that 45 students spent a total of 127 minutes on Q&A, which was approximately 18% of the total time spent on learning. Fig. 6 shows the percentage of learning time spent by students on accessing Q&A, ordered by the highest to the lowest percentage. We could not include data for 8 students who had chosen to take the survey, but not to register. We found the median percentage of time spent by students on accessing Q&A to be 13.6%.

We found that 91 Q&A out of 111 were accessed by students. Table III shows the top Q&A in terms of time spent by students reading them. It also lists the number of students who accessed the questions. We observed that these questions consisted of questions catering to both lower-order and higher-order thinking skills as defined by Bloom's taxonomy. They also consisted of interesting questions as well as questions which could be asked in job interviews. A question such as *how to pause / sleep thread or process in Android* also indicated that some students wanted to relate the concept being learnt to current and relevant technology such as mobile phones.

However, we found a contradictory trend while analyzing the student vote data. Table IV shows the top 10 questions according to the percentage of students voting for them as relevant questions. These Q&A mainly catered to lower-order thinking skills as per the Bloom's taxonomy such as *understand* and *apply*. This observation probably indicated that the learners' notion of relevance was related to practical and immediate learning goals such as understanding and applicability of the Q&A to familiar scenarios.

Fig. 7 shows the total time spent by students on each page. We found that during the experiment, most students primarily used the first page to assess the interface. Fig. 8 shows the distribution of average reading times for questions. The median of reading time was 0.38 min. We believe that such short time spent on Q&A is due to the time constraint of 15 minutes on students for assessing the interface.

TABLE IV. TOP Q&A IN TERMS OF STUDENT VOTES

Question	% of students	Bloom's skill type
What is the difference between a process and a thread	67	Understand
Finding kth-shortest paths?	58	Analyze [^]
Superkey, candidate key & primary key	58	Understand
Normalization - IDENTIFYING Transitive Dependencies	56	Apply
Process vs. Thread	49	Understand
Relations in 2NF and 3NF	49	Apply
How does lock work exactly?	47	Understand
The best shortest path algorithm	47	Apply
What is the difference between 3NF and BCNF?	47	Understand
How do you normalize one-to-one-or-the-other relationships?	42	Apply

[^] indicates a higher order thinking skill as per Bloom's taxonomy

VII. DISCUSSION

In this paper, we demonstrated that learning material can be made more relevant to learners by augmenting it with Q&A from social Q&A websites such as StackOverflow. In an experiment conducted using such augmented interface, we found a statistically significant correlation between perceived relevance of Q&A and learner preference for such an interface. We also found that more than 75% students preferred learning with such a learning interface. In specific, we found correlations between learner preference and perceived relevance of Q&A to examinations, future job content, past experience and future job expectations.

The aforementioned correlations could be attributed to learners' need for connecting theory to their world. For instance, using Q&A, they are able to imagine the content of their future jobs, scenarios related to job interviews, scenarios related to current and relevant technology, and their subsequent role as a practitioner. Analysis of the recommended Q&A suggests that StackOverflow Q&A offers a variety of questions addressing a variety of learning needs

such as higher order thinking skills, interview readiness and programming skills to satisfy the needs of a variety of students. We did observe a tendency of learners to choose questions catering to lower-order thinking skills such as *understand* and *apply* as per the Bloom's taxonomy. This indicates that for building relevance, immediate learning goals such as understanding a concept well and applying it to familiar scenarios need to be catered to in establishing relevance while learning.

In this paper, we also proposed an interface and a method for automated recommendation of Q&A from StackOverflow as an augmentation to any given learning material in computer science available as electronic text. This allows us to make the augmentation a part of learning management systems, electronic books and mobile study apps.

VIII. LIMITATIONS AND FUTURE WORK

The limitations of the work described in this paper include the relatively small number of students used for experimentation and the relatively short period of time for which they used the experimental interface. The time constraint in the classroom setup probably did not allow the students to explore the interface in detail and in a sustained self-study setting. In near future, we plan to conduct a similar experiment as a part of an online learning portal with a much larger set of students.

Also, a question is a construct that creates curiosity in a learner. We did not specifically examine the effect of curiosity in the experiment. Based on the classroom observations of students using the interface, we believe that curiosity also has an important role to play in the utility of Q&A and can be examined in future experiments.

In future, we plan to make the recommendations more personalized to learner interests. This might include classifying the questions into abstractions useful to learners such as *explanation*, *implementation*, *troubleshooting* and *suggestion* by refining the StackOverflow queries with verbs indicating question types as suggested by Allamanis et al. [34].

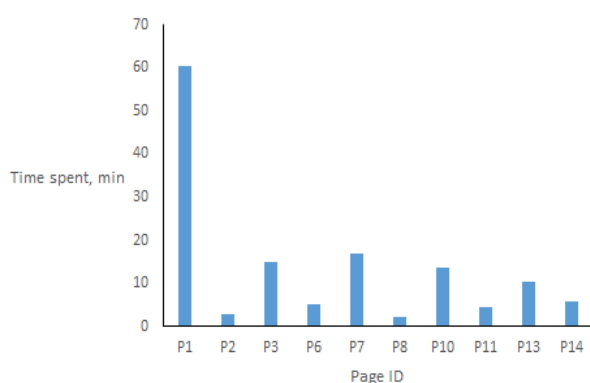


Fig. 7. Total time spent in minutes reading Q&A on each page of the learning material

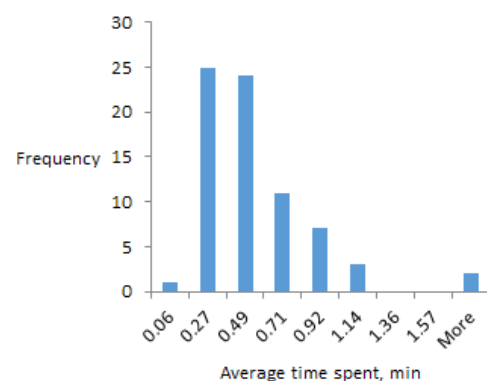


Fig. 8. Distribution of average reading time in minutes

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Blended Learning at Maths with Aerospace Engineering Freshmen

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Abstract—Instructing mathematics to engineering freshmen is a challenge not only because of their diverse backgrounds but also because of their high skills in digital technology. For this reason, a new approach has been considered in Aerospace Engineering at Technical University of Valencia (UPV) which, in addition to master classes, includes assignments specially designed to achieve mathematical competencies in the first year. These assignments reinforce the learning process of students and increase their competencies before each assessment test. On the other hand PoliformaT, an educational platform developed by UPV, and based on the Sakai project, has facilitated to develop a flipped teaching methodology in the one hour lab sessions in the first year of Aerospace Engineering. Thus a blended learning methodology, a combination of computer technologies and face-to-face classes, has provided very good learning outcomes results for Spanish standards. We present some results concerning our first year Mathematics course in Aerospace Engineering and the opinion of the students about this blended learning methodology.

Keywords—Blended learning, Mathematics in Engineering Education, Assessment and Evaluation Strategies/Approaches Laboratory Experiences, Teaching & Learning Experiences in Engineering Education, First and Second Year Program

I. INTRODUCTION

One of the main objectives under the Bologna Process has been to avoid passivity in students when they are in the classroom. Instead, focus has been placed in getting the students to be part of their own learning process [1].

In order to encourage this active participation several methodologies have arisen, such as problem-based learning, flipped learning, collaborative learning, online learning, etc. Combining some of these and other methodologies we find how the so called blended learning emerges, so that students can learn on their own, alone or in groups, and always maintaining focus on the acquisition of specific competences during the learning process [2].

On the other hand, the competences and skills developed in the subject of Mathematics are basic in all Engineering studies and among them the skill of a proper use of mathematical software must be worked in a natural and active way. With this in mind the authors are taking advantage of the powerful software MATHEMATICA at Aerospace Engineering following a blended methodology for the classes.

Mathematics I is a compulsory and annual subject delivered in the first year of BEng Aerospace Engineering [3] at the

Higher Technical School of Design Engineering (ETSID acronym in Spanish) of the Technical University of Valencia (Universitat Politècnica de València, UPV). It has got 120 contact hours (12 ECTS) from which 75% of them correspond to Theory/Problems (TP) sessions and the remaining 25% to Lab practice (LP).

The methodology used involves a blended methodology since flipped classroom is partially used by students to prepare lab classes in advance, as detailed in Section II. Is in these lab sessions where the educational platform developed by UPV, PoliformaT becomes very helpful. In section III we analyze the results obtained in Mathematics I of BEng Aerospace Engineering during the academic course 2013/14. We also present the students' opinion about the blended methodology applied in the subject. Finally, in Section IV we discuss the results and the questionnaire with the students' opinion.

II. BLENDED LEARNING

Blended learning occurs when learning takes place through several channels such as, combining Internet and digital media with the procedures established in the classroom with physical co-presence of teacher and students.

A. PoliformaT, the UPV's educational platform.

The use of educational platforms can enhance learning opportunities. All of the platforms have many utilities, and we find especially useful the ones called 'self-developed' because they allow improvements in their specific purposes, aspects and tools according with the demand of its users. PoliformaT has been developed by UPV and it is based on the Sakai project [4]. Sakai is based on reliable and extensible educational software distributed under an open source license. We dispose of tools like 'Resources', 'Modules', 'Chatroom' or 'Forums' but some features of PoliformaT have evolved throughout users demands such as the interconnection between tools like 'Schedule', 'Announcements' or 'Messages'. Other improvements include 'Drop Box' that now enables to download students files by groups whereas previously the download was one by one; 'Gradebook' where now it is possible to add comments to each mark improving the feedback; 'Polls' that allows to query students anonymously about different issues. It has also been incorporated several changes in the editor of the 'Test&Quizzes' tool. It incorporates a text editor, what makes the work more efficient, especially in Maths. It is essential to allow the use of different fonts, paste text from other software, including images, and

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create formulas. Currently the inclusion of formulas is allowed from LaTeX although some unsolved technical issues appear in questions of 'Numerical Answer' type by the use of '{}'. They are reserved to contain the correct answer but LaTeX frequently uses it with some characters. Recently, PoliformaT has implemented TURNITIN as a software tool for faculty staff. TURNITIN software is aimed to prevent plagiarism and it allows instant revision of delivered works by searching for coincidences in multiple information databases through 'Originality check', 'GradeMark' and 'PeerMark' [5].

B. Traditional and in-class learning

For theory and problems classes we use a traditional in-class methodology with master lectures.

To reinforce the contents seen in theory sessions, students should carry out certain tasks to implement such content. These tasks are performed outside of the class and therefore can become *collaborative learning* without being the specific methodology of these tasks. The tasks have been carefully designed to complement and assist in the learning process, which is part of a *problem-based learning*. However, the tasks serve mainly to develop the skill of solving problems (plan, resolution and interpretation). New concepts do not appear while doing them.

C. Flipped learning and online learning

Some contents of Mathematics curriculum are incorporated directly into lab sessions which asses into the lab sessions are key issues. For these lab sessions, we use MATHEMATICA as computer algebraic system and the educational platform, PoliformaT.

The current methodology has been achieved through an evolutionary process from the initial lab sessions and their corresponding evaluation to a situation in which we are delivering the one-hour weekly lab class based upon the *flipped class* methodology.

A flipped classroom is a methodology in which students can choose their own pace in the learning process and teachers guide and help them. With this approach students can achieve deeper learning by working harder and making a personal commitment to the process [6-8].

With this methodology the standard lecture in-class format is replaced with opportunities for students to prepare, review, discuss, and investigate the course contents with the instructor during class. There are several ways to flip a class, the main idea under this perspective is that students review lecture materials previous to master class and then attend theoretical classes to develop learning activities with an instructor [9].

In [10] there is an interesting summary with hints about different strategies for flipping classroom highlighting:

- Assigning readings, following up in-class discussion or quizzing as well as providing videos and readings for students to review and promote forum discussions by instructors fostering an online or hybrid class.
- Capturing lectures from classes and providing the recordings for students review after class.

- Assigning reading material outside of class or in class, and require students to teach part of the class by some media.

These approaches allow having access to the material when students miss a class, follow the course up with this material and finally, for those who join the group later, facilitates the updating with the first lessons.

This inverse classroom involves changes in the teaching practice for both, students and instructors. Students should modify their passive attendance to the traditional lectures and the teachers must develop suitable material for the new flipped setting. Moreover students should be ready to discuss in class stirring the students' participation.

Depending on the level of technology and time available, a flipped classroom may or may not include this technological component (CAS, videos, ...). Our methodology makes a reasonable use of technology in line with the strategy described above. An important aspect for success is that students are evaluated each week about the material they have been working by their own, as explained below.

Each group of LP consists of about 25 students and with such a small group the potential of MATHEMATICA is exploited. Our flipped learning implementation has got three different stages: *pre-class*, *in-class* and *post-class*.

The work of pre-class stage is made outside of class and it relies on the educational platform PoliformaT by providing a guide with topics and exercises that students should prepare before the lab session. This guide also includes theoretical aspects that they need and must know and their related MATHEMATICA commands.

Each week there is a lab practice session, the in-class stage. This begins discussing with students the different elements of their prepared session. In a second part of the in-class session we host an assessment where freshmen have to solve individually some questions and exercises posed through the platform and assisted by MATHEMATICA. In these questions, the instructor is available to help students if they ask for it.

The third part of each session, post-class stage, starts once finished the assessment when students check their answers and qualifications and teachers can detect unachieved skills both in general and in individual cases. In such cases some reinforcing tasks are proposed pursuing that the students achieve this skill. For example, by suggesting the review of virtual laboratories [11] and videos [12] that explain certain contents or, proposing conducted exercises with appropriate supporting literature.

Moreover following this methodology, students and instructors monitor the students' learning progress. The marks obtained in lab sessions have got an influence on the continuous assessment of the students who also must perform semester exams individually.

D. Other activities to facilitate competencies achievement

Along with this weekly flipped classroom in lab sessions, the students were also required to make some assignments to promote the work of the subject. They have to solve this task

during one week. Each assignment includes, between others, questions related to:

- Math problems with some degree of difficulty.
- Engineering related problems.
- Open questions with no closed answer.

Assignments are performed in a non-controlled environment (NCE), and therefore there are always some doubts about their authorship. For this reason students are requested to take a multiple-choice test under a controlled environment (CE), in-class, related with the type of the assignment exercises.

During the multiple-choice test under CE students can even consult their home assignments, so the multiple-choice test is not standard. Students know that they will be awarded with the same positive (negative) absolute input in success (failure) case and with 0 input in case of no answer.

III. RESULTS AND STUDENTS' FEEDBACK

There were 126 students of Mathematics I in BEng Aerospace Engineering during 2013/14. This participation serves as reference for relative values and percentages. 5 out of 126 had less than two attendances, and were considered as non-participants of the experience

The students' performance was as follows:

- The average on the 27 weekly lab sessions was 8.7 with a deviation of 1.7.
- The 4.7% (6/126) of students did not take the LP semester exams almost matching the students with non-attendance at LP sessions. Without considering these 5 students, the percentage drops to 0.8%.
- The averages obtained in the LP semester exams were 5.6 and 7.6 with deviations of 2.0 and 2.4, respectively.
- The global mark of assignments, green in Fig. 1, was obtained by weighing these two results. Most students performed better under NCE than at class under CE, blue and red respectively in Fig. 1. In few cases we found divergence between both values what leads to intuit that they received aid in the NCE assignment.
- The 8.7% (11/126) of students did not take the TP tests which correspond to 4.7% of students not considering the 5 dropouts.
- The average scores obtained in the three TP tests were 6.1, 6.6 and 6.9, with standard deviations of 2.4, 2.6 and 2.1, respectively.
- Finally 88.9% (112/126) of students passed the subject, 92.6% without accounting the 5 dropouts.

Assignment Grading

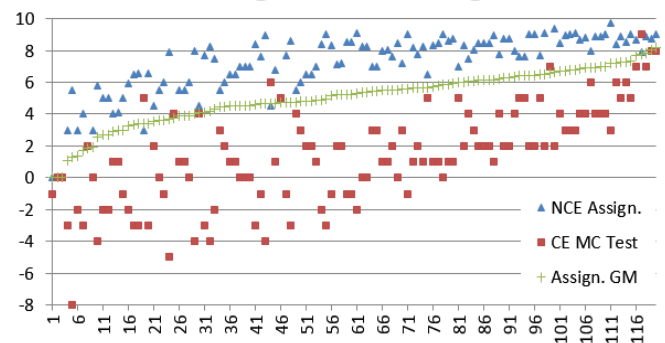


Fig. 1. Grades obtained by each of the 119 students in an assignment composed of two parts: Performance in a non controlled environment (NCE) whose grade is in blue (▲) and a multiple choice test done in a controlled environment (CE MC) whose mark is in red (■) where the NCE task could be consulted - in this case no answers obtained 0 points and wrong answers subtracted 1 point -. For this reason some red marks are negative. In green (+) the global assignment mark (GM) was 65% of the NCE part and 35% of the CE MC test, whose minimum possible value was taken to be zero.

We got feedback from students about the blended methodology applied in the subject by using a PoliformaT's tool called 'Polls'. This poll consisted in several questions, related with the organization of the subject and other issues.

The first question was meant to know the actual time spent by the students in the pre-class stage. The results show that most students did not take more than two hours a week of preparation (see Fig. 2).

Another question tested his/her opinion about the efficiency of using the platform as a means of evaluating the answers and it also shows that this method improves or at least facilitates the learning of subject contents (see Fig. 3).

We also obtained their opinion about the possibility of finishing the TP sessions by doing some questions through PoliformaT. In this case most answered do not know perhaps because they cannot imagine the way that these questions would be (see Fig. 4).

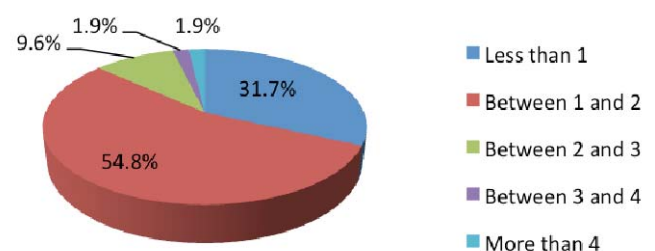


Fig. 2. How many hours do you spend on average a week to prepare each LP session?

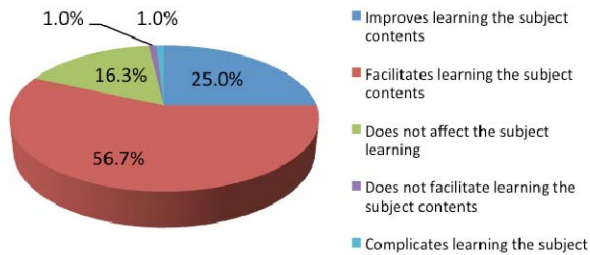


Fig. 3. Do you think that being assessed with PoliformaT at the end of each practical session is good for your learning process?

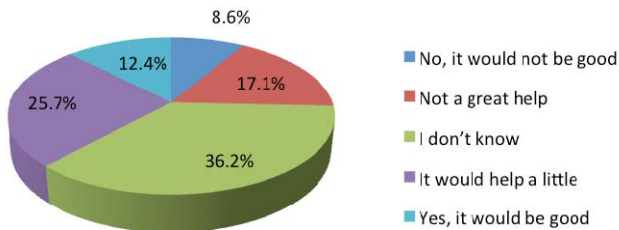


Fig. 4. Do you consider that it would be good for your learning process if each week you had to answer a quizz with PoliformaT about the concepts presented during the sessions of Theory-Problems?

In Figure 5, we show the students' opinion about the assignments and its importance in the learning process.

From the Poll it is clear that students do not have a negative perspective towards the use of a flipped methodology. Although the performance of this methodology has been developed only in LP sessions, its effects have had great influence on the results of TP. In our opinion this is mainly due to the constant review of concepts that students must carry out during the preparation of LP sessions.

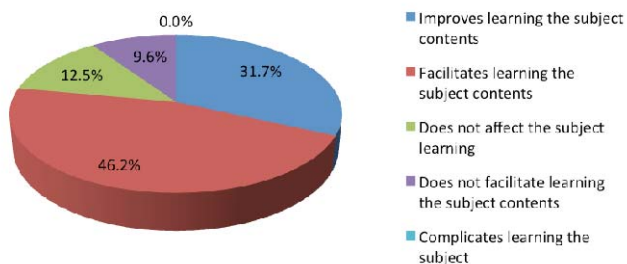


Fig. 5. In what assignments are concerned, I think that...

IV. SUMMARY

When active learning is performed, students get activities, tools and approaches to the subject that together with their motivation, attention, etc. make that their learning process is performed through a creative attitude. In this paper we describe the initiative taken in a basic subject of first year as Mathematics in Aerospace Engineering with the aim of favouring this kind of active attitude among students from the early stages of their university studies.

By means of a blended methodology, combination of many other methodologies, very good outcomes in Spanish standards have been achieved. Results of first year Mathematics course in Aerospace Engineering have been presented, where 95% students attendees was achieved at the end of the course, all of them taking all exams, and where a success rate above 90% has been experienced which is far of being standard at Spanish Engineering studies.

In addition we have collected the opinion of the students concerning the different facets covered by the blended learning methodology used and discussed their results in this paper.

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South African Student Perceptions of Practical Laboratory Work – a Case Study from Digital Systems 1

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Abstract

International accreditation bodies monitor and accredit engineering programmes offered by tertiary institutions based on the high standards set forth by the Washington, Sydney and Dublin Accords. These accords stipulate specific graduate attributes like problem solving, investigation, modern tool usage, sustainability, ethics, teamwork, communication, management and life-long learning. Many of these attributes may be assessed by means of practical work done by students in a laboratory. This paper presents student perceptions about practical work done by freshman engineering students for a module termed, Digital Systems 1. The paper firstly considers the importance of practical work in an engineering environment and then discusses the significance of student feedback. It then sheds light on the research methodology used in acquiring data for this research. Finally the results are analyzed which indicates that South African engineering students really enjoy practical work done in a laboratory. Student further indicated that it helps them to fuse theoretical knowledge gained in the classroom, but prefer to work alone as opposed to in groups. A key recommendation from this study is to encourage more group work among freshman engineering students so as to strengthening the vital graduate attribute of teamwork.

Keywords— practical work; student perceptions; entry level subjects; theory; freshman

I. INTRODUCTION

Mahatma Gandhi once said [1], “A customer is the most important visitor on our premises. He is not dependent on us. We are dependent on him. He is not an interruption in our work. He is the purpose of it. He is not an outsider in our business. He is part of it. We are not doing him a favor by serving him. He is doing us a favor by giving us an opportunity to do so”. These words are very applicable to education, where students are actually the most important customers who become the most logical evaluators of the quality of a course. This novel notion of asking students to provide their perspectives on effective teaching and learning was first introduced in the late 1920's [2] and has grown steadily to the

point of being included as one of the criteria [3] used in measuring the academic performance of academics.

The Central University of Technology (CUT) [4] is home to approximately 13000 students and offers National Diplomas and Bachelor of Technology degrees in various faculties, including the Faculty of Engineering and Information Technology. These engineering based programs are accredited by the Engineering Council of South Africa under the guidelines of the Washington, Sydney and Dublin accords [5]. This accreditation is usually performed by examining the evidence of theoretical and practical work completed by students and facilitated by academics [5].

Practical work performed in laboratories provides great insight into the caliber and attributes of the graduates, and should be reviewed periodically in line with Industry needs. One key review of the practical work involves obtaining student perceptions of whether the work was enjoyable, beneficial, challenging and relevant to the theory covered in a classroom. Previous research has revealed that senior engineering students in an electronic communication course indicated that they really benefitted from the practical work scheduled in a laboratory [6]. Many of these senior students have been able to successfully enter the workforce after completing their practical internships with Industry related partners [7].

However, what are the perceptions of freshman engineering students towards practical work done in a laboratory? This paper aims to present these perceptions regarding practical work done in a computer systems engineering laboratory. The importance of student feedback is firstly presented along with how theory and practice may be integrated into a module termed, Digital Systems 1. The research methodology is then substantiated and the results are presented in a series of figures.

II. SIGNIFICANCE OF STUDENT FEEDBACK

Feedback can be conceptualized as information provided by an agent with the aim of improving or enlightening the recipient [8]. It cannot be a once off process, but needs to be a continuous cycle, an evaluation cycle [9]. The evaluation cycle suggested by Hounsell is shown in Figure 1. The first step here

is to define the context of the evaluation and then devise a feedback strategy. The third step is to gather feedback and analyze it. The fifth step involves agreeing on a remedial action and finally implementing the changes.

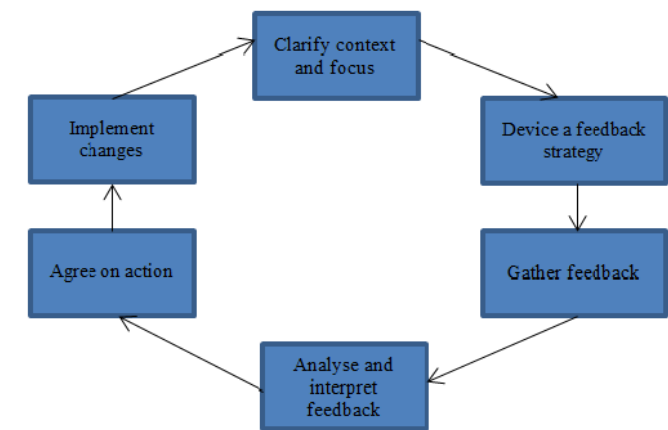


Fig 1: The evaluation cycle by Hounsell

In an educational environment, feedback can occur in many forms, with student feedback being a unique example. Student evaluation of teaching (SET) is seen as a way to measure teaching performance in higher education institutions [10]. The validity and reliability of student feedback have been studied in detail by many researchers, some of whom have come to the conclusion that it is indeed useful in evaluating teaching [11][12][13][14][15][16][17][18][19].

Research has further shown that student feedback positively impacts upon educators and their teaching ability [20]. Student feedback increases the likelihood that excellence in teaching may be recognized and rewarded, which surely provides motivation for instructors to gather and respond to this kind of feedback [16].

Perceived disadvantages of student feedback stem from the argument that there is no universal definition of effective teaching [2]. Other studies have commented on the correlation between a small sample size and its effect on valid student feedback [20] while the tendency to use grade inflation as a means to influence student feedback has also been noted [2].

Although disadvantages do exist in asking students to comment on the quality of a course, numerous advantages do exist in favor of it. However, student feedback should be sought to evaluate any changes that have been made to integrate theory and practice in a specific module.

III. INTEGRATING THEORY AND PRACTICE IN DIGITAL SYSTEM 1

Digital Systems I is a compulsory module for all Electrical Engineering students. This module usually comprises many freshman engineering students who have very limited prior laboratory experience. Many challenges exist in delivering a

freshman course [21] with one unique challenge relating to the large number of students attending a course [22]. In fact, average classroom sizes for this module range between 100 and 150 students per semester.

Digital Systems I is a Level 6 module according to the National Qualifications Framework [23] with 12 credits awarded to it. This means that students need to dedicate at least 120 notional hours to this module over a 14 week period. The purpose of Digital Systems I is to provide a basic introduction to the working of digital systems as contrasted to analog systems. The course aims to build a knowledge base for subsequent modules like Digital Systems II, III and Logic design III.

The specific learning outcomes of this module gives the freshman engineering student the ability to implement simple digital circuits, making use of different simplifying techniques and various digital devices. Student assessment focuses on building simple circuits for conversion between the various number systems, analysis of logic circuits, simplification using Karnaugh maps and building combinational logic circuits. All practical sessions are done in conjunction with the corresponding theory which is highlighted in Table 1.

TABLE I: Linking theory and practice in a Digital System I laboratory

UNIT	THEORETICAL CONCEPTS IN THE SYLLABUS	PRACTIAL ASSIGNMENTS IN LABORATORY
1	Introduction to Logic gates Gate	Identification of logic gates and their functions
2	Conversion from binary to decimal, to gray code, to hexadecimal, to octal and to BCD	Designing Binary to Gray and Gray to Binary converters
3	Boolean algebra laws and rules, De-Morgans theorem, Truth table construction, Standardization of SOP and POS terms, Boolean simplification using Karnaugh maps	Generating truth tables from logic circuits and redrawing the circuits using only NAND gates or NOR gates. Creating and building circuits from non-standard SOP/POS expressions
4	Combinational logic circuits	Designing 4 bit adder circuits using 7483 and 7486 IC's

Apart from the five practical experiments shown in Table 1, the students are required to do a practical test and a group assignment. The students submit their circuit designs on paper for the respective practical experiments and only construct their physical circuits after having their design assessed. The practical test is conducted after the conclusion of the 3rd practical experiment and focuses on reflecting on the previous experiments with a view to re-enforcing the graduate attributes of problem solving and investigation. Designing digital circuits to meet specific criteria and then investigating or evaluating their operation is assessed.

The group work assignment is completed after the 5th practical experiment. The students are split into groups of five where they are given a real-industry related scenario or

problem. The five students are then required to analyze the problem according to the theoretical concepts which they have acquired, design a circuit on paper as a probable solution, construct the circuit on a breadboard and then evaluate it to see if the problem has been solved. The practical mark (PM) of the students is calculated using the following formulae:

$$PM = \left(\frac{\sum(Assignments)}{5} \right) 0.5 + \left(\frac{\sum(Practical\ test + Group\ work)}{2} \right) 0.5$$

This PM is then used to calculate the course mark (CM) of the student. The CM also depends on the two written tests, namely the First test (FT) and the Main test (MT). The formula used for calculating the CM is as follows:

$$CM = (0.25 \times FT) + (0.35 \times MT) + (0.4 \times PM)$$

The PM has to be above 50% and the CM has to be above 40% for the student to gain entry into the final written examination. The final mark (FM) of the students is calculated based on marks scored in the main evaluation (ME) and the CM. The formula for the final mark is as follows:

$$FM = (0.6 \times ME) + (0.4 \times CM)$$

The formulae given above stress the significance of the practical work, which accounts for 40% of the CM. The practical assignments done in the laboratory consist of two main sections. The first section tests the theoretical knowledge of the student while the second section assesses their practical skills. In the theoretical section, the student has to prepare for the experiment. This can include drawing digital circuits, creating truth tables and answering theory questions relevant to the experiment. Each student is individually assessed prior to the laboratory session for the first section and the marks are captured on an MS EXCEL sheet.

The second section involves building the circuit using the different components provided to the students in the laboratory. This is done within the laboratory. Once completed, the student demonstrates the result to the lecturer or laboratory assistants. The student is assessed for the second time here based on the output of the circuit. The mark for the second section is added to mark of the first section on an MS EXCEL sheet to obtain the assignment mark. This mark is then used for calculating the practical mark (PM) described earlier. The written report of the theory work and practical work (with all marks attached) is stored in the laboratory for future reference.

IV. RESEARCH METHODOLOGY

An exploratory study is employed along with descriptive statistics involving quantitative analysis of the collected data. An exploratory design may set the stage for future research and usually involves only a single group of respondents [23]. Descriptive statistics are used as the results are interpreted with regard to specific freshman engineering students enrolled at CUT. Quantitative analysis is important as it brings a methodical approach to the decision-making process, given that qualitative factors such as "gut feel" may make decisions biased and less than rational [24].

The target population was restricted to freshman engineering students enrolled for Digital Systems I during 2014 ($n = 56$). An electronic response system (ERS) was used in a classroom environment to obtain student perspectives on specific questions relating to the practical work done in the laboratory. Closed-ended questions, featuring Likert scales, were used based on previous research which focused on student perceptions of practical work done in a laboratory [25][26]. Using this ERS in class ensured a high response rate, while the closed-ended questions did not require the participants to express lengthy views, as this is rather cumbersome with the ERS used to collect the results.

V. RESULTS AND DISCUSSION

The purpose of this paper is to present freshman engineering student perspectives of practical work done in a Digital Systems I laboratory. This is done by dividing the results into four sections. The first section focuses on whether the students were satisfied with the practical work. The second section focuses on whether the practical experiments helped students to better understand the course content. The third section focuses on whether the practical experiments were challenging and relevant to the theory presented in the classroom. The fourth section focuses on student recommendations regarding the practical work and on submitting their written practical assignments online via a learning management system.

The results for the first section revealed that 70% (40% strongly agreed and 30% agreed) of the students enjoyed the practical work. As a follow up question, the students were asked if they would recommend the subject to other students. Here, 50% (20% strongly agreed and 30% agreed) indicated that they would indeed recommend this subject to other students. These results are shown in Figure 2. This tends to suggest that the students were satisfied with the practical work, as enjoying and recommending a module are factors that may indicate student satisfaction [27].

The results of the second section are given in Figure 3. Here 86% (59% strongly agreed and 27% agreed) of the students agreed that Digital Systems I was a valuable learning experience while 65% (26% strongly agreed and 39% agreed) reported that the practical work helped them to apply new knowledge in solving engineering related problems. A further 81% (43% strongly agreed and 38% agreed) of the respondents indicated that the practical work helped them to better understand some of the theory given in the classroom. These results imply that the practical experiments are enabling students to understand and apply their newly gained theoretical knowledge in demonstrating the desired graduate attribute of problem solving which is prescribed by the International Engineering Alliance [5].

The next focus was on the relevance and difficulty of the practical experiments Figure 4 indicates that the majority of students (82% agreed) perceived the practical work as being relevant to the theory covered in the classroom. The practical work was viewed as challenging (70% agreed), but not too

difficult (12% agreed) by the majority of the respondents. This tends to suggest that the practical experiments have been

aligned with the theoretical instruction, thereby adhering to the principles of constructive alignment [28].

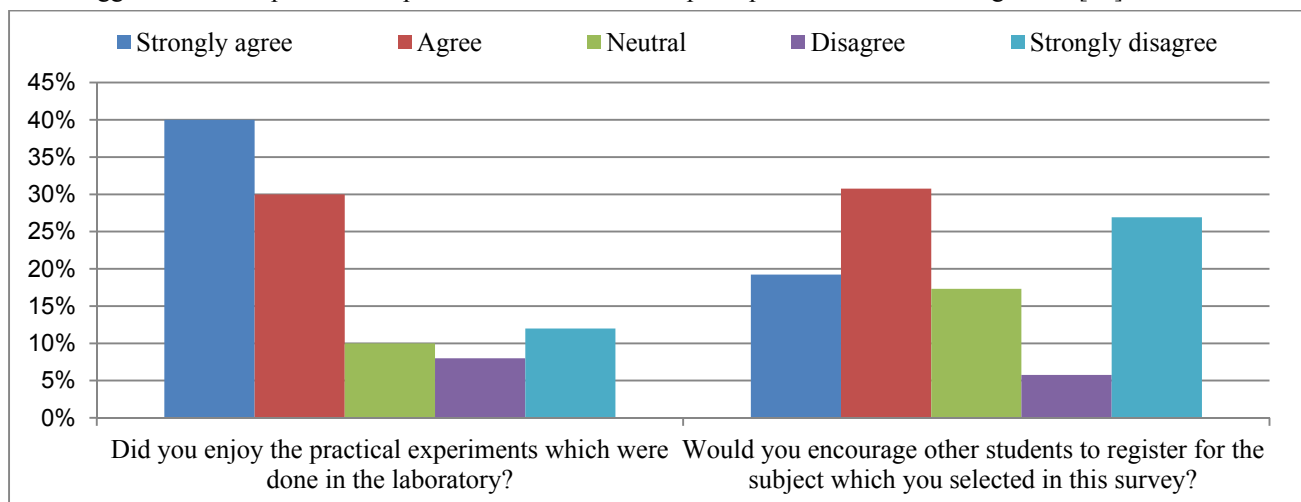


Fig 2: Student perspectives on practical work done in the Digital Systems I laboratory

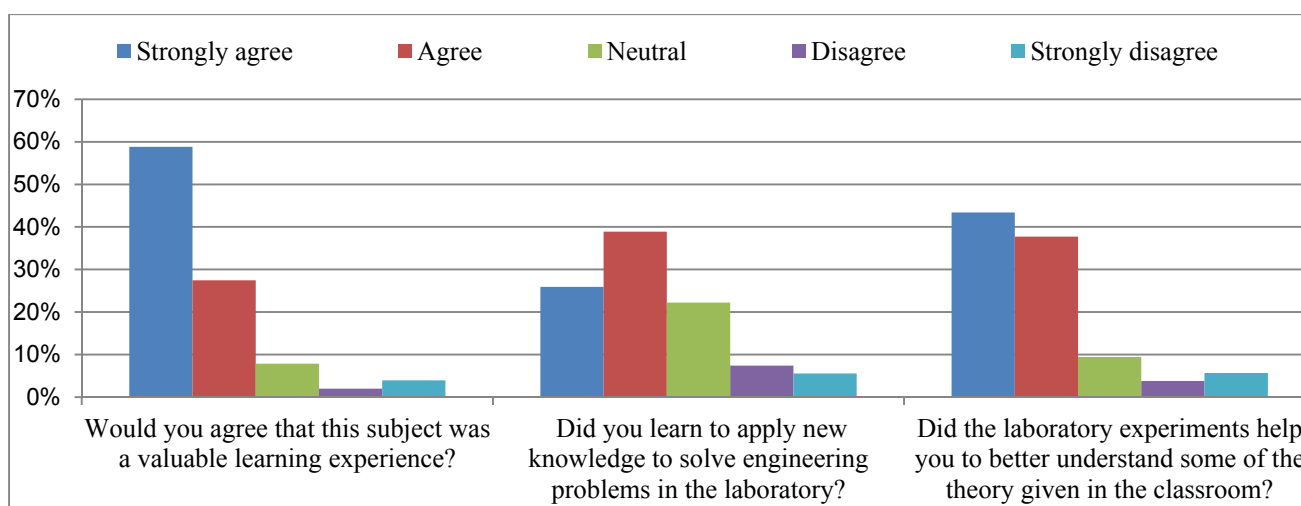


Fig 3: Student perspectives on subject knowledge gained after completing practical experiments in the Digital System I laboratory

The results of the fourth section considered recommendations regarding the practical work and its submission via an online learning management system (see Figures 5 – 7). The results indicate that 66% of the students feel they need to do more experiments in the laboratory, while 78% believed that they needed more time doing the experiments. Students also expressed the view that they would prefer to work on their own (70%) in the laboratory.

However, this goes contrary to the desired graduate attributes of teamwork and communication prescribed by the International Engineering Alliance [5]. CUT also has regular advisory committee meetings with Industry who often indicate that African engineering students struggle to work in groups. This therefore suggests that more emphasis needs to be put on group work, where the academic needs to incorporate principles of collaborative learning [29]. Encouraging group

work at this early stage of these students intellectual development may reverse the eventual viewpoint of senior engineering students towards the importance of group work in Industry.

Figure 6 considers recommendations relating to the practical work. 23% of students want more access to the laboratory during the evenings, while some students did verbally indicate that they would like to access the laboratory more during the day. In keeping with the trend of working alone, only 19% of the respondents indicated that they would prefer working in smaller groups while 23% feel that more computer simulations should be included in the practical work. This could improve the student's ability to demonstrate the desired graduate attribute of modern tool usage [5].

Figure 6 further highlights that only 9% of students want to submit their practical assignments online. With the drive

towards a more Green Environment where paper usage and printing needs to be reduced, this recommendation is difficult to adhere to.

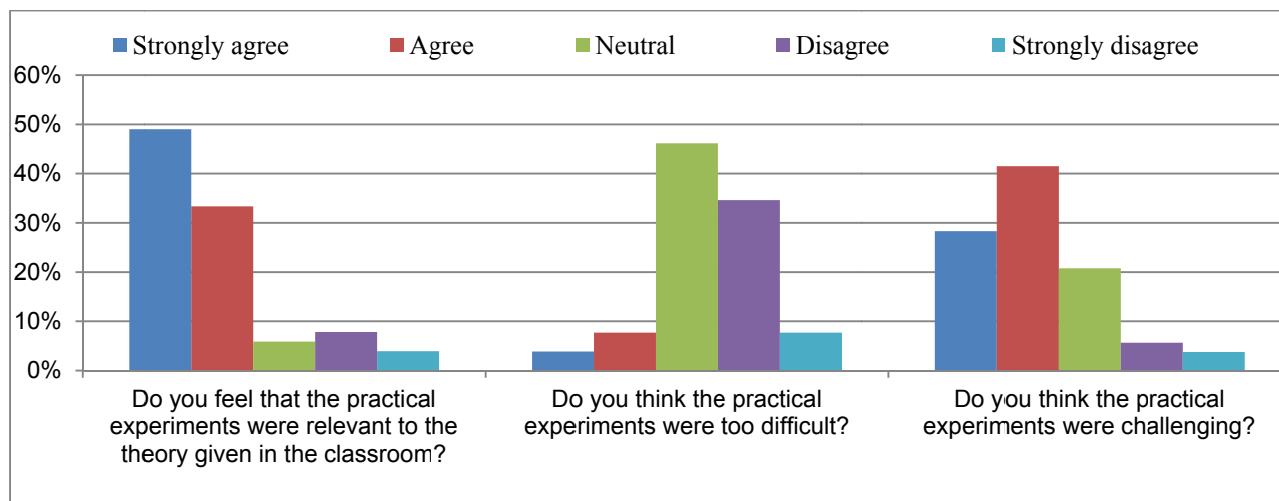


Fig 4: Student perspectives regarding the relevance between the practical and theoretical work

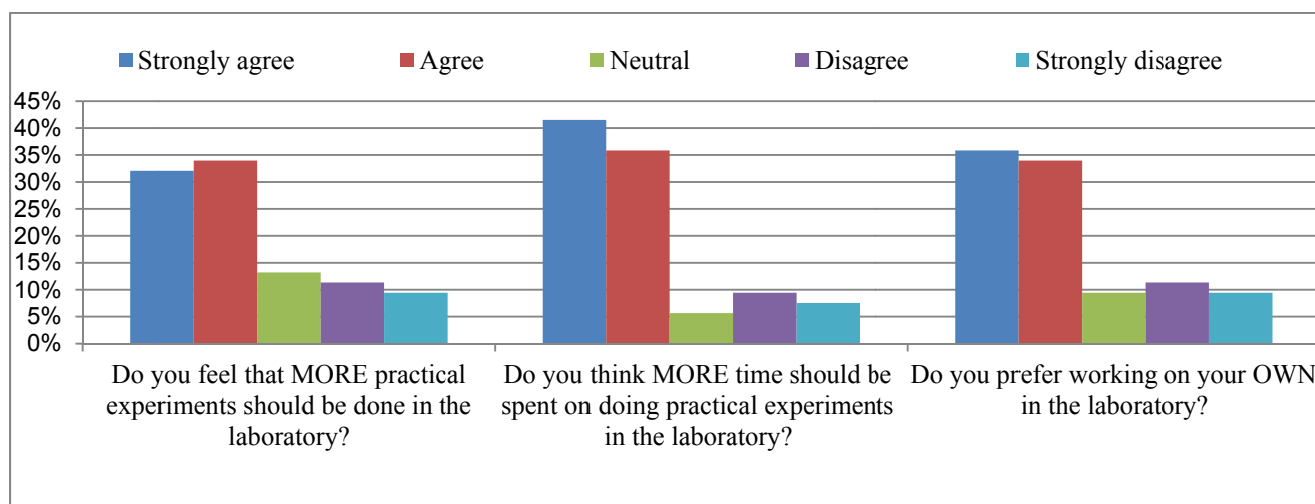


Fig 5: Student perceptions regarding frequency and duration of practical work

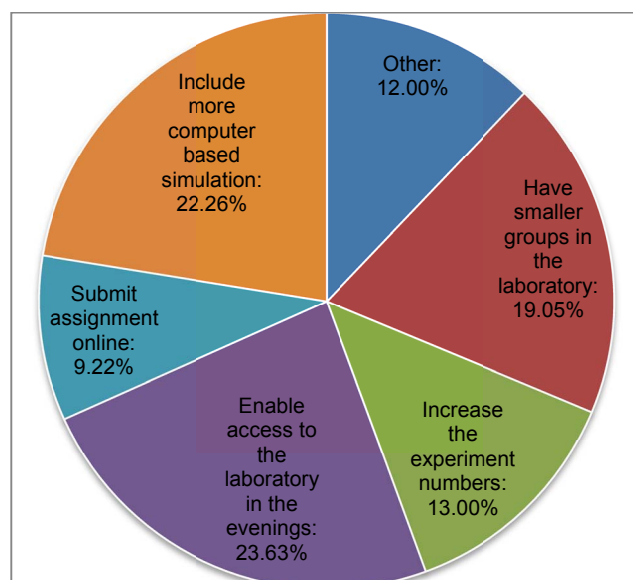


Fig 6: Recommendations from students to improve practical work

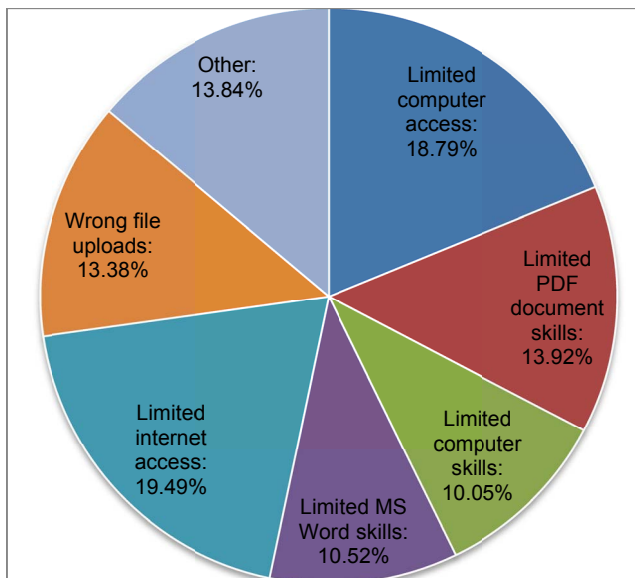


Fig 7: Feedback regarding why students would not want to submit their practical work online

Results of student reasoning for not wanting to submit their assignments online are shown in Figure 7, where no single overwhelming reason is provided. The predominant reasons are limited computer (19%) and internet access (19%). This could also be attributed to the fact that a good majority of students come from previously disadvantaged backgrounds [7]. However, limited e-skills of students also warrants attention (10 - 13% indicating that they have limited MS Word, PDF and general computer skills). A tutorial addressing this concern could be incorporated into the practical work thereby strengthening the graduate attribute of modern tool usage [5].

VI. CONCLUSIONS

The purpose of this paper was to gain insight into the perspective of South African freshman engineering students regarding practical work done in a Digital Systems I laboratory. The results indicate that the majority of student perceived the practical work to be enjoyable, beneficial, challenging and relevant to the theory covered in a classroom. This tends to suggest that the practical work is re-enforcing the theoretical knowledge of the students.

Students further recommended that the laboratories be opened for access after normal class hours and that the number of practical experiments be increased, with especial reference to more simulations. A possible recommendation would be to create awareness among students about specific online open computer laboratories and how to access them. Offices of lecturer assistants may also be moved to the laboratories in order to provide students with more opportunities to access the laboratories outside the normal laboratory scheduled time.

However, two key deficiencies were identified in that the majority of South African freshman engineering students do not prefer group work alone and in that these students are reluctant to submit their practical assignments online. Reasons for the latter include limited computer and internet access. A

recommendation should be to encourage CUT management to enter into partnerships with local Internet service providers to negotiate an acceptable Internet student package. As for the former deficiency, recommendations need to be made to academics to incorporate more group work into their practical instruction. Collaborative learning strategies need to be implemented. In conclusion, these results do suggest that freshman engineering students are fusing their theoretical and practical knowledge, experiencing a measure of satisfaction as they demonstrate the acquisition of important graduate attributes mandated by many accreditation bodies in the world.

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Cyber-Infrastructure Support for the Integration and Analysis of Student Success Data

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Abstract—Increasing enrollment and retention in science, technology, engineering, and mathematics (STEM) programs, particularly for students from underrepresented groups, has become a national priority. Institutions often have multiple funded and unfunded efforts that address student success and broadening participation. One challenge is that they are typically discipline specific with little interaction with complimentary efforts outside of the sponsoring department or college. Such isolation can hinder wider adoption of effective practices and the development of innovative programs based on lessons learned. This project, funded by the NSF Innovation through Institutional Integration program, focuses on defining the cyberinfrastructure and communities needed to support the discovery and integration of student-success projects. The paper is organized as follows: discussion of the motivation; presentation of the infrastructure and models created to connect data collected by various projects, units, and programs; and description of MetaShare, a metadata management system that captures metadata about artifacts in support of integration across projects.

Keywords—cyber-infrastructure; data models; expertise system; data discovery; community of practice; data integration; data management system.

I. INTRODUCTION

A national priority and a focus of many efforts supported through funding agencies is to increase the proportion of the U.S. population attaining college degrees, in particular students from underrepresented groups. This emphasis has given rise to a number of projects (also referred to as *initiatives* in this paper) that often target a particular discipline. While many of the initiatives have been successful, departmental silos and hierarchical structures have often made knowledge sharing and long-term support of effective practices difficult. To address this, the NSF Innovation through Institutional Integration (I³) program set interrelated goals [1] that include the following: increase synergy and collaboration across NSF-funded projects within and between institutions towards an educational environment where artificial boundaries are significantly reduced and the student experience is more fully integrated; expand and deepen the impact of NSF-funded projects and enhance their sustainability; promote innovative programming, policies, and practices that encourage the integration of STEM research and education; and encourage STEM educational or related research in domains that hold promise for promoting intra- or inter-institutional integration and broader impacts.

To meet the I³ goals, the University of Texas at El Paso (UTEP) proposed to build cyber-infrastructure, communication, and connection structures with a focus on broadening STEM participation. UTEP's I³ project has challenged faculty, administrators, and stakeholders to think strategically about the creative integration of NSF-funded awards. The I³ project has resulted in the development of the Expertise Connector website and Move Communities portal that connect expertise on campus. The focus of this paper is on the part of the I³ project that centers on the development of cyber-enabled technologies to document, share, and discover project information such as goals, activities, evaluation, and metadata, including relationships among projects that broaden participation in STEM fields at all academic levels.

After elaborating on the motivation and goals of UTEP's I³ project in Section II, the paper presents an overview of UTEP's efforts to build inter- and intra-institutional connections in Section III. Section IV describes the methodology for building the cyberinfrastructure that supports discovery, information and knowledge sharing, and inter- and intra-institutional connections. Section V describes the summary along with the preliminary results. The paper ends with future directions in Section VI.

II. MOTIVATIONS AND GOALS

The vision of UTEP's I³ project is to transform the university into one in which faculty are committed to sharing resources, collaboration is supported through recognition and rewards, effective initiatives are extended across the university, discussion among diverse faculty members and administrators stimulates new ways of student preparation and advancement in STEM areas, and proactive strategies are employed to identify effective avenues for sustainability. The project seeks to build the cyberinfrastructures for the university to establish a culture where sharing of practices developed by initiatives leads to innovation in the preparation of students for undergraduate research and graduate education.

Because investigators manage their own artifacts, e.g., publications, reports, workshop materials, outreach activities, and scientific data, they may be distributed across different repositories, such as Excel worksheets or databases, local computers, or servers. In addition, artifacts may be stored in various formats and different levels of granularity, which can complicate integration. Because provenance may not be

captured, data analysis can be challenging. Furthermore, initiatives often operate in isolation with little interaction outside the department or college. For example, Peer-Led Team Learning (PLTL) initiatives are run through the university's Entering Student Program, as well as the departments of computer science, chemistry, mathematics, and electrical and computer engineering. Each initiative collects its own data, performs its own evaluations and, as a result, may collect different types of evaluation data. Because of the difficulty in identifying who is doing what on campus, it is a challenge to compare or share data and ideas, which can hinder knowledge transfer and reuse. Initiatives are often not connected to broader institutional efforts, which makes wider adoption of effective practices and the development of innovative programs based on lessons learned more difficult.

Some of the related challenges that the university faces are the following: 1) the ability to track students involved in similar initiatives; 2) the ability to identify related efforts with the aim of determining their collective impact and institutionalizing efforts with significant results; 3) the ability for new initiatives to review recommendations for facilitating institutional assessment and evaluation and adopting existing instruments; and 4) the ability to collaborate and learn from other projects.

The expected outcomes of the cyberinfrastructure efforts reported in this paper are cyber-enhanced tools that facilitate discovery of student success data collected by initiatives across the university; a well-defined, efficient process for integrating data, which can be used to answer questions that promote understanding and adoption of effective student success practices; and mechanisms for identifying related initiatives and making recommendations to align related initiatives.

III. BACKGROUND

The proposed effort is defining a comprehensive solution supported by a change in culture at the university with support of upper administration and the development of cyberinfrastructure that connects people with tools to support collaborations. A key element of the project was the development of the Expertise Connector system [2] that publishes comprehensive information about researchers through information stored in Digital Measures (DM) (see Table 1). Through DM, faculty and professional staff enter their statement of expertise, keywords, links to their personal website and social network connections, and selection of aligned university's strategic areas. Research stories and associations with Move Communities (described next) are also part of a user profile. Because faculty and professional staff use DM for annual performance review, profile information is expected to remain current. The Expertise Connector is similar to other solutions such as Vivo [3] and Influent [4]. Both Vivo and Influent are intra-institutional approaches for discovering expertise. Influent bases the user profiles on publications garnered from Scopus. Influent, which is used by the UT System, also references Expertise Connector and vice versa.

The Move Communities infrastructure supported by Expertise Connector provides the ability for a researcher to

associate with a Community of Practice (CoP) in a particular area of interest. A CoP [5] is a group of individuals, who share an interest, concern, or passion, and who interact regularly to improve what they do. Move Communities connect people with people, people with experts, and people with information (e.g., resources on campus, related efforts, and effective practices). The intent is to encourage sharing and motivate action to address challenges and opportunities collectively. Example Move communities center on areas such as undergraduate research, cybersecurity, and engaged scholars.

Another critical component for making connections across the university is an infrastructure that facilitates documentation and management of metadata, i.e., data about the artifacts that result from research. Attaching semantics to the metadata distinguishes the I³ approach from others. Data-sharing in any context is facilitated by incorporating the attributes necessary to depict metadata typically done through standards. Rich metadata in such context promotes discovery, analysis, selection, aggregation or filtering, and reuse [6]. Data artifacts can be generalized through the definition of its class, meaning the data type of which they are members, associated standards, confidentiality policies, and formats used. The abstraction of such entities provides a re-usable structure that can detail metadata artifacts at a high-level, but provide enough information to ensure analysis-ready, interoperable artifacts [6]. Takeda et al. [7] proposed profile-based recommendations to suggest proper organization of data and assist in defining such things as related projects, standards, and instruments.

IV. METHODOLOGY

Fig. 1 presents an overview of the method used in defining the cyberinfrastructure. This section elaborates on each of the components.

A. Interviews

We interviewed university officials and evaluators to identify questions that potential stakeholders e.g., proposal writers, provost, deans, chairs, faculty, and staff, would be

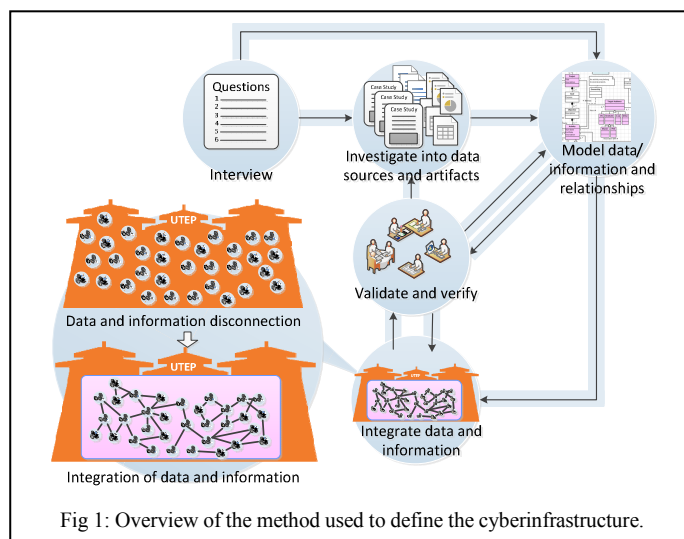


Fig 1: Overview of the method used to define the cyberinfrastructure.

interested in learning about student success and broadening

STEM participation. The following is a list of sample questions collected during the interviews:

- Which broadening participation initiatives are employed in academic programs that have significantly higher student retention rates of female students?
- For initiatives that address retention, what is the impact (e.g., retention in the major, retention in STEM, time to degree) within and across disciplines and departments?
- What are the differences in the PLTL approaches used in different departments?
- What are the impacts of PLTL on student pass rates?

B. Investigation into Data Sources and Artifacts

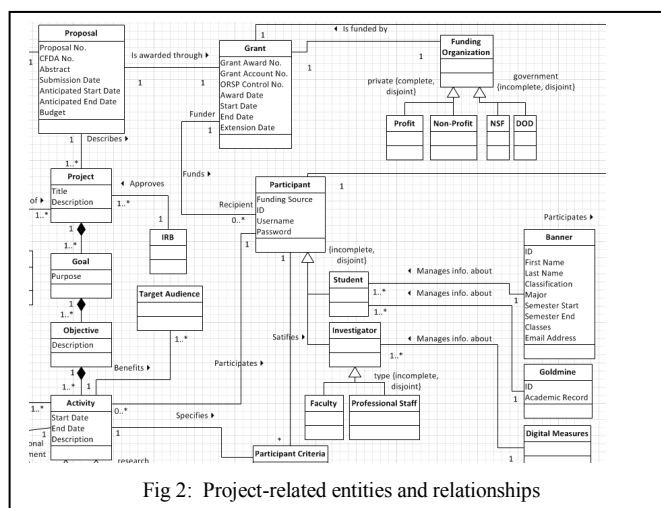
The motivating questions collected from the interviews guided our investigation into identifying various data sources and artifacts. Table 1 presents a summary of selected data sources referenced during the investigation process.

TABLE 1. Selected Data Sources

Source	Data and Artifacts
Banner	Banner manages student information.
Center for Institutional Evaluation, Research, and Planning (CIERP)	<p>The Common Data Report provides information about enrollment and persistence, transfer data, and student life.</p> <p>The Fact Book presents information about collection of frequently requested data: undergraduate and graduate student profiles, enrollment, and degrees conferred. Integrated</p> <p>The Integrated Postsecondary Education Data System Data Center Reports provides information about institutional characteristics, completions, enrollment, student financial aid, and graduation rates.</p> <p>CIERP conducts surveys to collect longitudinal data on different student perspectives and student reported information.</p>
Digital Commons	Digital Commons provides research and scholarly output submitted by faculty and graduate students of the individual university colleges, departments, and centers on campus.
Digital Measures (DM)	Digital Measures manages faculty members' professional activities and accomplishments for annual, tenure, and promotion evaluations.
Expertise Connector	Expertise Connector provides faculty and professional staff profiles, community profiles, center profiles, and research stories.
Goldmine	Goldmine manages students' academic history.
The Office of Research and Sponsored Projects (ORSP)	ORSP maintains full proposals submitted through the university and other information associated with awards.

C. Modeling of Data/Information and Relationships

The motivations for modeling sources of data and information are twofold: 1) the complexity of university systems and the lack of documentation of such systems make it difficult for faculty to know the primary sources of data and information; and 2) many investigators manage their own artifacts, resulting in the distribution of data and information



across different repositories. To address this, the project studied and analyzed data sources, data, and information managed by each data source. The analysis resulted in a set of Project-Data models using the Unified Modeling Language (UML) class diagram [8].

The project also analyzed the relationships among data and information to identify which motivating questions can be answered, determine the source for additional information needed to answer questions, and minimize areas of redundancy. Fig. 2 presents a snippet of the project-related entities and relationships managed by OSRP, the project investigators, and the metadata management systems.

In accordance with UML notation, a rectangle in the class diagram denotes an entity or concept, and an arrow represents a relationship among entities. Arrows are labeled with the name of the relationship. A triangle at the top of an unlabeled line denotes a generalization (“is a” relationship) with the tip of the triangle pointing to the parent relationship. A filled diamond denotes a composition. The notation “0..*” denotes a zero-to-many relationship and “1..*” denotes a one-to-many relationship.

To elucidate how the Project-Data models can support analysis, consider the following motivating question: “Which broadening participation initiatives are employed in academic programs that have significantly higher student retention rates of female students?” In order to answer this question, it is necessary to have access to information about students and projects. Using the Project-Data model, it is possible to determine which projects have broadening participation activities based on how they are tagged and, through the investigators associated with the project, it is possible to determine the academic programs involved. The ORSP is the primary data source for proposals and their associated data. As described in Fig. 2, a *proposal* may be associated with 1 to many *projects*. A *project* is comprised of 1 to many *goals*. Each *goal* is comprised of 1 to many *objectives*. Each *objective* is comprised of 1 to many *activities*, and each *activity* has 1 to many *target audience(s)*. Knowing who participated in an activity through the course number or the participant list, for example, we can harvest relevant information about each individual from Banner and Goldmine.

A question such as “What are the differences in the PLTL approaches used in different departments?” could be partially answered through analysis of *artifacts*, e.g., *evaluation reports*, and *activities*. Through discussions with faculty involved, for example in a CoP centered on peer mentoring, a deeper understanding of the differences could be obtained.

D. Validation and Verification

Information captured during the investigation, analysis, and modeling phases were validated and verified by domain experts through meetings in which walkthroughs and inspections of the Project-Data models were conducted. Validation and verification is an on-going activity as part of our continuous quality improvement model.

E. Integration of Data and Information

As depicted in Fig. 1, the Project-Data models serve as the foundation for developing MetaShare, a metadata management system designed to facilitate collaborations among researchers by guiding the documentation of project activities, metadata, and provenance. Furthermore, MetaShare supports analytical processing for data discovery and knowledge inference. The models described in Section IV.C were used to identify three key components of MetaShare that document the projects as well as integrate data generated from different sources. *Project* is the highest level of abstraction at MetaShare. Each project consists of *Activity* that accomplishes one or more project goals. At the lowest level of abstraction, MetaShare manages information about the *Artifact* - resources used, transformed, or produced by an activity.

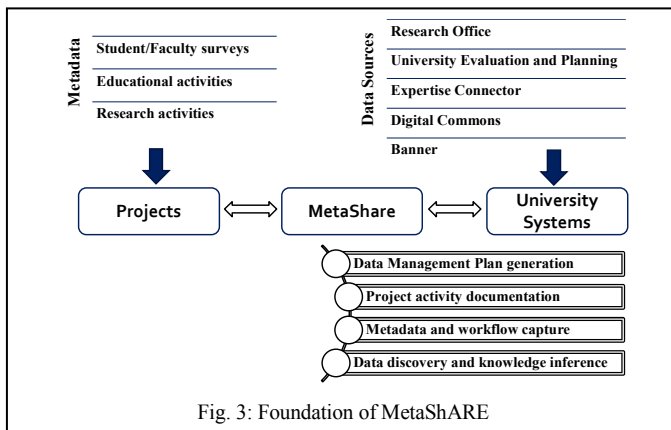


Fig. 3: Foundation of MetaShare

MetaShare connects to different data sources across campus as shown in Fig. 3, and it bridges the gap between projects and university systems. Currently, MetaShare connects with ORSP and DM. To facilitate data integration, MetaShare must map the attributes (fields) stored in different sources through a well-defined plan that includes standards and schemas to preserve semantic information. There are ongoing efforts [9], [10] to create standards to support data documentation and sharing, in particular with the requirement to define data management plans by many agencies. Most initiatives at the university, however, are rarely designed with the goal to share data. To address this challenge, the UTEP I³ project is working on a data-dependent, automatic mapping that takes the actual values of the fields to suggest a mapping

between data sources. Another challenge is the automatic identification of sensitive information that supports the process and policies related to data confidentiality. A successful integration of different sources will pave the path to generating effective set of queries that can help us answer the questions listed in Section IV.A. It will also help us to identify and recommend best practices for new initiatives.

V. SUMMARY AND PRELIMINARY RESULTS

To address the NSF’s I³ program goals, UTEP has defined the cyberinfrastructure that supports interactions among people through physical spaces, events that support in-person communication, and virtual collaborations supported by cyber-enhanced tools. In particular, UTEP has accomplished the following: the development of the Expertise Connector system to highlight expertise on campus, seed funds to support interdisciplinary research offered by the Provost’s Office, and an interdisciplinary (ID) network manager to support ID research and educational activities on campus hired by the Office of Research. The ID network manager also supports the development of Move Communities that operate as a CoP. The events for bringing researchers together have included the events sponsored by UTEP’s ORSP, such as the ID Research Symposium, Engagement Encounters, and Pop-Up meetings.

The UTEP I³ project team has identified the primary sources of data and information in support of student success initiatives at the University. Models have been created to illustrate the data and information that can be harvested and knowledge that can be derived from the primary data sources. The analysis of the models allowed us to determine what questions can be answered, identify the sources needed to access critical information, and detect potential areas for discovering new knowledge. The model has laid the foundation for developing a metadata management system, known as MetaShare, to support the ability of individuals to document relevant data, documents, and other artifacts derived from their efforts; generate data management plans; capture metadata and provenance; define workflows that elucidate how data was transformed; discover data/information and infer knowledge; and answer questions about student success.

VI. FUTURE WORK

The I³ project will be conducting two case studies in collaboration with CIERP. The first case study focuses on a large interdisciplinary research project that requires the integration and analysis of data from multiple sources. The questions center on trust and completeness. The second case study is centered on the Student Success Database managed by CIERP. As part of continuous quality improvement, the effort will include working with stakeholders to further refine the Project-Data models. We plan to evaluate the completeness of the models by developing a comprehensive set of questions and usage scenarios that are validated by stakeholders. We are also expanding the functionalities offered by MetaShare and extending MetaShare to incorporate semantic web technologies that support trust.

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Defining Moments:

The Link Between Definitions of Teaching and the Desire to Teach

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Abstract— In response to the well documented lack of highly qualified STEM educators in the United States, this work seeks to understand how to increase interest in K-12 STEM teaching among engineering students. This paper presents a preliminary framework and findings exploring factors that motivate the choice of a teaching career among the alumni of a small engineering college. In particular, it focuses on the relationship between the ways in which study participants defined “teaching” and “teacher” and their post-graduate interests and pursuits. Fourteen subjects participated in semi-structured, open-ended interviews designed to elicit an understanding of their definitions of teaching as well as the experiences and influences that shaped those definitions. Preliminary analysis suggests that participants with very narrow views of teaching and learning are averse to teaching, while those with broader definitions are likelier to engage in teaching, teaching-related careers, or consider them in the future.

Keywords—*Recruitment of STEM Teachers, Definition of Teaching, Teacher Motivation*

I. INTRODUCTION

In 2013, the US Department of Education released the results of the most recent administration of the Programme for International Student Assessment (PISA), which compared the performance of 15 year olds in mathematics, science, and reading in 65 education systems around the world. US performance showed no measurable increase from previous administrations of the assessment. Only 9% of US students performed at the top level in mathematics and only 7% in science, both of which are below the average national performance at this level among all countries taking part in the assessment. These results are also well below the performance of students in countries such as Singapore, China and Japan [1]. At the college level, the proportion of bachelor's degrees awarded in the science, technology, engineering and mathematics (STEM) disciplines is half that awarded in China and Japan [2-5]. Coupled together, the poor performance of K-12 students in STEM subjects and the lack of STEM college graduates adversely affect not only the supply of highly qualified employees in the growing technological market, but also the supply of future teachers, which compounds the cycle of poor performance in this area [2-7].

Despite increasing focus and attention on STEM subjects through the Next Generation Science Standards, the Common Core State Standards Initiative and state-level initiatives, there are not enough well qualified K-12 teachers to supply even

existing curricula, let alone support the reform and expansion of STEM education [1]. In a stark illustration of the problem, the National Taskforce on Teacher Education in Physics has concluded that less than half of the nation's physics and chemistry teachers hold degrees in those fields [6]. Yet even with White House calls for recruiting 100,000 new STEM teachers over the next decade, little progress has been made and little guidance is available for developing solutions to this problem [8-9].

In this paper we posit that understanding the development and evolution of undergraduate students' interest in and identification with teaching is a necessary first step toward designing and implementing new strategies for the recruitment of STEM college graduates into the teaching profession. Existing literature has sought to understand the retrospective motivations for in-service or in-training teachers [10-16]. Recently, a number of studies exploring graduate teaching assistants' identities vis-à-vis future teaching careers have added important insights into the educational landscape [17,18]. None, however, specifically address the development of initial motivation among engineering college students to enter the teaching profession in the STEM disciplines [10-18]. Understanding the experiences that underlie motivation and subsequent identification with teaching is a critical next step in learning how to build the STEM education workforce.

This work-in-progress paper seeks to characterize engineering graduates' construction of teaching as a profession as well as their interest in and/or actual pursuit of employment in education. This study is performed at a small undergraduate engineering school, which for the purposes of this work we refer to as Celadon College. Celadon offers only engineering degrees, embeds project-based learning throughout the curriculum, and has no formal K-12 teacher preparation program (see [19] for further description of the College). Despite this, our previous work indicates that Celadon's students are highly engaged with issues of teaching and learning. Celadon students and alumni demonstrate interest in teaching careers or enter teaching careers at a rate that is over double national averages for engineering graduates. Moreover, they participate nearly uniformly in informal peer teaching experiences, and exhibit a high level of pedagogical awareness [19].

II. METHODS

A part of a larger descriptive mixed-methods study, this work utilized a semi-structured, open-ended interview protocol

that was administered to fourteen participants who received their bachelor's degrees at Celadon between 2006 and 2014. The goal of the interview protocol was to allow study participants to reflect on defining moments in their undergraduate and pre-college careers that shaped their current understanding of teaching, the role of the teacher, and the process of teaching and learning. Participants were particularly encouraged to reflect on memorable anecdotes and personal influences throughout the interview.

Maximum variation purposive selection was used to sample from the respondents of our initial study to represent diverse graduation years, gender, and a broad variety of post-graduate experiences, including both teachers and non-teachers [20]. Most interviews were conducted via phone or Skype, with one interview conducted in person. Audio was digitally recorded for each interview and transcribed for further analysis.

Data was coded for important categories and themes [21-23]. Descriptive and analytical memos were then written to support the process of identifying emergent themes [24]. This preliminary work will be followed up with multiple layers of coding using the constant comparative method. Narrative summaries around further honed emergent themes will be used to form thematic matrices, with which to perform within- and across-case comparisons and as starting stages for an emergent theoretical framework [25].

III. PRELIMINARY RESULTS AND DISCUSSION

Preliminary findings indicate that how broadly graduates define teaching or what it means to be a teacher relates to their interest in becoming a teacher and engaging in teaching as a long-term pursuit. In what follows we describe how study participants discursively construct their own teaching identities through a carefully scaffolded inquiry about who a teacher (and a learner) may be and what rights and responsibilities a teacher (and a learner) may have. To date, we have identified a continuum, spanned by three broad categories, which describe how engineering graduates position themselves to act in relation to teaching within their ever-evolving individual story lines. We define those categories as *acknowledging differentiators*; *acknowledging experimenters*; and *active integrators*.

A. Acknowledging Differentiators

Acknowledging differentiators' definition of teaching greatly transforms and fluctuates throughout their interviews. Starting with a relatively rigid description of a teacher as an authority figure who "imparts knowledge or skills" to their students, *acknowledging differentiators* shift to a portrayal of their most memorable learning moments and construct a different situational interpretation of who a teacher may be. The two definitions are usually incongruent with one another. Therefore, *acknowledging differentiators* position themselves and their attributes with respect to these two definitions in a way that allows them to discursively justify their lack of interest in pursuing teaching as a career.

A typical example of how such a story line may develop is that of Shawn, a 2008 Celadon graduate and currently a Ph.D. student in civil engineering, who previously "spent five years as a sustainability consultant ... working with mostly Fortune

500 companies' sustainability departments to help them understand where the environmental impact of their products was and how they might improve that." Shawn originally defined teaching as an act of "convey[ing] information to somebody else in order to impart knowledge or skill to them that they can repeat." This definition seemed to align with Shawn's recollection of a time when he felt like a teacher,

... certainly many times in my role at the previous company where I was helping mentor new employees, sort of bring them on board and up to speed ... I've done a lot of workshops with clients on life-cycle assessment, sort of teaching them about the basics of life-cycle assessment and life-cycle thinking. ... so, it's sort of trying to convey that, um, that, like, insight or mindset or, like, perspective to somebody.

Throughout the interview Shawn continued to reformulate learning and teaching, subject to specific experiences or learning episodes he shared in response to the interviewer questions,

... coming from high school, where it was very lecture and theory based, going to Celadon, where it was very project based, particularly in the first year it was a very big shift in mindset to actually being able to, like, build stuff and do stuff rather than just memorizing things... I think that was certainly a very pivotal experience for me understanding what learning was and what teaching could be.

As a specific example of this "shift in mindset," Shawn recalled a time when his Celadon instructors responded to his question by "cryptically say[ing], 'I don't know. You should go try it out'." Although Shawn described this experience as "extremely frustrating," he also acknowledged it to be interesting and "probably helpful for building the sort of skills needed to explore something independently." It is this particular experience that allowed Shawn to articulate a drastically different role that an instructor may take, that of "creating an environment conducive to learning" where the skills to acquire and hone are "diagnosing and synthesis, creating new hypotheses, and ... the creative exploration."

This reevaluation of teaching and learning processes, however, seemed to diverge from Shawn's initial conceptions and, unable to find equilibrium between these two constructions, he reverted back to his original descriptions. At first, Shawn restored his definition of a learner,

I think it, it depends on which side of receiving of learning I'm on, like, the, the teacher, um, if you will, or the instructor, may be more interested in creating sort of a learning experience than in that imparting of knowledge. Um, whereas the instructee may be more aware of the teaching per se rather than the sort of creating something that's ripe for self-exploration...

Later in the interview, Shawn's characterization of teaching/teacher also recrudesced when, in response to a question about a time when he helped others learn, he

explained his role as a team leader on a human-powered vehicle team as,

less as conveying knowledge, and more about managing and collaborating. I just don't think of my role there as, um, teaching per se. Um, whereas at work, it was much more...like, there were sort of sets of skills that needed to be conveyed to student...

It is clear that Shawn attempted to discursively make sense of his experiences and rationalize his identity as a teacher vis-à-vis his old and new definitions of teaching and learning. Despite the evidence of the effectiveness of the newly outlined teaching and learning processes and the excitement about “teaching [the] stuff [he is] passionate about,” Shawn was unable to reconcile the two definitions. As a result, some of the characteristics that persisted in Shawn’s final construction of teaching and learning processes were the presence of an authority figure with content/skill know-how, imparting of knowledge and skills, and rigidity in the process by which this imparting takes place: the same things that he found less than useful for his own learning processes. Finally, and importantly, Shawn did not identify teaching in its own right as impactful,

I think that creating something somewhat tactile ... at the end of the day and see an impact [of it] ... is fairly important for me. And so, I think that rather than teaching as a career, having that impact in the private sector and creating the types of teams and relationships that I really enjoyed in the past is probably how I'll pursue that.

Shawn was able to acknowledge alternative ways of teaching but differentiated those as being used by others, for others, and in other environments. As such, an *acknowledging differentiator*, Shawn never defined himself as a teacher; teaching is what he could do, but not what he wanted to do.

B. Acknowledging Experimenters

Acknowledging experimenters' definition of teaching also greatly evolves throughout their interviews. Unlike *acknowledging differentiators*, these study participants evolve along with their definitions and find their new identity as teachers. This identity, although yet un-lived and with no explicit plan of being enacted, seems to be welcomed by all *acknowledging experimenters*.

As an example of an *acknowledging experimenter's* trajectory, Steph, a 2014 Celadon bioengineering graduate, who was about to start her first job as a designer, began her interview by describing teaching as “the opportunity to impart information on someone or to multiple people.” She then continued to elaborate by explaining that

[teaching] is when someone or something demonstrates knowledge or a skill for someone or something else. But it can be a two-way street. ... it doesn't have to be a teacher and student. It doesn't have to be people. ... it could be, you know, one professor or it could be a learning experience from each other as a collaborative group.

In rapid succession, Steph proceeded to expand her interpretation of teaching as a responsibility to influence others and their belief systems,

I think you have a whole influence... it's more than just knowing something and being able to share it. It's also understanding that students have their own belief system already ...as a teacher you need to both, um, influence in ways you want to and understand that students may not perceive [your goals] in the way you want to.

Soon after, when recalling a time when she felt like a teacher, Steph’s interpretation of teaching matured to include a need to listen, empathize, and individualize students’ experiences, while also simultaneously being able to step back and allow for an adventure that is an organic part of a learning process,

putting myself in [students'] shoes and trying to really understand what they're experiencing and trying to figure out where are they stumbling, what's the challenge for them ... every student...or every team had different dynamics and different ways they were working that I had to cater to ... while being cognizant of their team dynamics and trying not to mess with that, because [it] was [their] adventure.

This nuanced description of teaching, followed with an account of how simultaneously exhausting and rewarding her teaching experiences have been, led Steph to a somewhat surprising admission,

'Wow, I really kind of want to teach design.' Which is the whole, like, 'Oh, crap, education's throwing a wrench in what I want to do. Maybe I'll actually be a teacher, I don't know.'

Although Steph began the interview by declaring that she will be doing design work in the immediate future, her long term plans consist of “hopefully in the future go[ing] back towards biomechanics.” Nowhere in this declaration did she include a desire to pursue teaching as a career; yet, Steph’s discursive exploration of teaching and learning allowed for a construction of a new teaching identity, something that may allow for changing career goals.

An *acknowledging experimenter*, Steph’s positioning vis-à-vis a teaching career is based on active experimentation with the craft of teaching during her undergraduate experience and allowing for an epistemological shift in regards to teaching as a rich and enriching endeavor.

C. Active Integrators

Active integrators define teaching and learning processes in the most nuanced and delicate way and place creation of an environment where learning can happen at the core of their definition. For example, Tricia, a 2013 graduate who just earned her Master’s Degree in Education from another institution and became certified to teach high school physics, described the endeavor of teaching in the following way,

it's designing an educational experience for students. ... it's about creating an environment and a set of

conditions in which students will learn. So, it means ... creating structures and supports and guidelines that help students get to where you want them to be but also where they want to be. ... as a teacher, you have to have some goals and objectives of your own, but also students need some amount of freedom to make their own choices.

Later in the interview, Tricia explained that providing students with choices affords them agency and motivation to learn.

Active integrators described their evolution as learners and evolution of their definitions of teaching and learning. They shared their exploration into what it means to be an effective teacher and, in the words of another study participant, concluded that “the focus should not be on teaching at all. ... it should be on learning [as] focusing on teaching tends to focus on what the teacher is doing instead of what is happening with the person who is learning” (Christine, Class of 2007).

Through their journeys and through actively integrating their new experiential and discursive constructions of teaching and learning processes into their practice of teaching, *active integrators* were able to grow into their new identity and develop as supporters of the learning experiences of others. It is not surprising therefore, that the *active integrator's* identity converged on teaching: “I am a teacher. That is my identity,” shared Tricia.

IV. IMPLICATIONS AND CONCLUSIONS

While this is a work in progress, the preliminary analysis has yielded a potentially useful framework for understanding the orientation toward teaching among recent graduates of a STEM program. As is evident in the description of *active integrators* above, those who have already pursued a teaching career have developed more sophisticated schemas of how teaching is defined, identified with teaching as a profession, and constructed their own teaching identity through their self-defined and self-directed preparation to enter the field. As this study progresses to deeper levels of analysis, the exploration of the continuum between those who have no interest and those who may or do have interest in teaching but have not acted on that interest, particularly *acknowledging differentiators* and *acknowledging experimenters*, may yield greater understanding of the experiences that shape one's interpretation of and affinity to teaching. What are the cognitive and motivational processes that form one's identification with teaching and identity as a teacher? What experiences and discourses in one's undergraduate STEM environment that may contribute to development of self-esteem, self-efficacy, self-consistency, and self-regulation to support interest in and/or actual pursuit of employment in education? Through careful analyses of these questions, it may be possible to create an educational environment that facilitates development of pedagogical awareness and construction of teaching-related identities. By doing so, we may be able to shift students' interest and motivation along this continuum and foster the likelihood that they enter a K-12 teaching profession.

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InnoEscuela, Innovation in Secondary School Technical Studies

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Abstract—InnoEscuela is more than a learning experience, a programmed methodology to implement courses related to Technology and Computing which follows an innovative way of teaching. The methodology focuses on Project-based learning and team work. Students organize themselves in teams which are called innovative enterprises and they have to **decide** to create a solution to a social disadvantage, technical problem, or any other kind of need **they perceive**. That's why the core of the courses is focused to practice the whole Technological Innovation process.

Keywords—InnoEscuela; project-based learning; innovation; technology; computing; secondary; pre-engineering; innovative enterprise; student-centered teaching; motivation.

I. INTRODUCTION

Spanish Education System is structured very similarly to other countries. A first stage of primary education precedes the Compulsory Secondary Stage, where students are 12 to 16 year-old. It is at this stage of Secondary Education, where the educational curriculum offers a compulsory nature subject, Technology, focused on the study of materials, systems, devices, electrical and electronic circuits and programming. Course implementation is addressed by the Project Method and quite often teachers use an entire school year to implement this methodology to get students to make a practical device.

InnoEscuela program is specially designed to be directly applied in Technology as an added value to the current course for several reasons. First, students have to find a need or a problem in their surroundings and generate ideas to provide a solution. They have to decide to go for the most value added project. Second, the solution must correspond to a technical innovation thus requiring a stronger team effort. Finally, the program meets educational values such as to work as a team, to behave as an innovative enterprise, to be concerned about the people living in the students town, to take care of the natural environment and ultimately, to be able to overcome any difficulty and failure when performing the project which would prime them in the entrepreneurial and innovation spirit.

II. METHODOLOGICAL BACKGROUND

InnoEscuela is an educational program designed to join in the same context of technology discipline, the use of ICT, entrepreneurship and innovation in a real world practical work which is technically and economically feasible, sustainable and viable. Due to its novelty in bringing together so many different education aspects, the program is a real educational innovation in itself.

Teaching principles of the program are backed up in the Project method. According to traditional historiography, the project method idea is an original development of the American Progressive education movement. It was thought to have originally been introduced in 1908 as a new method of teaching agriculture, but educator Dr. William H. Kilpatrick [1], of the University of Columbia, elaborated the concept and popularized it worldwide in his famous article, "*The Project Method*" in 1918.

Kilpatrick identified in 1921 the term project to refer to “.... any unit of purposeful experience, any instance of purposeful activity where the dominating purpose, as an inner urge, fixes the aim of the action, guides its process, and furnishes its drive, its inner motivation.”, being, currently, the most accepted definition of PM, from a training and teaching standpoint.

Nowadays, knowledge management is more diverse and more complex, just as economical and financial market procedures, enterprise supervision or industrial and production management. In this way, since Kilpatrick, many authors [2] have contributed with educational publications improving project method execution and methodological actions. This is the case of L.J. Waks [3], the author of a brilliant work that relates project method to learning methodologies for the digital era. In his work, Waks reinvents the project method by addressing its scope through six elements that, according to a

sequence, will create a timeline of actions to consider when implementing it. Waks explains these elements sequences as follows: i) First project dealing in the group; ii) Determination of project situation in a social context, iii) Assessment of incident learning potential relative to learners' needs; iv) Needs evaluation of background knowledge; v) Scheduling of project tasks and; vi) Continuum project assessment and learning integration

The first and second elements determine the importance of learner participation while the other four offer a frame for a teacher to determine his or her role as an integration core between project and learners, extending his or her participation from identifying the needs of learners to the teaching of needed skills in order to facilitate the tasks to achieve the completion of the project.

III. AIM AND OBJECTIVES OF INNOESCUELA

InnoEscuela initial feature stands in its perfect adequacy to the subject of Technology and Computing, as it is conceived from the official curriculum. The methodology development is according to project-based learning, following the stages of problem solving. Thus, it requires no special didactical adaptation as it integrates in the work that is currently done in standard Technology classrooms. InnoEscuela is however contributing to educational innovation since students are the owners and responsible of their project, thus receiving additional values than those expected from conventional education. The first is the consideration of the technological innovation as one key compulsory specification for students to apply in the design of a Project, which might be focused as a social entity or an enterprise. The way to work will be conceptually similar to what those organizations usually do.

In addition, the way the program has been conceived tries that students' work with a blended methodology which includes several educational resources such as interdisciplinary character, Project based learning process, Self-directed learning techniques and Resources-aided learning

IV. THE ROLE OF THE TEACHER IN THE PROGRAM

As mentioned above, the way to teach young students will not follow a pedagogical path in the same way as it's currently done, as teacher's behavior might have to change from considering the content the most important. At InnoEscuela, program teachers are required to stop being the main access point to knowledge and information. Teachers background at InnoEscuela optimally also includes some knowledge of how enterprises or organizations carry out their innovation projects. Teachers play a significant role as knowledge managers and drivers, simultaneously with their responsibility to provide students with knowledge as a tool. As students are in charge of acquiring and collecting the information from different sources, teachers must behave as a guide providing the proper observations in order to drive students through the best data sources and advising them with the best ways to use the data.

This does not mean that teachers interact with students in a passive way. Actually, at InnoEscuela teachers are the core of all the activities involved in the processes to achieve the objectives, helping to prepare the plan through which the student will carry out the sequence of steps. As a guide, teachers will determine what's called the "*moments of learning*", discrete times in which the team must hold a meeting to read, select, calculate, just to understand certain information items, receive a brief lesson to cover some knowledge need from the teacher, etc. In order to determine the functional structure of the teaching-learning process and the role teachers have to play, the five moments of learning model [5] has been implemented. The model fits to a scenario in which teachers are responsible of planning the times when these moments of learning can be triggered. The nature and features of each one are, as defined by Mosher and Gottfredson:

1. **Moment of learning #1: First learning.** Every time a new knowledge appears, teachers will become an instructor. The instructions can be offered as an explanation of new contents or could appear when students are doing information searches. The latter is more difficult to detect except if the teacher has given to students the proper guidance to find the information.
2. **Moment of learning #2: Deeping Learning.** The first approach to knowledge has been completed and, the understanding channel of a specific contents is open. This is the time at which, students are able to develop new comprehensive strategies by themselves, once a new conceptual scheme is understood. Students are also able to deepen in the contents being still guided by teacher's explanations.
3. **Moment of learning #3: Remembering or applying what's learnt.** The learning scheme is done and the concept has been acquired. Contents are available to be applied in a practical way and students are able to reproduce the meaning of the contents.
4. **Moment of learning #4: Learn when things change.** Change is something that the human mind is used to. In fact, to deal with changes, nature has provided us with coping mechanisms. At the time a change occurs, a measurable parameter is the speed of response from the teams. Subsequently, the adaptation will require new ways to perform in order to follow with the project. They could be new calculations or even, new requirement definitions.
5. **Moment of learning #5: Learn when things go wrong.** When something goes wrong at the implementation step, it means that some aspects have not been considered at all in the previous definition process. This means that in the design or productive stages, some concepts or ideas were missing. In this case, learning is divided into two phases. First is to find out the cause that induced an improper work by weighing several diagnosis alternatives for figuring it out. Second phase will starts when the error reason has been understood. Then a feedback to solve the situation will be to generate.

These circumstances won't appear just once in the whole process of the Project making. Most likely, they are expected to appear quite often. Now is when the profile of the teacher as a guide will be more important. Gallagher et al [8] defined the role of the teacher in a project environment as "*instead of being experts or didactic instructors, they become meta-cognitive coaches*", in close reference to the guidance role. As knowledge facilitators, teachers induce students to think about their own thinking when being exposed to the problems that a project contains.

From students' standpoint, instructions are received and provided by the teacher when a moment of learning appears and this can be considered as a kind of discrete driven learning. In fact, students are the contributors in every stage of the working process. They assume any technical problem, they give certain solutions and select the proper ones, and they create the suitable documentation to convert the idea into a planned development. The idea is discussed and improved to finally be implemented. This requires a previous knowledge of the materials and tools to handle.

This simple proposal allows obtaining some other benefits beyond the mere team work, like the destruction of barriers that society tries to impose about the gender. From a traditional standpoint, some tasks are associated to males and some others to females. In InnoEscuela, this separation does not exist given that the starting point is the equality of capabilities no matter the gender, leaving out any kind of prejudice.

Given how wide technological knowledge source is, InnoEscuela provides a feedback to other subjects in the same way it needs other subjects' knowledge as part of the instructional source. Cross-curricular environment does reinforce global learning as an additional benefit.

V. ORGANIZATION AND IMPLEMENTATION

InnoEscuela has been designed as a Technology and Computing subjects program and is split into different years: a first course for 12-14 year-old students, a second course for 14-15 year-old students in coincidence with 3rd degree of Spanish Secondary Compulsory Stage, and a final course for those students in the previous year to access to Baccalaureate stage. Independently from the different focus and level of difficulty of each course, four phases are common in the development of the three courses as represented in Figure 1.



Fig. 1. Key blocks applied throughout a year program

In the first common phase, design of the innovative idea, the team is constituted as an innovative enterprise and the students draw the work to develop throughout the year, taking inspiration from the needs that they perceive from the environment surrounding them and making up their mind to the most potentially valuable proposal as an enterprise. In the second and third common phases, students will prepare the planning and will build the innovative idea prototype, assuming quality assurance policies keeping in mind the potential customers/users of the final product. Finally, students will develop a product launch that consists in the design of advertising campaigns and other actions to show to other people their product and convince them to use it.

Since InnoEscuela is sensitive to young students' own ideas, a culture of protection of innovations is promoted in the program through workshop modules and the writing of a simulated patent application document. In this way, the Spanish Patent and Trademarks Office [12] is collaborating with InnoEscuela in the development and design of industrial and intellectual protection material adapted to the different age of our students.

VI. INNOESCUELA RESOURCES: INTERACTION FOR STUDENTS AND TEACHERS

In each course, InnoEscuela provides a series of digital resources and educational materials available in a digital platform. These resources are free to be printed and copied, at the time students can use digital versions to work within the team. The educational materials available are:

1. Student notebook in each Secondary compulsory education course (12-14, 14-15 and 15-16 year-old), in Spanish as well as in English. A composition of the covers of the three notebooks is represented in Figure 2.
2. Teachers planning for each of the three courses, including didactical explanations and assistance, pedagogical and technical recommendations and descriptions of the external resources, to let them behave as a program facilitator with their students.
3. Didactical workshops for each course. Some specific knowledge pills are provided in the way of electronic presentations in order to introduce new knowledge and to make possible a continuous progress. Some of them are the Innovation workshop, the Industrial and Intellectual Property workshop, Web programming workshop, Arduino workshop, etc..
4. Workshops self-assessment activities



Fig. 2. Covers of the students notebooks

To access to the digital resources, a web page has been created at <http://www.innoescuela.org>, also available by .com and .es domains. The web is also the way to access to the digital platform in order to facilitate:

- Access to teams/companies materials
- Communications among innovative enterprises with the teacher and with other enterprises
- Assessment of teams' activities
- Teacher control of how each enterprise progresses and its evaluation

One of the features of InnoEscuela Program is the progression of contents offered throughout the year courses in parallel with the contents of the subject of Technologies and ICT. The optimal scenario is the exploitation of the program since the first or second course (12-14 year-old). However, methodology allows new students' enrolment in the following courses or even teacher's discretion.

Physical spaces to be used in this program are the usual specific rooms where Technology and ICT students are working in, such as group classroom and Technology workshop or computers room. Teachers will be free to decide how to use these spaces depending on their criteria, the needs of the Technology and ICT department or the restraints given a multiple use by several groups.

VII. THE EVOLUTION OF INNOESCUELA THROUGHOUT THE SCHOOL YEAR: STEPS FROM THE IDEA TO THE IMPLEMENTATION

Students start to work in InnoEscuela at the beginning of Secondary school which involves a change to unknown contents and organization from the Primary (Elementary) school. In Primary school, they are used to deal with already defined contents while in Secondary school they will have to improve their skills and abilities in order to become competent in several areas of knowledge. InnoEscuela has been developed to guide students in the acquisitions of mainly technical skills but also about economics, organization, innovation, linguistic, mathematical, communication and marketing. InnoEscuela intends to prime in them curiosity to find out how things work through the observation of their environment surrounding them, and what needs do they find that might be covered. Observations and ideas must be however guided and assisted by the teacher, as it's quite possible for teams to become mind-blocked or they might propose not feasible enough solutions.

Student teams, incorporated as innovative enterprises, are acquiring concepts about Innovation and Company Organization from the beginning in order to be used in the problem solving process through finding their environment's needs. InnoEscuela will guide them throughout the process to include any type of innovative idea in their project to build a prototype, which will be quality-controlled, promoted and protected under an InnoEscuela-type patent document quite close to the official one of the Spanish Patent Office. The

contents for the 12-14 year-old students (1st-2nd degree) will guide students through the following steps or chapters:

1. *The innovative enterprise*
2. *Our Innovation*
3. *We select and develop the innovative idea*
4. *Preparing the manufacture of our innovative project*
5. *We promote our innovation*
6. *Protecting out innovative idea*

14-15 year-old students (3rd degree) are characterized by having developed basic skills and having acquired enough knowledge to face electro-mechanical projects. Besides, their skills in motor technology are quite mature and their abilities have been improved to face projects that require both intellectual efforts and practical implementation.

Thus, InnoEscuela program proposes a new challenge by incorporating electronics in their innovative projects. In this third course, new didactic workshops will be learnt and a more professional focus is applied since new knowledge is provided: planning the building of the project and promoting their innovative idea, object or system by programming a web site. Students will be developing teamwork by the following sequence of chapters in 3rd degree:

1. *The innovative enterprise*
2. *Our Innovation*
3. *Selecting and developing the innovative idea*
4. *We plan our innovative project*
5. *Putting into practice our works quality control*
6. *We design our web page*
7. *We protect our idea*

InnoEscuela provided methodology could be just applied once in one course or could be deployed into the four Compulsory Secondary education courses. We recommend the latter option as continuous work for several years enhances the innovation and entrepreneurship abilities and skills, reaching its highest level in 4th degree (15-16 year-old). The focus in this course maintains the simulation of working as a company, but slightly modifies the way to apply Innovation.

This course has a multifaceted approach that encourages business action towards research and development of innovative products using modern technologies such as using Arduino as an essential part of the project, accessing to Remote Labs in order to experience research simulations, preparing a business plan to address the mass production of the innovative device and deepening their knowledge of computer tools. This work plan in 4th degree will have the following sections:

1. *Introduction to research*
2. *Founding our innovative enterprise*
3. *We train as researchers to qualify for Innovation*

4. *We develop the design of our innovative product with Arduino*
5. *We build the designed innovative product*
6. *Spreading our innovative product in the web*
7. *We do our business plan*
8. *Can we protect our innovative product?*

As it can be observed, the course will start with works related to research activities as a new way to implement the teaching format of “*Learning by doing*” prior to the making of the innovative project. Once the product or Arduino-based system has been designed, students’ team/company has to assign responsibilities to members in order to simultaneously work with the innovations hardware implementation and the programming of the device according to the design specifications. In figure 3, a part of the team is working in the making of the external aspect of the innovation while the other members (Figure 4) are programming Arduino board using any of the Arduino programming development tools such as Arduino IDE, Scratch for Arduino (S4A) [7] or Visualino[8]. A second option selected by some other teams has been the use of Scratch for Arduino (S4A) as the preferred interface to develop the program of the innovative system.



Fig. 3. A moment of the hardware implementation of a team project



Fig. 4. Plants growing surveillance students project by using Arduino control system

VIII. A DIGITAL ENVIRONMENT FOR EDUCATIONAL PURPOSES: INNOESCUELA DIGITAL PLATFORM

InnoEscuela Digital Environment (IDE) is an additional resource implemented for those teachers who prefer to use electronic documentation instead of the students’ InnoEscuela

notebook to write in it. It has been developed through Moodle environment. Each team/company notebook has been digitally created with edition possibilities. At InnoEscuela we recommend to use the electronic version of documents to be able to upload them to IDE. Teachers are granted with a specific teacher user’s password to access to any documents from their students innovative enterprises in order to complete the evaluation, assessment and communication with them.

IDE has also been developed to provide asynchronous communication between teachers and their students innovative enterprises as well as among these enterprises themselves.



Fig. 5. A team programming and setting up Arduino firmware

Available to teachers is an optimal assessment tool and also a guide to follow the progress of their students. The main IDE features are represented in figure 5, and the 1st/2nd course (12-14 year-old) specific aspect of IDE is in figure 7.

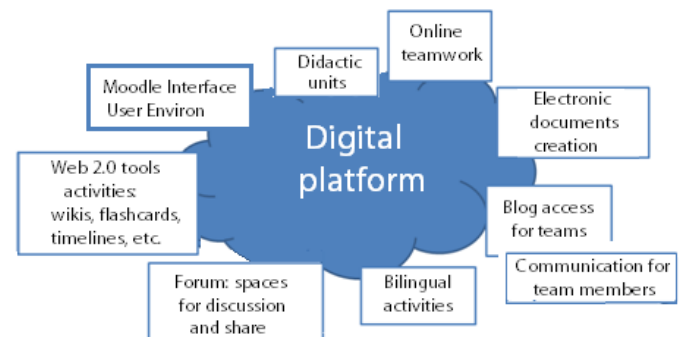


Fig. 6. Main features in the digital environ

To understand and get familiar with IDE, a user’s guide documentation has been created which is freely available to everyone, either current teachers or anybody interested in participating in the program.

With these assumptions, one of InnoEscuela development Partners, the Department of Electrical Engineering, Electronics and Control from Spanish University of Distance Education UNED, has developed the IDE as an e-learning application that responds to the needs described above.

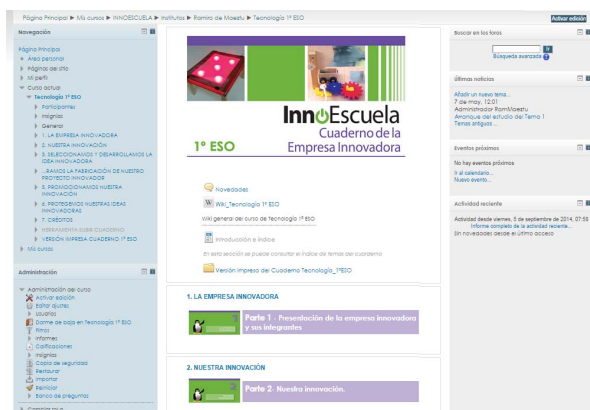


Fig. 7. Aspect of the IDE interface for 1st /2nd courses students

A review of existing e-learning platforms was performed. First approach was to know which type would fit better the needs of InnoEscuela program. As a final result, the application was developed as an e-learning platform whose main features are described as follows:

- Type of environment: **Moodle version 2.6**
- Operating system: **Windows Server 2008**
- Web support and Database Management System: **Suite Wamp 2.4**

Windows Server 2008 machine has been implemented on a virtual server with VMware technology. The main reason for this decision is motivated by two aspects. Firstly, the variable number of High Schools and Colleges expected to host in the environment and secondly, an expected large number of platform users working discontinuously will alternate periods of high usage with others of low utilization, requiring a robust behavior.

Based on these reasons, the use of a virtual machine is indicated to allow the variation of the main resources (processors, RAM, hard drives, etc.) in active work mode, avoiding to stop the services and being able to adapt to different IDE usage periods. In figures 8 and 9, some graphics of the performance of the virtual machine are represented. It can be observed that the virtual machine is suitably working according to the normal functions, which show that hardware is not a performance limitation.

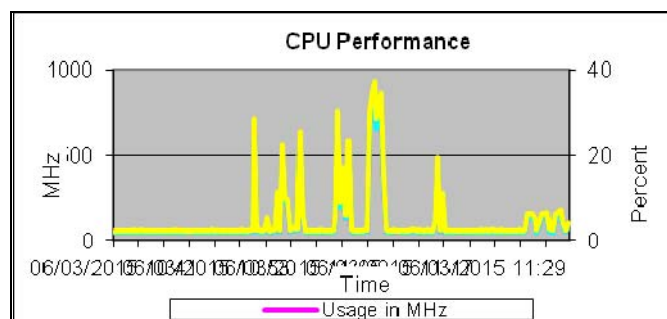


Fig. 8. CPU performance of the virtual machine that supports the application

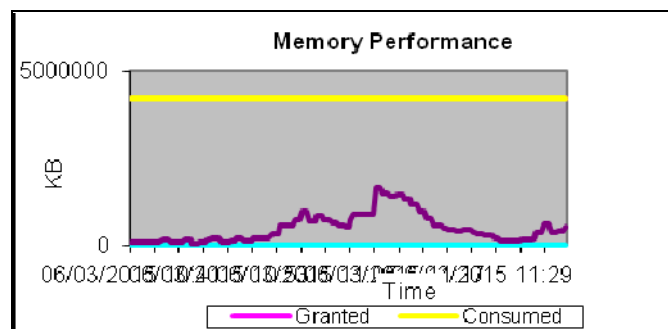


Fig. 9. Memory performance of the virtual machine that supports the application

When writtin this document, the IDE production stage is developed as follows:

- Number of courses = 54
- Number of users = 159
- Number of roles assignments = 155
- Number of messages in communication channels = 29
- Number of questions among users = 53
- Number of available resources = 364
- Average number of simultaneous participants = 2.71

A system of templates has been configured in order to create new courses and new categories when needed. Four profile categories have been created in the IDE, as represented in figure 10. Administrator is the highest entity in the IDE and is able to control any aspect of the Moodle environment which gives support to the application. The second level is the profile "Teachers" with complete capabilities to edit courses in which they are authorized to work and to create new courses inside the category.

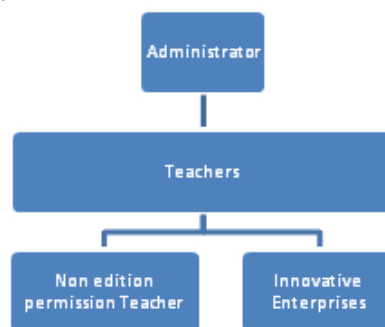


Fig. 10. Existing profiles in the application

At the bottom level, non-edition permission have been created for the access of Teachers and Innovative Enterprises who respectively will be guest lectures and students' teams. The rights of these two profiles are restricted to access to the courses in user's mode which includes downloading and uploading teams/companies documentation and activities, downloading of didactic workshops, qualifications display and access to communication channels.

A thematical development of the courses has been implemented in the IDE following the same InnoEscuela

organization desing as from notebooks, being variable depending on the course. Each of the stages or parts of each course are shown individually paged.

Hierarchized categories structure have been created (figure 11) from a first split into High Schools and Colleges to the activities at the lowest entity item.

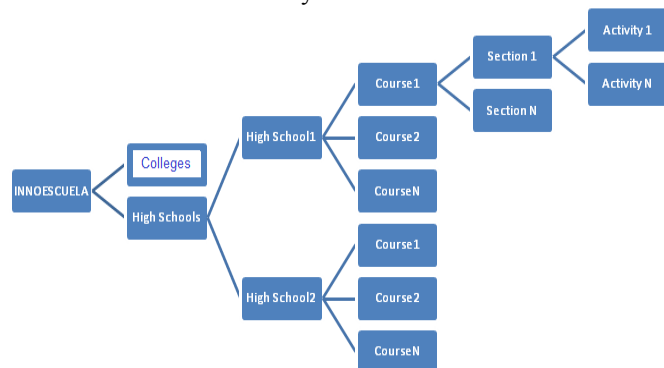


Fig. 11. Structure and categories in InnoEscuela application

The InnoEscuela Environment Development provides several capabilities according to the user's profile. The most significant are:

Access to IDE as an innovative enterprise:

- Access to the activities of downloadable content in each section of courses (Notebook and Workshops)
- Access to parts of the notebook that contain activities to be delivered to teacher
- Access knowledge tests applications (self-assessment tests)
- Access to general forums and specific course sections
- Access to Blogs and Wiki spaces by course
- Notification area, calendar per course and activity reports
- Internal messaging system, warning system events
- Access to Area profile settings to particularize their appearance and operation in the IDE
- Access to report of assessment scores and degrees in the courses where the team is involved.

Access to IDE as Teacher:

- Access to the activities of downloadable content in each section of courses (Notebook and Workshops) in edition mode in order to change aspects and contents.
- Creation of new topics in the events system and uploading of the activities schedule
- Wiki control in each course
- Deliveries assessment and control
- Edition of the evaluation system in each course
- Control of the attendance process of users
- Users groups control
- Display of permissions and control of his /her innovative enterprises
- Uploading of new courses and courses backup and restore.

IX. STUDENTS' EVALUATION AND ASSESSMENT

InnoEscuela is a program conceived under the premise of the active and permanent making of activities and tasks with a methodological design based on a sequence, that consists of starting a new task just when the previous task has been finished. Thus, the program will consider a type of continuous assessment of the activities developed by students' innovative enterprises.

Assessment will be applied through two areas:

- **Innovative enterprise scope.** It's recommended the use of the assessment plan provided in which evaluation criteria and assessment methods are identified.
- **Student personal scope:** Teachers may use as many assessment tools as they consider appropriate in order to assess the progress of the student in each of the stages according to their scope in each of the terms. Personal assessment of each student is recommended according to his/her progression as basic skills and competences [9] as described by UNESCO education programs, for which a specific section has been provided. Assessment and evaluation has been developed according key competences [10, 11], according to European Commission education policies and these have been also divided into sub-competencies and beyond, extended in specific descriptors. According to this assessment methodology, evaluation will be carried out and by extension, qualifications and grades.

According to the qualification system provided in InnoEscuela and available through the IDE, each teacher might decide the weight assigned to each task contained in each stage. However, a certain weight has been given as default for these assessment elements. A graphical layout of the qualification process has been represented in figure 12.

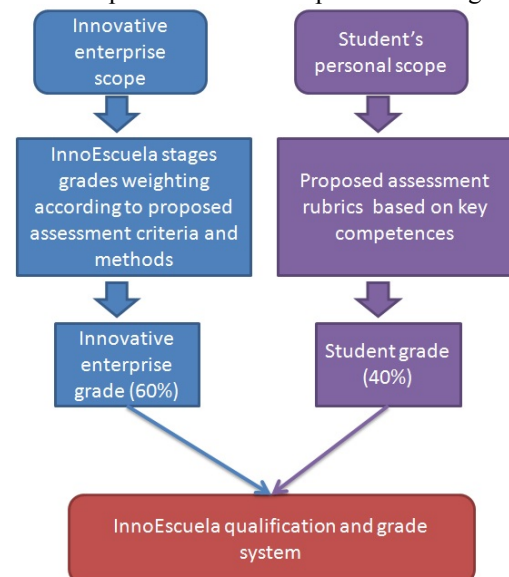


Fig. 12. Structure and categories in InnoEscuela application

It is recommended to apply a 60% of the final score to the innovative enterprise scope and a 40% to student's personal scope. Final score is left to teacher's discretion since he/she is the closest person to the subject. This means that the teacher will be able to determine the degree of scoring to apply to each InnoEscuela aspects and scopes, such as teaching of theoretical contents of the subject, use of Information and Communication Technologies, specific attitudes to face the work, use of English or Spanish as linguistic vehicle in order to make descriptions, evaluation of students' attitudes in the team and towards teamwork, etc.

Definitively, the application includes a delivery system to allow students upload the parts of the documentation for teacher to be able to correct and qualify the contents.

X. SOME PRELIMINARY DATA ABOUT STUDENTS' DEVELOPMENT

InnoEscuela is been applied for the first time in the 2014-2015 course. A number of 20 teachers of the Spanish territory are teaching Technology and ICT following the InnoEscuela program with almost 1,000 students aged from 12 to 16 year-old. At the moment of writing this communication, school year hasn't still finished and final scores haven't been graded.

However, in the past four year-courses, a pilot program has been carried out following the basis of InnoEscuela program. In this pilot experiences, some groups have been taught with the innovative methodology and have been compared with other students' groups who haven't applied the program. The evaluation of the pilot program has led us to design and create InnoEscuela since two main outcomes have been measured: an important improvement in final course average marks of 10% to 30%; and a great qualitative improvement in satisfaction and motivation in both teachers and students involved.

XI. CONCLUSIONS

InnoEscuela has been introduced as a program but also as a multiple source learning methodology to complement conventional teaching activities in courses related to Technology and Computing. InnoEscuela intends to contribute to technological innovation through a specific methodology that focuses on Project-based learning and team work. Students are organized in teams which are called innovative enterprises and they have to create a solution to a social disadvantage, a technical problem, or any other kind of need, with an only restraint: ideas to implement must content an innovation.

We, InnoEscuela creators, are proud of the final product and preliminar results since students recognize to learn more motivated, being crucial the ownership spirit of each creating team/company. Teachers involved in the program consider a

good proposal to transform the role of teacher from one conventional instruction-type to another that can be described as a guide or a facilitator of knowledge. The assumption of this new role permits to change the performance and efficiency of the teacher in class since he/she pay more attention to students development.

Acknowledgment

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Arts & Bots: Application and Outcomes of a Secondary School Robotics Program

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Abstract—Arts & Bots combines intrinsically creative craft materials, common robotics components, a custom programming environment and teacher professional development to create a flexible robotics intervention for secondary school classrooms. In order to engage students underserved by other robotics programs, Arts & Bots is oriented to support the creation of collaborative expression-focused robots, as opposed to more commonly implemented competitive task-focused robot activities. Specifically, Arts & Bots targets integration into traditional non-technical classes, such as literature and history, to reach a broader base of students than would be enrolled in elective technology programs. This paper describes three classroom implementations, including a secondary school poetry project. By including Arts & Bots in these core courses, we expose diverse students to engineering education activities such as hands-on experiences with computer programming, prototyping, and the engineering design process. We present our outcomes grouped within two primary themes: first, in Technological Fluency, we present students' self-reporting of concepts learned, confidence with technology, and breaking of technology stereotypes; second, in Complementary Non-Technical Skills, we present other skills students learned by participating in the Arts & Bots program.

Keywords—educational robotics; interdisciplinary education; technological fluency; secondary school engineering

I. INTRODUCTION

The diversity of new technological inventions is greatly affected by the creativity and background of technology developers. Considering the underrepresentation of women and minorities in STEM careers, it is evident that society is inadequately utilizing the creative capacities and diverse experiences that such underrepresented groups could contribute. In order to attract a wider diversity of students to pursue advanced training and careers in engineering, it is critical that students have pre-college experiences that allow them to practice engineering and help them to develop technological fluency.

Technological fluency is the ability to manipulate technology creatively and for one's own use; an idea espoused by our research [1] among many others [2] [3] [4] [5]. It is important to provide opportunities to develop technological

fluency to all students, yet the current practice of pre-college engineering education frequently limits engagement with engineering to a narrow population. In secondary school, engineering-focused extracurriculars often utilize high-intensity, contest-driven challenges as motivational hooks for students inspired by competition [6] [7]. Engineering and technology classes in secondary schools are usually offered as elective classes for students with pre-existing interest in engineering and technology. Unfortunately, these current approaches fail to reach students who are unmotivated by competitions or are uninterested in technology for its own sake.

Our intervention, Arts & Bots is aimed to engage a more diverse population of students, including those unmotivated or uninterested in existing technology interventions, in engineering practice. We look to achieve this through a robotics program that is focused on expression and communication over competition and that provides a non-technology context for technology use. The robot hardware kit, which is the basis for Arts & Bots, is designed to promote expressivity by combining intrinsically creative and gender neutral arts and crafts materials with commonly used robotics and technology components. Through programs like Arts & Bots, we believe it is possible to encourage a different style of student engagement than the status quo for secondary school engineering education and thus possible to attract a more diverse population of students to engineering careers.

II. ARTS & BOTS OVERVIEW

The Arts & Bots program started in 2006 with the goal of exploring the educational impact of expression-focused technology experiences. The Arts & Bots program initially began as an extracurricular intervention which aimed to diversify the Computer Science pipeline by engaging 11 to 14 year old girls [8] [9] [1]. At that time, others were also developing similar extracurricular programs for engaging students who were not interested in traditional robotics programs and competitions, by providing connections to robotics through creative interests, like music, art, and storytelling [10].

Following our initial implementation phase as an extracurricular program, we transformed Arts & Bots into an in-school intervention in order to reduce participant self-selection. By designing the Arts & Bots kit to enable craft-based building followed by choreographic programming, we

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Fig. 1. Student built robots, from left to right, robot theater (I Know Why the Caged Bird Sings by Maya Angelou), arm model, and historical figure (Alexander the Great).

connected technological fluency to arts education, which is well-regarded and supported in school systems and by students who may not have strong prior experience with electronics. We focused efforts on integration with non-technical, core courses in order to engage students in engineering and programming practice who would otherwise avoid enrolling in a technical elective course or extracurricular activity.

The Arts & Bots hardware kit includes a large number of aesthetically-oriented outputs including DC motors, hobby servos, and tri-color LEDs along with various interaction-promoting sensors including IR distance, light, and sound level sensors. Craft materials are chosen by the educator to suit her desired project. By implementing affordances for sound, lights, and choreography, we enable Arts & Bots to be flexibly integrated into secondary school topics such as poetry. Additionally professional development training on Arts & Bots has repeatedly enabled teachers in such non-technological disciplines to directly implement Arts & Bots as expressive elements of their student assignments [11], enabling the summative evaluation of student attitudes and student knowledge gains as reported in this article. While prior publications have concentrated on the iterative participatory design of the Arts & Bots hardware [9] and software elements [12], this report focuses on the educational evaluation of Arts & Bots in 7th and 8th grade core disciplinary courses.

A. Arts & Bots Curriculum Examples

Through professional development, we train teachers to use the Arts & Bots hardware and software, and to develop their own project which integrates Arts & Bots with the goals of their discipline [11]. We provide three examples of this type of curricular project in different areas: poetry, health and history.

1) Poetry

The first example is a poetry project. Beginning in 2012, a small public, junior-senior high school began implementing Arts & Bots in their 7th and 8th grade Language Arts classes. In this class, teams of two to four students chose poems from a list preselected by the teacher for their vivid imagery. Over seven class days (roughly 14 contact hours), these students worked in groups to analyze the selected poem and design a robot theater (Fig. 1, left) which they build and program to represent their poem. Students recorded audio clips of themselves reading the poem and incorporated these clips into

the programs they wrote. The class was jointly instructed by the Language Arts and Gifted Support teachers.

2) Joints and the Musculoskeletal System

The second implementation example took place in a health and physical education class. Two 7th grade teachers taught Arts & Bots to a combined health and physical education class on joints and the musculoskeletal system beginning in 2014. Teams of students created models of human joints (Fig. 1, center) which they could “personalize” with clothing and accessories. Students chose a joint for their project: knee, shoulder, or elbow. Teachers provided a limited number and variety of materials with an emphasis on using recycling and recycled material. The project covered 15 class periods (roughly 12.5 contact hours).

3) Historical Figures

The last example is from a technology education teacher who implemented an Arts & Bots project with 7th grade students. The project was spread over the course of the school year (roughly 20 contact hours) beginning in 2010. The technology education teacher integrated content in history, English, science, and math classes that were co-taught with each content teacher respectively. Students selected a historical figure from a list provided by the history teacher (e.g., Hercules, Alexander the Great, Pharaoh Hatshepsut). In history class, the students researched the life of their chosen figure. In English class, students wrote a biography from the perspective of their individual. Finally, with support from the math and science teachers, students built robotic models of their historical figures (Fig. 1, right) and programmed them to act out the biography.

III. METHODS

A. Hypotheses

We wish to understand the ways in which creative robotics activities within a disciplinary context impact student learning, and in particular, how student technological fluency is affected by this inclusive approach to technology exposure. Technological fluency itself is governed by two factors: student attitudes toward technology, and student technical knowledge. Each form of change is insufficient by itself in catalyzing a shift in the overall student-technology relationship. Empowered attitudes are required for students to apply

knowledge. Knowledge is required for students to be effective in acting on their attitudes. Thus, we propose two specific hypotheses relating to enablers of student technological fluency:

1. Arts & Bots increases student grounding of technical knowledge and technical skills.
2. Arts & Bots increases student motivation and confidence to engage with technology.

In addition to fluency-centered hypotheses, an important goal for the Arts & Bots pilots stems from our desire support the technology of all students. We believe that the incorporation of creative robotics into disciplinary core courses has the capability to attract a more diverse student population to technology and, thus, to a pathway toward technological fluency. Our third hypothesis relates specifically to the nature of inclusiveness achieved with the Arts & Bots program:

3. Arts & Bots engages a broad demographic of participants, across gender and across prior technological exposure.

If these three hypotheses are supported by our evaluation, then we believe that Arts & Bots successfully meets the need for an intervention which improves the technological fluency of a broader population of students through a different style of student engagement than the current pre-college engineering education status quo.

B. Assessment Tools

We organized the evaluation of technological fluency into two primary surveys reflective of our hypotheses: Student Knowledge with Respect to Technology (Knowledge) and Student Attitudes with Respect to Technology (Attitudes). We also collected basic demographics information from students, including race, age, grade level and gender for addressing the broadening demographics hypothesis. Student learning and attitudes were assessed through pre and post surveys given to students before and after their Arts & Bots project respectively. A small subset of students was interviewed following completion of their Arts & Bots project.

1) Knowledge Survey

The Knowledge Survey consists of six short answer questions, nine multiple-choice hardware component questions phrased as analogies, six multiple choice software questions, and ten multiple choice systems engineering questions. The short answer questions were slightly different between the pre and post-test version. The systems engineering questions are adapted from [13] and include 10 items describing actions of devices and subsystems. The students were prompted to indicate whether each action is an “Input”, “Output” or “Processing” of the system (Table I). This paper presents results from two short answer questions and the systems engineering questions. Hardware and software multiple-choice questions continue to be tested and refined.

2) Attitudes Survey

The student Attitudes Survey consisted of 7 short answer questions and 35 Likert-type questions. The short answer questions were slightly different between the pre- and post-test

TABLE I. MULTIPLE CHOICE QUESTION DETAILS

Multiple Choice Questions	Details	
	Number of Items	Answer Choices
Attitude Scales: Please select the answer that shows how you feel right now about the statement. There are no right or wrong answers, just be honest.	35	NO! no Neither yes or no yes YES!
Systems Engineering Scale [13]: Below is a list of actions. Check off whether each action is an input of information, the output of information, or the processing of information.	10	Input Output Processing

version. The Likert-style questions have students rate agreement with various attitude statements with grade level appropriate options: “YES!”, “yes”, “neither yes or no”, “no”, and “NO!” (Table I). The Likert-style questions fall into four attitude subscales: Interest (9 items), Motivation (9 items), Curiosity (8 items), and Confidence and Identity (9 items). This paper presents results from three short answer questions and from the Likert-style questions.

C. Demographics

In this paper, we present data and analysis from 7th and 8th grade students experiencing their first Arts & Bots project. Data were collected from six schools: five public and one independent; a mix of rural (n=3), suburban (n=2), and urban (n=1). Data were collected in 13 separate classes. These classes included six 7th grade classes covering: Accelerated Language Arts, Advanced Math, History, and Technology Education; and seven 8th grade classes covering: Academic and Accelerated Language Arts. Data were collected between November 2010 and April 2014.

The number of students in the data samples below varies slightly due to a number of factors. First, student absences resulted in unequal numbers of Knowledge and Attitude Surveys as they are sometimes applied on consecutive class days depending on class structure. Second, incomplete data collection by teachers led to entire classes having only pre- or post- surveys collected. Finally, our survey tools undergo regular refinement and modification of wording thus items that were introduced more recently may have fewer responses.

The analysis in this paper excluded participants who did not meet the following two conditions: 1) were enrolled in a middle school class, and 2) were participating in their first Arts & Bots project. This led us to exclude data collected from 19 twelfth grade students who were considered outside the target class level and data collected from 6 seventh grade and 34 eighth grade students who had prior Arts & Bots project experiences.

There are Attitudes Survey data from 139 students in 7th grade and data from 73 students in 8th grade. Of those, 98 seventh graders and 55 eighth graders completed matching pre- and post- Attitudes Surveys. There are Knowledge Survey data from 140 students in 7th grade and data from 89 students in 8th grade. Of those, 100 seventh graders and 44 eighth graders completed matching pre- and post- Knowledge Surveys.

D. Analysis

Students were assigned unique subject numbers, and names were replaced by subject numbers throughout the data. The analysis methods used for the three types of survey items (short answer items, Likert-type attitudes items, and systems engineering items) are described below.

Short Answer Coding: Open-ended questions were coded independently by two coders, each an expert in robotics. Survey responses were randomly assigned survey ID numbers to make coding blind to student grade level and whether responses were from pre- or post- surveys, when possible. Responses could be assigned multiple codes if they expressed multiple unique ideas without overlap. Unless otherwise noted, coding was done on the full set of data, and inter-rater reliability was calculated for this complete set (Table II). The top response codes are provided in tables for the following four questions: “What was the best thing that you learned during the project?” (Table III), “Did you enjoy doing this project?” (Table IV), “How did this experience change how you think about technology?” (Table V), and “Should other students have this experience?” (Table VI).

Attitude Scales: Analysis of the Likert-type questions was completed using binary scoring to eliminate any assumption of equal spacing between responses while reflecting the general attitude of the student. For this analysis, we used the binary scoring: (1) positive technology attitudes responses (“YES!” and “yes”) and (0) non-positive responses (“NO!”, “no” and “neither yes or no”). The item scores are inverted for negatively phrased questions: (1) negative technology attitudes responses (“NO!” and “no”) and (0) non-negative responses (“YES!”, “yes” and “neither yes or no”). As an item-wise analysis, we calculated a McNemar test for each Likert-type question, to test the hypothesis: the proportion of students responding positively to the statement in the pre-test was different from the proportion of students responding positively to the statement in the post-test.

Systems Engineering Scale: For each of the 10 multiple-choice questions, we assigned a score of 0 (incorrect) and 1 (correct) for each participant response. Each participant could then be assigned a systems engineering subscore on a scale from 0 to 10 representing the number of items he or she answered correctly. We then tested the hypothesis: the distribution of the student scores was different between the pre-test and post-test. The score distribution had an asymmetrical distribution where the number of students achieving a maximum score on the evaluation prevented a normal distribution. This indicated that the appropriate statistical test for our hypothesis was a Wilcoxon Signed Ranks Test, a non-parametric test for comparing the median score of the distributions.

IV. OUTCOMES

Through the data and analysis described, we identified two primary outcome themes: Technological Fluency and Complementary Non-technical Skills. Technological Fluency covers technical knowledge gains, confidence, and changes in technology stereotypes. Complementary Non-Technical Skills encompasses teamwork, perseverance, and

TABLE II. INTER-RATER RELIABILITIES FOR OPEN-ENDED QUESTIONS

Open-Ended Questions	Coding Agreement	
	Inter-rater reliability % agreement	Number of codes compared
How did this experience change how you think about technology? (post)	91.0%	N=199
Did you enjoy doing this project? Why or why not? (post)	84.4%	N=244
Should other students have this experience? Why or why not? (post)	84.4%	N=237
What was the best thing that you learned during the project? (post)	91.0%	N=210
What parts did Evan use to make the flower? (pre & post)	100.0%	N=193 ^a

^a. Inter-rater reliability was calculated on a subset of 193 responses out of a total of 359 responses.

several other personal skills. All student quotes included below are provided verbatim.

A. Technological Fluency

1) Learning about Robotics

As we hypothesized, students self-reported learning about robotics, technology, computers, programming, specific robotic components used in the class, and engineering design concepts across many different open-ended questions. For the following three open-ended questions, learning about technology was one of the top three most common student responses to each question. When asked “What was the best thing that you learned during the project?”, the majority of students (56.8%, N=139) described a technological learning gain. For example one student said “The best thing was just basically programing the hummingbird. When you tell something to do something and it works it feels amazing,” (8th grade male, academic language arts). When asked “Should other students have this experience?”, 17.7% of students (N=130) said other students should because they would learn about technology. When asked “Did you enjoy doing this project?”, 16.8% of students (N=131) reported that they enjoyed the project because they learned about technology. For example, a student said “YES! I didn’t know much about robotics before this project. I definitely feel more educated about robotics now than I did before this project. It was a GREAT learning experience!” (7th grade male, accelerated language arts). In response to the question “How did this experience change how you think about technology?”, 13.2% of students (N=129) reported that they learned something new about technology. For example, one student reported “i understand it much more now!!!” (7th grade female, accelerated language arts). These self-reported learning gains about specific and more generalized technology knowledge and skills are supportive of the hypothesis “Arts & Bots increases student grounding of technical knowledge and technical skills.”

In addition to self-reported technical learning, an open-ended knowledge question, designed to measure student understanding of robotic systems and components, indicated significant technical learning gains. Students watched a short video of a craft-based robotic flower catching a ball in its petals. After watching the video, they were asked “What parts did Evan use to make the flower?”. Student short answer responses were coded as being: 0) video could not be played, 1) I don’t know, 2) a non-technical answer, 3) a conceptually

correct technical answer but using incorrect terminology, or 4) a correct technical answer. Non-technical answers included craft materials, nonspecific technical parts (i.e. “robot parts”, “knob”), or structural parts not contributing to the robot’s function (i.e. “metal”). Correct technical answers included terms such as “servo motor”, “circuit board”, “gears” and “pressure sensor”. Correct technical answers that were misspelled were coded as correct. Sixty-nine students were unable to play the video on school computers in either the pre- or the post-survey and were excluded from analysis. A McNemar’s Test indicated there was a significant increase in the proportion (47.2% pre-, 95.5% post-) of students who gave a technical response, as shown in Fig. 2, to the question on the post survey, $\chi^2(1) = 41.09$, $n = 89$, $p < .0001$. This result supports the technical knowledge and skills hypothesis as these students demonstrated both increased knowledge of robot components and increased skill in describing a novel technological system.

Another part of the Knowledge Survey, the qualitative Systems Engineering Scale, measured significant learning gains between the pre- and post-surveys as shown in Fig. 3. A Wilcoxon Signed-ranks test indicated that the Systems Engineering knowledge subscore post-test (median = 8) was significantly improved over the Systems Engineering knowledge subscore pre-test (median = 7), $Z = -4.820$, $p < .0001$, $r = .41$, $n = 138$. These increases indicate not only an improved understanding of robotics, but also improvements in student understanding of the systems engineering concepts of inputs, outputs, and processing. This finding of increased technology systems engineering further supports the knowledge and skills hypothesis.

On two attitude Likert-type responses related to learning technical knowledge, there were significant differences found between the pre- and post-surveys. On the statement, “I am curious about how robots work”, McNemar’s Test indicated there was a significant decrease in the proportion of students who agreed with the statement on the post-survey, $\chi^2(1) = 4.84$, $n = 108$, $p = .043$. In addition, a McNemar’s Test indicated there was a significant decrease in the proportion of students on the post survey who agreed with the statement “I would like to learn more about robotics”, $\chi^2(1) = 7.2$, $n = 108$, $p = .012$. At first glance, these decreases in curiosity seemed discouraging; however in combination with the measured and self-reported gains in knowledge with respect to technology, we hypothesize that for some students the project was adequate

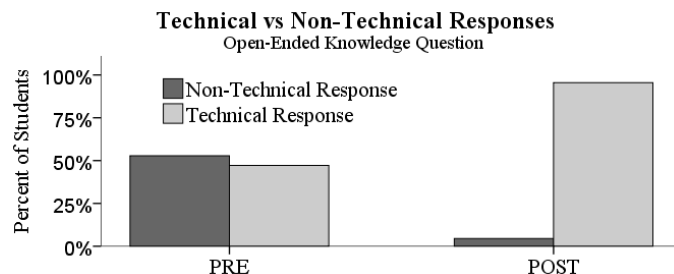


Fig. 2. Percent of students giving non-technical and technical responses on the open-ended knowledge question: “What parts did Evan use to make the flower?” (N=89).

in fulfilling their desire for learning about technology. This interpretation indicates that future implementations may be improved by placing more emphasis on the expansive and growing field of robotics and introduce Arts & Bots to students as a fragment of that field in order to seed new curiosity. In addition to this reported satisfaction of learning, we saw corresponding improvements in student confidence, described in more detail below.

2) Improved Confidence

Given the self-reported and measured learning gains in technology and robotics, it is not surprising to see that students had increases in confidence with technology as well. On the Confidence sub-scale Likert-type item, “I am not good at making robots” a McNemar’s Test indicated there was a significant increase in the proportion of students who disagreed with the statement on the post-survey, $\chi^2(1) = 5.7$, $n = 108$, $p = .024$. That is to say that the number of students who took a stand for their own abilities making robots increased. This interpretation is supported by findings from the earlier extracurricular Arts & Bots pilot, which also found an increase in student confidence with respect to robots [4], as well as by short answer responses described below.

Students answering the question, “How did this experience change how you think about technology?”, mentioned that they felt more confidence in their technology skills after the project (5.4% of students, N=129). Some students noted increased confidence in programming, for example, “I always thought technology was far too complex for me to ever have even a basic understanding of programming and how it works. I now know that I will be able to learn basic programming skills if I choose to do so” (7th grade male, technology education). Other students had increased confidence working with the hardware,

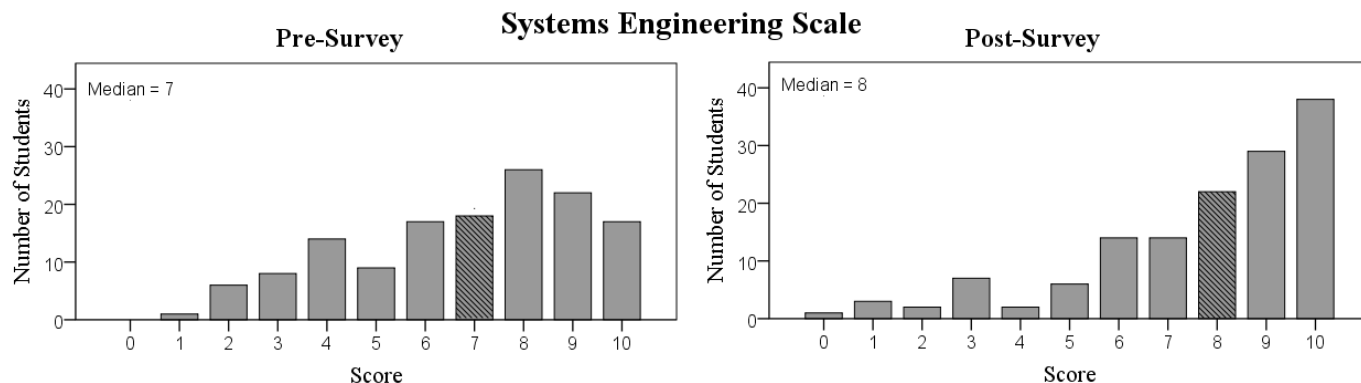


Fig. 3. Distribution of student scores on the 10 item Systems Engineering Scale, median score bar indicated. (N=138)

TABLE III. WHAT WAS THE BEST THING THAT YOU LEARNED DURING THE PROJECT? RESPONSE SUMMARY

What was the best thing that you learned during the project?	Percent of Students
	N=139
Technical Learning	56.8%
Teamwork (positive indication)	22.3%
Multidisciplinary Integration	6.5%

^a. Categories representing less than 4.5% of students not shown.

such as, “I think I got a lot better at learning how to hook things up to the humming bird, and it taught me not to be afraid of messing up” (8th grade female, academic language arts). Beyond confidence in specific technical skills, for some students, the experience also resulted in a shift in identity with respect to technology. For example, one student said “it made me feel more connected and confident using the robotic elements it made the technology feel more accessible instead of just something really smart people or nerds do” (8th grade female, accelerated language arts). This finding of increased confidence with technology in part supports the second hypothesis “Arts & Bots increases student motivation and confidence to engage with technology.”

3) Breaking technology stereotypes

One interesting aspect of the Arts & Bots experience is the way it challenged stereotypes students held about technology. When asked “How did this experience change how you think about technology?”, 17.8% of students (N=129) reported that they found that it was harder than they expected. For example, one student reported “This experienced changed how I think about technology because I thought all technology was easy for me. After completing this project I thought this was actually difficult.” (7th grade female, accelerated language arts). This was the highest-scoring sub-code for this question. However, we do not believe this simply meant that students found the project to be too hard. Instead, we believe that students gained a more realistic understanding of the challenges involved in complex, real world engineering design problems. Examining all students in our selected set (7th and 8th grade on their first Arts & Bots experience) with post-survey results, 23 students (17.8%, N=129) said that they discovered that technology was harder than they thought. Of these 23 students, 87.0% reported enjoying the project, 13.0% reported they did not enjoy the project. Stated another way, although students found technology more challenging than they expected, it did not indicate that students didn’t enjoy the project. In contrast, 11.6% of students (N=129) reported that they found that technology was less challenging than they expected. For example, one student said “After this experience, I thought that technology wasn’t as confusing as I thought it would be and that it wasn’t only an amazing learning experience but also a fun project.” (7th grade male, accelerated language arts). Since many students answered the question, “How did this experience change how you think about technology?”, with statements about how technology was either harder or easier than they had expected suggests that first-hand experience helped the students develop a more realistic metric of the complexity of technology development. This realistic metric of complexity is yet further support of the hypothesis “Arts &

TABLE IV. DID YOU ENJOY DOING THIS PROJECT? WHY OR WHY NOT? RESPONSE SUMMARY

Did you enjoy doing this project? Why or why not?	Percent of Students
	N=131
Yes - Technical Learning	16.8%
Yes - Enjoyed Technology	13.0%
Yes - Novelty of Experience	13.0%
Yes - Teamwork (positive indication)	13.0%
Yes – Fun Experience	12.2%
Yes - Enjoyed Building	9.9%
Yes - Vague Learning Gain	8.4%
Yes - Creative	5.3%
No - Teamwork (negative indication)	4.6%

^b. Categories representing less than 4.5% of students not shown.

Bots increases student grounding of technical knowledge and technical skills”.

Students also reported an increased appreciation for technology. The second most common response to “How did this experience change how you think about technology?” was from 17.1% of students (N=129) who reported that it increased their appreciation for technology. Responses coded as increased appreciation could include appreciation for the complexity of technology, understanding of applications of technology in everyday life, or reporting a new perspective on technology. For example, one student said “This experience makes me appreciate the people that do computer programming for a living.” (7th grade female, accelerated language arts), and “This experience changed my thought on technology because I used to think that technology was only cell phones and gadgets like those, but now I know that there is more to technology than meets the eye.” (7th grade female, accelerated language arts). Students mentioned increased appreciation for technology in their responses to other questions as well, though in smaller proportions: “Should other students have this experience?”, 2.3% (N=130); and “What was the best thing you learned during the project?”, 2.2% (N=139). The reported increase in appreciation for technology reflects student statements towards valuing the role technology plays in their lives and the world. Value is a contributing factor for motivation and thus these findings are supportive of the hypothesis on motivation and confidence.

Not surprisingly, given the creative and interdisciplinary nature of Arts & Bots projects, students also reported learning about creative uses of technology. 6.5% of students (N=139) mentioned the multidisciplinary nature of technology in response to “What was the best thing that you learned during the project?”. For example, one student stated “Poetry can be very difficult to understand, but using robotics and creating a visual view of the poem can help you understand it more.” (8th grade female, accelerated language arts). When asked “Did you enjoy doing this project?”, 5.3% of students (N=131) reported that they enjoyed the project because it was creative. For example, a student said “Yes, I like how people can be creative with their minds since [since] there are so many options of

TABLE V. HOW DID THIS EXPERIENCE CHANGE HOW YOU THINK ABOUT TECHNOLOGY? RESPONSE SUMMARY

How did this experience change how you think about technology?	Percent of Students
	N=129
More challenging than I thought	17.8%
Gained appreciation for technology	17.1%
Technical Learning	13.2%
Less challenging than I thought	11.6%
No change reported	8.5%
Increased enjoyment of technology	7.8%
Increased perseverance	5.4%
Increased interest in technology	5.4%
Increased confidence with technology	4.7%
Found technology to be fun	4.7%

^c Categories representing less than 4.5% of students not shown.

materials to choose from.” (8th grade male, accelerated language arts). This recognition of technology as a creative medium is aligned with both the definition of technological fluency as creative application of technology and the Arts & Bots program goal of providing a robotics intervention that is focused on creativity and self-expression.

Finally, students reported that Arts & Bots can influence perspectives on technical careers or that the learning is applicable to students’ futures. When asked “Should other students have this experience?”, 18.5% of students (N=130) said yes, because it would help their future or career. For example, one student said “I think other students should have this experience because it could increase your ability to one day go to college and maybe also have a career in technology.” (7th grade female, accelerated language arts). This was the second highest response category for this question, superseded only by yes because it was fun (33.1%, N=130). This demonstrates that students value the role that technology may play in the future lives and careers of their peers and believe that Arts & Bots contributes positively to this role.

In summary, student responses show that students’ understanding of the complexity of engineering design and technical projects became more grounded in reality, students came to appreciate technology in the larger world around them, students came to see that technology could have creative applications, and they considered the benefits of what they had learned from the project for their lives in the future.

B. Complementary Non-Technical Skills

1) Teamwork

Beyond the primary goal of improving the technology skills, knowledge, and attitudes that comprise student technological fluency, we also saw evidence of students developing non-technical skills. One of the most prominent non-technical skills mentioned by students in the short answer responses was teamwork and working with their peers. The learning of teamwork skills was the second most common code (22.3% of students) surpassed only by learning about

TABLE VI. SHOULD OTHER STUDENTS HAVE THIS EXPERIENCE? WHY OR WHY NOT? RESPONSE SUMMARY

Should other students have this experience? Why or why not?	Percent of Students
	N=130
Yes – Fun Experience	33.1%
Yes – Career/Future Benefits	18.5%
Yes - Technical Learning	17.7%
Yes - Vague Learning Gain	15.4%
Yes – Teamwork (positive indication)	10.0%
Yes – Novelty of Experience	6.2%

^d Categories representing less than 4.5% of students not shown.

technology (56.8%) when asked “What was the best thing that you learned during the project?” (N=139). For example, one student said they learned “Not to blame anyone for their mistakes because [you] will end up making at least one and you would not like to be blamed” (7th grade female, accelerated language arts). Teamwork appeared in the responses to other questions as well. For “Did you enjoy doing this project?”, 13% of students (N=131) reported that they enjoyed the project because they enjoyed the teamwork. When asked “Should other students have this experience?”, 10.0% of students (N=130) said yes because they would practice teamwork. For example, a student replied “yes because it changes your thinking on how you can do projects and work with other students” (7th grade female, accelerated language arts) and “Yes I think there are a lot of people my age that would like this, it brings both tech savy people and people who can work well with their hands together.” (8th grade female, academic language arts). This trend is especially notable because teamwork is not explicitly addressed by either the Attitudes or Knowledge surveys.

In addition to these self-reported teamwork learning gains, we also saw a decrease in the number of students who agreed with the statement “It’s important to me to know more about technology than most people” following Arts & Bots. A McNemar’s Test indicated this was a significant decrease in the proportion of students, $\chi^2(1) = 6.7$, $n = 108$, $p = .014$. At first look, this decrease in the perceived value of technological knowledge seems discouraging; however we believe that the relative value students apply to their knowledge and skills is changed through the teamwork aspects of the Arts & Bots project. This interpretation is supported by some student responses to open ended questions, for example “the best thing i learned in this projected [project] was that everybody did something to help the group so it would be teamwork” (8th male, academic language arts) and “That you need to make sure everyone is working and following along to the best of their ability so you get it done quickly.” (7th grade female, accelerated language arts). Student statements like the ones above directly support the idea that students not only learned the value of communication and teamwork but came to value the contributions of their teammates towards successful completion of a technical project of this scope.

Teamwork was such a large component of student experiences with Arts & Bots, we also see reports from students who had negative teamwork experiences. The highest

negative response code for “Did you enjoy doing this project?” was negative teamwork (4.6% of students, N=131). While most students mentioning teamwork found it enjoyable or beneficial, some students had negative teamwork experiences. Anecdotal reports from teachers suggest that teamwork is a very challenging area for middle school students, thus seeing both positive and negative reactions to teamwork is not surprising.

The prevalence of teamwork in the short response questions can be explained by the integral role that teamwork plays in Arts & Bots projects. The scope of these Arts & Bots projects was such that no single student could complete the project on their own. In addition, the complex, interconnected nature of an engineering design projects requires students to collaborate closely with each other, rather than simply working in parallel. In short, Arts & Bots forces students to practice teamwork.

2) Other Skills

While teamwork was the most prominent non-technical skill reported by students, several other skills also surfaced across the open-ended question responses. Perseverance was the most notable of these with 5.4% of students (N=129) reporting increased perseverance with technology in response to “How did this experience change how you think about technology?”. Responses stating that the project or technology was challenging but rewarding or worthwhile in the end were coded in to this category, for example, “.... The use of the different robot parts was challenging but very rewarding in the end, but not as challenging as expected.” (8th grade male, accelerated language arts). Perseverance surfaced in response to other questions in smaller proportions: “What was the best thing that you learned during the project?”, 2.9% (N=139); “Should other students have this experience?”, 2.3% (N=130); “Did you enjoy doing this project?”, 0.8% (N=131). Time management and problem solving skills were reported by a few students. In response to “What was the best thing that you learned during the project?”, 2.9% of students (N=139) reported time management. In response to “Should other students have this experience?”, one student reported problem solving skills, saying “yes, it helps with team work and problem solving skills.” (8th grade female, accelerated language arts). These skills and dispositions were not explicitly addressed by the hypotheses, the professional development, or the evaluation tools and thus these results suggest an interesting avenue for future work.

V. FUTURE DIRECTIONS

In the future, we plan to continue to: 1) expand upon the outcomes discussed above, as not all outcomes could be reported within the scope of this paper; 2) make improvements to the Arts & Bots system; and 3) explore new areas of evaluation. We plan on expanding upon our findings related to the development of teamwork and other non-technical skills by developing professional development and curriculum materials designed to help Arts & Bots teachers maximize these complementary gains. We will also seek to develop items for measuring these non-technical gains in more detail. We are also interested in the development of evaluations related to the multidisciplinary nature and curricular integration of Arts &

Bots to help assess the impact that Arts & Bots has on student learning of the core discipline, e.g., poetry.

While we have done analysis on the data from the full population of the Arts & Bots students, we would be able to gain more insight by comparing subpopulations. For example, in order to address our program goal and hypothesis of “engaging a broad demographic of participants,” it will be critical to further consider the knowledge and attitudes outcomes from the experience by different genders and by students with different experience levels. It will also be interesting to do further analysis of the differences of outcomes between the different student grade levels in order to help inform teachers in the selection of learning goals that can be achieved with this and similar projects in their particular classes. Longitudinal evaluation of students taking multiple Arts & Bots courses provides another interesting avenue for future work.

VI. CONCLUSIONS

We presented here results from the middle school creative robotics project Arts & Bots. The goal of the Arts & Bots program was to increase the technological fluency of middle school students. Evidence for this goal was found in student self-reported learning and enjoyment of the creative aspects of technology through participation in Arts & Bots.

Our hypotheses for evaluating the Arts & Bots program were:

1. Arts & Bots increases student grounding of technical knowledge and technical skills.
2. Arts & Bots increases student motivation and confidence to engage with technology.
3. Arts & Bots engages a broad demographic of participants, across gender and across prior technological exposure.

The first hypothesis was supported by student self-reported technical learning, significant improvement in technology component identification, significant increases in understanding of systems engineering concepts, and short answer responses demonstrating the grounding of technology concepts through first-hand experience.

The second hypothesis was supported by outcomes of self-reported confidence gains, an increase of students disagreeing with “I am not good at making robots”, and self-reported increases in student appreciation of the real life applications of technology.

The third hypothesis is still being evaluated and as described in the prior section, will be the subject of future work. Outside of the original hypotheses, we also saw strong self-reported outcomes related to teamwork, which warrant further explicit evaluation and augmentation thorough future program development.

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Virtual Experiments for Introduction of Computing: Using Virtual Reality Technology

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Abstract—Introduction to Computing is a public course for the first-year non-major undergraduate students, aiming at training students for the abilities in computer science and technology with computational thinking. However, as new computer technologies emerge continuously and rapidly, it is required for this course to accommodate more and more knowledge. Therefore the teaching contents are growing enormously, which makes it very difficult to cover all of them in limited hours, and therefore sets an obstacle in understanding computing principles and building up a clear and general picture of computing, especially for non-major students. As computer science and technology are becoming more and more essential for various disciplines and majors, it is urgent for the education community to find out an effective and propagable way to solve this problem. In this regard, we employ virtual reality technology to the experiment teaching of this course, and have developed 18 virtual experiments to support the whole teaching process. For example, Turing machine is a basic model for computer science and technology. However, since it is not a real machine, it is not easy for the students to imagine the working process of Turing machine and understand the related concepts. Another example, the execution of an instruction is very important to understand the principles of computer organization. However, as the information flow is invisible, it is difficult and time-consuming for the teachers to explain how an instruction is executed inside a computer. Therefore, 3D modeling and animation techniques are used to demonstrate the invisible micro-structure of computers, and human-machine interaction and visualization techniques are used to present the internal process of information evolution, thus constructing a complete virtual experiment system of this course, including demonstration experiments, verification experiments and interaction experiments. Our virtual experiments have applied software copyrights and served more than 12,000 students from five universities of China since 2013. The evaluation demonstrates that the virtual experiments have produced excellent results in both teaching effectiveness and learning efficiency, relieved the conflicts between limited hours and vast knowledge, and helped students understand and build up the knowledge of computing.

Keywords—virtual experiments, Introduction to Computing, virtual reality.

I. INTRODUCTION

Introduction to Computing is a public course for the first-year non-major undergraduate students, which has been offered in Chinese universities for more than twenty years. Computing technology has become one of the fastest growing domains since the new century. Though computer science is a discipline itself, it can promote the development of other disciplines, and many challenging and frontier research can be conducted using advanced computing technology [1]. Therefore, the development of various disciplines urgently requires computer science and technology to provide deeper and wider support functionalities.

In 1990s when the idea of information era had just swept across China, the goal of this course is to make students familiar with digital media and information tools, which is essentially culture popularization of computer. However, as the role of computer science and technology has become more and more important in various disciplines, the course of Introduction to Computing is now aiming at training students for the abilities of computational thinking [2], which also brings about the reformation and innovation in the goals, contents and means of teaching.

In the rebuilding of this course, some issues have drawn much attention and lead to comprehensive discussion.

On one hand, the concept of computational thinking proposed by Jeannette M. Wing [2] has been accepted in research and education communities in China, and Guoliang Chen further analyzed the connotation and denotation of computational thinking considering the actual situation of Chinese colleges and universities, and proposed the overall goals of the innovation in computing education [3]. However, it is still ambiguous with respect to how to effectively promote the computational thinking oriented reformation of computing education. For example, large amounts of knowledge are not only the reflection of computing discipline, but also a contradiction with the limited course hours. Therefore, it is very difficult to accommodate all these knowledge by using conventional means of teaching, especially when it comes to the invisible, abstract and complex concepts and principles.

On the other hand, experiments are essential for computing education. However, with respect to this course, the

experiments have been keeping the same since 1990s, which are mainly the usage of system software and application software. Therefore, the experiments of this course are not in the line with its teaching contents, and the lack of effective experiments has hindered the goal of computational thinking. Though it is very urgent and important to establish new experiments that match the goal and contents of this course, it is not easy to keep pace with the rapid changing technologies, which brings about obstacles to the new experiment system.

Aiming at the above problems, we design and implement virtual experiments for the course of Introduction to Computing using visualization and simulation technologies. Virtual experiments [4] and virtual laboratories [5] have drawn increasing attention from education and research communities all over the world.

An important advantage of virtual experiments is that students can conduct experiments on unobservable phenomena [4], [6-9]. In this course, the teaching contents severely involve the evolving process of information such as the data transmission on computer networks and the micro-structure of computers such as the execution of an instruction, which are all invisible and therefore cannot be observed by conventional physical means of experiments. Therefore, we use 3D modeling and animation techniques to demonstrate the invisible micro-structure of computers, and use human-machine interaction and visualization techniques to present the internal process of information evolution.

Besides, virtual experiments offer much higher efficiencies over physical experiments because they typically require less setup time and provide results of lengthy investigations instantaneously [10], which enables more efficient and effective understanding on the important and difficult points. This is very important for the course of Introduction of Computing which has very much knowledge and very limited course hours.

II. DESIGN OF VIRTUAL EXPERIMENTS

The development of computing technology has caused enormous impact on education, especially when it comes to the virtual reality technology, which is greatly changing the ideas and methods of education. Based on the virtual reality technology including visualization, human-machine interaction and simulation, we have designed and implemented the experimental system for the course of Introduction of Computing.

In this course, virtual experiments are beneficial in the following three aspects.

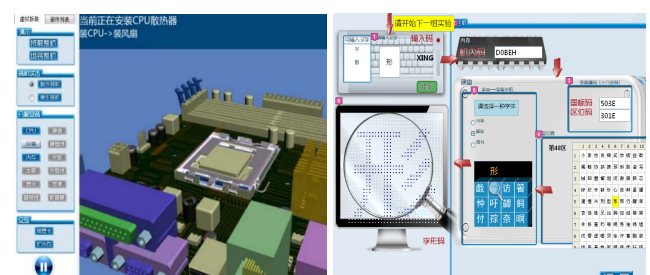
- Describing abstract concepts in the realization of computing.
- Presenting the organization and micro-structure of computers in the working principles of computers.
- Visualization of the unobservable process of the information storage, transmission and processing.

Using the virtual reality technology, 18 virtual experiments including demonstration experiments, verification experiments and interaction experiments are designed and implemented, which are listed in Table I.

TABLE I
LIST OF VIRTUAL EXPERIMENTS

No.	Virtual Experiment	No.	Virtual Experiment
1	Turing machine and virtual assembling of computers	10	Computer animation
2	Representation and calculation of data	11	Word processing
3	Character coding and information processing	12	Data management and data base
4	Execution of a computer instruction	13	Computer based problem solving
5	Process management and virtual machine	14	Execution of an algorithm
6	File management and disc recovery	15	Object oriented approaches
7	Communication in WAN and transmission of emails	16	Simulation and MATLAB
8	Cloud computing and virtual service	17	Computer virus and fire wall
9	Image generation and processing	18	Intelligent optimization

Some examples of the above experiments are shown in Fig. 1. With respect to the invisible process of information evolution, such as the running process of an algorithm, visualization techniques are used to develop verification experiments. With respect to the organization and micro-structure of computers, 3D animation and human-machine interaction techniques are used to develop interaction experiments. With respect to network security such as virus generation, transmission and attack, simulation techniques are used to develop demonstration experiments. Besides, various experiments are also developed to present the concepts and principles in data overflow, file management, process scheduling, network routing, etc., enhancing the understanding of knowledge for the students.



(a) virtual assembling of computers (b) searching for Chinese characters



(c) computer virus (d) ant colony optimization

Fig. 1. Some examples of the virtual experiments

III. CASE STUDIES OF VIRTUAL EXPERIMENTS

A. Experiment 1: Turing Machine

The model proposed by Turing presents the essential concept and principle of computing, and is a milestone for computer science. However, because it is not a real machine but an abstract model, physical experiments can hardly be conducted on Turing machine, which brings about difficulties in understanding such important knowledge.

Computer animation is a method to produce the effect of moving objects using a sequence of static images. In this experiment, 3D animation is applied demonstrate the Turing machine and its working process. The computation of 2^x is used as an example, and the rules, states, inputs and outputs are visualized. The experiment includes four 3D models, i.e., the punched tape, the read/write head, the state storage, and the output device. This universal machine model is put onto the screen, and its working process is demonstrated by 42 seconds of animation, which presents the components of the Turing machine, the input of the punch-tape coding, the states of the read/write head, and the output results. Fig. 2 shows the process of the animation, in which (a), (b) and (c) represent the frames at the 32nd, 34th and 36th second, respectively. The concept and principle of the Turing machine is demonstrated in this experiment, which is beneficial for both learning and teaching.

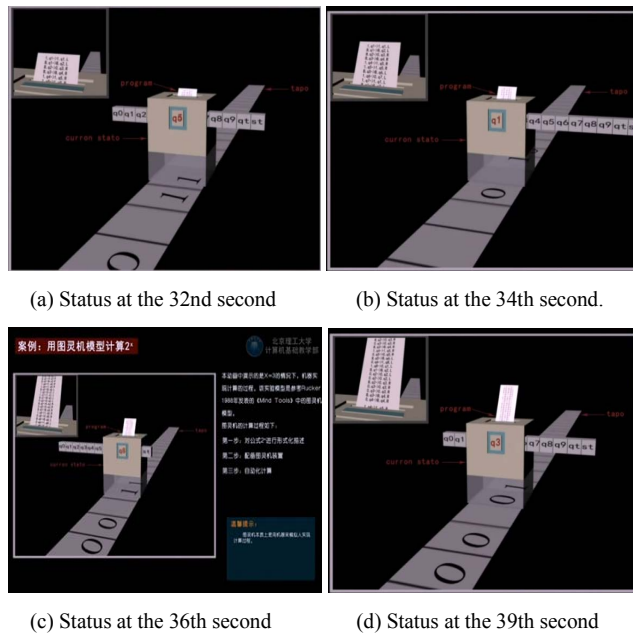


Fig. 2. Working process of the Turing machine

B. Experiment 2: Execution of an Instruction

Even if non-major undergraduate students have the basic idea of 0s and 1s in computers, it is still difficult to perceive the whole process of the capture, transmission, integration, processing, and output of information. This is because the invisibility of the internal micro-structure of computers and the evolution of information. Therefore, interactive experiments are developed to mimic and present the unobservable working

processes.

For example, a computer handles the instructions by repeating instruction fetching, instruction decoding and instruction executing. In order to mimic this process, the interactive experiment, i.e., the execution of an instruction, is designed and implemented, which demonstrates how the components collaborate with each other and how the information flows inside the computer.

The design of this experiment is as follows. Using visualization and human-machine interaction techniques, five stages are incorporated, i.e. interactively specifying the operands, fetching instruction from memory, decoding the instruction, fetching the operands from memory, and executing the instruction. Several important components of the computer, e.g., controller, adder, and storage, are illustrated, and the flow and evolution of the information are visualized. Fig. 3 shows the execution of an instruction, in which decoding and execution of the addition instruction are presented in (a) and (b), respectively.

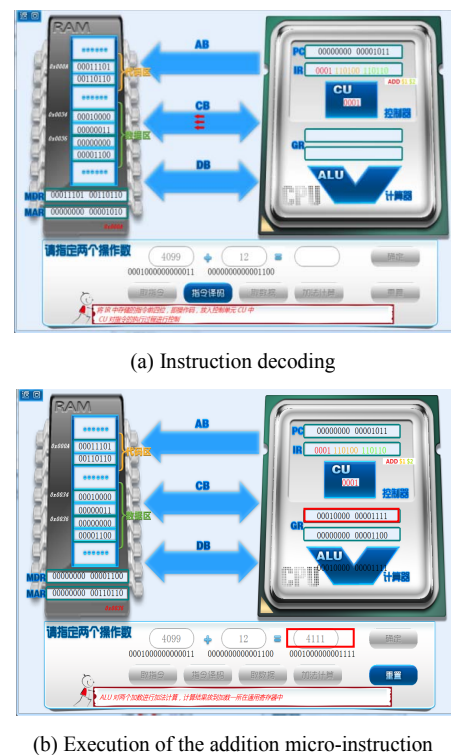


Fig. 3. Emulator for the execution of an instruction

As illustrated by Fig. 3, the interface of the experiment is divided into two main parts. The internal structures of the computer are shown in the upper part, and the human-machine interaction interface is provided in the lower part. The internal structure of the computer mainly includes the RAM and the CPU. Some details such as the sections in the RAM, the ALU and controller of the CPU, are also demonstrated. In addition, the three buses connecting the RAM and the CPU are emphasized, and the information flow can be dynamically displayed during the experiment. For example, Fig. 3(a) shows the decoding stage in the execution of the instruction, when the controlling information flow for instruction decoding is

transmitted on the control bus. Fig. 3(b) shows the status of the ALU and the information flow in the controller when executing the addition instruction.

Since this experiment involves a wide range of information, the experiment report is important for guiding the students to achieve the purpose of this experiment.

The recording sheet of this experiment is shown in Table II.

TABLE II
RECORDING SHEET OF THIS EXPERIMENT

Step 1 Assign two operands	
Question	Result
Operand 1, operand 2	
The address of the instruction in the program counter	
The instruction code at the corresponding instruction address in RAM	
The address of operand 1 in RAM	
The address of operand 2 in RAM	
Step 2: Fetch the instruction	
On which bus does CPU send the memory address to RAM?	
Where is the instruction received from CPU stored in RAM?	
What information is stored in MAR? What is its binary code?	
What is the memory address corresponding to the binary code in MAR? What data is stored at that memory address? Which register is the data stored in?	
What happens to the content in the program counter after it is accessed? Why?	
On which bus does RAM send the data in MDR to CPU?	
Where does CPU store the instruction received from RAM?	
What is the binary code in IR?	
Step 3: Instruction decoding	
What are the memory addresses of the operation code and the two operands in IR, respectively? (Please denote them by six binary numbers and four hexadecimal numbers).	
Where does decoding happen? On which bus does it send the result to RAM?	
Step 4: Fetch operands	
On which bus does CPU send addresses? Where is the address stored in RAM?	
Which register does RAM use to store the first operand? On which bus does RAM send it to CPU?	
Where is the first operand stored in the CPU after it is fetched from the RAM?	
Step 5: Calculate the addition of two operands	
Where does CPU calculate the two operands?	
When the addition is completed, where is the result stored in the CPU?	

IV. APPLICATION RESULTS

We have designed and implemented 18 virtual experiments which have applied software copyrights and served more than 12,000 students from five universities of China since 2013. These students come from more than 60 majors, and the results presented in this section are collected from 1,158 undergraduate students and 40 teachers in Beijing Institute of Technology. Two types of surveys were conducted, one of which was for the students and the other for the teachers.

The feedback from students is shown in Table III. As indicated in Table III, the motivation of study was enormously promoted with the application of virtual experiments, and most students found it easier to learn the knowledge and perform the experiments, and more effective to communicate in the group and with the teachers.

TABLE III
EVALUATION RESULTS FROM STUDENTS

Evaluated Factors	Items in the Factor	Results	Methods
Motivation	Experiment design	87% were interested in the virtual experiments.	Student survey
	Usefulness of experiments	83% found virtual experiments help them understand knowledge.	Student survey
	Grading criteria	75% were satisfied with grading.	Student survey
Knowledge and Experiment Process	Understanding of knowledge	85% found it easier to understand knowledge via virtual experiments.	Student survey
	Performability of experiments	98% completed the virtual experiments.	Student survey
	Setup experiment environments	89% found it easier to setup experiment environments.	Student survey
Collaboration in Teamwork	Teamwork in experiments	83% were satisfied with the shared environments.	Student survey
	Discussion in teamwork	80% found the discussion more effective via virtual experiments.	Student survey
Interaction with Teachers	Effectiveness of interaction	85% found the interaction more effective via virtual experiments.	Student survey

The feedback from teachers is demonstrated in Table IV, which indicated that most teachers found it more efficient and effective in teaching, as compared with the previous semesters without the assist of virtual experiments.

TABLE IV
EVALUATION RESULTS FROM TEACHERS

Evaluated Factors	Items in the Factor	Results	Methods
Efficiency	Knowledge contained	85% included more knowledge in the course.	Teacher survey
	Experiments completed	96% students completed more experiments in unit time.	Checked by teachers
	Preparation of experiments	98% spent less time in preparation of experiments.	Teacher survey
Effectiveness	Explanation of knowledge	85% found it easier to explain knowledge via virtual experiments.	Teacher survey
	Understanding of knowledge	The average scores increased 12%.	Quiz and exams
	Creativity	8% students contributed to the improvements of experiments.	Grading
Interaction with Students	Efficiency of interactions	85% found the interaction more efficient via virtual experiments.	Teacher survey
	Effectiveness of interaction	82% found the interaction more effective via virtual experiments.	Teacher survey

V. CONCLUSION

With the rapid growth of computing technology, various disciplines require computer science and technology to provide more powerful support, resulting in the innovation and reformation of the course of Introduction to Computing. In order to present the unobservable, abstract and complex concepts and principles, virtual experiments were designed and implemented. The application results show that the virtual experiments are beneficial for both learning and teaching.

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A New Signal Processing Course for Digital Culture

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Abstract—Signal processing algorithms, software, and hardware are being used in several fields including non-engineering areas such as arts and media. Students in these fields and particularly in the new Digital Culture major at Arizona State University (ASU) use signal processing tools in several of their projects and artistic endeavors. Yet the blind use of these DSP tools in other disciplines, without understanding their properties has been a long-standing problem. In fact, the broader issue is the disconnect between engineers that develop tools and artists that use them to design the next generation digital art applications. In that context, ASU has formed the Arts Media and Engineering (AME) School and more recently, the multidisciplinary undergraduate Digital Culture degree granting program. In order to provide formal training in signal processing to students that are non-Electrical Engineering majors, we piloted a new course titled Signal Processing for Digital Culture. This course, which is being offered online, teaches non-majors some of the basics of signal processing and covers several applications. The only prerequisite to the course is general sophomore calculus. This new online course contains several topics and is focused on an approach that teaches concepts by connecting theory to compelling applications. Future plans include introducing this course at Clarkson University as a Knowledge Area course open to students from all majors.

Keywords—signal processing, DSP online, digital culture, arts and media

I. INTRODUCTION

DSP systems are being used in many STEM related areas and non-engineering fields such as multimedia, arts, and digital music. There are several students in these fields, and at Arizona State University (ASU) arts students use signal processing software tools such as those embedded in Max/MSP [1] for innovative artistic and music synthesis demonstrations. Despite the high level knowledge of the tools by artists, there is a knowledge gap in using these tools while understanding their capabilities and limitations. For this reason, many undergraduate programs started developing their own signal processing courses by covering topics that are similar to those covered in entry level DSP courses in engineering.

In general, the blind use of DSP tools in other disciplines without appropriate understanding of their properties often produces errors in measurements and in the analysis of signals. For example, many students confuse the spectrum of

Concentrations offered in partnership with other ASU schools

- 43 hours of Digital Culture Core credits
 - 22 Digital Culture Studies
 - 9 Digital Media
 - 6 Digital Culture related courses
 - 6 Capstone
- 30 hours of Concentration credits
- 6 hours of theoretical/historical credits
- 41 hours of general studies credits

Fig. 1. ASU Digital Culture Undergraduate program and its degree concentrations with other disciplines.

the continuous Fourier transform with that obtained by the fast Fourier transform or have trouble differentiating frequency responses of analog systems versus those of digital filters. In general there is a disconnect between engineers that develop tools and artists that use them to design the next generation digital art applications. For this reason, ASU established the Arts Media and Engineering (AME) School and in 2012, the multidisciplinary undergraduate Digital Culture degree granting program (Fig. 1). These programs help create a workforce for several application areas such as interactive gaming, smart stages, digital music synthesis, environmental sound rendering and other applications.

The degree is flexible with many elective courses including Signal Processing for digital culture (EEE 394). This course was developed in Electrical Engineering for non-EE majors. This is being offered online and covers the basics of signal processing along with several applications. The only prerequisite to the course is general sophomore calculus. This new online course contains several topics and is focused on an approach that teaches concepts by covering popular applications. For example, we cover Fourier series and Fourier transform concepts by looking at spectra and harmonics in music signals. We cover filtering by looking at how linear systems are used in compression algorithms in cell phones and MP3 players such as iPods. We will develop computing modules for capturing and interpreting sensor data. Several other DSP concepts and applications are covered at the block diagram level with MATLAB software code

examples and object oriented programming simulations running on tablets and laptops.

Future plans include introducing this course as a knowledge area course at Clarkson University. Knowledge area courses are open to students from all majors. This course will be used to introduce digital signal processing concepts to students in non-Electrical Engineering majors.

We will assess the class with concept quizzes, student interviews and course evaluations. In the sections that follow, we present more details on new materials, content and software modules created for the course.

II. THE SIGNAL PROCESSING FOR DIGITAL CULTURE COURSE

In terms of proficiencies, the EEE 394 Signal Processing for digital culture course is described as follows:

Incoming proficiencies include: Basic Freshman Algebra 100, Basic sophomore Calculus, and Basic Sophomore Computational Tools. The above are prerequisites for the Signal processing for digital culture course. Outgoing Proficiencies include: Junior level Calculus, Computational Tools, Sensors and Signals, System Design/Development.

This signal processing class is for students in non-engineering majors. The course involves qualitative and quantitative descriptions of DSP algorithms, software and applications. Applications covered in the class include those in the arts, music, computing, engineering, financials, and biomedical areas. MATLAB and Java simulations are used to support the DSP concepts taught in the class. Code for all applications and examples will be given to all students. Outcomes include the following:

- The course will enable students to understand simple filtering and signal analysis algorithms and their applications; and
- The course provides skill-building experiences in terms of enabling students to express simple algorithms in MATLAB and Java-DSP.

The course includes the following topics:

Introduction to DSP, History and Applications; Sinusoids and Tones, Frequencies and Spectral Representations; Adding Tones and Superposition; Time shift and phase; Magnitude and phase representations of signals; Periodic Signals, Harmonics and their relation to Music and Vibration; Time-Varying Sinusoids and their Applications; Fourier Series Representations and Applications, Sampling and Aliasing; Oversampling, Digital to Analog (D-to-A) Conversion; Applications to Music and Other Signals; Sampling Rate Standards and Conversions; Sampling and Aliasing software demos; Simple Analog Filters and Frequency Responses, Digital Filters, Frequency Response of FIR and IIR filters, Special Filters for Music and other Applications; Audio Effects, Echo, Reverberation, Vocoder, distortion; Filters for Noise Reduction and Enhancement; Filters programmed as

Oscillators for Tone Synthesis; Examples of Filters for Images; Oscillators and Dual Tone Synthesis, Superposition, Linearity and Convolution; z -transform and transfer functions, Poles and zeros, Frequency Response, Stability; Introduction to Quantization; Applications of Filters in Signal Compression and Cell Phones [2]; Applications of Filters in Audio Compression (Algorithms in the iPod); filterbanks and applications to MP3 [3] and AAC; Psychoacoustics; Continuous and Discrete-time Fourier Transforms; the FFT and the frequency spectrum; applications of FFT in Communications (OFDM [4] and Wi-Fi), applications of FFT in music synthesis and transformations, modulation with the Fourier transform and the FFT; 2-D filters and transforms, JPEG, and MPEG; other applications in the medical, military and arts areas including applications of DSP in Stock Forecasting, DNA analysis [5], DSP and Solar Power monitoring [6], Biomedical applications, and sensors and health monitoring.

III. SOFTWARE DEMONSTRATIONS, LABORATORIES AND COMPUTER PROJECTS

The course uses five different platforms for computer exercises and software demonstrations, including mobile devices [1,7-15]. These are: MATLAB, LabVIEW, Java-DSP [11-13], iOS JDSP [10], and Android JDSP [14,15].

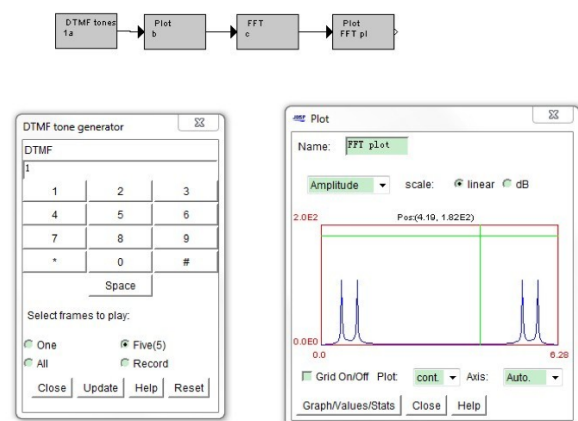


Fig. 2. DTMF demonstration of dual tones and FFT spectrum in Java-DSP (J-DSP).

The course provides several demonstrations in Java-DSP such as the one shown in Fig. 2, where the utility of IIR filters operating as digital oscillators is demonstrated. The simulation also demonstrates the application of the FFT in measuring the frequencies and identifying the digits. This is also assigned as a MATLAB exercise where the students program both the oscillators and the FFT and make measurements.

Another demonstration and homework exercise is developed in MATLAB where students are asked to configure a filter to create an echo effect as shown in Fig. 3.

Students also use the iOS and Android versions of J-DSP to associate MIDI sounds with sine waves and spectra. They are also assigned exercises to synthesize a song using MATLAB. In the class, students learn how to use spectrograms to assess

time-varying spectra of voice and different sounds. Fig. 4 shows the spectrogram of synthesized speech on an iOS device.

$$x(n) + b_2x(n - L) = y(n)$$

```
clc
clear all;
x = wavread('cleanspeech');
L=10; % L=100, 500, 1000, 2000
b=[1,zeros(L,1)',0.8];
y=filter(b,1,x);
sound(y)
```

Fig. 3. FIR filter configured to produce an echo effect with a sound file. MATLAB is used by students to program and evaluate echo effects for different delays.

IV. COMPUTER PROJECTS IN MATLAB

For skill building and programming experiences we provide a more comprehensive MATLAB programming experience where students are asked to program and simulate a music morphing function that makes use of the FFT. Through this exercise, students build theoretical knowledge on sound morphing and vocoding (Fig. 5), and also understand the use of FFT magnitude and phase. Segmentation of sound using windows (Fig. 6 and Fig. 7) in MATLAB, and frame-by-frame processing also helps them understand how sound is processed in DSP systems [16-18]. Issues of non-stationarity of signals also are part of this exercise.

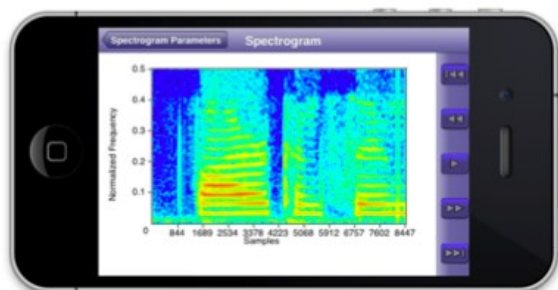


Fig. 4. Time-Frequency Fourier spectra of speech using the spectrogram on the iPhone. The function is also available in J-DSP and MATLAB.

V. PRELIMINARY ASSESSMENT

The class has been received well by students. Some of the students had difficulties in the beginning with understanding the mathematics of signal processing but noted that the block diagram approach of the J-DSP was very helpful. Students also had some difficulties getting comfortable with frame-by-frame programming in MATLAB and manipulating sound files. The online format of the class was also difficult for the students. This semester we are offering the class in a hybrid format where a once a week meeting is required for problem solving and Q&A sessions.

VI. CONCLUDING REMARKS

A signal processing class for digital culture was developed for online delivery. The class is intended for artists but will soon also be offered to non-majors in other disciplines. Some programming and mathematical difficulties emerged in the beginning of the course.

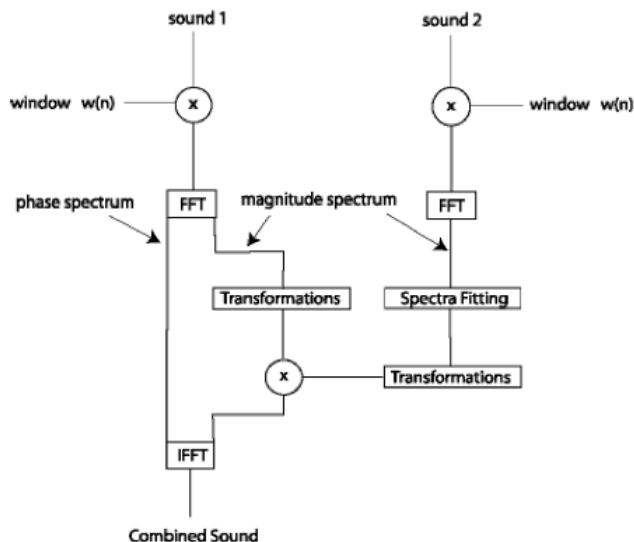


Fig. 5. Sound morphing using the FFT. Students learn how to program frame-by-frame processing and sound synthesis as well as the importance of magnitude and phase in vocoding.

As students became more comfortable with programming, block diagrams, and notations, some of these difficulties were overcome. The course is taught at a high level by connecting theory and applications and using block diagram programming to transfer concepts to students.

An additional problem was the need of a customized textbook for this type of course. Signal Processing First [18] was used, which worked very well for the STEM students in the class.

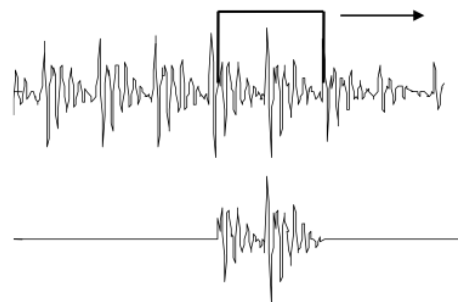


Fig. 6. Segmentation of speech signals using a rectangular window. Students learn how to develop MATLAB software for frame-by-frame processing and reconstruction. The framing is part of the sound morphing and other projects.

In future semesters, this course will be introduced as a junior-level knowledge area course at Clarkson University. This course will be used to introduce digital signal processing concepts to students in non-Electrical Engineering majors.

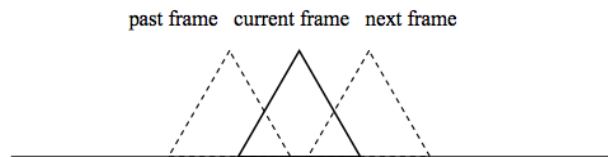


Fig. 7. Overlapped frames using triangular windows to combat discontinuities and jitter noise in sound reconstruction. Students are taught how to program overlapping frames and use overlap-and-add to reconstruct sound signals.

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An Approach to Improving Student Learning of Civil Engineering Concepts Using Case Studies

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Abstract—Engineering educators, professional organizations and practitioner have long recognized the benefits of integrating engineering case studies, especially failures into the civil engineering curriculum. One key benefit is that it provides a pedagogical tool that encourages students to address the complex challenges faced by engineers in the real world. The Civil Engineering Faculty at the United States Coast Guard Academy has successfully integrated case studies in several undergraduate courses to reinforce technical concepts. Case studies provided opportunities for discussion of engineering principles and concepts as well as fostering professional development in ethics and life-long learning. This paper discusses the implementation of case studies and the benefits to student learning especially in identifying problems and developing alternative solutions. Assessment data indicate that the use of case studies enhanced students' learning of engineering principles and improved their understanding of the problem-solving process.

Keywords—Case Study, Assessment, Student Learning, Bloom's Taxonomy

I. INTRODUCTION

A vast amount of published literature emphasizes that learning and retention are enhanced by engaging students in real project activities which simulate the actual work environment. Engineering educators have tried various learning paradigms such as: *case studies, project-based learning, interactive learning, active learning, role playing, flipped classroom and computer simulations*. These activities, complement the traditional classroom lecturing and are used by engineering educators to achieve a higher level of learning based on the six levels of cognitive domain in either the original Bloom's Taxonomy [1] or the Revised Bloom's Taxonomy [2]. The revised levels of learning (lowest to highest) include: (1) remembering (knowledge), (2) understanding (comprehension), (3) applying (application), (4) analyzing (analysis), (5) evaluating (synthesis), and (6) creating (evaluation). Educators have used Bloom's Taxonomy of learning to measure the student's level of understanding, evaluating, and creating engineering solutions.

Several engineering educators have tried to infuse case studies in the civil engineering curriculum or establish standalone case study courses. For example, Akili [3] described the steps taken in planning, developing, and

executing a case study or case history course in geotechnical/foundation engineering at Iowa State University. This course focused on cases that demonstrated the geotechnical practices in the region, pedagogies of engaging students in a collaborative learning environment, and allowing students to develop effective communication skills. Students in this course were required to be an active participant in the group and open class discussions. Cases were normally used to extend the learning experience beyond the traditional classroom activities. The case studies used in this course were related to real world issues that exposed students to the analysis and decisions encountered by practicing engineers.

Delatte, et al. [4] reported the results of various pilot studies that were performed over several semesters to assess the use of failure case studies in the civil engineering curriculum at Cleveland State University (CSU). Student learning through failure case studies was assessed through homework questions, exam questions, surveys, and focus groups. Students commented during the focus groups that the cases helped them make the link between theory and practice. It also helped build engineering identity and it demonstrated the relevance of the technical information presented in engineering courses to the real world. This project extended the work of implementing and assessing case studies at CSU to thirteen other participating universities. A number of educational resources including a website were developed to provide easy access to engineering students, educators, and practicing engineers.

Dai, et al. [5] introduced a case study undergraduate course in the civil engineering program at the Tongji University, China, to enhance learning and make the shift from deductive teaching model to inductive instructional strategies. The course was designed to facilitate the use of laboratory testing equipment as part of the case study investigations. Typical failure cases were obtained from the recent Wenchuan earthquake in China in order to prepare students to assimilate the post-disaster field investigation of failure modes. Students were taught the basic principles of seismic design and the practical engineer's responsibilities to the general public during the lectures. The case studies were used to involve students in seismic design, improve advance knowledge and

comprehension, and promote the professional and ethical responsibilities.

Similar attempts to enhance student learning and understanding of engineering principles are in progress at the United States Coast Guard Academy (USCGA) by integrating case studies into the curriculum. Solutions to real-world engineering problems are more complex and they require engineers to address various issues such as uncertainties, technical and nontechnical constraints, political, cultural, economics, communications, and the consideration of alternatives. One of the objectives of integrating case studies into the curriculum is to simulate these real-world scenarios. This paper is a work-in-progress and focuses on how case studies continue to be incorporated in several civil engineering courses at the USCGA. The emphasis of this paper is on three senior level courses that use case studies to tie together technical aspects, ethical issues, procedural issues, and to engage students at a higher level of thinking and learning.

II. CASE STUDIES IN CIVIL ENGINEERING CURRICULUM AT USCGA

The Civil Engineering Faculty at USCGA has successfully integrated case studies in several upper level undergraduate courses. These cases were used to reinforce technical concepts while providing an opportunity for discussion of engineering principles as well as fostering professional development in ethics and life-long learning. In this approach, case histories that tie together technical aspects, ethical and professional issues are identified and selected. These cases require students to synthesize or evaluate the technical and non-technical issues as compared with the concepts and principles they have learned in their engineering and general education in humanities and science courses.

This paper focuses on the implementation of case studies in two required senior design courses, *Geotechnical Engineering Design* and *Reinforced Concrete Design*, and in an elective course, *Water Resource Engineering*. As part of the ABET requirement of depth and breadth in four civil engineering sub-disciplines, the *Geotechnical Engineering Design* course was introduced into the civil engineering curriculum at USCGA in 2009 as a graduation requirement. The course is purely project-based with open ended problems that require students to make decisions and develop alternatives, similar to what is expected in actual engineering practice. By balancing the need for fundamental engineering instruction with that of cooperative learning, the development of problem-solving skills required for engineering practice is promoted in this course. The case studies used do not only involve design, construction but also legislative disputes to simulate real-life engineering practice.

The *Reinforced Concrete Design* course has been a traditional required course where students learn about the basic analysis and design of beams and columns, floor slab design, serviceability, and shallow foundation design. The course incorporates unique requirements of various team projects that

include: EXCEL programming projects; and the analysis, design, construction, and testing of full-scale reinforced concrete beams. Recently, the course was modified to include case studies and a multi-step design project that require students to analyze and design key components of a multi-story building. The new building design project was developed and coordinated with two other courses in order to simulate real-world projects. The addition of case studies and multistory building project was essential to transition the course to project-based learning and to advance student comprehension of reinforced concrete design. Several case studies have been identified from the published literature and strategically introduced throughout the semester. Case studies are used to either introduce a new topic in the course or highlight critical design and construction practices that should be considered during the design process. The case studies enhanced the classroom environment by engaging students in the discussion of what went wrong and what to do in avoiding similar mistakes when designing key components in a structure.

The *Water Resources Engineering* course was first offered in the Spring of 2014 as an elective course in the civil engineering curriculum. This course offers a basic introduction to the field of Water Resources Engineering. The goal is to expose civil engineers to a broad range of topics relevant to the field of water resources. Course topics include surface and groundwater hydrology, rainfall-runoff analysis, reservoir and river routing, probability and frequency analysis, computer modeling, water excess management/control, and watershed management. Case studies are used in this course to expose students to issues surrounding water resources and to challenge them to realize that engineering decisions are not solely based on hand calculations or computer simulation.

In general, case studies were used in these three upper level courses to enhance the learning experience beyond the traditional classroom activities and expose students to the analysis and decisions encountered by practicing engineers. The case studies provided background for specific topic (module), served as materials for problem formulation and identification, and served as illustrations for examples of engineering concepts and principles covered in these courses. The case studies tie together technical aspects, ethical issues, procedural issues, and help students engage in a higher level of thinking to synthesize and evaluate relevant concepts. The case studies were used strategically throughout the semester to provide students with an opportunity to make the connection between theory and real-life applications, as well as to generate interest in open discussion of engineering problems.

Suitable case studies were extracted from the following widely published resources: archives of the *Association of Engineering Firms Practicing in the Geosciences* [6], Delatte [7], Kaminetzky [8], Watkins [9], Johnson et al. [10], Gleick [11], and Rouge River project [12]. Examples of the case studies students received a week ahead of time in the three courses are summarized in Table 1.

TABLE I. EXAMPLES OF CASE STUDIES

Case Study	Problem Description/Statement	Learning Objective
Geotechnical Engineering Design		
Case 1: University building expansion, NJ	Dewatering and excavation support. Several challenges including underground utilities and limited access.	Addressing construction management issue and selection of suitable equipment.
Case 3: Leaning tower of Pisa, Italy	Inadequate soil investigation, effects of differential settlement, selection of suitable soil improvement & stabilization techniques.	Understanding of soil-structure interaction, importance of thorough site investigation and selection of suitable foundation system.
Case 4: Schoharie Creek Bridge failure, NY	Scour, inadequate bridge inspection and maintenance.	Importance of investigation and proper maintenance of bridges. Importance of understanding hydraulic forces on foundations.
Reinforced Concrete Design		
Cocoa Beach five-story cast-in-place concrete building collapse, FL	Inadequate design, poor construction, and quality control.	Addressing key construction issues including severe cracking and excessive deflection, proper rebar placements, punching shear strength, and lack of formwork design.
Skyline Center at Bailey's Crossroad high rise concrete building, VA	Catastrophic collapse of a high rise building due to quality control and lack of formwork plan.	Importance of proper quality control related to punching shear, formwork (shoring and re-shoring slabs), and ensure proper concrete strength before formwork removal.
Water Resources Engineering		
Flood control reservoir operation during the Great Midwest Flood of 1993	Following the Great Midwest Flood of 1993, concern was voiced that the US Army Corps of Engineers did not operate flood control reservoirs in an optimal manner therefore contributed to the damage.	Understand reservoir operating plans particularly for flood control; evaluate (in hindsight) the effectiveness of reservoir operations during an extreme flood event.
Combined Sewer Outflow (CSO) Case study	In the Rouge River Watershed, MI, water quality was improved through CSO reduction.	Practical understanding of how CSOs are reduced and further explanation of the detrimental effects of CSOs.
Three Gorges Dam China	Case study provides an overview of challenges and decisions that were faced during construction.	Understand the complexity of the decisions that had to be made during the construction of this dam
Watershed Management on Groundwater and Irrigation Potential in India	An increase in population has led to increased water demand for irrigation and agricultural purposes in semi-arid and rural areas of India.	Understand the impact of watershed management on the ground water and irrigation potential of a watershed facing drought like conditions.

Students were required to review each case and address key aspects on a template before class discussions. The grading rubric template provided students with guidelines of the following key aspects that must be considered while reviewing each case study:

1. *Review the case content* – Students were required to provide a 2-4 sentence summary on the case or “bird’s eye view” of the case. Key questions that must be addressed include: What is going on in the case? What are the facts of this case?
2. *Identification of the problem* – Students were required to identify the key issues of the case and develop a problem statement.
3. *Collection of relevant information* – In general, no additional literature review or search for new information is formally required. However, students are expected to make the connection with already acquired knowledge and evaluate if any additional information is required to fully assess the case. In a few of these cases, instructors purposefully withheld key information to get students more engaged in this step.
4. *Development of alternatives* – Students were encouraged to come up with alternative ways of solving the problem. Open classroom discussions facilitate the exchange of

ideas and students are encouraged to question the validity of each proposed solution.

5. *Selection of a course of action* – Having completed the first four steps, students are then encouraged to identify suitable approaches or solutions they think is most appropriate to address the issues based on the available information. Basically students are asked to select or identify the most appropriate course of action to resolve the problem. The cases presented may not have a straight forward solution.
6. *Recommendation of an implementation plan* – If a solution can be identified, students are required to proposed some form of implementation plan that may need to address any constraint defined in the problem statement.

III. ASSESSMENT

The template described above was used in the three courses as a standard grading rubric. Sample performances on case study 1 and 4 (see Table 1) used in the *Geotechnical Engineering* course are shown in Figures 1 and 2. In the figures, “Exceeds,” “Meets” and “Below” represent scores of at least 90%, 70%-89%, and less than 70%, respectively. General guidelines were given at the beginning of the semester with more discussions and emphasis followed based on student performance after submitting their analysis of each case. For example, Figure 1 indicates that most of the students adhered to the template guidelines and showed good understanding of the concepts. Performance was fairly good on most components of the rubric. However, 55% and 67% of students performed poorly on “problem statement” and “alternative solutions”, respectively on the first case study presented in the *Geotechnical Engineering Design* course. Therefore, more emphasis and guidance were provided on the subsequent case studies and this resulted in modest improvement in student performance on case study 4 as shown in Figure 2.

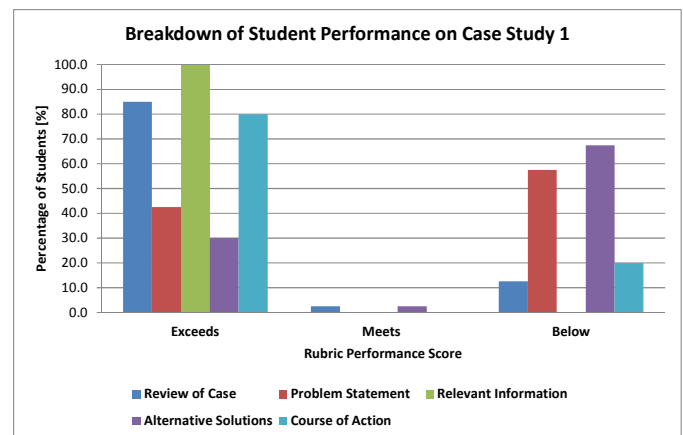


Fig. 1. Student performance geotechnical engineering case study 1

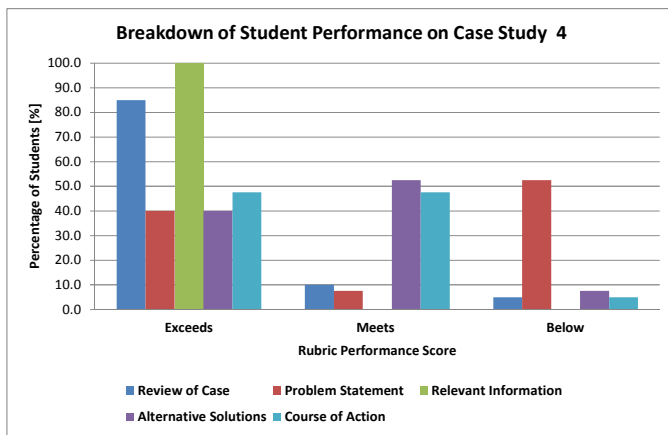


Fig. 2. Student performance geotechnical engineering case study 4

In general, students struggled to adequately identify and develop problem statement and 50% of the students still performed below expectation in case study 4. The faculty is investigating suitable approaches to expose students to more opportunities of developing problem statement to enhance their understanding in this area.

Similar trends in student performance shown in Figures 1 and 2 were also observed in the *Reinforced Concrete Design* and *Water Resource Engineering* courses. Overall student performances in the three courses for the graduating class of 2015 are presented in Figure 3. The figure represents average overall student grades on four case studies in each course. Most students are either meeting or exceed expectations. The *Geotechnical Engineering Design* and *Reinforced Concrete Design* courses are both offered in the fall semester. Both courses are design-focused with a common semester project that further exposes students to high levels of critical thinking. The *Water Resource Engineering* course is offered in the spring semester as an elective. The grading rubric is under continuous review based on the feedback received from students and faculty experience during each semester.

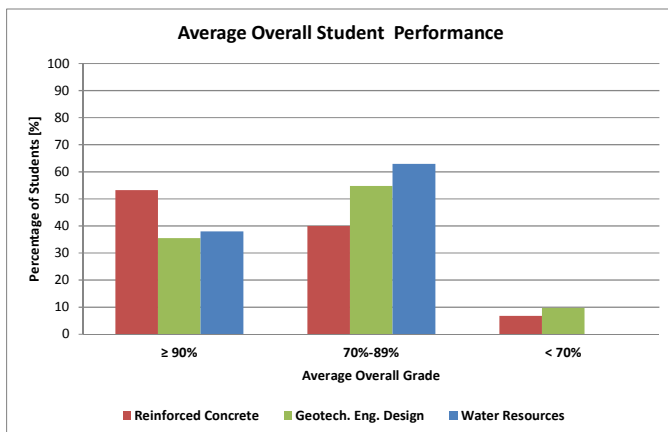


Fig. 3. Average Overall student grades for the Class of 2015

In addition to the graded assignments, student feedback was collected using in-class surveys. The focus of the survey was to have students self-assess their understanding of the principles and provide feedback on the effectiveness of the instructional method in meeting the course objectives. Students commented that project-based learning and the use of case studies improved their learning and comprehension. It also enhanced their ability to make the connection between theory and practical applications. They felt better prepared to complete their capstone design project and ready to work as civil engineers.

IV. CONCLUSIONS

The Civil Engineering Faculty at USCGA has successfully integrated case studies in several undergraduate courses. This paper focused on the implementation of case studies in two required senior level courses, *Geotechnical Engineering Design* and *Reinforced Concrete Design*, and in an elective course, *Water Resources Engineering*. The selected cases were used to reinforce technical concepts while providing an opportunity for discussion of engineering principles as well as fostering professional development in ethics and life-long learning. Using case studies or project-based learning as an active learning methodologies are powerful tools educators can use to engage students in the learning process and help students make the connection between theory and practice. In general, students exposed to case studies and project-based activities achieve a higher level of learning through this exposure to real-world problems. It was also observed at the United States Coast Guard Academy that Students who experienced this process during the fall semester performed better on their capstone projects in the spring semester. It is anticipated that in the future, case studies will also be introduced in some lower level courses. This will enable faculty to monitor any progressive changes in students' learning and professional skills resulting from the use of case studies throughout the Civil Engineering curriculum. With more targeted assessment data, faculty will be able to make continuous improvements to the program. The goal is to progressively infuse case studies and design throughout the four year Civil Engineering curriculum.

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A Project Component in a Web Engineering Course

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Abstract—Web applications are an extremely important and ubiquitous part of today's world. Students must not only know how to develop them from a technical perspective, but in doing so need to understand how to follow the proper principles of software engineering - delivering the project on time, on budget, and in a high quality manner.

At the Department of Software Engineering at the Rochester Institute of Technology, we offer a Web Engineering course which not only introduces students to a variety of web technologies, but more importantly it shows them how to use them in a collaborative environment while properly utilizing web engineering methodologies. The course includes a significant project component requiring students to use a variety of contemporary technologies and resources to create a robust web application. The main premise of the project is for each group to create a web portal using both custom-built and already existing components. The project takes place over the entire 15 week course term, includes multiple releases, and has students work in teams of 4-5.

This innovative project component has received significant praise from both students and faculty members while fulfilling an emerging area of our curriculum. Students enjoy the real-world nature of the project and the ability to work with contemporary technologies in a format which closely mimics what they will see in industry. This paper outlines the educational objectives, project details, some sample project results of our class offering, as well as student feedback about the project. The goal of this work is to share the project, its importance, and lessons learned for use at other institutions with similar educational goals.

Keywords—Web Engineering, Software Engineering, Computing Education

I. INTRODUCTION

Creating high quality web applications on time and on budget can be in many ways more difficult than traditional application development. Developers must not only master web development technologies, but different methodologies as well. Web-deployed development is likely to have a significantly higher amount of all three types of maintenance (corrective, adaptive, and perfective) by its very nature; evolvability and ease of deployment are a major reason why it is so popular. In addition to focusing on maintainability, developers need to balance the concepts of uptime, security, worldwide availability, and accessibility with a torrent of different browsers, devices, and screen resolutions currently in use and in the development pipeline.

Web engineering is defined as the systematic, disciplined, and quantifiable approach to development, operation, and maintenance of web-based systems and applications [13], [18], [20]. While similar to software engineering, the concept of web engineering differs in several key areas [6]. A higher emphasis is placed on growth and change, compressed

schedules, performance criticality, and small teams working on very short schedules [5]. While many institutions offer classes directed towards developing web applications or software engineering, very few offer courses in web engineering - the successful combination of the two concepts [1], [2]. Because of the critical elements described above, the application of engineering principles to this particular type of development is critical.

At the Department of Software Engineering at the Rochester Institute of Technology (RIT), we offer a Web Engineering course to help meet the demands that students would face when tasked with creating web applications. The purpose of this course is to instruct students in using proper web engineering principles and to allow them to practice doing so with a prominent course project. This project component includes teams of 3-5 students, runs the entire (15 week) semester, and involves creating a web application in multiple iterations using a variety of contemporary technologies and resources.

The goals of the project are to reinforce course concepts, allow students to gain experience creating web applications, and the application of web engineering concepts. Secondary goals include reinforcement of in a team skills and the opportunity to use current technologies. Student teams are expected to fulfill all steps of the software development lifecycle including the successful creation of all necessary requirement, design, test, and deployment artifacts, and development of the product using proper web engineering principles. This project has proven to be invaluable at reinforcing academic concepts discussed in the classroom as well as providing an enjoyable real-world experience for the students.

The rest of the paper is organized as follows: Section III describes the course including learning objectives. Section IV provides an overview of the project detailing requirements, deliverables and evaluation methods. Section V relates a sample project and some student feedback. Section II presents some related works. Section VI describes challenges and future work, and Section VII concludes the paper with a summary.

II. RELATED WORK

While several institutions offer courses in web engineering [1], [2], we are not aware of any which use a project component such as the one we present. Preston [17] discussed the importance of using real-world projects similar to ours in computing courses and found that through practical project applications, classroom principles were significantly solidified for the students. Several other works have discussed their success in using real-world projects in computing engineering courses as well [10], [11], [15].

TABLE I. WEEKLY TOPICS & PROJECT DELIVERABLES

Week	Classroom Topics	Project Deliverables	Project Point Total
1	Course Introduction, Introduction to Web Engineering	Team Formation	0%
2	Introduction to Web Development Technologies		
3	Javascript, JQuery	Requirements Documents	10
4	Web Services		
5	Web Testing	Design Documents, Test Plan	10
6	Exam, Twitter Bootstrap	Beta Release	3
7	R1 Presentations	Release 1 (R1)	20
8	Introduction to Databases	R1 Post Mortem	4
9	HTML5		
10	Security - Abuse & Misuse, Threat Modeling		
11	R2 Presentations, Security - Defensive Coding, SQL Injection	R2	20
12	Exam, Usability in Web Applications	R2 Post Mortem	4
13	Analysis of Web Traffic		
14	Emerging Web Technologies		
15	R3 Presentations, Final Exam	Presentation, R3, R3 Post Mortem	5, 20, 4

Van der Duim et al. [22] spoke about the “Free Riders” problem where some students working on teams do not contribute as much as their peers. Students reported several reasons for free riding including lack of project interest, lack of social skills, and overall course workload. Other works have also reporting similar problems for software engineering projects [9], [19].

Deshpande et al. [5] described the concept of web engineering, why it is needed, how the concepts helps improve web application development, and how it should be incorporated into education and training. The work argued that while software engineering was relevant to conventional application development, web engineering was needed for web application development due to the differences in testing, development, and maintenance. Ginige [6] discussed many of the failures in the development of web applications and also argued for more of a web engineering approach when developing web applications. More recent works have begun to extend web engineering into more specific focuses, such as security [3].

III. ABOUT THE COURSE

The Web Engineering course has been offered at RIT for three years, with the primary goal being to instruct students in how to properly apply software engineering principles to the creation of web applications. A 300-level course, and typically taken by upper-division students in sections of 25-30, approximately 130 students have taken the course so far. While this is an engineering and not a programming course, specific technologies such as .NET¹ and jQuery² are discussed and concepts such as web services and security are covered. Students are primarily evaluated on their comprehension of engineering principles and not specific technologies or programming abilities.

The students taking the course are typically upper-level Software Engineering students and have a reasonably high level of development experience. A good portion of the students are very experienced with web development - having gained expertise either through personal projects or internships. Typically one third have extensive experience, one third have some experience, and the remaining third have little or no exposure. Exams and homework are two thirds of the final grade, and the project is one third. Prerequisites include Introduction

to Software Engineering, Personal Software Engineering, and some basic programming courses.

Some of the biggest areas of emphasis include customer elicitation skills, requirements documentation, and acceptance testing within the context of web engineering. The weekly topics, project deliverables, and suggested project point totals of the course are shown in Table I; further details may be found on the course website³. Instructors are encouraged to deviate from our course plan as they see fit and as new technologies and concepts become prominent.

IV. ABOUT THE PROJECT

A group project is an important aspect of the course; research has found projects to be extremely beneficial to student learning [4], [7], [20]. The project lasts the entire term of the course (15 weeks), and has student teams creating deliverables throughout. Team size is targeted to 3-5 students, as this is often the size of groups in industry and has been found to be conducive to student learning in previous research [7], [16]. For simplicity and student support purposes, a web technology platform should be chosen by the instructor. For the last three years, we have chosen the Microsoft .NET framework as the core of the project, although we expect other institutions to select the technology based upon preference and student competency.

The main premise of the project is for each group to create a web portal using both custom-built and already existing components. This is accomplished through web service and Application Programming Interface (API) calls, with possible sources including Google's, FaceBook's, and Yahoo's APIs.

A. Project Requirements

When crafting the course project, several considerations were at hand. First, we wanted it to represent a real-world product, using-real world technologies. This is important since the goal of the project is to emulate what the students would see in their careers after college. Additionally realistic development goals help to further challenge and encourage students [8], [12], [20]–[22]. Second we wanted to foster student interest in the project. Developing a solution using APIs from well-known and respected companies proved exciting to the students. This

¹<http://microsoft.com/net>

²<http://jquery.com/>

³<http://www.se.rit.edu/~swen-344/>

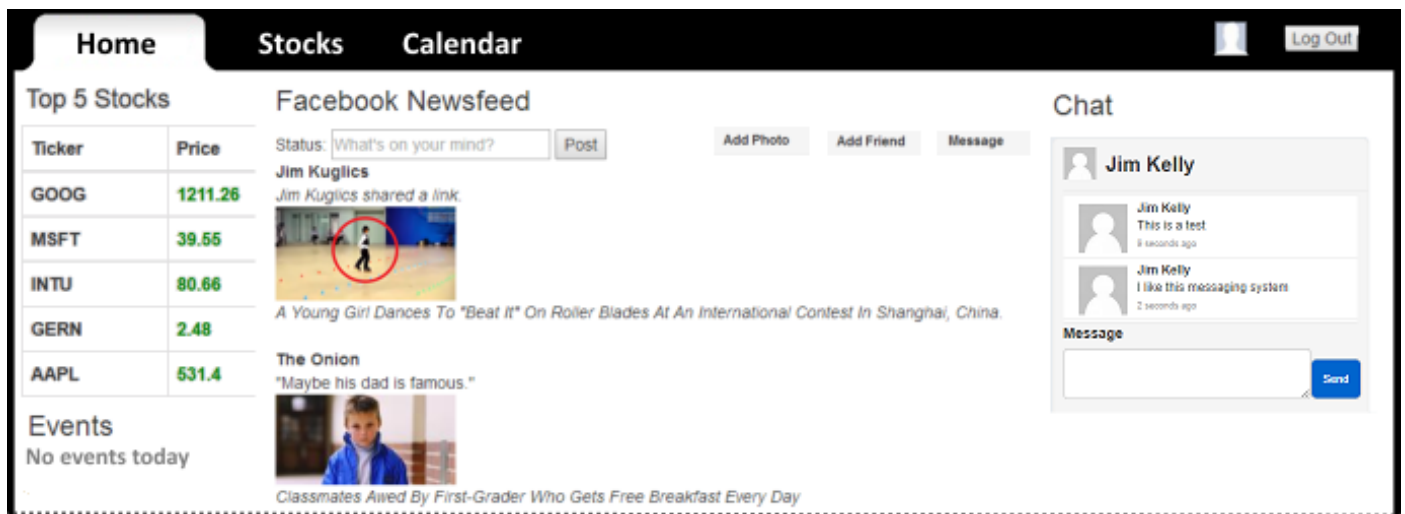


Fig. 1. A Sample Completed Student Project

enthusiasm has helped them to remain focused and drive their desire to learn and apply ingenuity.

The instructor takes on two distinct roles for the project: teacher and customer. The way the customer reacts to student questions significantly differs depending on what role the instructor is currently playing. While representing the role of teacher, the instructor gives project advice and answers technical questions whenever possible. As the customer, an attempt is made to mimic a client in the real world, and students are encouraged to clarify requirements as such. So that students may understand which role the instructor is playing, they are encouraged to ask whenever they are unsure and begin their statements with “As the customer” or “As the teacher.”

The goal of the project is to create a personalized web portal that would be customized for each user. We choose to require that the user be able login with their Facebook account, as Students of the millennial generation have been found to be more engaged with programming projects that have social relevance [14]. Once the user has logged into the application, they are to be exposed to several pieces of personal, customizable information. Perhaps the most significant is an area on the main page which is very similar to the wall in the traditional Facebook application. For this section, students are asked to again tie into the Facebook API to retrieve the necessary data. They are required to modify the appearance of these items and apply aspects of usability covered in the course. Various other Facebook APIs such as photo albums, chatting with friends, and status updates were used in similar ways.

In addition to the relatively simple API interaction, the students are also required to write custom software that has its own functionality and also interacts with external data services or feeds. One example is a simple stock/share price module requiring the user to enter a stock that they have fictitiously purchased along with the purchase price and number of shares. This information is to be stored in a student created MS-SQL database and information such as the current share price is to be retrieved from a third party web service (i.e. Markit

On Demand⁴ or Yahoo⁵). The student’s page is expected to display the current stock price, the day’s high and low price, and the amount of money the investment has made or lost for the user so far. A chart is also to be displayed for the stock, retrieved using an external feed of the group’s choice. Other potential aspects of the application include a weather-based component and a chat feature. The development cycle has a secondary goal of familiarizing students with HTML5, javascript, database design, and the use of libraries such as Twitter Bootstrap⁶ and jQuery. A sample end-result screenshot is shown in Figure 1.

Teams are also expected to write their code in a clean manner while using a version control system of their choice, such as Git⁷. Since teams are to produce multiple releases, each team is provided with a Windows Server virtual machine to deploy their project to, and are expected to produce and adhere to a robust deployment strategy. Finally, teams are required to use proper defensive coding practices to protect against SQL injection and cross-site scripting attacks. Instructors may choose to place more emphasis on specific aspects such as usability, security, testing, etc.

B. Weekly Actions & Deliverables

In order to mimic the iterative nature of typical web application development cycles, we require teams to submit multiple project releases. These submissions also serve to reinforce the importance of maintainability and extensibility in web applications. While we encourage instructors to deviate from this plan as they see fit, we have outlined our deliverables and project releases below, based on a 15 week semester. Suggested timing and point totals are listed in Table I.

⁴<http://dev.markitondemand.com>

⁵<http://finance.yahoo.com/q/hp?s=API>

⁶<http://getbootstrap.com/>

⁷<http://git-scm.com/>

Week 1: Team Formation

Teams are formed using an on-line survey where students are encouraged to indicate who they would and would not like to work with and their level of experience with web development and software engineering. The instructor's goal is to create balanced teams who are likely to work well together.

Each team is required to self-assign several roles including team coordinator, development coordinator, and testing coordinator. In our case, the course is comprised of upper level students making self-appointed roles appropriate; in the case of more novice students, the instructor may want to appoint team roles, possibly choosing to rotate them in order to allow each student to experience each role.

Week 3: Requirements Documents

Students are provided with a requirements document template which they modify based on their conversations with the customer/instructor. As with all project artifacts, teams are expected to keep these documents up to date for with each release throughout the term.

The grading on these initial document deliverables is not aimed at ensuring that the teams have a completely accurate document on their first attempt. The main goal is to have followed the proper guidelines for producing these deliverables and producing an adequate effort in creating them as accurately as possible. During the second half of the class, each team is given the opportunity to meet with the instructor to elicit requirements and to ask general project questions. In this and future interactions, the students are also able to negotiate expectations with the customer. They are encouraged to show prototypes, screenshots, and anything else they deem useful to the customer. The goal is not to limit customer interaction or punish inquisitions as long as they are reasonable, rather the aim is to encourage customer interaction and elicitation.

Week 5: Design Documents & Test Plan

As with the requirements document, teams are provided a template design document and are expected to use the requirements they've been provided and elicited from the customer as input in its enhancement. Some expected document components include UML diagrams (state, sequence, and class), interface design, and basic database design. Teams are also expected to create a test plan for their project. In our course offerings, teams are instructed to create acceptance tests in a simple excel document. Instructors may choose to have teams use a more robust tool should they see fit.

Week 6: Beta Release

The initial project release is intended to be a lightly scrutinized preview of Release 1 (R1). If time allows, Instructors are encouraged to allow teams to conduct a short 5 minute demo of their applications and a basic progress report, eliciting feedback from their classmates. In our case, students have enjoyed seeing the progress of their classmates and gaining this extra feedback before their first major release.

Week 7: Release 1 (R1)

At this time, teams are asked to deliver a partially working

version of their application and a 15 minute presentation. Teams are also expected to submit all updated project artifacts including the requirements document, design document, and test plan. Some key deliverables are basic connections with the external APIs, a deployment strategy, and cursory implementation. We do not evaluate usability or database setup for this initial release.

The Software Engineering Department at RIT places a large emphasis on the student skills of public speaking, presentation, and internal and external communication. With the first release, each group is asked to give a 15 minute presentation highlighting some of the major aspects of their product and some of the technologies they have encountered. Other aspects of discussion are team roles and dynamics, a short demonstration of their application, and plans for the second release. The presentation is oriented as a progress report for the customer.

We ask teams to identify any missing features or requirements not able to be delivered for the initial release. In order to help persuade the students to divulge these undelivered items, they are told they will be penalized much less significantly for any items that they have declared to have missed (as opposed to the instructor/customer finding them). This forces the students to take ownership of their mistakes and be open and honest with their customers, which we feel is an especially important concept once the students graduate to the real world. Hopefully these self-identified problem areas are addressed by the team and defeated in upcoming releases. Assisting in this, students are also required to complete an online, 360° survey rating their teammates and themselves in order to identify problematic areas and team members who are not contributing as much as they should to the project.

Teams may be evaluated upon the quality of their presentation, updated documentation, and created software. Scores may be influenced by team contribution, adherence to process (i.e. using the repository effectively), and metrics such as defect density.

Week 8: R1 Postmortem

Each team creates a self-reflection document containing that went well, what can be improved, and how. Teams are encouraged to think deeply, but to refrain from discussing the overly technical issues they have encountered, as this activity is designed to focus on team, project, and process. Postmortems are evaluated on their thoroughness, identification of strengths and weakness, and plans to overcome these deficiencies. We have seen quality submissions in the 3-5 single spaced page range, but individual instructors may alter this guideline as they see fit.

Week 11: R2

Teams submit their projects, updated documents and conduct a presentation in a similar fashion to their first release. In order to save class time, team presentations may be abbreviated to 5 minutes, or even excluded at the discretion of the instructor. Teams are evaluated on how well they are updating their documentation, adhering to web engineering principles, and the quality of their application. Some expected additional features for R2 include better usability, use of

a database back-end, and a new messaging or chat component.

Week 12: R2 Postmortem

This is similar to the R1 postmortem, but should show more advanced thought and problem resolution.

Week 15: R3 & R3 Postmortem

The final project release is conducted in a similar manner to the first two releases, but with a longer student presentation time. This will allow teams to discuss and reflect not only on R3, but on the entire project as well. Some expected deliverables for this final release include robust security, fully integrated external APIs, a local database, and demonstrations of usability.

The final postmortem should be due a few days after the project, to allow consideration of not only the final release, but the presentation and its preparation as well. Grading should consider all components of the project, including the final product, updated artifacts, postmortems, the presentation, and peer feedback.

V. STUDENT FEEDBACK

A screenshot example of the finished product is shown in Figure 1. Included in this example is Facebook login integration, the top 5 stocks based on user preference, a Facebook news feed with the ability to post to the user's timeline, a daily events display, and a chat plugin which may be used to message anyone also using the application. Other pages not shown include a stock price simulator and a Facebook-integrated calendar feature.

In recent examples, many many teams have decided to use Bootstrap for their UI, a Pusher Chat⁸ widget, and a Yahoo stock API⁹. Because of ease of implementation, a local SQL database has typically been used to store user data. Groups are encouraged to research other APIs, feeds, and sources of information when creating their application, and the API discovery process has been a valuable part of the overall student learning process.

Student feedback has been very positive. At the conclusion of the term, students are asked to fill out an anonymous course evaluation survey. Many students have commented about how much they enjoyed the project, and how much they learned during the 15 week term. Table II shows the student responses to three applicable questions in percentage format.

TABLE II. END OF COURSE SURVEY RESULTS

Survey Question	Agree	Neutral	Disagree
The project was relevant to the course	86%	10%	3%
The amount of project work was appropriate	93%	0%	6%
I learned a lot in the course	85%	11%	4%

VI. CHALLENGES & FUTURE WORK

While the project has seen considerable success since its inception three years ago, there is still work to be done and

areas of improvement. Like with many team based projects, a problem we encountered was how to deal with students who do not contribute to the project. This is a dilemma which is not at all unique to this project and occurs in a wide variety of software engineering student projects [22]. One way which we have dealt with this issue was to ask students to fill out a brief peer review survey after each major project deliverable. The goal has been to identify non-contributing students and address the situations recorded by students as necessary. The use of explicit team roles has also served to alleviate this problem slightly.

Instructors can expect students entering the course to have a diverse range of experiences and skillsets, making it difficult to balance between having the project topics be challenging enough for the more advanced students and being simple enough for the less advanced students to not be left behind. This problem may be mitigated through the use of course prerequisites, but it is a challenge that instructors will need to balance with each course offering.

Web development is comprised of fast moving technologies. This includes new tools, languages, and perpetually changing APIs. This means that the course will need to be constant evolving to include these new technologies which will involve significant diligence by the instructor for lectures, the course project, and in class activities. We've also encountered issue with APIs changing in the middle of term, which proved to be troublesome to many of the teams. This did however teach them a valuable lesson about risk mitigation, reactive designs, and the constantly changing nature of the web. While web technologies change at a tremendously fast rate, and keeping the course up to date is always a challenge, Instructors need to remember that the primary focus of the class is on instructing proper engineering principles; programming is of secondary importance.

VII. SUMMARY

Using proper web engineering principles to create web applications which are on time, on budget, and high quality is an important skill for students to master. We have created a project component within our Web Engineering course in order to reinforce the class's concepts with the goal of resembling a real-world project with components that may be seen by the students soon after graduation.

Over the last few course offerings, we have refined the project to better suit the learning objectives of the course and to keep it relevant with the fast-paced nature of web technologies. We have also seen a significant amount of student interest and enthusiasm about the project, which has carried over into the course as well. Students returning from their first jobs as web engineers have also stated that the project had prepared them well for their job and the situations they faced. Because of the success we have experienced, we encourage others to consider the use of this project in their Web Engineering courses.

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Analysis of the Utilization of Web 2.0 Resources in Secondary Education and Advanced Vocational Training Studies

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Abstract— This paper presents a study to address the use of Web 2.0 tools in education. The study focuses on secondary education and is limited to the region of Madrid (Spain). The main objectives of the study are to determine the involvement of both teachers and students in the use of Web 2.0 tools. Moreover, we will also examine the different parameters associated with the acceptance and application of Web 2.0 resources. Finally, we will describe the different patterns of interaction of both students and teachers with respect to these digital platforms. As a result, we will be in position of assessing the convenience and acceptance of artifacts based on the Web 2.0 paradigms to be used as effective resources to improve the students' learning experience.

Keywords-words: Web 2.0, Media Education, School 2.0, Knowledge Society.

I. INTRODUCTION.

The term Web 2.0 Websites comprises those Websites that facilitate information sharing interoperability, user-centered design and collaboration in the World Wide Web. There are several tools that allow to share information in the Web 2.0 such as blogs, wikis or social networks as well as other sites that share resources like Google Drive for documents, Youtube for videos, or Dropbox for online storage. Among these tools, there are also learning platforms like Moodle or Claroline and virtual classrooms such as Edmodo, Virtual Virtual Teacher or Tutor.

Our aims are to analyze the acceptance of Web 2.0 tools in the classroom and the involvement of teachers in their use. Therefore, the main objectives of the research activities reported in this paper are presented below:

1. To perform a study of the use of Web 2.0 tools in the classroom in the region of Madrid and to assess the implication of teachers in their use.
2. To evaluate the acceptance of Web 2.0 tools by teachers.

3. To determine whether the use of Web 2.0 tools is widely accepted by students (according to teachers' opinion).

4. To identify predictive factors for a lower use of Web 2.0 tools by teachers in the classroom.

The rest of the paper is structured as described in the following. First, we will present the state-of-the-art after reviewing the previous research on the use of Web 2.0 tools by teachers. Then, the methodology used to carry out our study will be described. Finally, our main results and conclusions together with some threads to validity will be exposed.

A Web 2.0 site allows users to interact and collaborate to join efforts in the process of creating contents that will remain available for a given virtual community. This approach radically differs from static websites where users are limited to the passive viewing of content that have been created for them.

The main aspects featuring the Web 2.0 technologies are enumerated in the following [9]:

1. The term Web 2.0 groups different interactive approaches that have in mind the social component of the net. Provided with these new mechanisms, Internet has acquire a more participative dimension, enabling the exchange of information and several forms of contact among users through individual blogs, wikis, social network sites (Second Life, Facebook, etc), image or video sharing sites (Flickr, YouTube, etc.)
2. The Web 2.0 is and attitude and not precisely a technology. It's most relevant aspect is that it makes clear the next evolutionary steps of Internet.

Facebook is an example of typical social networking projects that, in general, has been developed using the figure of social networks as the main support for students' learning process. [11]

Free Software is any software respectful to the freedom of its users and to the social solidarity of their communities. It is common to associate Free Software to software with no cost, but this is a mistake, because there are free software that you have to pay for using it. Not every free software is free. And above all not every no cost software is free software. [7]

To sum up, free software is defined by the four freedoms of software users.

- Freedom 0: The freedom to run the program for any purpose.
- Freedom 1: The freedom to study how the program works, and to change it for any particular purpose.
- Freedom 2: The freedom to redistribute copies.
- Freedom 3: The freedom to improve the program, and release your improvements (and modified versions in general) to the public, so that the whole community benefits.

Also you should have the freedom to make modifications and use them in your work or free time privately, without even have to announce that this modifications exists [8].

We will take as a reference some figures in the education in Europe and in Spain. That will show us how important can be the use of the web 2.0 tools for the classroom. All of this will give us an idea of the current situation about this topic, in Europe and in Spain [10].

II. STATE OF THE ART

The Society of Information has risen as the result of the implementation of information and communication technologies (ICT) in daily life. The greater use of the ICT paradigms has changed, in many senses, the way of developing many of the activities of the modern society.

The Knowledge Society arises in the context of the Society of Information. The main characteristics of the Knowledge Society are the open access to information, the freedom of expression and the linguistic diversity.

Therefore, the fields of study of our research are Education, Communication and Web 2.0 supporting tools. We considered that it was important to investigate these fields due to the importance that the Regional Administration was giving to the introduction of ICT, particularly the Web 2.0 tools, in education. The incorporation of Web 2.0 tools in teaching is having a great impact in education and the use of these tools is expected to increase according to the principles of the Media Education

and School 2.0, which will be explained later in this summary.

In the Society of Information, a change in "what" we teach and "how" we teach is needed. This new Society forces us to rethink the role of teachers, students and taught subjects in education. Therefore, teachers should try to encourage collaborative works in the classroom, which can be supported by mechanisms such as the Web 2.0 tools.

To the best of our knowledge, there are no studies addressing the particular use of Web 2.0 resources in Spanish secondary education. Therefore, our research study covers the lack of information regarding two relevant points: The Media Education and School 2.0.

With respect to the Media Education, it is noteworthy that skills such as the ones related to the use of many languages, to critical thinking, and to the interaction with others in real and/or virtual modes, should be potentiated [1].

Concerning the Education 2.0, it is noteworthy that the advances occurred in education based on the communication model 2.0, i.e., the Web 2.0, is based, inter alia, on the use of social networks. The active interactive joint of teachers and students is also closely related to collaborative learning and authorship for example blogs and wikis.

Education and Education 2.0 are related through the emergence of the communicative model 2.0 in which both teachers and students are active participants in the communicative act, that is, a continuous exchange of roles where both teachers and students can be authors or co-authors of the information and knowledge. According to the authors of et al. [1], The Web 2.0 has changed the rules of the game and allows Internet to contribute collaboratively in the construction of collective knowledge from individual acts of group communication that can occur in cyberspace and real space.

The receiver and the transmitter of the information are transformed into an EMIREC which sends and receives messages [2]. In this model, the role of the students substantially changes. As the learning focuses on the students, they should take an active role building the teaching-learning process. It is expected that the students are able to exercise autonomy, to develop critical thinking, to adopt collaborative attitudes and to use the theoretical knowledge to solve real problems. This model of communication enhances the possibility that the students cast its own messages through different languages, strengthening the educational proposal of personalized education, as well as affective and emotional processes that occur in all educational relationship.

In addition, the digital literacy is a new concept that should be taken into account when considering the training of teachers in the Media School. Literacy is the education

that everyone needs to live in society. A new model of literacy is needed in the digital society: the digital literacy. Furthermore, this new literacy, defined as the basic capacity to understand and to express in different languages and meanings, is constructed collaboratively between teachers and students, as defined in [4]

What we teach and the way we teach it should be changed. Therefore, the role of the teachers, students and contents in learning should be redefined.

Currently, we are part of a networked society, mainly due to the Internet, that has changed the processes, interests, values and social institutions in the way we knew them. Internet has propitiated new ways of relationship, that wouldn't have been possible without the technological advance. As indicated in [5], Internet is the heart of a new paradigm that currently constitutes the base of our lives and of our ways of relationship, work and communication. Internet processes the virtuality and transforms it into our reality, constituting the network society, which is the society where we live.

We cannot forget the importance of TIC in the school. As specified in [6], The implementation of TIC needs several capacities such as cooperation, capacity of initiative and dynamism in the working places, to be able to work in groups, interactive learning between the members of the group, communication, to be able to work with abstract concepts, to identify and solve problems, aptitude to make decisions, being able to seek and to use the information, predisposition for the permanent training and other.

The appearance of these technologies demands to train teachers, as most of them are not familiar with TIC resources and lack the necessary skills to use them.

The immense majority of the administrators, educational managers and teachers are digital immigrants. (...). These professionals rarely use the digital technologies and are very resistant to modify their conception of the world of the work based on the industrial models of ends of the 19th century [1].

III. METHODOLOGY

In the following, we describe the methodology conducted to perform our study.

A. Inclusion of teachers

First of all, this is an observational study in which teachers from secondary schools in the region of Madrid have been electronically surveyed. No exclusion criteria were established.

It is also directly select the teachers and the center in which they operate. 51 were randomly selected centers of the Community of Madrid and went to the centers getting

contact with teachers of Secondary and Vocational Training to ensure that the sample is as random as possible.

We will consider two distinct populations: Teachers of Secondary Education and Training in the specialty of Computer and Teachers of Secondary Education and Vocational Training non-specialty Informatics (Electronics, training and career guidance, etc ..)

B. Data Collection

To achieve the objectives of the study a questionnaire asking about different aspects, such as the professional profile, the opinion on the usefulness of Web 2.0 tools for teaching, the involvement of teachers in the use of Web 2.0 tools and their perception of student interest in the use of these tools, was designed (Table I).

The structure of the questionnaire is as follows: Professor Facts, Facts Institution, Facts Teaching and Evaluation of Web 2.0 Tools (from 1-5).

Teachers from different schools of the Region of Madrid (both, public and private) were invited to fulfill the questionnaire. The questionnaire will consist of an HTML form heading to a PHP page which will register received data received into a MySQL database. Later, every data will be exported to the SPSS statistic package.

The decision to conduct surveys with 20 questions, both secondary teachers (Mathematics, Physics, Chemistry, Biology, Geology, English, etc ...) as teachers of training courses and degree courses which the subject is taken the subject taught are more accustomed to using the Internet in classrooms of Secondary Schools of the Autonomous Community of Madrid with different profiles ages (21 and 35, of 36-50 and 51-65 years) and professional (official and temporary).

This is done in order to make the results more reliable extrapolating the sample to all types of faculty as teachers of vocational training covers both the specialty of Computer Science, as other (Telecommunications, Electronics, Training and Employment Guidance, etc).

These 20 questions will let us know in a general way what is the use given to the Web 2.0 tools in the classroom but in the study to be conducted through the SPSS [12] tool such questions so we can be encoded obtain robust results and allow us to determine exactly what percentage use these tools and if they do regularly or sporadically, how many hours a week they use, that kind of activity used (individual, group, theoretical, practical) whether these tools promote student participation in class, etc.

This differentiation of different age profiles and different professional categories, are made in order to ascertain as accurately as possible, whether age and professional status substantially influences the involvement of teachers in the use of Web tools 2.0 in the classroom.

C. Statistical analysis

For the descriptive analysis of quantitative variables the mean was calculated. Qualitative variables were expressed as percentages. Comparisons between means were performed using Student's T test for independent samples. Qualitative variables were compared using the chi-square (χ^2) test and the Fisher's exact test. Statistical significance was considered at $p < 0.05$ for the all the comparisons.

A binary logistic regression model was used to estimate the effect of the different variables on the use of Web 2.0 tools. All the variables which reached the statistical significance in the univariate analysis were included in the multivariate analysis. Thus, in the multivariate analysis, the dependent variable was the use of Web 2.0 tools.

D. Justification of the questions of the form.

Questions 1 and 2 give us information about the degree of learning of Web 2.0 tools at both learning as if they are a good resource for learning.

Questions 3 and 4 for determining whether Web 2.0 tools enhance communication between students and teachers.

Questions 6 and 7 indicates whether the use of Web 2.0 tools are an advantage (facilitates their work) or undesirable (workload) for teachers.

Question 8 to determine whether the use of Web 2.0 tools in the best interests of the students in the subject studied.

Questions 9 and 10 to determine if Web 2.0 tools contribute or not a good academic and failing to school failure.

Questions 5, 13 and 14 give us information about the degree of knowledge of students and teachers in the field of Web 2.0 tools.

Questions 11,12, 15 and 16 for determining whether Web 2.0 tools enhance participation, collaboration, cooperation, teamwork and level of student creativity in the classroom.

Question 17 and 18 gives us information about the degree of readiness of students and teachers in the use of Web 2.0 tools.

Question 19 lets us know what subjects or subjects Web 2.0 tools are used

Question 20 tells us whether specific training in the use of Web 2.0 tools is adequate.

TABLE I. THE QUESTIONNAIRE FULFILLED BY THE TEACHERS IS SHOWN ABOVE.

Number	Question
1	Do you consider Web 2.0 Tools are an academic resource useful For Teachers?
2	Do you consider using Web 2.0 tools favor learning in students?
3	Do you consider using Web 2.0 tools contribute to a better student-teacher communication?
4	Do you think using Web 2.0 Tools contribute to better communication between the students?
5	Do you consider Web 2.0 tools encourage acquisition of autonomous knowledge and skills by students?
6	Do you think using Web 2.0 Tools facilitate teaching?
7	Do you consider the Web 2.0 Tools assume considerable workload for teachers?
8	Do you consider Web 2.0 Tools promote student's interest for the subject studied?
9	Do you think Web 2.0 Tools have a positively impact on the academic student performance?
10	Do you consider Web 2.0 tools can contribute to avoid academic failure?
11	Do you consider Web 2.0 Tools improve student participation in class?
12	Do you consider Web 2.0 tools encourage partnership and cooperation attitudes among students?
13	Do you consider appropriate the level of knowledge and management of students on Web 2.0 tools?
14	Do you consider appropriate the level of knowledge and management of teachers who knows Web 2.0 tools?
15	Do you consider Web 2.0 tools improve group work of students?
16	Do you consider Web 2.0 Tools improve the level of creativity of the student?
17	How do you rate the initial willingness of students to use Web Tools 2.0 as a part of teaching resources?
18	How do you rate initial willingness of teachers who knows Web 2.0 as a part of teaching resources?
19	Do you consider is indispensable the incorporation of Web 2.0 Tools in the subjects you teach?
20	Would you consider proper dedicate Web 2.0 tools training aimed at students?

IV. RESULTS

The actual sample size calculated is 120 teachers, but Eighty-one teachers have fulfilled the questionnaire so far. The main characteristics of the teachers included are summarized in table II. Seven fifty-five (47,51%) were male.

(84,16 %) over 30 years and 19 (15,84 %) with more than 30 years of experience. The majority of them were officials (70%) and 70,83% worked in public centers. Approximately half of them (54,16%) were teachers of Computing Science.

Although the surveyed teachers (120) declared that the use of Web 2.0 tools reinforces and benefits the students' learning process, only 63% of them acknowledged using these tools frequently. In addition, only 33% of the teachers being using Web 2.0 tools manifested to use them during whole sessions in the classroom. When focusing on teachers that used the aforementioned tools, only 59% of them did it to work in group. Of all teachers, 85 (75,22 %) are the public center.

On the other hand, with respect to the interest shown by the students in the use of Web 2.0 in the classroom, the majority of teachers that used them (79%) considered that students are very enthusiastic about the use of these tools. A small proportion of teachers (6%) answered that the implication in the use of these tools varies widely and it depend on the characteristic of the student. In teachers' opinion, the students that used Web 2.0 tools seemed to do it for both individual and group tasks.

In the multivariate analysis, to be teacher of Computing Science was the only variable independently associated with the use of Web 2.0 tools in the classroom (odds ratio=7.9, confidence interval 95%=2.5-24.5).

Up to 80% of teachers consider that Web 2.0 tools are useful for teaching. 20% do not use these tools probably because they are not accustomed to these technologies, they have no training or because they do not have enough resources.

Only one third of the teachers that use the Web 2.0 tools do it throughout the whole class.

The majority of teachers that use Web 2.0 tools do it for working in group. This result should be underlined as suggests that teachers know the collaborative character of these tools.

Technological elements always seems attractive to the students (mainly at that age) and that should be use to introduce them in the classroom. Many teachers think that the use of these elements contribute to arouse interest of the students. In addition, these tools offer many facilities to promote and participate in group activities although obviously there are ways of interaction requiring presentiality such as debates, exhibitions, etc.

TABLE II. RESUMES THE MAIN CHARACTERISTICS OF THE TEACHERS THAT FULFILLED THE QUESTIONNAIRE.

Feature	Categorí s	% of participants
Gender	Male	57 (47,51 %)
	Female	63 (52,49 %)
Age	Between 21 and 35 years	19 (15,84 %)
	Between 36 and 50 years	61 (50,83%)
	Between 51 and 65 years	40 (33,33 %)
Experience	Over 30 years	101 (84,16,%)
	Under 30 years	19 (15,84 %)
Type	Officials or fixed	84 (70 %)
	Interins	36(30 %)
Centers	Public	34 (70,83 %)
	Private or concerted	14 (29,16 %)
Area	ICT	65 (54,16 %)
	Non-ICT	55 (45,84 %)

The results of the questionnaire it follows that:

1. **The percentage of male gender among ICT subject** was heigher than the frecueny of mala gender among non-ICT subject. Among as teachers from the ICT subjects, 39 (60%) were men while among non-ICT teachrs 33% where men.
2. With respect to the training in ICT use, in public centers the percentage of teachers that received an especific training in ICT was heigher among those from FP than among those from ESP (65 vs. 54 %) while teachers from no-ICT subjects received low training. Among teachers from private centers, FP teachers from ICT subjects were these who received a more intensive training.

3. Among teachers that received training, 39% were from public centers, fifty six teachers were trained, of which the public schools are 84%.
4. With respect to the number of years of teaching experience in public schools, the mean teaching experience was higher in ESO teachers than in FP teachers. A possible explanation for that is that to be a teacher in a public school access is by opposition also FP is a type of education where newly established subjects and many very current training courses. In private-aided schools, as happens in public schools and years of experience is higher among teachers of ESO and FP.
5. Finally, the number of teachers using Web 2.0 tools was 94.16%). In general, FP ICT are teachers who use these tools more (44.24%). In public schools, the ICT FP (33.62%) are the most teachers use these tools, which is logical since their subjects are mainly technological. In private-aided schools, ICT FP (11.50%) are the most teachers use these tools, for the same reason as above.

V. CONCLUSIONS

Our results suggested that although most teachers believe that the use of Web 2.0 tools promotes the students learning, only half of them use these tools for teaching and only one third acknowledge to be implementing actively the use of these tools in the classroom. In general, teachers think that the use of Web 2.0 tools in the classroom is well accepted by the students.

To teach Computing Science was the only factor independently associated with a greater use of these tools in the classroom (8-fold higher than among teachers in other specialties). The age of the teacher (older age) is associated with a lower use of Web 2.0 tools.

This study underscores the need for action to generalize the use of Web 2.0 tools in the classroom, with particular emphasis on the older teachers and among teachers from other specialties from Computing Sciences. Future studies should aim to identify the handicaps for the implementation of these tools in order to adopt strategies (procurement, training courses, etc.) to avoid them.

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An Intelligent Student Advising System Using Collaborative Filtering

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Abstract—We propose a web based intelligent student advising system using collaborative filtering, a technique commonly used in recommendation systems assuming that users with similar characteristics and behaviors will have similar preferences. With our advising system, students are sorted into groups and given advice based on their similarities to the groups. If a student is determined to be similar to a group students, a course preferred by that group might be recommended to the student.

K-means algorithm has been used to determine the similarity of the students. This is an extremely efficient and simple algorithm for clustering analysis and widely used in data mining. Given a value of K, the algorithm partitions a data set into K clusters.

Seven experiments on the whole data set and ten experiments on the training data set and testing data set were conducted. A descriptive analysis was performed on the experiment results. Based on these results, K=7 was identified as the most informative and effective value for the K-means algorithm used in this system. The high performance, merit performance and low performance student groups were identified with the help of the clusters generated by the K-means algorithm. Future work will make use of a two-phase approach using Cobweb to produce a balanced tree with sub-clusters at the leaves as in [11], and then applying K-means to the resulting sub-clusters. Possible improvements for the student model were identified. Limitation of this research is discussed.

Keywords—K-means; clustering; collaborative filtering; rules; intelligent academic advising system; course.

I. INTRODUCTION

In tertiary institutions, online academic advising systems can provide prompt advice as and when required, and thus enhance student experience and save staff time and other institutional resources. Therefore such systems are gaining popularity. Research into such systems and development of such systems are in progress. In [1], the authors describe a Web-Based Decision Support Tool for Academic Advising. In their study, 90% of users, consisting of 20 undergraduate students and 5 faculty members, found their system effective and efficient. They consider four models of advising: prescriptive, developmental, integrated and engagement. They also discuss the importance of making systems that are more than data repositories and including more intelligence so the systems are able to

provide reliable advice that students do not have to check back with human advisors. In other words, systems that provide reliable advice.

The advice given by academic advising systems will vary, from student to student, depending on a number of factors such as the academic performance of the student concerned and the major area of study and also may be impacted by other factors such as the nationality, age and gender of the students. There are also academic regulations and rules, which can be applied to provide simple answers to basic questions with the assistance of normal SQL queries.

Goals for academic advising include development of suitable educational plans, selection of appropriate courses, interpretation of institutional requirements, enhancement of student awareness about available educational resources, evaluation of student progress toward established goals and development of decision making skills with reinforcement of student self-direction [1]. Others have used such systems to verify their tracks towards their degree program.

We propose a web based intelligent student advising system using collaborative filtering, a technique commonly used in recommendation systems. This technique assumes that users with similar characteristics and behaviors will have similar preferences [3, 4]. With our advising system, students are sorted into groups and given advice taking into account the relevant factors and also considering their similarities to specific groups. A major use of the online advising system we have proposed and prototyped is to help students choose courses from over fifty courses and five interlinked pathways in the Bachelor of Computing (BCS) program. If a student belongs to a particular group, a course that other students in that group have preferred or performed well in, may be recommended to the student.

The system is developed to be integrated into our current student management system, PeopleSoft. Therefore, our students don't need to create a profile to use this system. Real student data with complete records for the last four years (2011 to 2014) of all 743 students enrolled in over 50 courses in the Bachelor of Computing Systems (BCS) was anonymized and used in training and testing the prototype. Data included academic transcripts as well as biographic data.

K-means algorithm is used to cluster the 743 students into a number of clusters. This is an extremely efficient and simple algorithm for cluster analysis, widely used in data mining. Given a value of K, the algorithm partitions a data set into K clusters [5, 6 and 7].

K-means was chosen at this stage, instead of other clustering techniques, due to its ease of use and fitness for purpose. In the next stage of this project, we will have more knowledge on the data. Cobweb will be used to produce a balanced tree with sub-clusters at the leaves as in [11], before applying K-means to the resulting sub-clusters.

A prototype of the proposed system has been developed for concept approval. This prototype is implemented in ASP.NET and MS SQL database server. The system consists of two main components: a simple question and answer (QA) component and an intelligent advising component (IA) [8].

The QA component maintains a list of frequently asked questions (FAQs) of undergraduate students. A number of academic rules have been implemented, so it can answer routine questions like “am I eligible to take course X next semester?” This component is aimed at helping students in the development of suitable educational plans, selection of appropriate courses, interpretation of institutional requirements and increasing students’ awareness of the multitude of educational and other (such as counselling) resources available to students.

The IA component uses records from our current student management system. This allows the two systems to be integrated easily. There is no need for a student to create a new profile; instead, advice will be given taking into relevant, current student data. Academic and biographic information relating to the student concerned, is extracted from the student management system and used to identify which predefined group the student belongs to, and advice given taking into consideration, among other things, the specific characteristics of that group. It attempts to answer questions like “What courses should I take next semester?” This component is aimed at helping students in the selection of appropriate courses and development of decision making skills with reinforcement of student self-direction. K-means algorithm has been used to generate student groups.

A testing and experiment (TE) component is added for data gathering and experiments. The TE component helps to understand the characteristics of the different student groups and to select a suitable K value for K-means algorithm.

743 Bachelor of Computing student records from 2011 to 2014 were used as the data sample. From these records, ethnicity, age, gender, GPA and courses the student had taken were extracted. Based on these data, we gained a general understanding about the characteristics, performance and the interests for different student groups. The system is trained accordingly to provide useful and helpful advice.

In the rest of this paper, the overview of the system is provided first, the experiments related to K means are then discussed, the testing results and future improvements are discussed after that, and a summary is given at last.

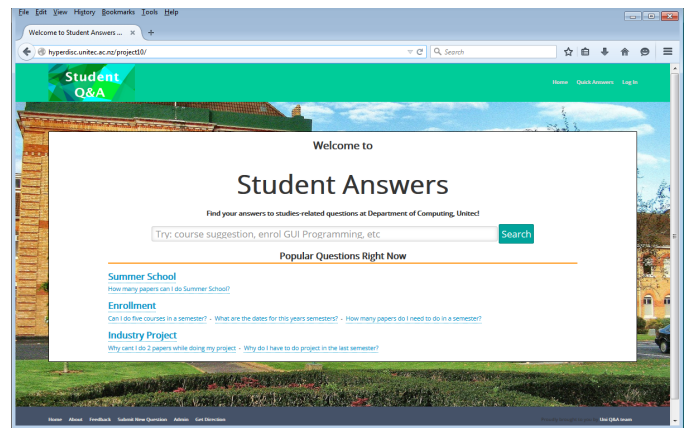


Fig. 1. The home page of the student advising system.

II. THE SYSTEM OVERVIEW

A. The question and answer (QA) component

This component is a basic system that answers questions to common questions students often ask. Examples of questions answered using this feature are:

What are the requirements to do capstone project?

How many papers can I take in Summer School?

In answering simple questions like the above, the system does not access any data specific to the student but a general database of stock questions and answers. Fig. 1 shows the home page of this system.

However, some tiny bit of intelligence is built in, to cater to the changing frequency with which questions are asked at various times during the year. For example, during the period just before Summer School, questions regarding Summer School are listed at top. This also helps the students by making them aware of things they may want to look at while using the system. Fig. 2 shows an example of this type of question and answer system. A number of academic rules has been implemented, so it can answer routine questions like, “Am I eligible to take course X next semester?” with the help of SQL queries.

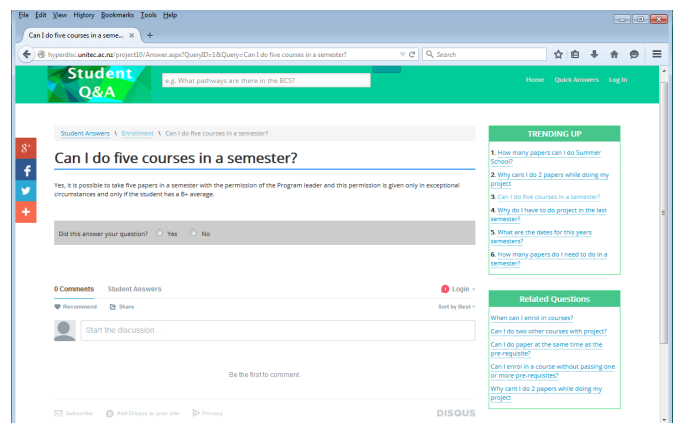


Fig. 2. An example of question and answer.

B. The intelligent advising (IA) component

As the records in our current student management system are used, the information can be extracted from the data is limited, thus the attributes can be used to model a student are limited. The students are modelled by using the existing data as closely as possible. The advising system is expected to help improve the students' performance. Much of existing research around the world use GPA to measure student performance [8]. Research also shows that students' performance depends on many factors such as gender, age, student's competence in English and even nationality and ethnicity. Some other factors that have a significant impact on student performance have been identified as students' communication skills, learning facilities, proper guidance and family commitments related stress [9].

According to [9], students' academic accomplishments and activities, perceptions of their coping strategies and positive attributions, and background characteristics, including family income, parents' level of education, guidance from parents and number of negative situations in the home, were indirectly related to their composite scores, through academic achievement.

According to [9], the student performance should be improved if the administration of the college provides proper learning facilities; the student performance should be improved if the students have good and effective communication skills and have good competence in English; the student should perform well if they are properly guided by their parents and also by their teacher.

Based on the available data, previous research findings and our experience teaching into as well as leading (one of the authors) the program over the past 13 plus years, we loosely related and defined, as a first approximation the following attributes.

- GPA: Relevant to performance.
- Age: Relevant to family stress, e.g. mature students are more likely to have family commitment.
- Ethnicity: Relevant to English competency and family background.
- Gender: Relevant to learning style and how they can cope with the provided learning facilities.

Based on the above attributes, the samples were partitioned using K-means algorithm. Seven experiments were conducted on the 743 records for $k=2, 3, 4, 5, 6, 7$ and 8 . A descriptive analysis on the clusters was done to select a suitable K value and to find the major features for different student groups. The top twelve courses taken by the students in each cluster were also identified. The data was then split into two data sets: training data (372 records) and testing data (371 records), to test the validity and usefulness of the advice given. The experiment results from training data and testing data are compared to evaluate this approach and identify possible improvements.

For a particular student, the similarity between the student record and the predefined clusters from the sample data will be measured by the squared distances from the record to their centroids, the shorter the distance, the higher the similarity. The record will be identified to belong to the cluster with the mi-

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nimal distance, and the data in the identified cluster will be used to provide suggestions to the student. The following is an example of such suggestions from the system (Fig. 3).

C. The testing and experiment (TE) component

The K-means is an extremely efficient and simple algorithm; however, it does have shortcomings that were taken into consideration during the development of the system. Most importantly, it assumes that there is prior knowledge of the data set, due to the size of the algorithm (K value) being defined in advance. Another issue is that cluster analysis does not use category labels that tag objects with prior identifiers, i.e., class labels. The absence of category information makes data clustering unsupervised learning [6].

To determine the K value, TE component provides an environment (Fig. 4) which allows the researchers to experiment with seven K values (2, 3, 4, 5, 6, 7 and 8) on the whole sample data set (743 records). The results are displayed in a combination of text and graphic format. For a given K value, the graph visualize the attribute (GPA, age, ethnicity and gender) distribution and the course selection distribution for four majors (Software Development, Networking and Security, Business Intelligence and Other) for each cluster. The text results provide more detailed information. The top 12 most popular courses for each cluster have also been identified (Fig. 5).

Similar experiment environments are provided for both of the training data set (372 records) and testing data set (371 records), which allow the researchers to experiment with ten K values (2, 3, 4, 5, 6, 7, 8, 9, 10 and 15).

III. THE K-MEANS EXPERIMENT

Let

$$X = \{x_i\}, i = 1, \dots, n \quad (1)$$

be the set of n d -dimensional points to be clustered into a set of K clusters,

$$C = \{c_k\}, i = 1, \dots, k \quad (2)$$

Where $d=4$, representing GPA, age, ethnicity and gender.

Student Answers \ Personalized Questions \ What papers should I take next semester?

What papers should I take next semester?

Course recommendations

Based on your previous levels of study, we strongly recommend the following courses:

- ISCG6441: Visual Game Design
- ISCG6422: Multimedia Programming
- ISCG7425: Java Enterprise Programming
- ISCG6425: Data Warehousing

Additionally, below is a list of courses that you might also consider taking in your next semester(s):

- ISCG7410: Information Systems Management
- ISCG7414: Business Systems Analysis
- ISCG5331: Client Operating System Environment
- ISCG5332: Fundamentals of Network Infrastructure
- ISCG6330: Server Operating Systems
- ISCG6332: Configuring Network Infrastructure
- ISCG6400: Hardware Technology
- ISCG6402: Network Administration and Support
- ISCG6413: Testing and Quality Assurance in ICT

Fig. 3. Example of the suggestions from the IA component.

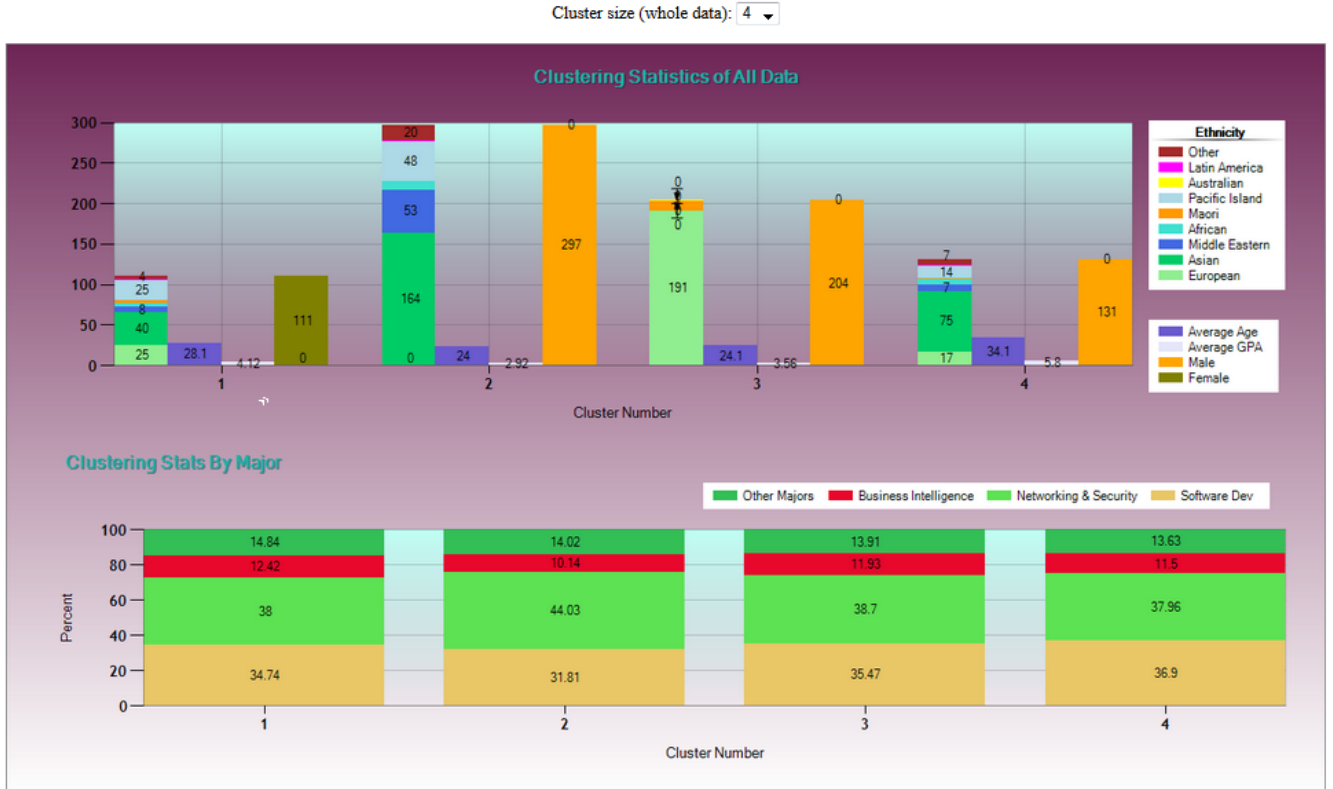


Fig. 4. The experiment environment for the whole sample data set.

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ISCG5410: Information Systems in Business (Completed 39 times)
ISCG7430: Project (Completed 21 times)
+ Top 12 most popular courses:
1. ISCG5430: Professional Skills (Completed 61 times)
2. ISCG5401: Operating System Fundamentals (Completed 56 times)
3. ISCG5423: Introduction to Databases (Completed 55 times)
4. ISCG5400: Hardware Fundamentals (Completed 54 times)
5. ISCG5420: Programming Fundamentals (Completed 51 times)
6. ISCG5403: Networking Fundamentals (Completed 40 times)
7. ISCG5410: Information Systems in Business (Completed 39 times)
8. ISCG6411: Project Planning and Control (Completed 37 times)
9. ISCG5422: Multimedia and Web Development (Completed 37 times)
10. ISCG6420: Internet and Web Development (Completed 29 times)
11. ISCG6400: Hardware Technology (Completed 26 times)
12. ISCG6410: Information Gathering (Completed 22 times)
Cluster 2
+ Software Development:
ISCG5423: Introduction to Databases (Completed 160 times)
ISCG5430: Professional Skills (Completed 151 times)

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Fig. 5. The text experiment output example.

Let $GPA(c_k)$ represent the average GPA of cluster c_k ; $Age(c_k)$ represent the average of cluster c_k . Let m represent the K value for a particular experiment. Let $SDTEV(GPAm)$ represent standard deviation of $\{GPA(c_1), \dots, GPA(c_m)\}$; $SDTEV(AGEm)$ represent standard deviation of $\{Age(c_1), \dots, Age(c_m)\}$. For L experiments, L standard deviation $\{SDTEV(GPA1), \dots, SDTEV(GPAL)\}$ and $\{SDTEV(AGE1), \dots, SDTEV(AGEL)\}$ will be obtained. The larger standard deviation should reflect the larger amount information provided by the clusters in the experiment.

A. The Selection of the K Value

To determine the K value, seven ($L=7$) experiments have been conducted on the whole sample data set, $n=743$, for $K=2, 3, 4, 5, 6, 7$ and 8. Seven standard deviation $\{SDTEV(GPA1), \dots, SDTEV(GPA7)\}$ and $\{SDTEV(AGE1), \dots, SDTEV(AGE7)\}$ have been obtained. These values are depicted in Fig. 6 to identify a suitable K value.

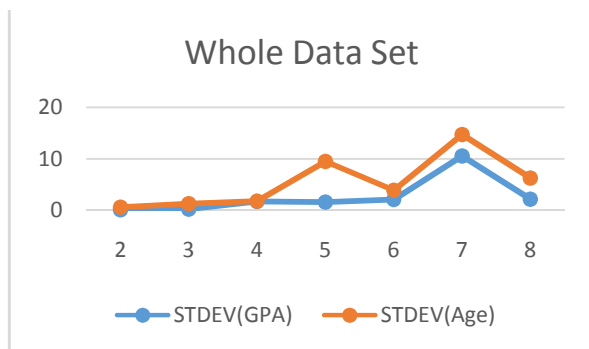


Fig. 6. The standard deviation for GPA average and age average.

It can be clearly observed that when $K=7$, both standard deviation for GPA average and age average are much larger than the other K values. This suggests that the clusters obtained from $K=7$ provide more information than the clusters obtained from other K values. A close look at the individual clusters produced in this experiment, clear characteristics can be identified for each cluster. Cluster 1 consists of all the young female students; cluster 2 consists all the young male students with very high GPA and most of them are of Asian background; cluster 3 consists of all the young male students with very low GPA and most of them are of European background; cluster 4 consists of all the young male students with very high GPA and most of them are of European background; cluster 5 consists of all the male students with low GPA and mixed ethnicities; cluster 6 consists of all the middle aged students with high GPA and of mixed ethnicities; cluster 7 consists all the male students with merit GPA and of mixed ethnicities. Therefore, the clusters generated by the K means algorithm on the whole data set are informative and effective.

B. The Training Data

To verify the value $K=7$ obtained from the above seven ($L=7$) experiments on the whole sample data set, the data was split into two data sets: training data (372 records) and testing data (371 records). Ten ($L=10$) experiments on the training data set ($n=372$) were conducted for $K=2, 3, 4, 5, 6, 7, 8, 9, 10$ and 15 . Ten standard deviation $\{SDTEV(GPA1), \dots, SDTEV(GPA10)\}$ and $\{SDTEV(AGE1), \dots, SDTEV(AGE10)\}$ have been obtained. These values are depicted in Fig. 7 to verify the K value.

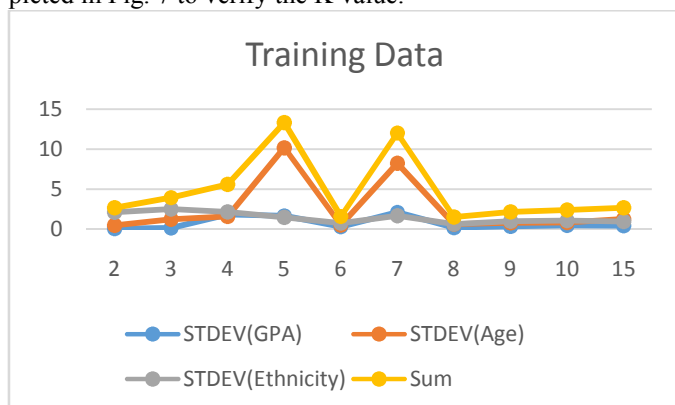


Fig. 7. The training data STDEV for GPA, age, ethnicity and their sum.

It can be clearly observed that when $K=5$ and $K=7$, both standard deviation for GPA average and age average are much larger than the other K values. The standard deviation for ethnicity does not make too much difference. This suggests that the clusters obtained from both $K=5$ and $K=7$ provide more information than the clusters obtained from other K values. Which value to take?

C. The Testing Data

As K means is unsupervised learning, there are no predefined labels for the clusters. We would like to check how meaningful it is if we use the course related information obtained from the training data to provide advice for our students.

The training data and the testing data are two data sets randomly and equally split from the whole data set. It is fair to assume that these two data sets should have similar distribution. We classify each testing data record by using the training data clusters, if the resulting testing data course distribution is close to the training data course distribution, then this approach is promising.

Fig. 8 shows the standard deviations of GPA, age, ethnicity and their sum for the clusters generated from the testing result. The standard deviation distribution of the testing result is quite similar to the training data except that there is a slight difference when $K=5$. However, it can be clearly observed that the standard deviation distribution of the testing result is very similar to the whole data set, in particular when $K=7$, both standard deviation for GPA average and age average are much larger than the other K values. The whole data set size is larger than the training data set size; it should be closer to the actual data. So this approach is promising and $K=7$ is the most suitable K value for this system.

D. The comparison of the Training Data and Testing Result

Fig. 9 shows the training data course distribution (percentage) against the clusters and the testing result course distribution against the clusters when $K=7$ for Software Development major, Fig. 10 shows the same data for Network and Security major, Fig. 11 shows the same data for Business Intelligence major, Fig. 12 shows the same data for the other majors.

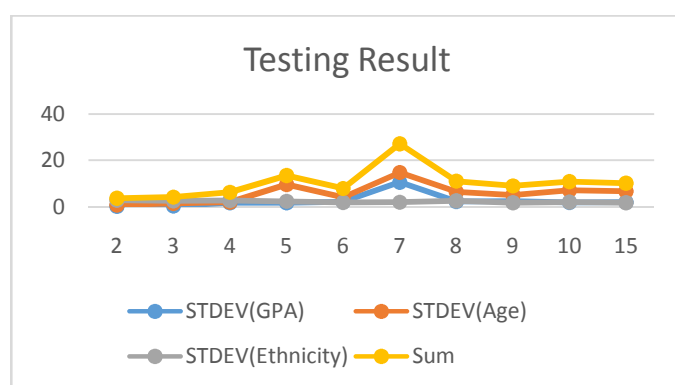


Fig. 8. The testing result STDEV for GPA, age, ethnicity and their sum.

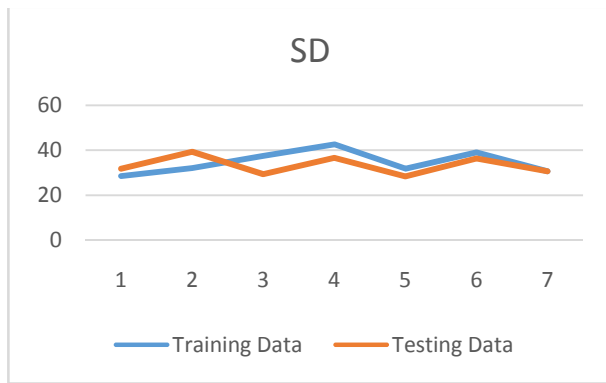


Fig. 9. The course distribution against the clusters for SD major.

It can be observed that the course distributions in the two cases are quite close for all the majors in general, except for cluster 3; there is a big difference (around 10%) for all the majors. Further investigation is required to find the reason for this and the way to improve this. It is still meaningful to use the training data to predict the preference of the testing data.

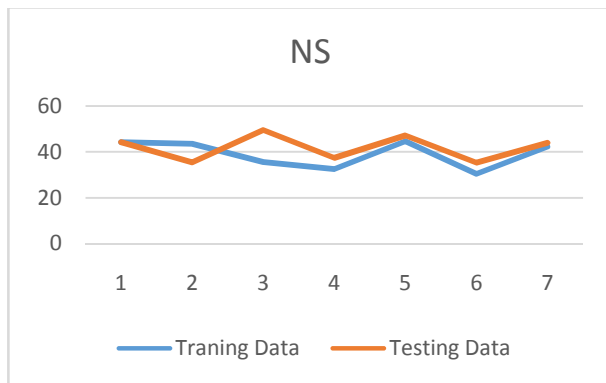


Fig. 10. The course distribution against the clusters for NS major.

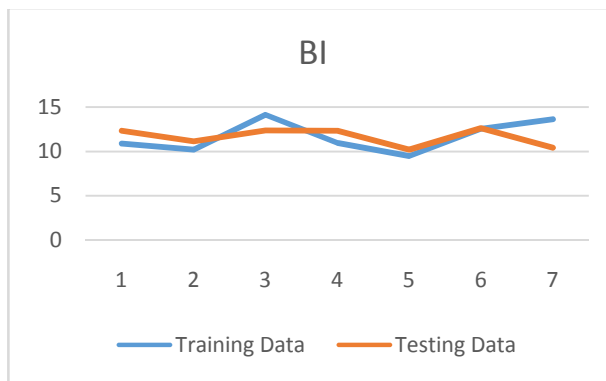


Fig. 11. The course distribution against the clusters for NS major.

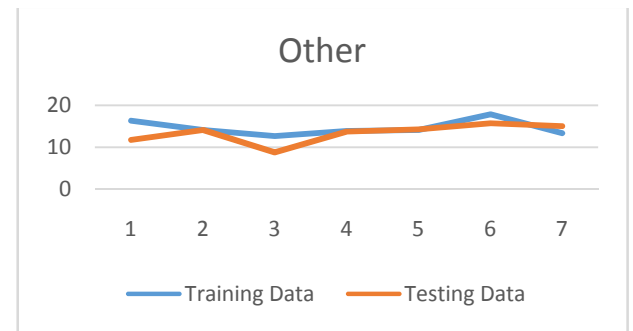


Fig. 12. The course distribution against the clusters for Other major.

E. The procedure to provide recommendations

Given a student record x_i , we could provide the study pathway the student could take or the courses the student could take for next semester. The following is the procedure to follow in providing advices in the IA component.

- 1) Generate clusters $C = \{c_k\}, i = 1, \dots, k$ by using the K means algorithm on the whole data set, where $k=7$.
- 2) Identify which cluster x_i belongs to, say c_m , where $7 \geq m \geq 1$.
- 3) Find out the top 12 most popular courses in c_m , eliminate those x_i has taken, recommend the rest to x_i .
- 4) Calculate all the average marks for all the courses taken by the students in cluster c_m , eliminate those x_i has taken, recommend five courses with the highest average marks.
- 5) Recommend the most popular pathway (major) in cluster c_m to x_i . This is particular useful to new student or for a student who wish to change major.

IV. DISCUSSION

We have a discussion on all the clusters when $K=7$ for the whole data set (Fig. 13).

For $K=7$, if we classify the clusters according to the average GPA, we can have three levels. High performance level, $GPA > 5$, including cluster 2, 4 and 6 (male, European + Maori + Asian, could be mature students); merit performance level, $4 > GPA > 2$, including cluster 1 and 7 (female or male, aged around 25.5, mixed ethnicities); and low performance level, $2 > GPA$, including cluster 3 and 5 (male, aged around 24.2, mixed ethnicities).

An interesting fact is that cluster 3 and 4 have very similar characteristics except that the average GPA for cluster 3 is 1.88 and the average GPA for cluster 4 is 5.81. What could make this difference? By looking at the clustering statistics by major, it is noted that 43.27% courses taken by the students in cluster 3 are network and security courses, only 30.51% courses taken by these students are software development courses. On the other hand, only 34.53% courses taken by the students in cluster 4 are network and security courses, and 39.97% courses taken by these students are software development courses.

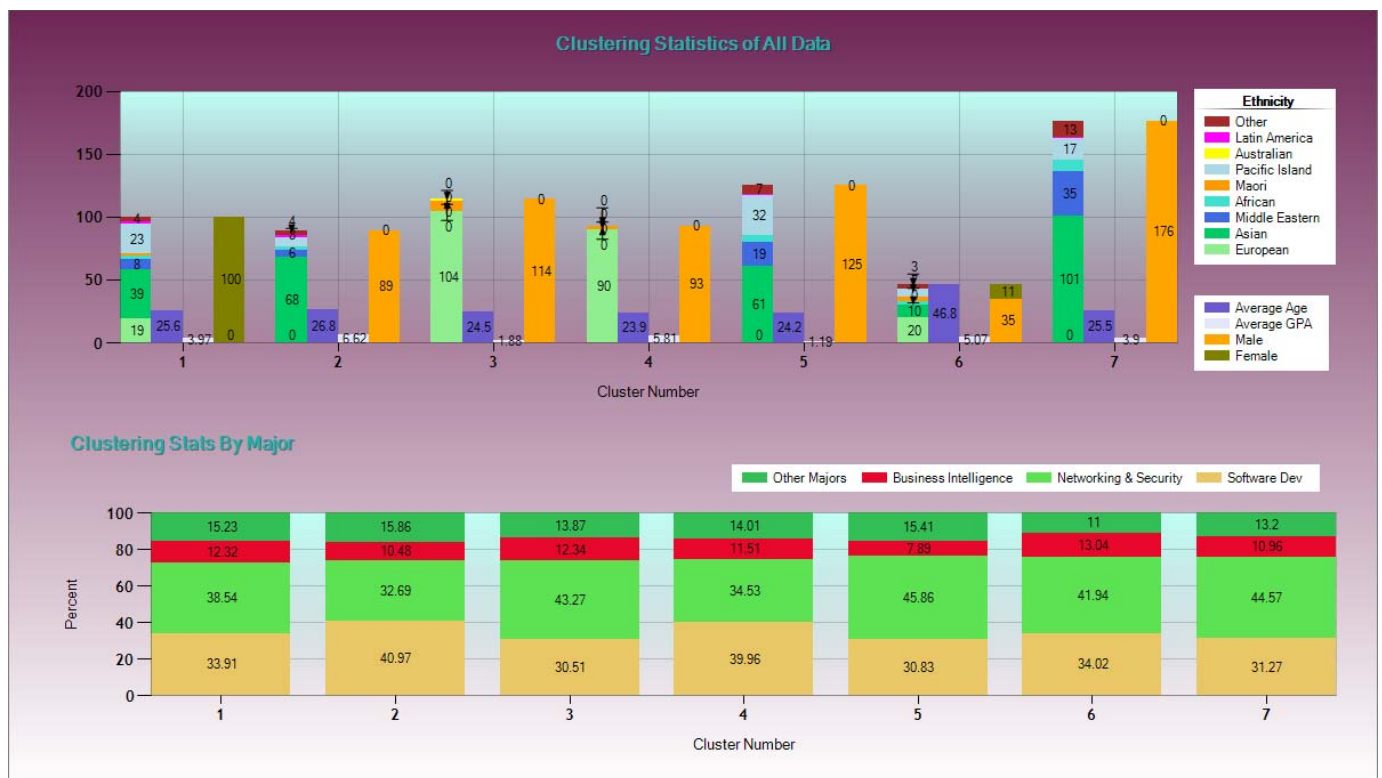


Fig. 13. The whole data set clusters for K=7.

The following is a comparison of the top 12 most popular courses for cluster 3 and cluster 4.

Excluding some basic courses such as “Operating System Fundamentals”, “Professional Skills” “Information Systems in Business” and “Project Planning and Control”, we have the following two lists:

Top most popular courses for cluster 3 are:

- Hardware Fundamentals
- Introduction to Databases
- Programming Fundamentals
- Networking Fundamentals
- Hardware Technology
- Multimedia and Web Development
- Network Administration and Support
- Information Gathering

Top most popular courses for cluster 4 are:

- Programming Fundamentals
- Hardware Fundamentals
- Introduction to Databases
- Multimedia and Web Development
- Networking Fundamentals

- Project
- Database Design & Development
- Hardware Technology

From the above two lists we can see that cluster 3 has four network & security courses and three software development courses; cluster 4 has three network & security courses and four software development courses. And also, in cluster 3, the network & security courses have higher priority and in cluster 4, the software courses have higher priority. This suggests that the low performance students prefer network & security courses, while the high performance students prefer software development courses.

Examining all the clusters in the high performance level (cluster 2, 4 and 6), software development courses are much more popular than network and security courses in cluster 2 and 4, cluster 6 is an exception, however the student average age is 46.8 which is also an exception.

Examining all the clusters in the low performance level (cluster 3 and 5), network and security courses are consistently (43.27% and 45.86%) popular while software development courses are consistently less popular (30.51% and 30.83%).

Cluster 5 and 7 are in the similar situation, however, the GPA difference between the two clusters is not that larger, 1.18 and 3.3. Still network courses are more popular in cluster 5 than cluster 7. On the other hand, business intelligence courses are more popular in cluster 7 than cluster 5.

The above also suggests that the low performance students are more likely in network major and high performance stu-

dents are more likely in software major. So in addition to the four attributes used modelling a student in this system, major is another possible attribute.

V. SUMMARY

Based on our experiment data, it was identified that when $K=7$, the clusters generated from the K means algorithm are more informative and effective.

An outline of the procedure to provide recommendations in the IA component was given. These recommendations can only provide a rough guideline to the students for course selection and major selection.

It is meaningful to use the training data to predict the preferences of the testing data; however, there is a big difference (around 10%) in the course distribution for cluster 3 for all the majors. Further investigation is required to find the reason for this and the way to improve this.

The K-means experiment results on the whole data set ($K=7$) suggested that male students aged between 24 and 27 in the software major, mostly of European, Maori and Asian backgrounds, as well as middle aged (around 45) students are more likely to be high performance students. On the other hand, young male students with network major are more likely to be low performance students. Strategies on how to help low performing students to improve their performance and the high performing students to maintain their level of high performance should be developed and integrated into the advice given by this system.

The experiment results also suggested that major is a possible factor that is related to the students' performance. In the next version of the system, in addition to attributes (GPA, age, ethnicity and gender) in the current student model, major should be added as another attribute in the student model.

Existing records in our current student management system are used. While this facilitates the seamless integration between the advising system and the current student management system, the information that can be extracted from the data is limited, and therefore the attributes that can be used to model students are also limited.

Another area to explore is how closely these results based on the 743 student records represent the entire student population.

Further work is planned using a two phase approach similar to the work done by [11] combining the well-known Cobweb

algorithm with K-means. Cobweb will be used to produce a balanced tree with sub-clusters at the leaves as in [11], and then K-means applied to the resulting sub-clusters.

Future work will also involve taking learning styles into account as well as how best to incorporate advice regarding new elective courses in to the system.

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Campus Integrated Project-Based Learning Course in Civil and Environmental Engineering

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Abstract—A hybrid project and service based learning course has been introduced in the Department of Civil and Environmental Engineering (CEE) at the University of Illinois. The primary objectives of the course are to develop engineering problem solving, professional, and business skills earlier in our CEE undergraduate curriculum by having student teams identify open-ended, ill-defined campus/community problems or opportunities, develop a feasible project scope, and propose sustainable solutions.

The unique features of our course include (1) a blend of service and project learning with faculty instructors partnering with the campus engineering staff to assist with team project mentoring, campus data collection, local field trips, and case studies, (2) formal course assessments through pre and post-class survey and student focus group interviews, and (3) weekly instructor meetings that consist of faculty, teaching assistants, department administrators and engineering staff updating the course during the semester and planning major changes for the next course offering. In this paper, we describe the course organization and its curricular evolution along with evaluation data from student surveys and focus groups as well as the impact of routine instructor community of practice meetings.

Keywords—project based learning, interdisciplinary team projects, case study, field trips, service learning

I. INTRODUCTION

With a new generation of highly motivated engineering student who yearn for hands-on experiences, project and service based learning curricula are a key asset for preparing engineering students for solving 21st century societal challenges as well demonstrating the importance of the university campus experience. Project-based learning (PBL) involve student engagement in open-ended, complex problems and direct student activity towards producing an end product [1]. Student projects are based on challenging problems that parallel similar activities of practicing engineers [2]. Successful exposure to open-ended problems, which present students with conflicting goals, are integral to the development of the ability to apply the principles of engineering while serving within their profession [3]. In addition, students are able to work more autonomously in generating realistic products which allows them to construct and reflect on their own learning. Chinowsky, Brown, Szajnman, and Realph [4] note “by empowering students to learn outside of classroom lectures and developing contextual situations in which they can apply content, universities are much likelier to produce graduates who are able to apply their knowledge in the real world and continue to build upon it in the absence of lectures”.

PBL courses are not new to engineering [5]. One of the motivators in wider adoption of PBL courses within engineering programs has been the industry. Gaps between graduates’ knowledge of principles of engineering and their ability to apply and synthesize these principles were noted [6], as well as a fragmentation of their knowledge [7]. More recently, employers have demanded greater development of students’ non-technical skills such as written

communication, project management, and teamwork [8]. Several studies have found gains in these “in-demand” skills from active participation in both problem and project-based learning [9]. In addition to improvement in non-technical skills, students engaged in PBL score higher on performance assessments, skill-based assessments, and long-term knowledge acquisition as compared to traditional didactic instruction [10-11].

Service learning (SL) courses simultaneously engage students in academic activities and community service experiences, which provide non-structured academic content and develop non-technical skills, such as, communication, and community engagement. [12-13]. SL experiences were also found to improve professional skills such as decision making, ability to make presentations, and improve interpersonal skills [14]. Webb and Burgin [12] found “significant parallels between factors contributing to successful community engagement and effective teaching and learning by students”. SL was also linked to greater retention of students within engineering programs, particularly for students who are members of minority groups [9].

Fully integrating PBL or SL into large, historical engineering departments are challenging because of the inertia in changing the significant quantity of fundamental science and engineering classes as well as campus level minimums for the number of humanity and social science classes. Therefore, Civil and Environmental Engineering (CEE) curricula evolution has generally lagged updates seen in newer departments (e.g., bioengineering, systems engineering).

The University of Illinois’ Department Civil and Environmental (CEE) continues to be a top-ranked program in the U.S. For years, the college of engineering and CEE undergraduate curriculum has provided students with very strong background in the fundamentals of science and engineering but with limited integrated exposures to team projects accept in the senior year as required by ABET. Based on alumni surveys, observations of other institutions engineering curricula, need for greater professional competency, and the literature [15-17], several faculty recognized the gap in our curriculum to provide a team-oriented project or service experience for early-year undergraduate students that could fulfill multiple learning objectives such as developing interdisciplinary problem solving, professional skills (leadership, project management, and entrepreneurial), and business skills (communication, interpersonal, and teamwork). In 2013, a hybrid project and service based learning course was launched to fulfill the aforementioned objectives with four instructional components: (1) self-selected team projects, (2) faculty presented case studies, (3) field trips to local civil infrastructure facilities, and (4) regular assessments through weekly instructor meetings, formal surveys, and student focus groups.

Through an intimate collaboration with the campus facilities and services engineering group, this course is

"intrapreneurial," giving it a unique flavor of service learning mixed with projects that are more constrained in scope. This course provides a unique experience for our early year undergraduate in civil engineering by combining project and service based learning. Through this integration, we hoped to realize gains in both content knowledge and non-technical skills such as writing found in traditional faculty led project courses while also finding gains in interpersonal skills found in traditional service learning courses.

II. COURSE OVERVIEW AND ASSESSMENT

Our hybrid CEE project and service based learning course offers a blend of team-oriented semester projects, discussion-driven case studies, and instructor-led field trips to local infrastructure facilities. Students collaborating in teams of three to four select a campus problem or opportunity of interest. With mentoring from a team of interdisciplinary faculty from Departments of CEE, Agricultural and Biological Engineering, English, and the campus engineering staff, teams define and scope the problem, develop a realistic project management plan, and eventually propose a sustainable solution. Project themes revolve around engineering sustainability, which engages teams in learning opportunities and creates synergy across many disciplines. Table I is an example of several of the projects students accomplished over the past two years. Through team project work, receiving peer-to-peer team project reviews, and instructor feedback, students develop necessary life-long learning, professional, and business skills that are under-emphasized in our current engineering curriculum.

TABLE I. TEAM PROJECTS

2014 Project Tiles	2013 Project Titles
Feasibility of Green Wall Building Retrofit at Krannert Art Center	Evaluation of algae-based bio-binder for asphalt replacement
High efficiency toilet upgrades and water management	Energy production from swine manure
Feasibility of Solar Panel Parking Lot	Evaluation of the possibility of using raw water on campus
Introducing LEED Lab Campus Course	Business Instructional Facility (BIF) energy assessment – LEED Platinum Certified
Grey Water Collection and Use in Campus Buildings	

Formal student surveys and focus group data collected by evaluation professionals in the College of Education, combined with the weekly instructor meetings, and collaboration and mentoring from faculty with engineering education expertise, helped refine the course over a two-year period. A result of these formative evaluation activities and discussions during the weekly meetings led to the conclusion

that students' writing/communication and project management skills need strengthening, and thus the course evolved to formally include these objectives. In addition, significant class time is allotted for students to conduct their team project work and receive guidance and mentoring from course faculty and campus engineering staff, teaching assistants, and other subject matter experts.

III. UNIQUE COURSE FEATURES

This hybrid course combines aspects of project and service based learning experience while encouraging engineering faculty and campus facilities and services engineering staff (i.e., course instructors) to collectively mentor student teams. An instructor's community of practice was established from the initial course development and implementation in order to foster ownership among multiple faculty members so that longevity of the course is assured. Research has demonstrated that regular meetings and broad faculty engagement along with departmental leadership involvement is the most significant factor in maintaining the stability of a course. Course changes are done in conjunction with formal student feedback from surveys and focus groups, as well as feedback from the engineering education on how to adapt evidence-based reforms in the course (e.g., use of active learning with i-clickers and successful practices adopted from other PBL and SL courses). Additionally, the case studies instruct students in the process and skill of solving engineering problems that are required for their team projects. Field trips provide an exciting student experience on the complexity of engineering infrastructure and a connection to their career studies and projects. Finally, the second hour of the weekly class was reserved primarily to establish regular interactions between the student teams and faculty/engineering staff mentors.

IV. COURSE BACKGROUND AND FORMAT

The hybrid PBL and SL course in CEE is two credit hours and meets once per week. The course is designed for sophomore students in CEE but is broadly advertised throughout the campus to include any engineering or non-engineering disciplines. The class is organized with a faculty course director, multiple faculty instructors who present case studies, lead field trips, and provide expert feedback; engineers from the campus facilities and services (F&S) department; and two teaching assistants, who actively participate in weekly classroom activities. Several additional professors and community professionals contribute to several case study lectures throughout the semester. A professional writing instructor from the English department is also now part of the course, providing students with formal feedback on their semester project reports and presenting technical writing tips.

Throughout the semester, seven case study lectures (see Table II) are presented by faculty on contemporary topics covering a particular area in infrastructure engineering and sustainability. The main case study objective is to teach students the process of engineering problem solving by examining real engineering challenges and opportunities. Prior to each case study lecture, students are expected to read background material on the lecture topic and take a ten-

question quiz. Each case study is designed to be interactive with the faculty delivering probing questions via i-clicker technology in order to lead to facilitate faculty-student dialogue and promote additional inquiries.

Several case studies are integrated with field trips to local civil and environmental infrastructure facilities. The four field trips, listed in Table II, combined with the case study lecture, provide students with opportunities to actively participate in a complex engineering problem and solution in the classroom and in the field, experiencing live and the multidisciplinary nature of designing and building civil infrastructure facilities.

Team projects are key to teaching students how to define a problem or opportunity, propose a solution or feasibility study to their problem, identify what component can be solved in a semester time span, execute a plan of action, and communicate the results in various formats (proposal, interim report, presentations/poster, and final report). This team format is intended to acclimate students to working across disciplines at an earlier point in their undergraduate educational experience than what is normally required in our CEE department. One of the course's goal is to transform our more traditional approach of solving problems in early years of CEE education from a compartmentalized and individual approach into multidisciplinary problem solving team with students from different CEE concentration areas and across the campus.

TABLE II. CASE STUDIES AND FIELD TRIPS

Case Study Lectures	Faculty / Expert	Field Trips
Urban Stormwater Management and Green Infrastructure	Professor, Environmental Hydrology and Hydraulic Engineering	Urban stream passing through campus and designed for city stormwater management and visual amenity
Wastewater Treatment and Biofuel Production	Professor, Agricultural & Biological Engineering	Champaign-Urbana wastewater treatment plant
Power Generation and Infrastructure	Director, Campus Facilities and Services	Campus Cogeneration Abbott power plant
Building Information Modeling (BIM) and 4D Visualization for Construction	Professor, Construction Management	Construction project of new student residence hall integrated with BIM
Construction Material Recycling – Resource not Waste	Professor, Transportation and Construction Materials	
Structural Health Monitoring of Railroad Bridges using Wireless Smart Sensors	Professor, Structural Engineering	
Urban Design and Human Health	Professor, Landscape Architecture	

Teams are formed after several weeks of formal and informal project idea exploration. Students take an initial

pre-semester survey on project themes that they are most excited about and then during multiple organized sessions, students communicate with each other and campus experts and instructors to better define project themes. During the next step, students draft a three-page proposal laying out project objectives, scope, tasks, required resources, and project timeline. As the semester progresses the students gather project information and data via the literature, interviews, observations, and interactions with mentoring from the course faculty and experts. An interim project report is required two-thirds into the semester that provides valuable feedback to teams and allow for changes to projects to meet end of the semester goals. At the end of the semester a final project report is submitted summarizing the findings and accomplishments by the teams. The course culminates in a team project poster presentation that is judged by practicing engineers from the campus and local community.

Informal technical feedback is provided weekly by student-instructor interactions and by the teaching assistants during class and office hours. Technical writing comments are first provided by the English instructor for all deliverables, secondly through peer review, and finally during final grade assignments for each deliverable by course faculty. Students have verbal communication opportunities during periodic three-minute presentations given by each team to communicate project objectives, status, and key findings.

V. COURSE ASSESSMENT AND EVOLUTION STRATEGY

Several key components of the course development and reformation actively utilize student assessment and evaluation data along with weekly instructor meetings. To assess the effectiveness of the course in accomplishing its learning objectives and gather formative feedback to inform course improvements, students were asked to complete questionnaires at the beginning and end of the semesters as well as volunteer for an end of the semester focus group discussion. A complementary WIDER grant from the National Science Foundation, focusing on evidence-based active learning reforms for science, technology, engineering, and math courses, was instrumental in providing expertise from an external evaluation team from the College of Education. This team led development of the survey instrument and focus group guide and conducted the data collection and analysis activities with approval by the University of Illinois Institutional Review Board.

The course was designed to include a cooperative teaching environment with weekly meeting of primary instructors (faculty and campus engineering staff), teaching assistants, and teaching pedagogy experts during the semester and monthly meetings off-semester. This enables necessary changes to the course during the semester while also giving time for strategic planning and changes for inclusion in the next course offering. All instructors were invited to participate and provide feedback to the instruction team. The weekly instructor meetings assessed the previous week's case study activities, including the field trip and project progress, and provided mid-course adjustments as

needed. Long-range planning and course refinement occurred primarily in the off-semester course meetings.

A. Student survey

At the beginning and end of the semester, students were asked to anonymously and voluntarily complete an 18-question pre/post-survey, which included both close- and open-ended questions. Survey questions were designed to assess the following: 1) students' perceptions of the helpfulness of course activities and the course overall for their engagement and learning; 2) changes in students' perceived level of engineering, professional, and business skills and perceptions of engineering as a profession; and 3) influence of the course on students' future engineering-related career plans. Additionally, student demographic data was collected including gender, race/ethnicity, international and language status, and academic standing. Pre-post changes in students' responses to select survey items before and after students completed the course helped provide evidence of the effectiveness of various components of the course for developing students' knowledge and skills and perceptions of engineering as a profession. The surveys were completed by 61% of the students. Both survey results were analyzed by course instructors and teaching assistants. Post-survey results were analyzed by the external evaluation team.

B. Student focus group

At the end of the course, all fifteen students were invited to voluntarily participate in a focus group discussion conducted by the external evaluation team who had not previously associated with the students. Two forty-five minute group interviews of 7 (4 male, 3 female) and 6 students (4 female, 2 male) were held during class time. Open ended questions were given to spark feedback and discussion regarding general topics such as the course structure, the students' assessment of what they learned, skills they used, and how this course has influenced their understanding of the engineering profession and their role in it. Interviews were audio-recorded, with permission from all participating students, and anonymous transcripts were analyzed by the external evaluation team and summarized for the course instructors [5].

VI. ASSESSMENT RESULTS

In this section, we provide brief descriptive information regarding students who participated in the 2014 survey, focus group interviews, and changes to the course made based on the evaluation data. We provide the survey mean on a 1 to 4 point scale, where 1 means either poor, not interested or not important and 4 means excellent, very interested or very important. A sample of the some of the key results are summarized next.

A. Course Format

Students reported that all aspects of the course enhanced their learning experience. Students scored the best components of the course to be field trips (3.88), research experience (3.75), project-based learning (3.63), and developing their project-management skills (3.63). Additionally, in both the questionnaire and focus groups,

students reported that interacting with practicing engineers was helpful because these interactions exposed them to different areas of engineering. They also reported that the field trips were helpful because they provided hands-on, experiential learning, and the project proposals were helpful for learning project management skills, e.g., start a project, set a timeline, and technical writing as noted in the student quote below:

I find the opportunity to develop and pursue a project to completion the most helpful. This class exposes underclassmen civil engineering students to the field because they choose a project to tackle and complete the project in a given period of time. Just like they would in the industry. It is a unique class that allows students to develop technical and applied skills rather than the theory that is learned in most other classes. – Student

Students valued having multiple instructors for hearing a diversity of perspectives, especially at the beginning of their projects, and for learning about a variety of engineering subfields as noted in the following quotation.

The four consistent instructors that we had, they each specialized in something different, so if we went to one instructor and asked them for advice, it would be different than what another instructor would say. That's good because it helped us get different views, and we decided which view we wanted to integrate for our own proposal. It was really good to have multiple resources to go to. – Student

B. Learning and Engagement

Students rated the course most helpful for thinking about the material rather than just memorizing it (3.75), understanding what it means to be a professional in this discipline (3.63), building on prior knowledge in this discipline (3.63), taking ownership over what I learn rather than only relying on the teacher (3.63), feeling excited about learning (3.63), and working with peers to solve problems (3.63). Students noted that they developed a variety of important skills related to project development and management including how to write proposals, how to interact with other professionals in the field, communicating data, and working with others. Additionally, several students stated that this course helped them realize the value of doing projects that had a real impact on people and society.

I think starting a project from the beginning, and trying to imagine where it's going to go two months from then was really helpful because that's not something we'd done before, but it's going to really pertinent to our careers. – Student

Survey results taken before and after completing the course, shown in Figure 1, show the change in overall student self-rating of their project, communication, and teamwork skills. Collectively, the students self-assessed an improvement

from mostly fair (2.79/4.0) to (3.52/4.0) good/excellent in their own project, communication, and teamwork skills, most significantly in their written communication. Overall, the student focus group responses had mixed reactions about the writing instructor despite strong self-assessment of the importance of technical writing. International students felt the writing instructor support was helpful and improved their proposals.

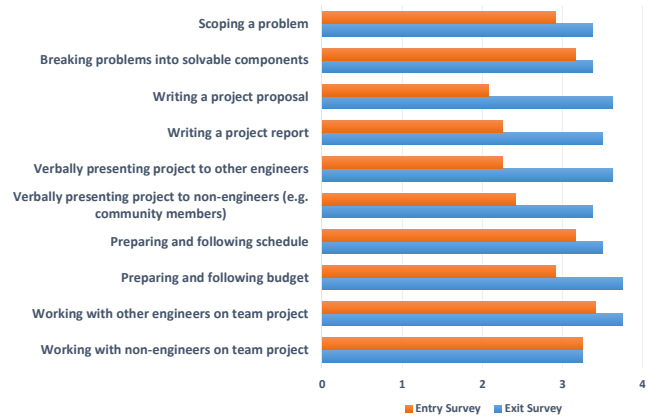


Fig. 1. Students' self-rating of project, communication and teamwork skills before and after completing the course in fall 2014

VII. SYNTHESIZING COURSE ASSESSMENT INFORMATION

Results of the student feedback relative to the overall course objectives, fostering improved student-instructor engagement, and implementing a collaborative teaching and feedback environment within a community of practice was largely successful. Multiple instructor involvement with their own particular specializations was an effective method for discussing a wide range of topics and added a layer of confidence that students were receiving exposure to the latest research and trends in many fields. As one student put it “it’s really nice having each topic presented by someone that knows it really well—and specializes in it.” Another student benefit of involving experts to present case studies is that data being presented about real projects familiar to the expert hold students attention and sparks discussion.

The critical mission of campus division of F&S is to support the academic engine of university, and a connection to F&S was a critical component of this course. The partnership with F&S connected students to their projects with data sets and campus F&S engineering professionals. One student said, “One of our ideas could actually be implemented in the university—knowing that, that’s pretty cool.” F&S has been instrumental in refining problem statements, providing data, mentoring students, and presenting a case study and hosting the field trip at power plant and their continued participation in our course is critical.

When students were asked what the most important skill that they learned in the course was, their overall comments expressed how important professional writing is and the

value of good communication skills, which validates keeping a technical writing aspect to the course as well as continued opportunities for student presentation of projects. Field trips were ranked as the most interesting aspect and the most helpful for understanding the roles of engineers. Although arrangement and supervision of field trips are time consuming, clearly students gain tangible experience from them and thus they are an essential part of the class. Case studies provide an early opportunity for many students to learn what engineers do and show students how to frame a problem, which in turn assists them in their team projects and future classes.

VIII. COURSE CHANGES STEMMING FROM STUDENT AND INSTRUCTOR FEEDBACK

The student and instructor feedback led to changes between the first and second year of the course. The main changes included adding a case study on structural health sensing and monitoring as well as adding an English department instructor to provide formal technical writing feedback to students prior to instructors grading the delivered reports. Teaching students how to write clear project objectives, how to define a problem, and how to establish tasks and distribute them among team members during the course's first offering was not overly successful but during the second offering formal training was given and the students responded positively. The course schedule was also altered to give more in-class time during the beginning of the semester for students to develop their project ideas. Finally, time was given at multiple points in the semester for students to orally present their project progress both for their benefit, and so that teams could learn what the other teams were doing.

Modifications to the next offering of the course in the fall 2015 will include refining the project identification process to include assignment for individual students to generate project ideas based on campus needs, presentation of each student's top two project ideas, and delaying team formation and initial project proposal deliverable. Several case studies will be introduced earlier in the course to accommodate more time given to project idea development. A learning management system software (ScholarTM) will be implemented to allow for online collaboration across and within the teams, a semantic writing tool for project reports, pre-class quizzes, peer review, instructor grading, report editing statistics, permanent archiving of the team projects, and scaling the class to larger number of students. The introduction of this course into CEE is currently only an elective but effort is underway to make it a core requirement for sophomores in our undergraduate CEE curriculum. Finally, the pedagogical innovations and lessons learned from this course is already impacting senior design course in our CEE curriculum.

IX. CONCLUSIONS

The development of a hybrid project and service based learning course at the sophomore level for the Department

of Civil and Environmental Engineering at the University of Illinois provides a major shift from the traditional faculty lecture format used in most CEE courses. Additionally, transforming students' traditional way of solving problems from an individual, compartmentalized approach to a multidisciplinary problem solving team approach at earlier years in the undergraduate curriculum will acclimate students to think like an engineer and allow them to work across disciplines more efficiently in the junior and senior years. The primary objectives of this course are to teach students problem solving, professional competency, and business skills as well as to identify as a CEE. The objectives are met through intimate collaboration with the campus engineering staff, discussion-driven case studies led by the course instructors, field trips to local civil infrastructure facilities, and most importantly through student-defined team projects related to a problem or opportunity observed on our campus through hands-on learning experience.

Current successes in the course derive from a strong instructor community of practice that facilitate activities such as weekly meetings during the semester and monthly meetings when the class is not in session, discussions of improvements, and incorporation of research based instructional strategies. Formal course assessments rate student-instructor interactions and subject expert feedback as an important aspect of the course. The course's success is also intimately linked to the expertise provided by campus engineering personnel, evaluation experts, engineering education experts, and English writing expertise. Additionally, the collaborative teaching environment ensures that the course reforms are sustainable over the long term.

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Using Modern Pedagogical Tools to Improve Learning in Technological Contents

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Abstract— According to Federal Council of Engineering, in Brazil the Engineers deficit is estimated at about 20,000 per year on several areas of engineering. Among other factors, one of the causes of this deficit is the high failure rate in the disciplines within the technical area which causes students to take up to twice the time required to complete the course. This phenomenon is also reflected in the Vocational courses of the Engineering area mainly because the students are teenagers that quickly discourage before traditional classes. Therefore there is a failure to achieve the goal of education and considering the specificities of each student deficiencies. One of the issues that has been extensively studied in recent years is how we can improve the teaching of technical subjects in vocational courses and engineering that, in Brazil, have a failure rate that reaches 40% in some cases. In countries with more developed education, such as Finland, Sweden, Korea and others, they are already using more modern methods aimed at excellence in learning, such as "Project Based Learning", "Collaborative Learning", "Learning by Doing", "No Child Left Behind", among others. These methods change the educational philosophy and teaching bases, putting the student as a central element of learning and working their specificities and self-development in a participatory and motivating environment. Thus, this paper presents the use of these modern methodologies applied to technical vocational education in the Federal Institute of Amazonas, in Mechanical Areas, Electronic and Electrical Engineering, in subjects in which failure rate reached 40% when using the traditional teaching used by the Campus. The results of using these methodologies in four groups involving about 120 students demonstrated substantial improvement in the learning of technical subjects, with consequent reduction in the failure rate and increase the motivation and self-esteem of students to give continuity to the studies in this area and join Engineering courses.

Keywords - Project Based Learning; Collaborative Learning; Learning By Doing.

I. INTRODUCTION

In Brazil there is a deficit of professionals from the fields of technology. Particularly in the area of Engineering, this deficit reaches 150,000 professionals as pointed out by the study conducted in 2012 by the National Confederation of Industries - CNI. In addition, the offer of courses in technology is limited; the situation becomes more complicated because of the high rates of dropout and retention of students. Due to failures in technical disciplines, students have no success in completing their courses. Usually, in Brazil, the students feel demotivated in traditional classes which do not catch their attention.

In these traditional classes, more often, the specificities and weaknesses of each student are not considered, and this can be

understood because the philosophy of education in Brazil is more centralized in the teacher and in the contents that have to be shown.

The necessary students' motivations to the conclusion of their studies and ingress in the engineering faculty are a problem in vocational education in Brazil. Some of the students who started a vocational course in engineering area did not continued in the same area; instead they changed to another course/area when they went to the university.

Another problem when the student starts in a vocational course in Brazil is the disabilities originated from basic levels. Consequently, it is necessary the search of new methods, alternative teaching and learning processes to improve this condition that negatively influences the development of technological professional education in the country.

Furthermore, in [1] the author says that the environment of education needs to adapt to the actuality. Currently the changes that came with the digital age and new technologies have made the teacher to reconsider his goals and teaching methods. The first step indeed is to identify what is the key knowledge and skills that students need in a digital age and how the technology is changing everything, including the context in which the contents are taught. Is it effective to use only a blackboard and chalk where the students are accustomed to the interactivity of smartphones and social networks? Therefore it all has to be evaluated and considered.

Granted that in countries where the education has excellent results, such as Finland, Sweden, Korea and others, they have used more modern methods to obtain the excellence in learning, for instance Project Based Learning, Collaborative Learning and Learning by Doing, among others. The Finnish education to illustrate is among the best in the world. One of the factors behind this success is the constant formation and teacher training both in educational area as in operational area, also investment in modern tools and equipment that facilitate learning in the classroom, technical laboratories and computer resources [2].

In Brazil there are more than 500 campuses in the Federal Institutes of Technological Education - IF, that are a net of public college sponsored by Brazilian government, free of charge. These Institutes are nowadays the main place to study vocational courses and also engineering courses.

In the Amazonas state, There is an IF called Federal Institute of Amazonas - IFAM, where it was started a project to improve the teaching and learning processes using modern pedagogical tools applied to technical vocational education. Were chosen two different Campuses and three vocational technical courses divided in four groups involving about 120 students. The first Campus is from Presidente Figueiredo city, in the middle of Amazon rainforest, and the other one is from Manaus city, the capital of the Amazonas state. In both Campuses the results show a substantial improvement in the learning of technical subjects and the increase of student's motivation.

II. MODERN PEDAGOGICAL TOOLS USED IN THIS WORK

In this digital age, several countries started the use of new pedagogical and technological tools, and there are several "innovative" approaches to teaching that actively involve the student in a "student centered learning" perspective.

There are actually a wide variety of approaches to facilitate students learning together (as opposed to learning individually). In this work we used three of this approaches that are described in the next subsections: Collaborative Learning, Learning by Doing and Project Based Learning. These approaches are considered new and modern at IFAM according to our reality; despite they are used in other places since years ago.

A. Collaborative Learning

The most common definition to collaborative learning is the situation in which two or more students learn or try to learn together some content [3]. The learning could occur in a small group, in a class, in a community with thousands of people or in a society with hundreds of thousands of people. Many authors, including [4] and [5], consider the collaborative approach more efficient then individual approach.

Collaborative Learning is an educational philosophy, not just a classroom technique. In all situations where people come together in groups, it suggests a way of dealing with people which respects and highlights individual group members' abilities and contributions. In the collaborative model groups would assume almost total responsibility for answering the question, solve the problem or execute the project.

In Collaborative Learning, the group determines if they had all the elements to realize their job. If not they look for other information sources until they have the necessary knowledge. A basic planning is necessary and the tasks divisions are decided by the group work. Each member contributes with his skills to obtain synergy. Although it is true that work in group is not a trivial task (especially in Brazil) and the natural leaders appear in the group to facilitate this challenge. The group would decide what to do, how to do and how to show their results, but the final product is determined after consultation with the teacher. [6]

The teacher has an important contribution in this process, which is not specify the actions but rather assess the progress of each group and provide suggestions about each group's approach and the results achieved. The teacher would be available for questions and would facilitate the process by asking for progress reports from the groups, facilitating group discussions about group dynamics, helping with conflict resolution; he will act as a coach.

According to Vygotsky [7], the students are capable of performing at higher intellectual levels when asked to work in collaborative situations than when asked to work individually. Group diversity in terms of knowledge and experience contributes positively to the learning process. There are several benefits to apply Collaborative Learning, and in [8] some of them are presented, based in students' feedback after a Collaborative Learning project and the results with main answers were as follow:

- Benefits Focusing on the Process of Collaborative Learning
 - Helped understanding
 - Pooled knowledge and experience
 - Got helpful feedback
 - Stimulated thinking
 - Got new perspectives
- Benefits Focusing on Social and Emotional Aspects
 - More relaxed atmosphere makes problem-solving easy
 - It was fun
 - Greater responsibility- for myself and the group
 - Made new friends
- Negative Aspects of Collaborative Learning
 - Wasted time explaining the material to others

The major challenge in this job to use collaborative learning was the Brazilian culture. Brazilian students are very social and creative but usually they have an aversion to commitments and difficulties to punctuality and deadlines. Because of this, the teachers' action was fundamental to help them to stay focused in their tasks.

B. Learning by Doing

One of the most important problems when we are using traditional teaching methods is that students are not learning skills; these teaching methods are centered in teachers and in transferring contents that can be found in the learning goals defined in school curriculum [9].

In vocational technical courses there are the practical classes but, in some cases, this "practice" is used to confirm or valuate the knowledge. For instance, a student from Mechatronics course needs more than to know about the technological contents, he needs to know how to do a specific task.

The Learning by Doing approach, or experiential learning, can be defined as "the strategic, active engagement of students

in opportunities to learn through doing and reflection on those activities, which empowers them to apply their theoretical knowledge to practical endeavors in a multitude of settings inside and outside the classroom” [1].

The Learning by Doing method disposes the student as the central focus of learning. It makes him able to build cognitive learning through proposed problems that submit him to the motivating situations.

Thus, the student ceases to be passive in the education system and becomes the central object of his own development. The teacher is no longer the only knowledge provider. The lectures with unilateral transmission of knowledge disappear to transform the class in a room for interaction with the construction of knowledge fostered by discussion and research, encouraging the participation of the student inserted in a group.

The choice of this work in using Learning by Doing method is to improve the student's skills to help them climb the pyramid of taxonomy of cognitive domain, as shown in Figure 1, in which the student is leaving the remembering level to achieve levels of applying, analyzing, evaluating and even creating.

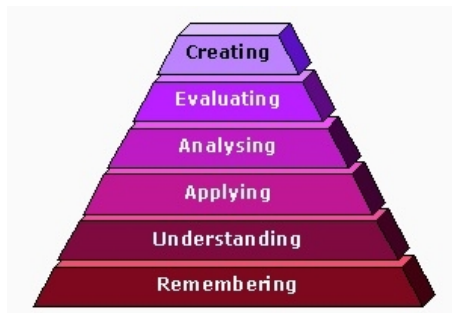


Fig. 1. Revised taxonomy of cognitive domain. Image: © Atherton J S (2013) CC-NC-ND [10].

There is a wide range of design models that aim to embed learning within real world contexts, and all of them focus on learners reflecting on their experience of doing something, so as to gain conceptual insight as well as practical expertise. Kolb’s experiential learning model [11] suggests four stages in this process:

- Active experimentation;
- Concrete experience;
- Reflective observation;
- Abstract conceptualization.

The result of Learning by Doing approach is a curious, motivated, challenged, creative and with entrepreneurial spirit student, ready to lead and work as a team. In general, the classes become a discussion workshop on real problems and the teacher becomes a mediator, far beyond a simple transmitter. The student who had been subjected to this methodology in the learning period is able to make practical and harmonious decisions, as experienced unusual situations

in practical applications of simulated problems or even real world problems.

C. Project Based Learning

In recent years Project Based Learning – PBL, one of the most effective tools used in technical subjects and engineering education, has become increasingly accepted as a useful concept in engineering education. PBL is becoming the favored pedagogical model for teaching engineering design to transform methods of teaching to address more complex open-ended real-world problems [12].

In [13] the author makes a Project Based Learning (PBL) review. PBL is a learning model that organizes learning around projects. According to definitions found in books and handbooks on the subject, projects are complex tasks supported in challenging questions or problems involving students in planning, problem solving, decision making, or investigative activities; Gives the opportunity to the student to work with relative autonomy; culminates in realistic products or presentations.

Projects involve students in a constructive research and an investigation is a process directed to a target that involves research, knowledge building and resolution. One question involved in this issue is, "what a project must have to be considered PBL?" There are five criteria [13] for the answer to this question. The five criteria are centrality, guiding question, constructive investigations, autonomy and realism.

In short, in PBL the projects are the central teaching strategy. Students learn the central concepts of the discipline through the project. PBL projects are focused on questions or problems that lead students to find the core concepts and principles of a discipline, besides involving constructive investigations.

An investigation is a process driven by goals that involve research, the construction of knowledge and resolution. But in order to be considered as a PBL project, the central activities of the project should involve transformation and construction of knowledge, new insights, and new skills for the students. All of this combined with the autonomy and realism.

The projects do not take pre-determined paths. PBL incorporates real-life challenges, where the focus is authentic problems or issues (not simulated) where solutions have the potential to be implemented.

Based in [14] we can affirm that project based learning matches some important teaching principles:

- Situation relatedness: Contents are arranged according to concrete current or future situations.
- Action relatedness: Contents offer assistance and orientation for concrete actions.
- Science relatedness: Contents are oriented both by the level of knowledge as well as by the topics and methods of the respective scientific discipline.

- By examples: Contents were selected so that the wealth of knowledge is depicted by a few typical cases (which are representative for similar issues).

Several studies have suggested standard steps for PBL; however the specific local conditions should be guiding these steps because we need to evaluate the availability of time, physical space, laboratories, equipment, and human and financial resources. Considering the nature of the courses involved in this work, we present the following steps for a generic PBL, which can be adapted to other situations.

- Analysis of the learning domain and involved skills
- Division of the class in groups
- Recognition of each participant in his group
- Conception of collaborative activity
- Planning of collaborative activity
- Implementation of collaborative activity
- Partial evaluation of collaborative activity
- Adjustments and corrections in the implementation
- Presentation of the final result
- Overall project evaluation.

Throughout this process, the teacher's role is to guide and advise, rather than to direct and manage, student work. This is crucial because the students that start their courses in Federal Institute of Amazonas are not used to working by project and therefore has difficulty in self organizing, despite the ease of work in group.

III. APPLYING NEW PEDAGOGICAL TOOLS TO IMPROVE LEARNING IN TECHNOLOGICAL CONTENTS

The teaching philosophy of Federal Institute of Amazonas vocational courses is to foster qualified students equipped with integrated knowledge to science and technology with critical thinking and ethics. One way to attend this is improving the learning and teaching methodologies. In this Section we show how we applied the new pedagogical tools discussed in section II.

A. Expected learning outcoming

First of all, before starting the use of modern pedagogical tools, it is important to set what is expected to the student to achieve when he takes part in this kind of methodology. In this case, after completing the projects, the students should be able to do the following:

- Work collaboratively across disciplines (informatics, electronics, microelectronics, etc.).
- Demonstrate proficiency in the use of appropriate knowledge and tools to solve open-ended real-world problems;
- Gain experience in hands-on, problem solving and team interaction.
- Improve academic performance.

- Demonstrate effective oral and written communication skills in the context of collaborative teamwork.
- Communicate with companies and find opportunities or problems to be solved;
- Understand the fundamentals of project management.

B. PBL implementation methodology

The PBL was developed in stages, starting with a presentation to students about the new learning method based on a project, including collaboration and practice. Then, the class was divided into groups of four to five students who, at first, were presented in the group to realize affinities, strengths and weaknesses of each one. After these initial stages, the used methodology can be summarized in the flowchart shown in Figure 2.

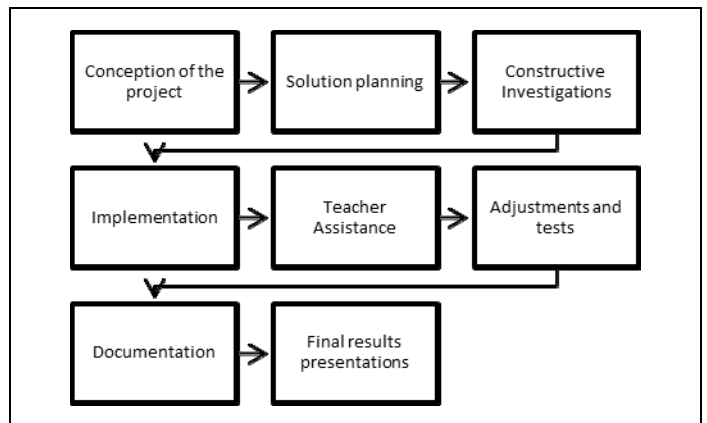


Fig. 2. PBL Methodology used in this work.

The time required for each stage depends on the available time and project complexity. In this work the PBL was developed in a semester and the actions in each stage were:

- *Conception of the project*: The students themselves choose which projects they will work on. They observe community problems that could be solved and have ideas to start their projects.
- *Solution planning*: After students had picked a project, each group, they plan next steps and how to obtain resources needed to support the chosen solution to the problem.
- *Constructive investigations*: Using books, articles, internet and others sources, they make investigations in a collaborative environment that involve research, the construction of knowledge and problem resolution.
- *Implementation*: Students in teams implement their projects in a collaborative and experiential way.
- *Teacher Assistance*: Not only at this moment but especially when the first problems occur, the assistance of one or more teachers is fundamental to help students in their projects administration.

- *Adjustments and tests:* Students make tests and improvements in their projects until the goal is achieved.
- *Documentation:* After all project adjustments, the group writes a technical report about their project, including diagrams, components list, drawings, etc.
- *Final Results Presentation:* The projects are presented to the community and teachers to the assessment of the groups projects. The grading can be based on individual and group performance as well as theoretical learning on project management as it was made here.

IV. APPLYING NEW METHODOLOGIES IN CAMPUS PRESIDENTE FIGUEIREDO

A. Course description

Campus Presidente Figueiredo-CPRF is located in a rural area distant 107Km from the capital of Amazonas state and was founded in 2010. Among others, it offers Mechanics and electrical vocational courses. These courses are offered as full-time and the students take high school along with the vocational course. There was among the students a high failure rate in technical disciplines, difficulty in learning and lack of motivation especially in technical disciplines. Teachers at IFAM apply a variety of teaching and learning methods to support the learning performance of the students. Traditional forms of teaching and knowledge transferring such as the traditional lectures have been being complemented by more self-responsible and activating forms of learning. One of the main reasons is that students do not learn solely through listening but also through facing up and dealing with the learning contents.

In this context we applied modern pedagogical tools, mainly PBL projects, for the students from the last year of these two courses to engage and motivate them to continue in the technological and engineer areas.

B. Project Results

About 60 students of Mechanics and electrical courses of CPRF vocational courses took part in the PBL projects. The Projects have been pooled into twelve teams. The idea or the project itself was suggested by the students themselves.

To obtain success using PBL methodology and allow that students conclude it in a positive perspective, it was important that the projects should fulfill the following:

- be a real problem in their fields and be of direct benefit to the local community;
- include mechanics, electrical, and electronic key components;
- be suitable for 5 students and equivalent to 10 weeks of workload;
- Consider environmental issues and sustainability;
- Include technological innovations.

The steps as shown in Figure 2 were taken to the development of the PBL projects. As a result, follows a list of actual projects developed by IFAM –CPRF students:

- Thermal energy powered engine;
- *Canecatron*: mug liquid mixer;
- Homemade air conditioner;
- Fan;
- low cost irrigation system;
- hydropower generator;
- wind power generator;
- automatic clothesline;
- thermal energy powered car prototype;
- Beetlebot;
- Stirling motor;
- Mousebot.

Specifically one example of the projects is a low cost irrigation system. One student's family has at their place a vegetables plantation. As part of her routine, the student had to wake up very early to water the plantation, and it needs to be watered twice a day. This team implemented an automatic irrigation system using recycled materials that worked as planned and is now being used in the student's plantation (Figure 3).



Fig. 3. Automatic irrigation system being tested - one of the PBL projects implemented at CPRF.

To this end, during the implementation of the projects students had to seek for new knowledge, applying therefore the self-learning methodology in a Collaborative Learning perspective. To consolidate this knowledge the students had to build the actual part of the project, which characterize the Learning by Doing methodology. At every stage of the project the teacher's support was important both motivating and guiding the student's actions.

The students implemented the projects and after all adjustments the projects were presented to the community and the contribution of each student had been graded. The grading was based on individual and group performance as well as theoretical learning on project management.

It can be assumed that almost all students that took part in projects liked the experience. This is a very important fact concerning the question of motivation.

In conclusion, some statistical data are shown in Figure 4 and Table 1. The first one shows a comparison between the approvals rate applying the traditional teaching and the modern pedagogical tools (PBL) approach in the two classes where the projects were taken. It is possible to see that both of them improve the approvals, especially in the mechanics course. The second one shows the class grade point average with and without PBL approach. After applying modern pedagogical tools (PBL) in teaching, students' performance had improved substantially. Where the improvement were 24,8% and 67,8%, and again, the biggest improvement occurs in mechanics course. This confirms the potential of this methodology.

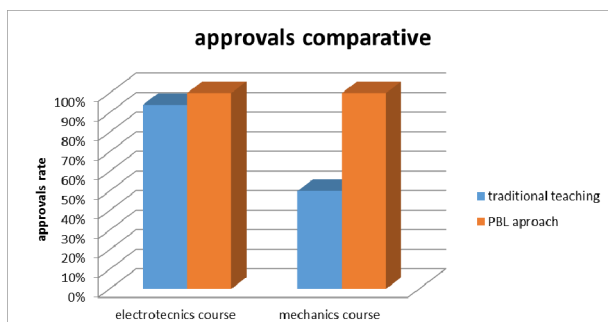


Fig. 4. Comparison between the approvals rate applying the traditional teaching and the modern pedagogical tools (PBL) approach in the two classes where the projects were taken.

TABLE I. CLASS GRADE POINT AVERAGE APLYING PBL APPROACH AND WITHOUT PBL APPROACH.

Class GPA	Mechanics students	Electrical students
Without PBL approach	5,63	7,65
Applying PBL approach	9,50	9,55
Percentage Improvement	68,7%	24,8%

Table 1 – This is a comparative of Class GPA with modern pedagogical tools (PBL) approach and without PBL approach.



Fig. 5. PBL projects and students in the implementation stage. The pictures show diferent groups acting in diferent projects.

The PBL Project exhibition, Figure 5, has become a mandatory item on the development of the activities of teaching, research and extension at CPRF making it a determinant factor in the formation of our students for the labor market and promotes the motivation for continuing in engineering courses.

V. APPLYING NEW METHODOLOGIES IN CAMPUS MANAUS DISTRITO INDUSTRIAL

A. Course description

Campus Manaus Distrito Industrial - CMDI was founded 23 years ago in the city of Manaus, Amazonas state capital, which has about 2 million inhabitants and more than 600 industries of electronics devices and motorcycle. CMDI offers courses in engineering area, acting in engineering and vocational technical education.

Among these courses, there is a vocational technician electronics course integrated to high school, where the student studies full time both in high school and vocational technical course. In this course, as others in the same area, we have observed students' demotivation for the technical contents in the last year of the course.

In this context, the electronics course was chosen for the implementation of PBL with concepts of collaborative learning and learning by doing. The course has two classes divided in 30 students, and the PBL was applied to both classes in the last year of the course (third year), reaching 60 students.

B. Projects Results

The methodology presented in Figure 2 was used. To motivate the projects, it was applied an initial learning process of technical knowledge based in research in media, newspaper and regional real problems that could be solved using electronic systems prototypes developed in classroom. Among these real problems, were presented to students the difficulties of people with disabilities or some kind of disease as an opportunity to propose new ways to help them. Thus encouraging and stimulating the students to use the technology to solve problems like inclusion of people with special needs (Figure 6).



Fig. 6. Visiting a children with special needs school (a) and wheelchair users association (b).

The experience was significantly better when students visited schools for children with special needs and a wheelchair users association. The students could experience the everyday life of these people.

In the next step the class was divided into groups of 3 to 4 students to start the projects. Each group defined the problem to be treated and one possible solution. Many students had deficiency in the previous formation and they did not have the expected knowledge or skill required to students in the last year course. Because of that was essential to identify weaknesses and strengths through reviewing contents and technological tools required for the projects development.

The implementation of prototypes were made in electronics and automation laboratories; which have the necessary tools, machines and measuring equipment to assemble and identify possible errors to make adjustments in the prototype. This stage was very important in the learning process. The groups searched the necessary theoretical knowledge using Collaborative Learning and found the ways to execute their planning with success in developing their prototype, applying the Learning by Doing approach.

As an example, Figure 7 shows a robot prototype controlled by mobile phone via Bluetooth, developed in the laboratory with acrylic parts and low cost electronic embedded system. This project consists in use the robot to navigate in environments with difficult access, without human intervention.

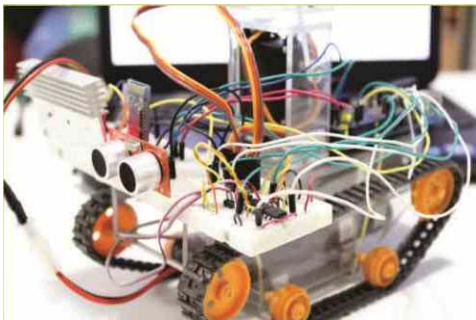


Fig. 7. Robot prototype controlled by mobile phone via Bluetooth.

The main result of the modern pedagogical tools was the student learning improvement, as one of them said: "now I'm really learning to be an electronics technician and began to understand those things that I studied before and did not know why." Concerning to the projects, 70% of the groups conclude the project and 30% did not succeed in completing the project, in most cases because of lack of organization and planning or even for lack of dedication to the project. However, all groups had effectiveness in learning of contents expected for the course.

As a result of the use of the mentioned modern pedagogical methods, it was not possible to quantify gains on issues such as drop out and failure rate, because in the last year course these rates are already low even in traditional teaching. However, were observed important improvements in the following aspects:

- Students perception of the opportunities in the real world and relate this to their training and future career;
- Work in team in a collaborative environment
- More independence in the students own learning
- Work under pressure and have to obtain results with the limited resources, especially time;
- Motivation to learn and complete the project
- Proud to present to teachers, parents and friends the result of their work.

As an additional result, some of the best projects were presented in science and technology fairs, some of them receiving awards and even being chosen to participate in national events. One of these projects was the braille phone, a mobile phone designed to send messages in braille for blind people (Figure 8). This project was presented in the Science and engineering Brazilian fair and gained the first place in engineering area. Nowadays the student is cursing electrical engineering at the university.



Fig. 8. The prototype of the braille phone, a mobile phone for blind people designed to send messages in braille.

VI. FINAL REMARKS

In a digital age where students have easy access to lots of information, most of them confused and disconnected, the professional education in Brazil needs to reformulate its teaching and learning methods, not using only traditional methods but using modern pedagogical methods, which this work demonstrated to be an important way to improve the quality of education, encouraging students to give continuity to their studies in engineering area.

Developing this work in schools where traditional teaching is used by most teachers was not an easy task. The teachers involved with the project had to break some paradigms involving the school, and convincing students and parents about the new method. We observe that the greatest difficulty to apply the new methods was the cultural shifts from passive learning to learning by doing and collaborative work, something unusual for students, although they had enjoyed the experience.

The results show that educational levels increased, the students were more motivated and the involved teachers satisfied to see the good result of their work. The applied modern pedagogical tools reached what we expected and in addition it served as a parameter for other teachers who saw the

results of the projects and felt interested in knowing and applying the same methods.

The next steps are multiply this successful experience and training other teachers to use these and others modern pedagogical tools, with the objective of taking the professional education at IFAM to an excellence level.

ACKNOWLEDGMENT

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Evaluation of Student Learning Outcomes in Fourth Year Engineering Mechatronics through Design Based Learning Curriculum

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Abstract—This paper focuses on evaluation of student learning outcomes in fourth year engineering mechatronics through design based learning curriculum. The purpose of all engineering degrees is to provide strong grounding with principles of engineering science and technology. By learning engineering methods and approaches in an academic environment, graduates can enter the world of work and tackle real world problems with innovation and creativity. In many cases, academic staff are responsible for driving and setting high expectations in their classrooms. Sometimes staff are expected to teach subjects outside their expertise. This research paper is concerned with evaluating student learning outcomes through feedback sought from students on design-based learning approach.

Keywords—*Design based learning; Project based learning, Students learning outcomes; Engineering education;*

I. INTRODUCTION

Design-based-learning (DBL) education is a form of project/problem based learning in which students gain knowledge while designing a solution (object or artifact or report) meaningful to the students. It involves collecting information, identifying a problem, suggesting ideas to solve it and evaluating the solutions given. Once students have chosen the problem to focus on, they design a solution to solve it. Finally, the students receive feedback on the effectiveness of their design both from the facilitator and from other participants. Design-based learning is especially used in scientific and engineering disciplines. Students at Deakin University in Australia are given the opportunity to provide feedback on the units they are studying and the teaching staff through the use of a course-experience survey. The course-experience survey collected anonymously from students gathers student evaluations of the quality of the unit, its material and the way it was taught [1]. The course experience survey is collected every semester, which gives an opportunity to compare the student experience of the fourth year engineering unit when it was taught through design based learning curriculum. The project in this unit involves students designing, building, and demonstrating a simple robot. The DBL in this unit was a very effective approach for student learning.

II. DIFFERENT LEARNING PEDOGOGIES

A. Project Based Learning

Project-Based Learning is perceived to be a student-centered approach to learning. It is predominantly task-oriented and facilitators often set the projects. In this scenario, students need to produce a solution to solve the project and are required to produce an outcome in the form of a report guided by the facilitators. Teaching is considered as input directing the learning process. The project is open ended and the focus is on the application and assimilation of previously acquired knowledge.

Engineering students require the opportunity to apply their knowledge to solve problems through project-based learning rather than problem solving activities as those do not provide a real outcome for evaluation [2-4]. One of the greatest criticisms of traditional engineering pedagogy is that it is a theory based science model that does not prepare students for the 'practice of engineering'. Self-directed study is a large part of a student's responsibility in project based learning modules [3, 5-7].

B. Problem-Based Learning

In this type of learning and teaching, students are usually presented with a situation, a case or problem as a starting point. The role of the teacher is to be a supervisor of the learning process. The subject knowledge gained by students is considered to be about the same for problem-based learning as it is for traditional teaching methods, however it does aid in developing creative thinking skills for problem solving. In this approach, students learn how to learn. Using problems or cases from real life in teaching is effective for motivating students and enhancing their learning and development of skills. Students need to learn how to find information when needed as this is an essential skill for professional performance.

Problem solving is a component of the problem-based approach. Problem-based learning (PBL) focuses on problem scenarios rather than discrete subjects and the selection of the problem is essential in PBL [8-10]. The teacher acts to facilitate the learning process rather than to provide knowledge and solving the problem may be part of the process. Here, problem scenarios encourage students to engage in the learning process. The learning process is the central principle, which enhances students' motivation, and is a common element in

problem and project-based learning. PBL is an approach to learning that is characterised by flexibility and diversity, which can be implemented in a variety of ways in different subjects and disciplines. Students work on their own learning requirements and teachers support this learning [11-14].

III. DESIGN BASED LEARNING IN ENIGNEERING

Design based learning (DBL) is one type of project-based learning which involves students engaged in the process of developing, building, and evaluating a product they have designed [15]. In engineering science classrooms, DBL opens new possibilities for learning science. Working and completing design based activities can make students feel proud of their achievements, as well as building up their confidence as thinkers, designers, and that will benefit them through their education and life. Design based learning encourages a thriving learning context for students' active participation and construction of knowledge instead of passively learning about engineering science from textbooks and lectures [16]. Overall, design based learning supports encouraging evidence that this project/problem based learning increases students' science content knowledge and engagement working on the design challenge, enables students to transfer knowledge into another task, learn through collaboration, and develop students' positive attitudes towards engineering design education.

At Deakin University, the engineering program increasingly involves Design-Based Learning, or DBL projects at different levels of course structure. It engages students in real-world assignments. It starts right from the first year of engineering. In the DBL projects students will work in a group of approximately four to six students on absorbing innovative issues. In this way, students will gain an idea of the field of work and students will learn to work in a team and try to solve problems by using technical and psychological knowledge. This is important, because in the future students will often cooperate with people from other disciplines. Students will often be the bridge builder between (technical) specialists, the consumer and society. The Design-Based Learning program is a cutting-edge, inquiry-based curriculum that engages students in simulations and understanding of essential questions. Engineering science and technology are at the core of its challenging multi-disciplinary curriculum.

IV. SENIOR MECHATRONIC DESIGN AT DEAKIN UNIVERSITY

All senior mechatronic-engineering students enroll in SEM433, Mechatronic Design. Running over 12 weeks, the course has been taught both on-campus and via distance education [17]. For over 20 years, Deakin has offered an accredited Bachelor-of-Engineering degree via distance education and online learning [18, 19]. The enrollment numbers are on average 15 on-campus and 6 off-campus per year. The course has five key learning goals. On completing the course, students can:

1. Become experienced in dividing a complex design problem into a set of subsystems and then integrating the separate solutions into a final design;
2. Understand how the various disciplines of their undergraduate course can be combined in a single system design;

3. Comprehend the time, cost and availability constraints that must be faced in engineering practice;
4. Solve open-ended problems in the basic areas of mechatronics;
5. Achieve competence in expressing design concepts in formal reports;
6. Design and make a device capable of fulfilling the given task definition.

A. The basic project

In this course the students must build some kind of robot. Early offerings required the students to build a simple robot that could navigate through a maze, or follow a line around a painted track [20]. The original microprocessor for this course was the eight-bit 68HC11, mounted on a board specifically designed for our students [21]. The project encompasses all the elements of a mechatronic design project:

- Mechanical parts for chassis, transmission, and steering.
- Sensors for detecting the elements of the problem.
- Motors to drive and steer the robot.
- Analog electronics for motor drives.
- Digital electronics in the form of logic devices and the microprocessor.
- Computer programming to give instructions to the robot.
- System design to draw everything together within the required budget.

B. Sumo-robots

In the last few years this robot has been a "sumo robot" [22]. This is a robot that must push another robot out of an arena. The problem is given to the student from the point of view of a company seeking tenders for a job. The task of the sumo robot is to push or lift the opposing robot out of a circular arena. There are three phases to this task:

Phase 1: The sumo robot are placed in the arena facing away from a gray box. It must find the box and push or lift it out of the arena within 3 minutes. The box is 200-mm × 200-mm × 200-mm and weighs 500 g.

Phase 2: The sumo robots are placed in the arena facing a plain gray box. It must evade the box (which will be attacking!) for one minute and stay within the arena.

Phase 3: The sumo robot are placed in competition with the other robots.

The competition is knock-out competition. Each match between two robots consists of up to three games of three minutes each. The first robot to win two games wins the match. In the first round, robots with similar times from the first phase are matched against each other. The winners of the first round play each other. If there is an odd number of robots, the robot with the fastest time from the last round will automatically enter into the next round without having to compete in the

current round. Points are awarded based on how many rounds a robot survives.

C. Robot specifications

There are a number of constraints applied to the students' robots:

1. The robot is to be completely autonomous.
2. The robot must be purpose built, no off-the-shelf robots allowed.
3. The sumo robot itself must fit inside a box that is 200-mm long \times 200-mm wide \times 300-mm high.
4. The robot can weigh no more than one kilogram.
5. The robot must have some status indicators. (Indicating at least attack and evade status.)
6. The surface will be flat.
7. The robot is to be initially placed on the field by the student facing away from the opponent.
8. After placement, it must not be touched by anyone until the task is completed or failed.
9. The arena will be circular with a diameter of 1540mm.
10. The arena will be matt black with a 20-mm wide white line around the edge.
11. The arena will be raised from the surrounding ground by at least 10-mm.
12. If any part that comes off a robot and falls or is pushed outside the arena, then that robot loses that game.
13. The robot that touches outside the arena first is deemed the loser.
14. A robot must start a game in the same pose that it was when placed in the box used to check its dimensions.
15. A robot that damages another robot (apart from damage expected in robots pushing each other) will be disqualified.
16. No weapons! But a lifting mechanism is allowed.
17. The total expenditure on the project must not exceed \$A150 (Note: this sum does not include the cost of the microcontroller but will include one set of batteries).

This specification is given and each student must build a prototype to get the job. As specifications in industry are never complete, the students do not receive a complete one either, but must collectively suggest various ideas to fill the gaps of the specification. The lecturer then adjudicates on the final specification as the client. All this is put forward in relationship to the lecturer's industry experience and it spurs the students to settle on a specification that is to their advantage when designing their own robot. The brains of this robot is the Arduino 16-bit microcontroller that the students interface to the mechanism and into which they program instructions.

D. Assessment and competition

The grading is calculated from a preliminary report (20%), a final written report (30%), demonstration of the finished product (40%) and project construction (10%). To be eligible to obtain a pass in this unit students must achieve at least 50% in both of the project demonstration and construction assignments. On-campus students undertaking this unit take part in three hours of weekly lectures and tutorials for the first six weeks, followed by six more weeks of three-hour lab sessions to work on their project. Off-campus students work on their project at home, guided by content posted to the course website (fig.1), a published study guide [23], and by direct communication with the lecturer. Weekly web-conferencing tutorials are also given to for the off-campus students [24]. Weekly lectures are also recorded and posted to the course website (fig.2).

The major difference between senior engineering students and the engineer in industry is the amount of experience they have. Students are at the stage when they should be able to research a topic for themselves. To this end, each student is given one topic on robotics, such as motors, controllers or batteries, to become an "expert" on. When students ask about an item that is in your topic, it is expected that the expert will answer before the lecturer does. Bonus points are given based on how well the student does. The lecturer is the backup in that case that the expert does not know a particular answer to a question. The report assessments also contain a section for expert topic areas. Expert topics include batteries, motors, gearing, steering, chassis, sonar, light sensors, programming, uP interfacing, and motor control.

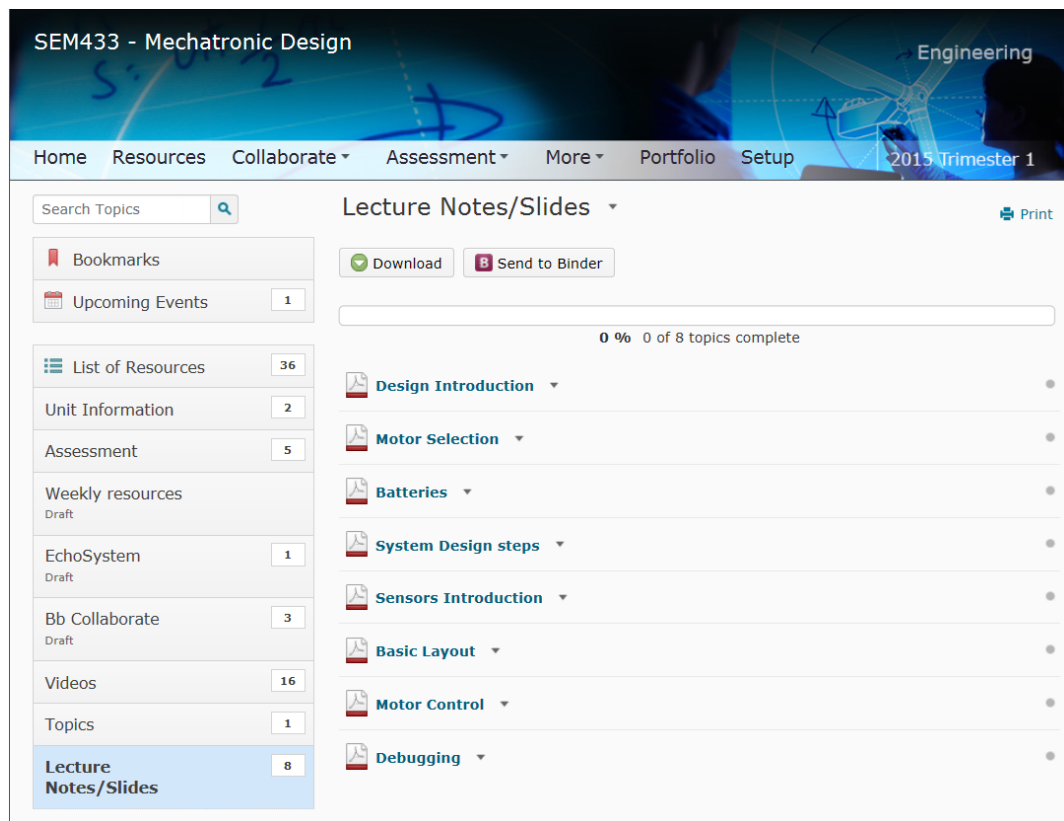


Fig. 1. Sample of the Mechatronic-Design course website.



Fig. 2. Example of a lecture video on servos.

Once the students have built their robots, there is a competition at the end of the semester as their robots battle each other, with some extra credit for the winner (that is the one who wins the “tender”.) This is a day of both frustration and fun. Frustration as the students try to fix last minute problems, and fun as they pit their robots against each other. This includes the off-campus students, who are given the option to send their robots to the lecturer to run in the competition, or to attend the event in person. Most off-campus students elect to attend and in doing so meet the other students

with whom they have been communicating during the semester.

E. Purpose of the reports

The first report is a written project proposal pertaining to the problems presented in the project. The proposal is viewed as a document that sets out and guides the development process of the student’s solutions to these problems, which would be used by a project manager to guide a team. In this case, the student is both the manager and the team. The proposal seeks to answer several key design questions:

- What is the problem?
- What is the proposed solution?
- What is the mechanical part of the solution?
- What is the electrical/motor part of the solution?
- What is the sensor design?
- What is the proposed strategy design?
- Expert topic?

The section with the proposed mechanical solution presents first an outline of the general approach to solving the problem of chassis and mechanical design. It includes computation of speed and torque requirements, motor control/steering strategy, a sketch of the design including details of wheel, motor and battery placement, computation of the minimum turning radius

of the robot, and a description of the number, type and placement of the sensors to be used along with explanations of all decisions made.

The proposed electrical/motor solution presents an outline of the approach to motor selection and control. It includes selection of motor type and performance. If the design is based upon a pre-existing motor then the suitability of the motor must be demonstrated and its torque, current, and power determined. There is also a calculation of electrical current and power and thus details of the battery requirement. Students must also estimate of the run-time it would take for the robot to cover a distance of 50 m and the remaining power in the motor battery at the end of such a run. And the students give a description of the electronic motor-control interface.

The sensor design includes a description of the number, type and placement of the sensors to be used along with explanations of all decisions made, a description of the sensor/controller interface with any debugging aids that may be required, what sensors will be used and why, and how the sensors will be connected and powered. Finally the proposal presents an outline of the approach to artificial intelligence and control, including a summary of the strategy to be used by the robot in the execution of the task, including the system response to all possible sensor conditions. Students construct a workflow chart as a timetable for completing the project, including a list of design, implementation and evaluation tasks to be completed.

The final report contains a project update, comments on the robots functionality, possible improvements, cost of the project (including bill of materials) and the listing of the final software code.

V. RESULTS AND DISCUSSION

Fig. 3 shows a typical student's robot in the competition circle. The robot is seeking its opponent before the two try to push each other out of the arena. An example design and a brief showcase of the robots and the resulting competition have been posted to YouTube:

- <https://www.youtube.com/watch?v=Hp6gX0PB33U>
- <https://www.youtube.com/watch?v=dnP8bsA-nyY>

Fig. 4 shows typical grades for this course. Four years are shown. Many of the resulting projects are of excellent quality and this trend has existed for several years. Off-campus grades were comparable with on-campus grades.

At the end of each semester, students are asked to evaluate the course by replying to a survey [1]. Students respond to statements on the course material, website, feedback on assignments, and quality of the lecturing. They use a five-point Likert [25] scale (5 = strongly agree, 1 = strongly disagree, 3 = neutral) to indicate what they think about a number of statements.

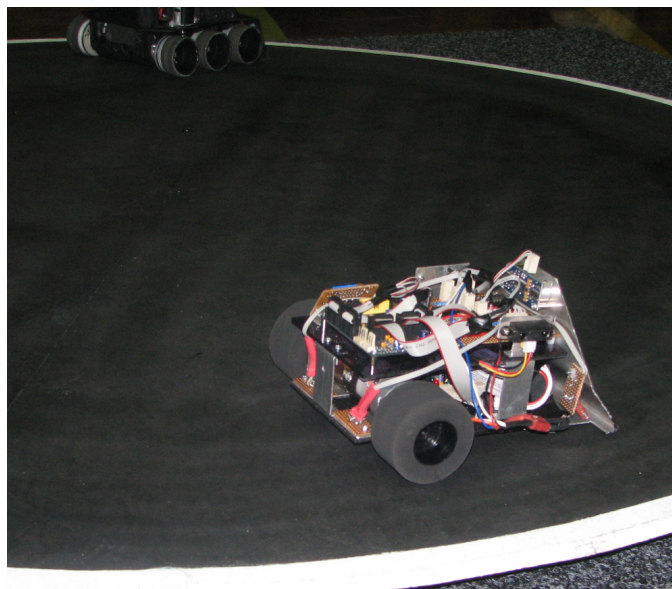


Fig. 3. Student sumo robots in the arena.

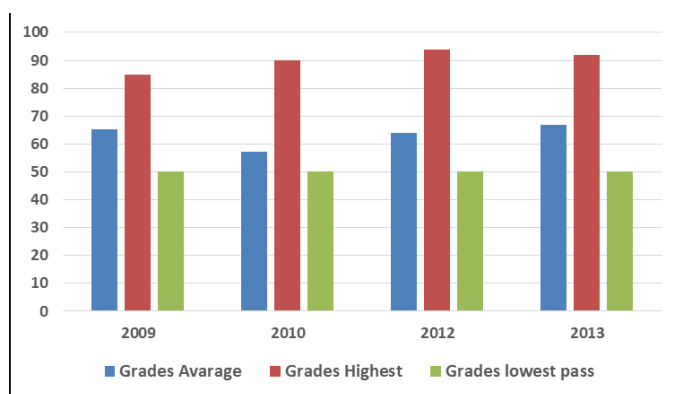


Fig. 4. Typical average grades (percent) in senior mechatronic design. The minimum passing grade is 50%.

One statement concerns the students' satisfaction with the lecturer, and another concerns the students' overall satisfaction with the course. Students are also invited to make comments on the quality of the course. Sample evaluation scores over the period 2009-2013 are shown in fig. 5. In general, the student satisfaction with this course is quite high, among the highest in the Deakin School of Engineering. We note that although on-campus and off-campus satisfaction with the teaching are nearly the same, the off-campus satisfaction is slightly less than the on-campus satisfaction with the course overall. This difference disappears when one considers the spread of responses. When asked what the best aspects of the course were, students replied with the typical comments in table 1. Student comments tend to be very positive.

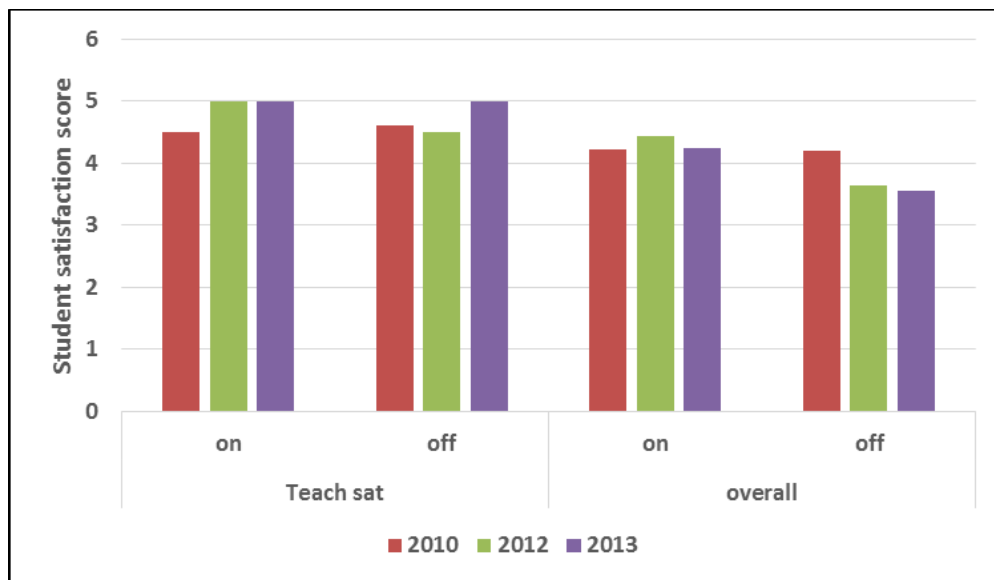


Fig. 5. Scores of student satisfaction with the teaching (left) and the overall course (right), off-campus and on-campus. Perfect satisfaction is a score of five.

TABLE I. STUDENT COMMENTS ON THE BEST ASPECTS OF THE COURSE

I learned a heap. Will help with my major project.
Being able to use the knowledge from the degree to put together a full project to create a sumobot.
That we were able to build an actual robot, instead of just do the theory about one.
The challenge of bring all the parts together. Especially being taught how to use the milling machine not only to do circuits but more importantly how to use Solidworks files.
It truly is the definition of engineering - the practical application of knowledge. Best aspects: - Video lectures. I can't stress enough how important it is for those of us off campus.
The building, hands-on experience.
The more positive aspects of this unit are essentially those which it sets out to achieve namely the practical problem solving of an open ended task. I found this project puts a lot of emphasis on the detail of a design as it is not a theoretical exercise and nothing will look after itself.
Provided materials were succinct and helpful.
Awesome (recorded lectures) were very helpful during the design phase.
I can honestly say that I have learnt more in this unit than any other so far - and because I've applied this knowledge I will actually retain it.

We often find that students who have completed this unit and go on PhD studies, will help the lecturers with this unit in following years, even building a new robot to enter the competition again. When this happens the lecturers can use their experience as further inspiration for the students. We also found that the practice of having individual student experts on specific aspects of building a robot very beneficial to student learning [26].

This course has been offered both on-campus and off-campus for many years. In spite of the significant differences between the two cohorts [27], our experience with this course shows that at least in mechatronics, a successful distance-

education undergraduate engineering program can be provided, affirming the claim that universities should be able to provide engineering education “anytime, anywhere” [28].

This course has been built on the design-based learning model of education, and in the context of a senior project course it has proven to be highly successful. Other courses in our School have experimented with design-based learning in on-campus and off-campus modes [29, 30]. Current work is focusing on obtaining specific student perspectives and opinions on increasing the DBL content across all engineering majors, and extending DBL further in off-campus teaching [31-33].

VI. CONCLUSION

The purpose of an engineering degree program is for the student to gain a strong foundation on fundamental applied science, using that knowledge to design and make solutions to real-world problems. Deakin University in Australia teaches a design course for senior mechatronics students whereby they design and build a small “sumo robot.” The course is an excellent example of design-based learning in engineering education. In addition to being delivered to on-campus students, off-campus students (who do not attend on-campus classes) have also successfully taken this course for many years. The percentage of students who pass this course has been quite high over the years, and it receives a great deal of positive feedback from its students. Our School is now investigating how design-based learning can be incorporated into other courses in its engineering programs.

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A Business Intelligence Model for Online Tutoring Process

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Abstract—This work aims to implement business intelligence strategies in an educational institution based on the distance education, particularly in the online tutoring process. In this paper we propose to use the business intelligence paradigm to analyze the online tutoring process, based on the data collected on the interactions of students and teachers in a virtual learning environment, and the results recorded in the institutional academic system of evaluations. This analysis should answer the following questions: 1) Can we define a model of online tutoring that can adapt to each student profile? 2) Can we predict the success of an online tutoring process for a course and a student given? To this purpose, this paper presents three aspects: characterize and determine the key elements in an online tutoring process, build a descriptive model of the online tutoring process, and build a predictive model of the success of the online tutoring process. The models to be defined will be based on data mining techniques, and will be obtained from the current data stored in transactional databases of the University. This data is preprocessed with ETL techniques to build a multidimensional model, and the key elements are obtained through operations OLAP.

Keywords—Business Intelligence Systems, Data Warehouses, Learning Analytics, Online Tutoring

I. INTRODUCTION

Business Intelligence (BI) has a high range of use based on the information and knowledge hidden in an organization, to reach its strategic and tactical objectives [1, 3, 9]. But this paradigm must be used correctly following the objectives, processes and situations in the organization, to allow the good decision-making about tendencies, opportunities, etc. in the organization. Some key concepts for BI are the determination of the current and target situations, and the definition of the correct indicators to be used for strategic analysis.

BI encompasses data, information and knowledge management, modeling of processes and policies of the organization, with a previous data processing procedure to guarantee a high quality of the data to be used. That is, this data must be integrated, cleaned, inconsistency must be eliminated, etc. But the main points to generate knowledge are the tasks of data mining or *OLAP* (On-Line Analytical Processing). They allow specific analysis of the different subject previously defined like strategic or tactical goals for the organization.

In the last decade has had a great development of technologies (tools, environments, etc.) for BI [3, 9]. Nowadays, it is necessary to define strategies about how to use properly BI in specific domains. Each domain needs analyze their data in their own terms, according to its goals, based on their organizational processes, etc. There is a gap between the organizations and the BI paradigm that must be solved.

In this paper we propose a first intent to bridge this gap on the domain of education, by introducing the notion of *Learning Analytics* (LA) like the specific aspect to be exploited for a BI project in the education context. LA is defined as the use of data of an educational organization (of the students, of the learning process, etc.) to build models, etc., in order to improve the learning process [2].

The LA in the domain of *Business Intelligence Systems* (BIS) requires historical data and/or data collected from various sources of an educative environment. LA needs data warehouses and a careful process of extraction, transformation, load and store data of the educational organization. In this paper, we'll present some of the aspects of the BI systems' linked at the domain of LA, such as: methodology, lifecycle, modeling techniques and finally, some indicators for a study case.

Particularly, we analyze an online tutoring in order to define the LA procedure to be carried out in this context. An online tutoring is the process of tutoring in a virtual environment like the *Virtual Learning Environments* (VLE), where teachers and learners can be in different places and moments.

This paper focuses on study this specific model of education (online tutoring), in order to define three key concepts: target situations, indicators, and how they are analyzed from a LA process based on BI. The main contributions of the paper are: i) the definition of the target situations and indicators in the context of an educational BI project, ii) the design of a process to capture the strategic business goals, the situations that influence these goals, and the indicators to measure their fulfillment in an educational organization, and iii) the demonstration of the procedure in a real-study case to analyze the strategic goals in an organization

For the implementation phase we used different BI

techniques, like data warehousing, OLAP, data mining, etc. The system gathers data from different functional systems such as: the system of students register, VLE, etc.

The rest of the paper is organized as follows. Section 2 introduces key aspect about BIS, LA, and online tutoring concepts. Section 3 presents the target situations and the indicators to make LA using BIS in an online tutoring. Section 4 presents a complete example, and Section 5 discusses and analyzes our results.

II. THE THEORETICAL ASPECTS

This section introduces the three key concepts in our work.

A. The concept of Business Intelligence System

During strategic planning, SWOT (Strengths (internal, favorable), Weaknesses (internal, unfavorable), Opportunities (external, favorable), and Threats (external, unfavorable)) analysis [2, 3] is often used to identify the internal and external factors that are favorable and unfavorable for fulfilling certain goals. An objective of a business defined during strategic planning, basically: i) may be refined into subgoals; ii) may be satisfied in more than one way; and iii) its satisfaction may be affected by other objectives.

We propose to model the SWOT for each business objective like a target situation. Intuitively, a target situation defines a partial state of the world in terms of things, their properties, and interrelations among them. The target situations are the organizational state that we like to reach.

A BIS permits analyze business information in order to support and improve management decision making across a broad range of business activities, and in particular it gives knowledge to help in the decision. BIS leverages the large data infrastructure investment, for example, in ERP systems, where substantial business aspect like its knowledge is not exploited. Investment in BI systems is very interesting to produce this knowledge, but there is a complete absence of a specific and rigorous method to measure the realized business value. BIS have the potential to maximize the use of information and knowledge to create a smart platform of organizational analysis [1, 3, 9].

Normally, BI uses collected data during the daily operational processes, and transforms the data into information and knowledge [3, 9]. The main characteristics of BIS are: the capability of providing representative information to the high-level management of an organization, to support strategic activities (goal setting, forecasting, planning, etc.), and also tracking performance (gather, analyze, and integrate internal and external data in indicators). BIS can access both historical and real-time data to define views of the information and summarize it into indicators for the different members of an organization.

Normally, a BIS provides the information that executives need for strategic and tactical decision, that often requires

the combination of data from ERP and non-ERP applications (integration), in unusual reports different from daily transactions, to take real time decisions based on them. The main differences between ERP and BIS are:

- ERP systems are transaction-processing and BIS is based on the extraction, analyze, and visualize information from ERP and standalone systems (for that, it uses components like data warehousing, tools capable of collecting, processing, storing and retrieving data from different sources, friendly graphical user interfaces, OLAP, data mining, etc.).
- BIS is oriented towards business opportunities rather than transactional needs, for strategic decisions.

In [1] describes detailed the components and architectures of a BIS. In general, a BIS lifecycle follows traditional development of a software project: initial study, project planning, analysis, design, construction, and implementation. A main point are the data, which can be exploited in different BI studies if they are extracted, processed and stored correctly, and are improved in successive versions.

B. Learning analytics

LA can be defined as the utilization of data produced by the students in order to build models, knowledge, etc. and analyze them to improve the learning process by predicting and advising to the students, discovering of knowledge and information necessary during their learning, etc.[2, 14]. The interests to use LA can be [2, 14]:

- For educational organizations, to improve current courses or develop new curriculum offerings;
- For administrators of educational institutions, to take decisions about matters such as marketing, recruitment, performance problems, etc.
- For students, to improve their learning processes, patterns of learning, achievements, with tailored assessment materials, learning pathways, etc.;
- For the professors, to identify 'risk' students, in terms of drop out or course failure, to predict the students requiring extra support and attention, etc.

LA is different of the field of educational data mining (EDM). In general, EDM is based on the intelligent tutoring paradigms, and LA focuses on Learning Content Management Systems (LCMS). For some authors, EDM encompasses LA [2, 14], which combines institutional data, models (predictive, descriptive, etc.) and statistical analysis, to create knowledge for the students, professors, or administrators, in order to improve academic behavior. Some aspects that increase the interests in LA are:

- The important number of components of the online educational platforms: VLEs, LCMSs, the student records, etc.
- The important quantity of data from these components about student background, learning process (for

example, from VLEs), interesting to apply BI techniques to these educational data.

- The necessity to have evidences about the progress of the pedagogical process, etc., in real time.
- The desire of an educational organization to improve its online education in order to give a high quality education.

Some important domains for LA are [2, 14]: BI, Data Mining, Web analytics, Social Network Analysis, Artificial intelligence, and Statistics. Some examples of LA software tools are:

- SNAPP: a learning analytics tool that visualizes the network of interactions resulting from discussion forum.
- Student Success System: It provides indicators to understand why a student has problem, predict student performance and identify students into risk.
- LOCO-Analyst: a context-aware learning tool for analytics of learning processes taking place in a web-based learning environment.
- BEESTAR INSIGHT: a real-time system that automatically collects student engagement and attendance, and provides analytics tools and dashboards for students, professors and administrators.

Some problem opens are the ethics of the data collection, of the analyses, etc. (see [2, 14] for more details).

C. Online tutoring

Online Tutoring (OT) is the process of tutoring in a virtual environment where teachers and students can be in different spaces and time [4, 5, 6, 7, 10, 12, 13]. Online tutoring has different approaches; it is addressed to different users, and has different interfaces and online learning methodologies. The online virtual environments usually imply Learning Management Systems (LMS), VLE as Moodle, etc.

The tutoring can be a group of students simultaneously logged (many-to-one tutoring), or a student independent learning, with tools for self-reflection, knowledge construction, collaborative or group-based learning, etc. (e-moderation) [13]. The online tutoring can be asynchronous, which is tutoring where the student submits a question and the tutor responds at a later time, or synchronous online tutoring where is shared an interface, such that both the tutor and the students are online at the same time. Generally, a tutor is a professor who has responsibility for teaching in a program in a university. Two necessary assumptions about online tutors are that they possess sufficient academic qualifications and have specific training to develop online communication. Online tutoring requires three components [4, 5, 6, 7, 10, 12]:

- A educational method (pedagogy), with instructional support;
- One online tutoring management to coordinate and

organizes the service;

- A usable user interface and technical support to maintain both the hardware and the software operational.

OT supposes a self-motivated and independent student, based on constructivist principles, focuses on achieving goals of learning, student autonomy, self-reflection, collaborative learning, and communities of learning.

The similarities between online and face-to-face tutoring are the needs for roles in the group and to encourage in-group interaction, and the differences are the needs of a computational structure and the definition of online activities. In general, the online activities are known as e-activities, with the following characteristics [4, 5, 6, 7]:

- They define relevant learning activities;
- They are based on key topics to provide engagement and motivation.

There are tools for e-activities like worksheets, online bulletin boards, etc. The typical stages for learning in online tutoring are four [4, 5, 6, 7]: i) Access and motivation, ii) Online socialization, iii) Information exchange, iv) Knowledge construction.

III. OUR BUSINESS INTELLIGENCE SYSTEMS' METHODOLOGY

In this section we propose a methodology for educational BI projects. Our methodology defines the main steps in all BI project, and allows reuse the specific methodologies, tools, etc. from other domains inside of its steps. For example, data mining methodologies, data preprocessing techniques, among others. Our methodology starts from the main aspects to be considered in a BI project: define the target situations, define the indicators to find out if these are reached, and identify the data/semantic mining tasks to calculate these indicators. Based on these ideas, we propose a methodology to develop BIS projects compose by the next steps [1, 3, 9]:

A. Stage 1: Definition of the target situations

In this case, we define the strategic questions that the BI project must respond. Normally, the target situations are the strategic questions that the organization must respond. These target situations justify the BI project, and define the business needs and opportunities identified. The target situations describe specific organizational states that are important to improve their performances. These situations have a high influence on the business of the organization, and normally, with the current operational data, it is impossible to obtain the response to reach them. They require strategic information that must be extracted from the operational data. That is, they require the extraction of the knowledge hidden on the operational data of the organization, using data/semantic mining tasks.

The target situations define the indicators to be obtained. A successful organization analyzes these strategic situations defining indicators, in order to help the organization to make the correct decisions to reach these situations. Generally, these indicators quantify various aspects of the organizational activities, for this it is necessary to monitor the organization. The indicators in a BIS normally are obtained from data/semantic mining tasks or from OLAP operations. It can be composed of other indicators, and normally is a complex computation because it represents the generation of knowledge.

The first main point in this step is to define the target situations. These situations describe different types of states in an organization: strengths, weaknesses, opportunities and threats. To analyze these states, and in particular to know if the organization is close to it, normally are defined indicators. More specifically, we identify indicators what can be observable.

The second main point in this step is to define the indicators. The indicator definitions are based on the organization's mission, and require discovering strategic knowledge to achieve the goals. Therefore, analyzing those indicators are important tasks in any strategic planning process. During the strategic planning process, the indicators allow making decisions at the decision points. At each point, one option is chosen from a pool of available options using the information and knowledge provide by the indicators. In some cases the indicators exist, or must be calculated from various sources and ERP systems of an organization from its different functional areas, for example financial, inventory, purchase, order management, production, etc.

B. Stage 2. Data Model of the BI project

Now, we need to determine the source of data to be used to calculate the indicators, that is, to carry out the analysis around the question. Normally, during this stage is designed the data warehouse which contains both historical and current data, and its optimizations, for fast query and analysis. Data warehouses are based on multi-dimensional databases design, in order to consider the main data required to respond to the target situations. Traditional relational database systems can handle these situations, but using multiple queries (in many cases, the queries are so complex that are difficult to maintain). Data warehouses require the extraction, transformation and processing of data for a high-level integration and analysis, for these reasons, in this stage are defined these tasks. The data warehouse is very important for the BIS, because it prepares the data to be used on the BI project (clean, correct, normalize, etc.). Some of the steps in this stage are:

- Analyze the operational data of the organization, that is, in this step are identified the data sources, with its ER diagrams, attributes and references between data.
- Design the Multi-dimensional database, which defines the logical and physical model. The data model is used to define the data warehouse
- Design the ETL process (extract / transform / load),

which depends on quality of data sources.

The multidimensional models represent an extension of the relational model and normally are based on a star schema. They consist in the relationship between some dimensions and facts or measures, to define an n-dimensional cube based models that use a multidimensional view over an individual data. In BIS, the multidimensional model must allow to respond to the business requests. We need a business vision over data structure, so the star schema or the n-cube based models must incorporate business aspects or demands, not only the facts or the relationship between data. The performance indicators are calculated from these data.

C. Stage 3. Extraction of knowledge (indicators) based on the target situations of the BI project

In this stage are defined different types of models or metrics for statistic interpretation, and analysis of the target situations, using the respective indicators. At this level are used technologies like OLAP, data mining, etc. The OLAP engine is a query generator to explore and analyze summary and detailed information from multi-dimensional databases. Typical OLAP operations are "slice and dice" data by various dimensions, "drill down" into the source data, or "roll-up" to aggregate levels (for more details about these operations see [1, 3]). OLAP provide tools for "what-if" analysis, to find the trends and patterns within the data, but it will not discover hidden relationships or patterns. For these tasks are required more powerful tools like semantic/data mining techniques. These techniques make it possible to discover hidden trends or rules that are implicit in the data. Patterns or models discovered by them are validated and then to become operational tools to be used in decision processes. OLAM (on-line analytical data mining) systems are OLAP systems used for data mining in multidimensional-data.

The definition of the OLAP operations is very complex because it must give new knowledge or information hide in the data warehouse according to the indicators. Must be analyzed what data must be slicing and dicing, or data that must be rotated, and drill down or roll up over hierarchical levels. So, it is necessary a multidimensional model in which these operations can be made easily, in real time; OLAP operations that define relationship between dimensions, facts and hierarchies to calculate strategic indicators.

Regarding to the data mining or semantic mining tasks, they are very complex. There are specific methodologies for this step. The main aspect to consider is that the data/semantic mining tasks must be very well defined, and for each one there is a very important step of preparation of the data composed by two aspects: the definition of the conceptual view of the data (the different attributes to be considered to build the predictive or descriptive models), and the construction of the operational view of the data (that is, the extraction of the data to build the models and test

them). If these views are wrong, the results of the data mining or semantic mining tasks are wrong too.

IV. STUDY CASE

In order to show our methodology, we propose here a study case.

A. Description of the BI Project

A problem of BI systems is measuring success. In deploying a BIS there are many risks involved: system design, data quality, and technology obsolescence. Decisions based on business process BIS should not be viewed only as a data repository or a large set of data. Instead, system's implementation should concern on conceptualizing new data models, processes, and indicators that form the content of BIS.

Particularly, our goal is to test LA like a result of a BI project on the domain of OT. We have tested our approach in an Ecuadorian university where one of the main activities is the distant education. Particularly, the Universidad Técnica Particular de Loja (UTPL) has a distance campus based on a competency-based teaching model. In this model, the student is the central actor in the educational process, and the process is mediated by a teaching team, tutorials, resources learning and new technologies [10, 12]. For online tutoring, UTPL uses: a Virtual Learning Environment (VLE) which is based on MOODLE platform, a Video Conference System, e-mail, phone tutoring, etc. The students in distance modality through the forums, chats and video conferencing in the VLE, can get points for their subjects [10, 12]. Therefore, the teacher must meet certain activities that enable the communication and evaluation of teaching-learning process. Among the activities that the teachers should develop are:

- Propose at least a forum, a chat and videoconferencing every two months.
- Post an ad per week throughout the academic year.
- Answer the question of the students through the email
- Upload educational resources.
- Define questionnaires for the students

For the UTPL, describe information and knowledge of the organization is very important, in order to analysis the OT process at the university: the performance of the students, the model used of distance education, etc. Here, we use our BI approach for LA of OT.

B. Our Business Intelligence Systems' Methodology applied to the study case

Stage 1: Definition of the target situations

For the UTPL, the target situations to be detected in order to make strategic decisions about the future of this type of studies are:

- Is it possible to define a model of online tutoring for the computer career, to increase student participation? (descriptive model)

- Can it predict the success of the online tutoring for a given year and a specific student? (predictive model)

These target situations describe specific organizational states of the UTPL, very important to improve its performance; the main states are: What is the quality of the online tutoring model of the UTPL? And What is the performance of the students?

Based on these target situations, was defined a set of general indicators that allow describe these states: rate of success of the student, behavior of the students and professors on the OT platform (messages, chats, etc.), among others. Now, with these target situations and indicators we describe the rest of stages in order to determine/analyze them.

Stage 2. Data Model of the BI project

The start schema of the multidimensional model defined in this BI project for the study case is the shown in the Fig 1. The main aspect here is to specify the key indicators to build the models that allow analyzing the target situations. In the case of UTPL platform for the OT process, the key indicators that can be obtained are:

- Number of students (numEst)
- Rate of success (Taprob)
- Num Ressources load
- NumTaksDefined
- NumCommentsProfessorStudent
- NumREAS
- NumMessReceived
- NumMessRead
- NumMessRep
- NumChatDefined
- NumParticChat
- NumForumsDefined
- Prediction (indicador) (pred_aprob)

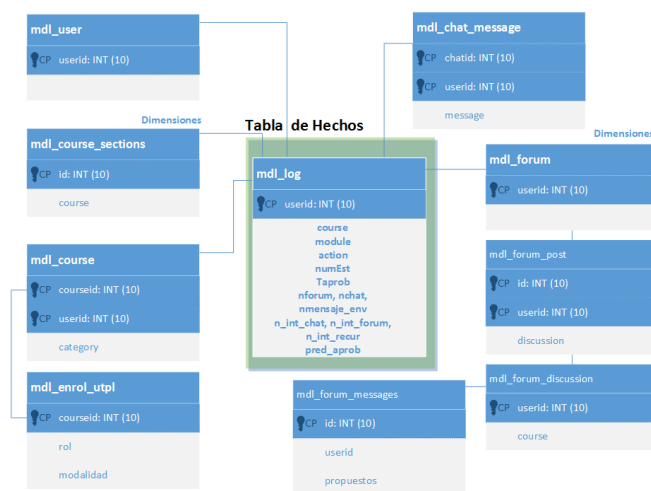


Fig. 1. Multidimensional model

These variables describe specific aspects that represent elements to characterize the OT on the UTPL according to its computational platform (VLE and academic system). The multidimensional model is defined using these indicators as base (see Fig. 1). The fact table is composed by these indicators, among other variables. Additionally, there is a dimension to describe the courses, and the rest of dimensions describe the different activities during a course (chat, message, forums, etc.) in the OT platform. This information is extracted from the UTPL platform using ETL operations. The details of the ETL operations are given in [15].

The indicators are going to define the descriptive and predictive models. Some of these indicators are calculated using OLAP operations from the multidimensional model presented on Fig. 1. In Fig. 2 we show the schema of the VLE platform of the UTPL, and Fig. 3 gives an example of an OLAP operation to determine one of the indicators: NumForumsDefined.

Stage 3. Extraction of knowledge based on the target situations of the BI project

In this step are built the descriptive and predictive models. That is a typical data mining task. Due to the importance of this task, in the next section is described the procedure. The indicators of the previous phase are the conceptual view used during the data mining tasks.

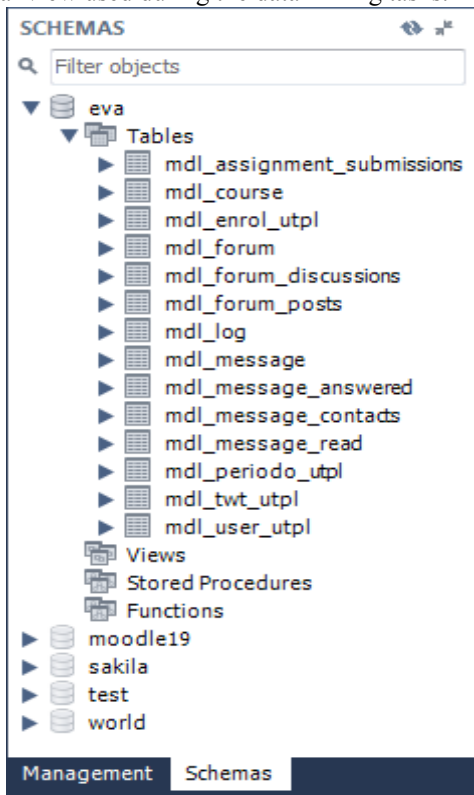


Fig. 2. Schema of the VLE platform of the UTPL

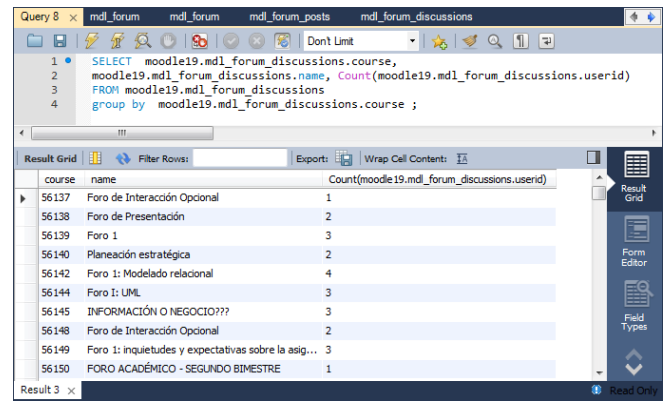


Fig.3. OLAP operation for the NumForumsDefined indicator.

V. DATA MINING TASK FOR LA OF AN OT

In this study the data mining techniques play an important role to uncovering information about the students and the interactions that are generated in the VLE, in order to better understand the OT process and optimize the use of resources used in this environment. For this, classification algorithms are considered to predict the performance rate of students in the courses where the OT process were developed. We also consider association rules in order to determine a descriptive model that characterizes the use of the tools on the platform during the OT process. The building of the descriptive and predictive models need several steps:

A. Descriptive model of the OT for the computer career

To obtain the descriptive model of the first target situation, the data was first preprocessed and then three experiments were performed with association rules, in order to obtain the model with the best results. The association rule allows discovering interesting relations between the indicators about the OT process (in [11] there is a good description of this technique). It identifies rules about the relationship among our indicators using the information on the multidimensional model and different measures of interest. The R tool was used (its "arules" library) [16].

In this way, in this paper are used associative rules to discover relationship among the indicators (descriptive model), based on three experiments:

- First Experiment: 10 attributes are used. In general, not very significant rules were obtained.
- Second Experiment: 9 attributes are used, and are deleted the attributes where the possible values of their instances are little.
- Third experiment: 8 attributes are used, and the best results are obtained, with meaningful and interesting rules. For this case are used the next attributes: Ads (NumCommentsProfessorStudent), Learning Resources (Num Ressources load), Forums (NumForumsDefined), Tasks (NumTaksDefined), REAS (NumREAS), Chats (NumChatDefined), NumMssEnv (NumMessRep), NumParticipantesChat (NumParticChat).

For this third experiment were obtained rules 24, which are shown in the Fig 4.

According to the results of the Fig. 4, the first 6 rules are considered very obvious, or of little interest, which is reflected in the measures of support and interest. In the case of rules 4, 5 and 6, they represent an interest of 68% approximately. In particular, the rules 12, 20 and 21 are the more significant.

They describe very well the relationship between the attributes involved. We observe a significant level of support and confidence in these rules, that highlights the dependence between four variables mainly: Ads, Forums, Chat and REAs we can see the percentage of correctly classified instances is of 91.7736% and incorrectly classified is 8.2264%. This can be corroborated with the Fig. 5 that determines the attributes with more relationship.

Based on these results we respond to the first target situation: Is it possible to define a model of online tutoring for the computer career, to increase student participation? We can conclude that it is possible to define a model of OT process to optimize the utilization of the VLE platform, that is, the quality of the OT model of the UTPL.

## 1	{}	=> {Recursos}	0.950	0.950 :
## 2	{}	=> {Foros}	0.975	0.975 :
## 3	{}	=> {Anuncios}	0.983	0.983 :
## 4	{Chats}	=> {Recursos}	0.681	0.988 :
## 5	{Chats}	=> {Foros}	0.681	0.988 :
## 6	{Chats}	=> {Anuncios}	0.681	0.988 :
## 7	{Recursos}	=> {Foros}	0.933	0.982 :
## 8	{Foros}	=> {Recursos}	0.933	0.957 :
## 9	{Recursos}	=> {Anuncios}	0.933	0.982 :
## 10	{Anuncios}	=> {Recursos}	0.933	0.949 :
## 11	{Foros}	=> {Anuncios}	0.958	0.983 :
## 12	{Anuncios}	=> {Foros}	0.958	0.974 :
## 13	{Recursos, Chats}	=> {Foros}	0.672	0.988 :
## 14	{Foros, Chats}	=> {Recursos}	0.672	0.988 :
## 15	{Recursos, Chats}	=> {Anuncios}	0.672	0.988 :
## 16	{Anuncios, Chats}	=> {Recursos}	0.672	0.988 :
## 17	{Foros, Chats}	=> {Anuncios}	0.672	0.988 :
## 18	{Anuncios, Chats}	=> {Foros}	0.672	0.988 :
## 19	{Recursos, Foros}	=> {Anuncios}	0.916	0.982 :
## 20	{Anuncios, Recursos}	=> {Foros}	0.916	0.982 :
## 21	{Anuncios, Foros}	=> {Recursos}	0.916	0.956 :
## 22	{Recursos, Foros, Chats}	=> {Anuncios}	0.664	0.988 :
## 23	{Anuncios, Recursos, Chats}	=> {Foros}	0.664	0.988 :
## 24	{Anuncios, Foros, Chats}	=> {Recursos}	0.664	0.988 :

Fig. 4. Best rules obtained.

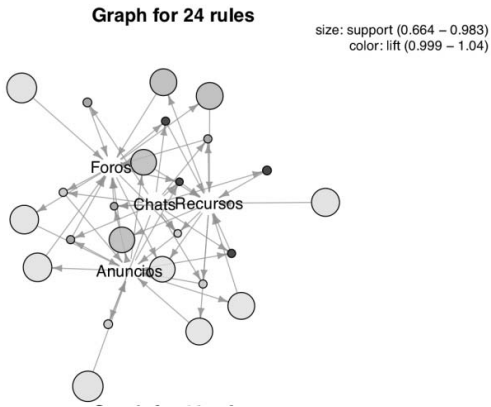


Fig. 5. Relationship between the attributes

For example, we can identify the student participation in the tools of the platform, and determine which are being less utilized, that could contribute to the learning process of students.

B. Predictive model of the success of an online tutoring for a given year and student

For the second target situation, the next experiments are proposed in order to predict the rate of performance of the students in a given course. Particularly, a predictive model is constructed using Bayesian networks. A Bayesian network is a probabilistic graphical model that represents a set of variables and their conditional dependencies (see [8] for more details about this technique). In our case, we define a probabilistic graphical model to predict the rate of performance of the students, using the indicators of the multidimensional model.

The dataset used refers to demographic and academic data of students corresponding to several semesters. The experiment was conducted in Weka with a dataset of 67825 instances. For training is considered 66% of this dataset and the rest 34% to the test. Attributes considered for this experiment are shown in Table I.

TABLE I. ATTRIBUTES USED IN THE MODEL

ATTRIBUTE	DESCRIPTION
ECV_ID	Certification ID
COE_ID	Educational component identifier
ETR_CODIGO	Promotion Code
GCR_CODIGO	Credit code
DISCAPACIDAD	Disabilities
ESTADO_CIVIL	Marital Status
GENERO	Gender
CENTRO MATRICULA	Place of registration

Classes to predict were Promotion Code, which has the value: approved, reprobates, and others. The confusion matrix obtained is shown in Table II.

TABLE II. CONFUSION MATRIX

a	b	c	<-- classified as
9915	19	634	approved
130	8758	130	reprobate
918	0	2566	other

As we can see the percentage of correctly classified instances is of 91.77 % and incorrectly classified is 8.23%. Based on this matrix, we proceed to calculate the precision and recall metrics to measure the model performance.

- Precision: 90%, that means 90% approval predictions are correct.
- Recall: 93%. That means, the 93% of the students who will pass the courses are included in predicting.

Consequently, for the proposed objective the results obtained are considered acceptable, since the model allows to project approval rate that subsequent semesters could have.

In response to the second target situation: Can it predict the success of the online tutoring for a given year and a specific student? The model obtained can predict the rate of performance of a new student in a given course.

VI. CONCLUSIONS

BIS has a powerful impact on strategic decisions to reduce the time and to improve the quality for making decisions. BIS improves the quality of management in organization through new types of technologies and techniques for extracting, transforming, processing and presenting data, in order to provide strategic information. One of the major risks in the process of developing a BIS is the system design that stem from poor conceptualization of an enterprise. A solution for covering this risk is characterizing each domain and defining the specific elements to be considered during a BI project.

In this way, in this paper we specify an approach to develop BI project in an educational organization, based on LA. We propose a methodology based on target situations, and the indicators to be considered to study each one of these situations. Our methodological approach focuses on applying BI in OT process in a University.

Thus, the LA were specified for OT process, where particular target situations are required to be analyzed in order to study the performance of an OT process using the BI paradigm. Unlike other works, in this study various data mining techniques considering aspects of BI in the context of LA for OT process are combined. The results are very

interesting, and next works need to think in procedures to define indicators automatically for BI project in an educational organization based on LA, in order to exploit the advantage of these paradigms.

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Design and Impact of a Classroom Intervention to Support Teaming Metacognition

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Abstract— Exercises to bolster student metacognition relating to teaming performance and thereby teaming performance itself were designed and deployed alongside an existing teaming performance instrument and a survey investigating the frequency of teaming-centric metacognitive events. The results suggest that the exercises were successful in raising students' metacognitive awareness of aspects of their teaming performance but did not achieve a corresponding rise in teaming performance itself. Additional learning tasks helping students translate metacognitive awareness into higher performance may be required. Overall teaming performance rose by a small amount in both the experimental and control cohorts and did not appear to be influenced by the metacognitive development exercises.

Keywords—*metacognition; teaming skills; team project*

I. INTRODUCTION

The overall efficacy of active learning techniques in improving undergraduate course learning outcomes is well documented [1-4], and more recent work in engineering education has moved towards building a deeper understanding of what specific elements of learning environments and learning tasks are most effective and how best to implement them [5, 6]. Research into collaborative learning also contributes to understanding effective active learning principles and practice for multi-student activities, including such areas as designing or selecting team-appropriate tasks [7, 8] and preparing students to work together to solve them [9, 10]. Based on the growing body of research supporting learning task design at a granular level along with discipline- and topic-specific investigations into pedagogical efficacy, educators increasingly have the ability to design and deploy research-based classroom interventions instead of relying on experience or best-practices alone.

One popular active learning technique that could potentially benefit from such research-based learning task design efforts is team engineering projects. Team projects sharply gained popularity in engineering following the finalization of new ABET standards in the year 2001, which included new “professional skills” required of engineering graduates, including teaming skills [11]. Active learning methods including team projects were quickly identified as a pedagogical method that could support student acquisition of professional and technical skills simultaneously [12, 13], while also receiving the aforementioned benefits of active learning.

Team projects are also seen as a means to prepare students to solve problems situated in societal contexts [14, 15] similar to those found in industry [16]. Given these facts, there exists a strong need in engineering to guide students in the acquisition of effective teaming skills. While a wealth of literature on team formation, support, and performance already exists for the undergraduate academic environment, vigorous research continues in this area and substantial room exists for innovations in teaming skills instructional design.

This paper presents the initial efforts and results from an active learning task design drawing upon research in active learning, teaming, and metacognition to target improvement in students' teaming skills performance in two discrete areas – team interaction and regulating team working processes. Performance in these areas is plausibly mediated by metacognition. While some interventions have been proposed in these areas in engineering contexts [17, 18], including interventions explicitly incorporating aspects of metacognition [19-21], exploration of the intersection of active learning and metacognition in engineering instruction remains limited. For this study, exercises intended to bolster student metacognition in the teaming contexts of interest were designed and deployed alongside an existing teaming performance instrument. The results suggest that the exercises were successful in raising students' metacognitive awareness of aspects of their teaming performance, but without a corresponding rise in teaming performance. Additional learning tasks helping students translate metacognitive awareness into higher performance may be required. Substantial future works are outlined to address limitations in theory and methodology identified through the implementation of this study.

II. METHODS

A. Background

The assessment of aspects of metacognition has been attempted by numerous means, including “questionnaires, interviews, the analysis of think-aloud protocols, observations, simulated recall, on-line computer-logfile, and eye-movement registration” [22, pp. 8]. While different methods clearly afford the ability to work with different sample sizes and present more or less of an obstacle to collecting detailed data, other benefits or pitfalls of metacognition assessment methods may be less clear. Veenman identifies an ongoing “need...to

determine far more precisely what metacognitive knowledge or skill component can be assessed successfully by which method [22, pp. 9].” One key distinction between methods that has been identified is whether the data-collection method is “on-line” or concurrent with the metacognitive activity being assessed, or “offline” and data is collected before or after the metacognitive activity being assessed. It is recommended that both on-line and offline data be collected until metacognitive measurement is better understood [22].

This study’s assessment efforts in metacognition were supported by the availability of Tarricone’s comprehensive Taxonomy of Metacognition [23]. This work exhaustively synthesizes previous research to provide a broad, inclusive overall structure of human metacognition. This structure can be employed by pedagogical researchers to delineate the facets of metacognition targeted for intervention or measurement. While the overall structure of metacognition provided by Tarricone is too complex to discuss in detail in this work, specific elements of it targeted by this study can be listed. First, growth in knowledge about metacognition in general and metacognitive knowledge of teaming skills tied to interactions between team members in particular (both varieties of declarative metacognitive knowledge) were targeted during the intervention through assigned readings and in-class discussions. Second, procedural metacognitive knowledge of task was targeted by giving students practice with some basic procedures cultivating and benefitting from metacognition in a teaming context. Third, successful practice required students to increase their awareness of metacognitive feelings, essentially taking a higher degree of notice of specific team-related thoughts related to teaming performance. Finally, increased fluency of metacognitive skills and executive function in the teaming domain was also sought as an outcome of the learning tasks, whereby students would regulate their teaming behavior based upon the previously listed metacognitive knowledge and awareness, improving their teaming performance. The details of the experimental procedure and sample will be discussed next.

B. Overview & Sample

The experiment was undertaken on a convenience sample of students from two sections of a first-year engineering course, with one section selected to receive the experimental intervention (120 students) and the second section to act as a control (114 students). The sections were served by different instructors at different times of day. International students comprised approximately 25% of the sample from each section. Both sections performed four peer assessments of teaming performance spread across the term, and both sections completed two administrations of an online survey into the frequency of specific metacognitive behaviors. The experimental section also received an intervention composed of a short reading assignment and lecture relating specific aspects of teaming with specific metacognitive actions, followed by a class-length (110 minute) exercise overlaying metacognitive awareness cues onto an unstructured team project working period. This exercise included logging occurrences of specific teaming-relevant metacognitive events (see Fig. 1) and each student’s worksheet was collected for analysis.

C. Data Collection

The four peer assessments were administered at regularly spaced intervals across the semester with the well-known and robustly validated CATME [24] peer assessment system. Evaluations of self and peer performance across the five dimensions of the instrument (Contributing to the team’s work, Interacting with teammates, Keeping the team on track, and Having relevant knowledge, skills, and abilities) were gathered. The initial CATME evaluation was used to assess the comparability of the experimental and control cohorts. While the overall average teaming performance between the two sections was comparable (difference in mean overall performance <1.5%), the control section’s standard deviation for Keeping the team on track was found to be more than 20% higher than that of the experimental section, suggesting that the match between the two cohorts is not ideal for statistical comparison. This is believed to be due to the fact that the control section was at a time of day favored by a minority of students, leading the class cohort to be comprised of either very dedicated students or relatively less organized and accomplished students, with relatively fewer students with moderate performance. The relatively weak statistical control provided by the control section did not greatly detract from the interpretability of the results. As peer evaluations have been repeatedly demonstrated to correspond well to actual student performance [25, 26] the third and fourth sets of CATME results for ‘Interacting with teammates’ and ‘Keeping the team on track’ were also used as measures of teaming performance before and after the experimental intervention.

The online survey (see Table 1) asked students ten Likert-scale multiple choice questions and presented two open-response text prompts. The multiple choice questions asked students to rate the frequency that they experienced specific metacognitive events in three areas derived from CATME’s teaming performance behavioral anchors. CATME uses sets of several actions, performed at various levels, to behaviorally anchor student evaluation of self and peer teaming performance for each of its five dimensions. For example, when measuring performance in the ‘Interacting with Teammates’ dimension, students are asked to determine whether the team member being evaluated more closely matches “Listens to teammates and respects their contributions” or “Asks for and shows and interest in teammates’ ideas and contributions” [24, pp. 626] among other options. In contrast, the survey simply asked students how often they would agree with the statement “I notice that I ask for and show an interest in teammate’s ideas and contributions” while working with their team on a scale including never, rarely, sometimes, often, and ‘all the time’ as potential responses. Without behavioral anchors, there is little reason to believe that a response of ‘sometimes’ from one student is comparable to the ‘sometimes’ of another student, but a desire to create a short survey that could be administered in class with a high completion rate and the intention to use pre-post changes rather than absolute measurements of metacognitive event frequency for analysis decided the issue. The open-response questions asked students to describe a recent notable event in their team and to describe their approach to managing their team’s workflow. Time was provided in class for both

TABLE I. ONLINE SURVEY PROMPTS

Question Number	Question Prompt (select from never, rarely, sometimes, often, all the time): When working with my teammates on class work...
1	I consider how best to present information to the team or an individual team member so that they are most likely to respond constructively to it
2	I notice instances where something I said seemed not to have been understood, and either confirm that it was understood or clarify my statement(s)
3	I notice when I think there may have been a mistake and consciously act to understand
4	I notice that I monitor the progress my team overall is making and try to change things if the progress is not adequate
5	I notice that I monitor the progress an individual team member is making on a given task
6	I notice that I give teammates timely, specific, and constructive feedback
7	I notice that ask for and show an interest in teammate's ideas and contributions
8	I notice that make sure that teammates stay informed and understand each other
9	I notice that provide encouragement or enthusiasm to the team
10	I notice that I ask for or respectfully received feedback from a teammate
11	Please consider a notable team-related event or occurrence in your team in the last few weeks. This event could be positive or negative but it should be important enough that you can remember it clearly. As if you were seeing your team from the outside, how would you describe what occurred? Please include what you think each member of your team was or might have been thinking before, during, and after the event.
12	Please write a few sentences describing how you approach the task of keeping your team's efforts on track and productive

the pre- and post- administrations of this survey for both the experimental and control sections.

The experimental section was asked to complete a reading prior to arriving in class on the day of the in-class metacognition exercise. The reading was written for the purpose of this study and was approximately 500 words in length. Students were briefly reminded of the importance of teaming skills to engineers, introduced to the idea of being consciously aware of teaming performance and using this awareness to improve teaming outcomes. The reading also briefly introduced the exercise to be performed and asked students to consider what examples of specific actions might look like in their team, such as a team member checking on the team's progress on a task, or a teammate confirming understanding of a recent communication. These prompts were intended to increase the probability of metacognitive feelings being consciously noted when the actions were later exhibited by teammates or themselves. The word 'metacognition' was avoided and language was chosen to communicate the concepts with a minimum of new vocabulary and with an emphasis on simplicity, to permit all students (especially ESL students) to

understand the reading. A short lecture and discussion was given in the class before the exercise was begun, reiterating the points in the reading and again asking students to contemplate specific examples relating to themselves. The lecture and discussion occupied approximately ten minutes.

The in-class worksheet (see Fig. 1) asked students in the experimental section to mark down the number of times they engaged in one of seven specific metacognitive activities in five-minute intervals using checkmarks. Students made a checkmark each time they noted that they had engaged in a listed metacognitive activity. The seven activities were further shortened versions of the three CATME-derived 'Keeping the team on track' and the four 'Interacting with teammates' prompts employed in the online survey. The prompts were further shortened for the worksheet to allow for fast reference by students as they noted metacognitive events in passing. The majority of students' time and attention during this activity was to be directed towards working with their teams on an ongoing class design project, and the ability to quickly identify the correct column to mark the occurrence of a particular metacognitive event in was seen as key to allowing the design project work to continue naturally. Setting the teaming metacognition exercise as an overlay on top of regular working time was seen as more likely to allow the transfer of metacognitive awareness and constructive teaming responses based upon it to additional in-class and out-of-class team working times. The instructor periodically reminded students to engage with the worksheet as they worked on the project. The earlier distinction between on-line and offline measurement of metacognitive events is blurry with this measurement technique on a per-student basis because some students filled out their worksheet regularly throughout the working time as metacognitive events occurred (online) but others assessed their metacognition only when directed to by the instructor, filling in their sheets retroactively (offline). At the end of the class period, the worksheets were collected for analysis. The control section engaged in the team working time without any directed metacognitive exercises.

III. RESULTS

CATME peer evaluation data was available for 100% of students who completed the course in both the experimental (n=120) and control sections (n=114). It should be noted that CATME performance data is the product of both self and peer evaluation. While some students did not contribute to some CATME evaluations, as long as their peers did, some assessment for each student remained available. Therefore, not all measurements from CATME of student performance have an equal amount of observation behind them. It was found that teaming performance in the target areas increased for students in both the experimental and control sections by relatively small amounts between the initial and final CATME surveys. In the control section, the average performance on a five-point scale rose from 3.98 to 4.13 in Interacting with Teammates (a gain of 3.1%) and from 3.94 to 4.12 in Keeping the Team on Track (a gain of 3.5%). In the experimental section the average performance on a five-point scale rose from 4.06 to 4.12 in Interacting with Teammates (a gain of

Time	A Team Member...						
	Checked on team's progress	Checked on individual's progress	Gave or received feedback	Asked teammate for their ideas	Made sure a teammate understood something	Brought enthusiasm to the team	Gave me feedback on my team interaction(s)
11:40							
11:45							
11:50							
11:55							
12:00							

Fig. 1: Sample of Blank Worksheet

1.1%) and from 3.89 to 4.10 in Keeping the Team on Track (a gain of 4.2%).

As the practical significance of these results is limited and as previously mentioned the experimental and control sections are not ideally matched, the statistical significance of the teaming performance difference between the experimental and control sections was not assessed.

The pre-post set of metacognition-focused online reflections was completed by 79 of 114 students in the control section (69% response rate) and 113 out of 120 students in the experimental section (94% response rate). In the control section, the average performance on a five-point scale across all ten multiple choice questions rose from 3.68 to 3.88 (a gain of 5.6%) and from 3.71 to 3.87, a gain of 4.4%. Thus, higher gains were observed in the control section. Details of student responses to the survey appear in Table 2.

The in-class worksheets completed by the students in the experimental section were analyzed for potential relationships with responses to the CATME instrument and the metacognitive awareness survey. Worksheets were available for 112 students for whom CATME self and/or peer evaluation scores were available and who had completed the pre and post metacognitive awareness surveys. No significant correlations were observed between the number of instances of metacognitive awareness reported on the worksheet and teaming performance as measured by CATME, either holistically or between questions derived from specific dimensions on the worksheet and the corresponding area of CATME performance. However, a Pearson correlation coefficient of -0.19 was found for the relationship between the number of instances of metacognitive awareness reported on the worksheet and the change in scores between the pre and post metacognitive awareness surveys, at a P-value of 0.045. It should be noted that the linear relationship between factors implied by the use of the Pearson correlation coefficient represents an exploratory conception of the phenomenon; there is not yet enough evidence to support assertions about the form

of any such relationship. However, as an exploratory analysis, this finding has implications which are discussed later.

Finally, text from the open-text-responses questions was examined. Analysis of this data was largely informal, using Wordle (<http://www.wordle.com>) to look for macro-scale differences. Responses to the first open-text-response prompt, asking students to relate an account of a recent notable teaming event, did not appear to differ between the pre and post surveys or between the experimental and control groups. Responses to the second question (asking students to relate their approach for managing their team's work) seemed largely unchanged between surveys for the experimental group, but the control group showed a substantial rise in the use of certain words such as 'track', 'time', 'task', 'sure', and 'keep'.

IV. DISCUSSION

CATME teaming performance scores and scores on the metacognitive awareness survey rose, for both the experimental and control sections. However, in most cases the growth reported was not large. Some individual prompts, such as #9 on the metacognitive awareness survey ("I notice that I provide encouragement or enthusiasm to the team") did show growth greater than 7%, suggesting that growth in metacognitive awareness may not be evenly distributed across the performance areas. Overall, the fact that some growth was reported on average for both sections and both instruments suggests that existing class procedures supports some level of metacognitive awareness in the teaming context and some teaming performance growth. However, the low levels of growth reported align with the continued need to develop and deploy more effective pedagogies for teaming skills.

The fact that performance was found to increase by larger amounts for the control section is not interpreted to mean that the intervention was counterproductive. It can be noted that the control section's starting metacognitive awareness scores were substantially lower for prompts where the control section gains were sharply higher than those of the experimental

TABLE II. ONLINE METACOGNITION SURVEY RESULTS

Prompt	Experimental Section				Control Section			
	<i>Pre-Test</i>	<i>Post-Test</i>	<i>Change</i>	<i>Change %</i>	<i>Pre-Test</i>	<i>Post-Test</i>	<i>Change</i>	<i>Change %</i>
1	3.95	4.04	0.09	1.8%	3.94	4.03	0.09	1.8%
2	3.65	3.84	0.19	3.7%	3.64	3.81	0.18	3.5%
3	3.75	3.95	0.19	3.9%	3.85	3.99	0.14	2.7%
4	3.66	3.84	0.18	3.5%	3.74	3.89	0.15	3.0%
5	3.35	3.44	0.09	1.8%	3.31	3.44	0.13	2.5%
6	3.60	3.70	0.10	1.9%	3.46	3.81	0.35	7.0%
7	4.01	4.16	0.15	3.0%	4.00	4.11	0.11	2.3%
8	3.77	4.00	0.23	4.6%	3.63	3.96	0.34	6.8%
9	3.54	3.92	0.38	7.6%	3.61	3.99	0.38	7.5%
10	3.78	3.81	0.04	0.7%	3.63	3.81	0.19	3.8%

section. This suggests that the control section may have had more room for skills growth. The text-mining results also suggest that the control section showed more changes in how they discussed teaming activities.

Another reason to doubt the intervention was counterproductive is that students may confuse metacognitive awareness of performance with performance itself. Students were prompted to respond to questions that are about noticing whether they take a specific action, not whether they do take a specific action. However, this is an offline measurement of metacognitive activity and presents students with an opportunity to conflate their performance in noticing ongoing actions with their performance in actually performing the related action. For instance, students could perform the teaming action without having consciously noticed the opportunity to do so or students could improve their noticing of opportunities to take specific actions (which would be an improvement in metacognitive awareness) without actually implementing the related teaming action, then mark themselves poorly by focusing on the action element of the prompt rather than the 'noticing' element.

One indication that this may have occurred is the statistically significant ($P = 0.045$) negative correlation between engagement with the in-class metacognition logging worksheet and scores on the metacognitive awareness survey. The fact that students who engaged more extensively with the worksheet tended to report a lower level of metacognitive awareness on the post-intervention survey suggests that the instrument may be measuring something other than it was intended to. It seems likely that students who engaged more deeply with the worksheet raised their internal expectations of their performance in teaming metacognition and then gave themselves lower scores on the survey. This is similar to models of self-efficacy ("a person's estimate of his or her capacity to orchestrate performance on a specific task," [27, pp. 183]) where increased knowledge of a domain may in fact change individuals' perceptions of success and in fact lower their self-efficacy within that domain. For example, in a study

of teacher professional development on engineering group of middle school teachers were reported as having lower self-efficacy for teaching computer programming after learning a new programming language [28]. The fact that a difference was measured suggests that the intervention may have an impact and may hold some promise for later, more precisely implemented and better supported interventions. For example, as no correlation was detected between the rise in metacognitive awareness survey scores and teaming performance, students may require more support in translating awareness of teaming actions or opportunities for them into constructive responses leading to higher teaming skills performance.

V. FUTURE WORKS

While the increases in teaming performance and metacognition in the targeted areas observed in both the experimental and control sections is positive, and the probable rise in student metacognition suggested by the experimental results is heartening, the goal of this ongoing project is to design and implement an intervention that not only increases student metacognition in targeted team-related areas but translates that increased awareness into actual and constructive actions taken by the students in their teams. As discussed, this was not observed in the results from the initial intervention. Therefore, future works are planned to restructure the intervention and its assessments, working towards the goal of measurably improving student teaming performance.

It is anticipated that future iterations of this intervention will scale up the quantity and frequency of time spent in class explicitly dealing with teaming metacognition, employ varied interventions starting earlier in the course, increase the sample size, take additional steps to promote consistency in class practices between the experimental and control groups, and give additional training and emphasis on translating awareness of teaming issues into constructive actions.

Increased support for and emphasis on accurate peer ratings through the CATME system will also be implemented. The

relatively high initial scores, relatively static scores over time, and relatively high number of students whose ratings decline noticeably over the term suggest that some students may not have engaged deeply with the CATME rater training materials or rating process. Increasing student rating capability and motivation may yield more reliable measurement.

The limitations of the reflective survey of metacognitive frequency used in this study suggest that improved, additional, or alternative assessment methods may be appropriate. While the future assessments to be employed have not yet been selected, one potential avenue is to infer the use of metacognition through team actions while engaged with a problem, similar to Schoenfeld's work with metacognition in mathematics [29] or the NOME coding for naturalistic engineering settings developed by McCord [30]. As it is hypothesized that social anxiety may be one mediating factor between metacognitive teaming awareness and concrete teaming action, assessment of this and other potential mediating factors may be considered in future research works.

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Seamless Cross-Platform Integration of Educational Resources for Improved Learning Experiences

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Abstract—The main contribution of this work in progress is an open source architecture for seamless integration of open access educational resources located in heterogeneous learning management systems (LMS) distributed across the network. One of the main advantages of the proposal is the simplicity in creating, managing and making available new content that builds on the existing material in different repositories. Some previous works addressed similar issues but either in simpler environments, i.e., when the distributed systems were homogeneous, or they require extensive knowledge to take advantages of the integration, from the point of view of both the content creator and the manager of each learning system. Our solution exploits the possibilities offered by the Content Management Interoperability Services (CMIS) interface typically present in many content repository platforms allowing users to browse and interact with contents stored in several heterogeneous places. Some preliminary results show that it is possible to efficiently combine engineering learning material taken from our technical university with other online resources made available from different educational institutions. Moreover, two extensions, currently in development, aim at providing seamless videoconferencing integrations between the teacher and the learners as well as at supporting remote laboratory sessions by means of controlling programmable objects in remote laboratories with real-time video feedbacks for the students.

Keywords—Electronic learning, Courseware, Content management

I. INTRODUCTION

In the latest years the wide availability of digital technologies and communication networks that allow access to plenty of material led to the production of a huge amount of didactic materials. These documents in electronic format, often called Learning Objects (LOs), comes in widely different types. Hence, the educators can often use them even beyond the environments for which they were originally made.

To store and properly index learning objects a considerable amount of software solutions have been developed in various forms. These systems are named *Learning Management Systems*, e.g., Moodle [1] and Chamilo [2]: they provide content repository features so that users, typically teachers, can upload and store their materials with the final aim of organizing them into self-contained courses. Other systems, the so called *Enterprise Content Management* systems such as Alfresco [3] and Nuxeo [4], provide the users with only general repository functions including indexing and basic search and share functionalities.

However, the number of platforms and repositories available for e-learning purposes is increasing rapidly [5]. The

direct consequence of this rapid expansion is the production of a vast number of LOs which can be used to create entire on-line courses. However, the drawback of the situation is the increasing amount of heterogeneity among *Learning Object Repositories*. Moreover, different institutions (e.g., universities) typically perform different choices in terms of chosen LMS and their configurations. Therefore, LOs are useful only if they are used within the scope of the organization for which they have been developed.

From the point of view of reusing LOs, one of the main issues is that typically LOs do not contain information about what is possible to do with them. In particular, each LO repository typically specifies a set of rights which is, in general, different from the one of the others, making it very difficult for a user to freely use the LOs without carefully dealing with the specific constraints of each object. However, even when freely usable LOs are found, the LMS employed by the educational institutions may pose obstacles to such use, for instance due to the difficulty in using the content or the complexity of the interfaces offered by the tools. To avoid this situation, the recent trend is to develop tools that allow accessing, in an easy way, the content of the repositories and directly perform actions through the use of simple web interfaces [6]. Our proposal is following this trend but, in addition, it aims at integrating together the repositories of many different institutions that can be based on different software and technologies.

Concerning this aspect, the so called Unified E-learning Repositories (UER) [7] are moving towards this direction. In particular, they offer the possibility to connect, from a centralized point, to a variety of repositories. However, since the repositories involved are typically homogeneous, this causes difficulties in the implementation phase, for instance when different institutions that do not use the same system are connected or merged together.

Nearly all the mentioned approaches attempted to deal with the situation by offering new instruments, oriented at both content creation and handling. To overcome these issues, in this work we present an innovative approach that, instead of proposing and developing yet another complete set of products as done by most of the works in literature, reuses most of the tools that have already been deployed trying to exploit their full potentials as much as possible. The key idea is to exploit the features provided by the so-called CMIS (Content Management Interoperability Services) API [8]. By means of this API it is possible to access, from a centralized web platform, a number of distributed repositories which can be

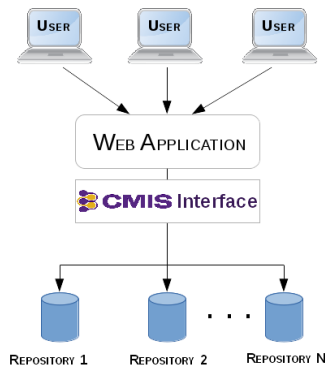


Fig. 1. Block diagram of the proposed architecture.

of different type and be physically located in different places, i.e., directly the repositories located at different institutions.

The main features of the proposed platform are the easy-to-use interface and the possibility to rapidly compose and share learning objects with a few clicks, without the need to download anything for local processing. Since one of the main targets of the proposed platform is engineering education (EE) we believe it is necessary to guarantee, to all users, the basic freedoms to read, edit and redistribute content as well as the system itself. The former aspect is addressed by selecting, as default, the Creative Commons BY-SA license [9] for the contents, whereas the latter is guaranteed by means of licensing all the developed software under the GNU GPL v3 [10] license. In this way the students will be free to learn even by investigating the source code of the learning architecture itself. Moreover, this solution also suits the requirements of the Italian government that strongly encourages the use of open standards for interoperability. Therefore, the approach is suitable for being selected as one of the official platforms to be used in the context of electronic education. In fact, it has recently been submitted for evaluation in a government call seeking national-level solutions for e-learning.

Note that the platform is a work in progress as it is currently being extended in two important directions to provide an improved and more integrated learning experience. First, a videoconference system is being integrated, since we believe that it is necessary to address the increasingly common case in which not only the teaching material is available online, but also lectures are given entirely by means of the Internet. Through the integration of a videoconferencing tool there will be the possibility not only to prepare the course contents for a frontal lecture but also to directly use the platform as the primary way for teaching. The second direction is particularly aimed at practical subjects such as engineering, where it is absolutely important to learn by doing. We are extending the tool to support remote laboratory sessions in addition to the more traditional remote lectures. Some preliminary experiments are currently being conducted, experimenting with interactive remote robot piloting sessions in which students develop code that is then run on the robots, which are in turn observed remotely through video streaming.

II. SYSTEM DESCRIPTION

A. Motivation

The general aim of this novel architecture is to provide access to a number of heterogeneous repositories of LOs through a unified web interface which is the reference for all the activity performed by both the teachers and the learners. To this aim we provide a set of pre-configured tools to perform the most important operations such as searching, querying, downloading, sharing and merging of LOs to create new ones. The platform is designed in an extensible way so that new tools can be integrated. As it will be explained later, we are currently working towards including functionalities such as remote lecturing and remote laboratory interaction.

B. Technical Specifications

The block diagram of the proposed architecture is shown in Fig. 1. To achieve modularity and extensibility, during the design phase a number of frameworks have been analyzed. Drupal [11] has been selected to build the first prototype since it boasts a modular design which is well suited for our aims. Wherever necessary the front end has been designed using the Bootstrap [12] framework. In addition, many modules are already available under open source licenses which allowed the Drupal active community of developers to extensively test them. We relied on a LAMP (GNU/Linux OS, Apache web server, MySQL database and PHP) web stack to host the platform since it is one of the most common configurations that can be typically very easily deployed on most servers running open source software. Moreover, LAMP stacks can be easily set up on any platform and plenty of tutorials and resources are available in the network to guide in this process.

To test the platform with different repositories, we initially selected the Alfresco Community Edition and Nuxeo, which are the platforms adopted by the two universities in our city. However, the platform is ready to interact with any CMIS-compliant solution.

C. Web Interface and Typical Usage

All users (students and teachers) access the platform by means of a web interface, through any recent web browser. The landing page immediately presents all the most important actions, i.e., search and download. Learning objects are retrieved through simple web downloads, therefore almost no technical knowledge is required. They can be downloaded in their native format (e.g., PDF for documents or AVI files for video) or exported in the form of a ZIP file with an embedded HTML5 presentation. In other words, the ZIP includes an HTML file that, when clicked, plays back all the content in the form of an HTML5 presentation.

The basic actions that all users can do include:

- search for a content by formulating a query;
- check the description of the results and select the desired ones (a screenshot of the developed user interface is shown in Fig. 2);
- export the content in several formats, including a user- and device-friendly HTML5 presentation.

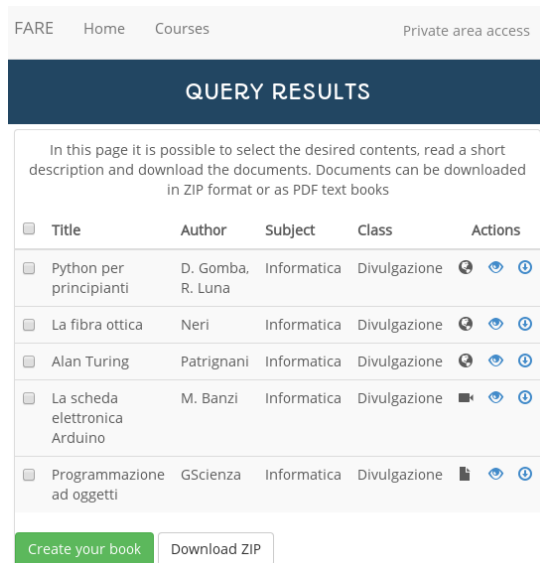


Fig. 2. A sample screenshot of the user interface.

The latter possibility has been particularly appreciated by both the student and the teachers as it allows to present the content of the LO, in the form of an automatically generated slideshow, by simply using a recent web browser that supports HTML5. Moreover, such an approach is able to deal with the variety of devices that students may use to watch the content, i.e., the standard PC screens, tablets, and smartphones.

Other functionalities are available after authentication. For instance, students can save their searches. Teachers, instead, are presented with a larger set of functions. For instance, they can also upload content through the browser, as well as extract contents from LOs and merge them automatically in new virtual objects that can then be shared and made available to the students as if they were regular LOs. Moreover, the teachers can also export the content in formats particularly suitable for teaching, e.g., with large navigation buttons and media formats suitable for presentation on electronic interactive whiteboards.

D. Improvements vs Previous Systems

The proposed platform improves over existing ones especially in the activities where it is needed to rapidly compose and share learning objects with a few clicks. Other systems typically require to familiarize with sometimes complex editing environments or require to download content for local processing. In our system nothing needs to be downloaded locally for processing since during the design phase this has been deemed too complex, error prone, and unintuitive especially for less skilled teachers. Note that, while our initial tests addressed the EE field, we aim to build a system for any discipline and school level.

Moreover, one of the key functionalities is that access to and search of learning objects are completely transparent regardless of the heterogeneity of repositories in which they are hosted: the platform automatically manages transfer, merges, creation of new content, and it also provides permanent links to the newly defined content.

Finally, videoconferencing tools are being integrated with a dual purpose: traditional remote lectures as well as interaction with remote laboratories. In the latter case the functionality

will be used to remotely observe real objects (e.g., remotely programmed robots) in action as if students were actually in the lab. We believe that this feature is currently unique for this system.

III. TRIALS AND USAGE

A. Current Testing

The platform has already been tested by including some EE content taken from the e-learning repository of our university. Moreover, some teachers added self-produced content in the form of booklets or short essays about computer-related topics. We are currently linking the electronic repository of the other university in our city so that additional material coming from the Computer Science course of study can be added.

To evaluate the effectiveness of the proposed system we asked the participants to fill up a questionnaire about their user experience with the system, from both the technical point of view (e.g., response times, appropriateness of the results, etc.) and the user friendliness (e.g., intuitiveness of the interface, navigability, difficulties in finding features, etc.). Moreover, users could also provide free comments.

Summarizing the preliminary feedback obtained by means of the questionnaire, the teachers involved in the tests confirmed the user friendliness of the interface also for the most complex tasks that required to interact with different LOs to create new ones that can be made immediately available for the students. The HTML5-based presentation feature was particularly appreciated in the free comments section, primarily because it is a very easy way to preview and experience the contents.

B. Future Directions

As mentioned in the Introduction, the platform is a work in progress. In fact, it is currently being extended, on the basis of the users' feedback, along two important directions to provide an improved and more integrated learning experience.

First, a videoconference system is being integrated in the platform, since it is necessary to address the increasingly common case in which not only the teaching material must be available online, but also lectures should be given and available entirely by means of the Internet. The videoconferencing module is being developed integrating the Big Blue Button [13] communication suite. The new web application landing page will feature an additional area that include the possibility for the educator to rapidly start a remote lecture and invite the students to join it. The students will see all the currently available lectures and they can immediately join them if desired. The teachers can benefit from an *interactive board* in which they can load presentations. The contents saved in the private area are directly inserted inside the interactive board component of the system. In this way whether a teacher is physically in class or is delivering an on-line lesson, the contents of the repository are seamlessly and immediately available for fruition.

A second promising direction is aimed at educational areas such as engineering, where the practical part plays an important role. In other words, for these subjects it is absolutely important to learn by doing. We are currently

extending the platform to support remote laboratory sessions in addition to the more traditional remote lectures. To start the development activities we are focusing on a *robotics* course that we are trying to incorporate in our platform. For this particular teaching activity the robots include both software and hardware components, the former being developed by the students. It is clear that, in such a situation, a satisfactory experience can be difficult to achieve if it is not carried out in a real laboratory. Furthermore, the difficulties of handling the hardware can represent a huge obstacle especially when students with limited experience are involved. Moreover, the cost of the hardware components, i.e., robots, may be non-negligible therefore they cannot be acquired in large quantities.

To address this situation a virtual solution could be used, where the real robot is substituted by a virtual avatar. This approach would allow the students to create the algorithm and then test it on the virtual simulator. Though this is certainly an option that has also been explored in the past [14], dealing with actual devices is sometimes preferable from the point of view of the students since the activity is perceived as more real.

Therefore, our approach focus on the so-called *hybrid laboratory*. This approach needs a physical lab where the robots are set up, as well as a web platform to interact with the robots. In this case the students are able to program the robot and then send the source code to the platform that will check it and compile the code. In case the results are suitable for running on the actual hardware, the executable code will be loaded inside one of the robots in the laboratory and the software will be executed to animate the robot. The students will be able to check the behavior of the robot by controlling the real-time video stream from the laboratory thanks to a streaming tool integrated in the platform, which could also be a special session created by means of the previously discussed Big Blue Button software suite. Although at the current stage we still need the human operator to load the software into the robot, we are planning to automate this task by means of wireless connections between the robot and some dedicated servers in the lab, so that there could be just one human operator performing only supervision and maintenance tasks. We are currently experimenting with the robotic toys series *Lego Mindstorm* [15].

C. Eliciting Additional Participation

The most difficult part of deploying an effective system is to ensure that participation is sufficiently high and make sure that most of the users are active. We are planning to increase the participation by means of agreements with locally-funded projects about improving high-school teaching. In particular, the system will be part of the “School 2.0” activities (starting September 2015) of the “Fondazione per la scuola” [16], an initiative of the “Compagnia di San Paolo” foundation, funded by banks, regional and local government institutions and higher-education institutions. The “School 2.0” will involve students and teachers in nearly all high schools in the Torino area, therefore the amount of users involved is expected to increase considerably. This will be an ideal experimentation in light of a possible adoption of the system at the national level, if the submission to the government call seeking national-level solutions for e-learning will be successful.

IV. CONCLUSIONS

This paper described an open source architecture for seamless integration of open access educational resources located in heterogeneous learning management systems (LMS) distributed across the network and managed by different institutions.

A key advantage of the proposed architecture is the simplicity in creating, managing and making available new content which can be either uploaded or directly created by means of the web-based interface from parts of objects already available even in different repositories, without the need to download them for local processing. Our solution exploits the possibilities offered by the Content Management Interoperability Services (CMIS) interface present in many content repository platforms so that the users are presented a uniform and repository-independent interface for all the contents in all connected repositories, even in the case of heterogeneous repositories.

Preliminary tests with some teachers and students showed great interests from both categories. Moreover, the tests allowed to check the functionality of the system by combining engineering learning material taken from our technical university with other online resources made available from different educational institutions.

On the basis of the users’ feedback, two extensions of the platform are currently being developed. One aims at providing seamless videoconferencing integrations between the teacher and the learners. The second aims at creating the infrastructure necessary to remotely manage and control physical objects (such as robots) in remote laboratories allowing the students to perform practical experimental activity as if they were in the laboratory itself by means of a live video feedback.

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Analysis of Integration of Remote Laboratories for Renewable Energy courses at Jordan Universities

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Abstract—MUREE project aims at the development of courses for training specialists about renewable energy production by combining face-to-face learning with on-line attendance. In this sense, remote laboratories are nowadays essential for distance education, even more within MUREE project, since Jordan students are not able to use face-to-face traditional laboratories due to their different physical location. These remote laboratories can be employed by instructors within their virtual classrooms, so that students can carry out their on-line experiments from anywhere and at anytime. For MUREE project, remote laboratories are seen as pedagogical elements that must be fully-integrated into a the learning/teaching process. Therefore, this work focuses its attentions toward the integration of remote laboratories into Learning Management Systems (LMSs) and, additionally, discusses the advantages and disadvantages of this approach.

Index Terms—Distance Education, Remote Laboratories, On-line Experiments, Learning Management Systems (LMSs).

I. INTRODUCTION

Within the field of Engineering Education making practical experiments is essential, as an accompaniment to magisterial classes, in order to enforce theoretical and practical concepts. This task is much more complicated in distance education, since students attend mainly to virtual classes. Therefore, the use of remote laboratories can help them to minimize this inconvenient. In addition to this, online evaluation experiments will help instructors to prepare suitable evaluation on-line experiments, in similar conditions as students are in the same physical location as the real laboratory.

According to this, the main objective of the MUREE project [1], which supports this work, is the development, integration, accreditation, and evaluation of renewable energy courses in the context of Engineering degrees from several universities in Jordan. This project follows the guidelines proposed by the Bologna process, and considers the previous experimentation with renewable energy equipment, in order to allow us to study the best approximation of remote laboratories.

Institutions can desire to share their laboratories by means of the integration of laboratories into shared courses among different universities, avoiding the need to reproduce the same deployment in each institution. The sharing of laboratories, not only cost, but also allows students to have a wider offer of laboratories. So, this is a key element for choosing a particular integration methodology for this project. From the MUREE project perspective, the integration of the remote laboratories into a Learning Management System (LMS) satisfies the need of pedagogical support for experimentation. There are different methodologies to perform this task in the literature which will be explored in this work, thus finding out the most suitable for our purposes.

In this work we pay attention to the main three ways of integration of remote laboratories into LMSs. The first approach is based on the use of middleware that expands the capabilities of the remote laboratories. This middleware is known as Remote Laboratories Management Systems (RLMSs). The second analysed approach is the extension of learning content standards to include the remote laboratories. Finally, the most suitable approach from the perspective of this project is the use of the extension mechanism provided by LMSs themselves. The main advantages and disadvantages of three approaches are explained in the following sections. Finally, the main benefits of the chosen approach are detailed.

The rest of this paper is organized as follows. In Section II, the most popular laboratories are described. Section III analyzes how to perform the integration of remote laboratories into learning environments. The discussion about the main benefits of integrating remote laboratories into LMSs is detailed in Section IV. Finally, Section V highlights our final remarks and suggests guidelines for future work.

II. REMOTE LABORATORIES

A *remote laboratory* is a software and hardware equipment that allows students to remotely access real devices located at a particular institution. Users access this equipment as if

they were in a traditional hands-on-lab session, but through the Internet or a network. According to this, there are many examples and classifications in the literature [2]–[4].

Renewable energy is not new for remote laboratories. For instance, remote laboratory experiences to perform activities related to the quality of the generation of energy can be found in [5] and [6]. Similarly, several renewable energy laboratories can be found in the literature. In [7], authors propose a laboratory used to analyze the creation data of the eolian energy. In particular, it consists of a real eolian turbine monitored by a set of sensors, deployed in conjunction with a meteorological station. Data are stored in a shared database, so that students can create their own client applications. As for remote laboratories focused on the solar energy, there are several examples, such as [8], [9], and [10]. In this project, two remote laboratories, a solar panel laboratory and a wind turbine laboratory, are developed as prototypes for testing the integration process. More details of this are given in [11], where the technical implementation details, the designed experiments and the gathering of experiment data are detailed.

However, despite the widespread use of remote laboratories, they have several design and construction issues that have not received much attention. On this topic, we can mention [12], where the impact of the selected technologies for the development of remote laboratories is analyzed. But most of the published literature focuses only on the objective of a certain application within a conducted course showing their functional and operational aspects [13]. In previously mentioned work [3], a study of 42 different remote laboratories concluded that they use different software architectures without being reused or shared among universities.

The lack of common standards in lab definition and connectivity specifications is one of the major impediment to the adoption and wide-scale networking of labs for teaching and training purposes. It is clear that an standard access interface can help in this direction. There are several projects oriented towards the creation of repositories of remote laboratories, classification ontologies and metadata standards for remote laboratories such as Lab2go [14] and *Laboratory Description Language* (LDL) [15].

III. ANALYSIS OF THE INTEGRATION OF REMOTE LABORATORIES INTO LMSs

A Learning Management System (LMS) is a software application that eases the provision of theoretical online classrooms by means of integrated features and tools such as administrative tools, synchronous and asynchronous communication tools, assessment and tracking tools, multimedia sharing tools, and standard compatibility. The goal is to make use of all the services provided by open-source LMSs, such as Moodle [16] or Sakai [17], and apply them in the remote practical laboratory sessions. Thus, several initiatives have been launched to integrate remote laboratories into LMSs. This section tries to summarize these projects.

A. Remote Laboratory Management Systems

In case an institution desires to share a remote laboratory among other institutions, they need some additional resources. Another component to take into account is that remote laboratories are in many cases expensive equipment and are confined to the private usage of their owner university due to the complexity of their inter-operation. Additionally, in order to solve the problem of providing practical skills to students despite the lack of equipment and funds in educational institutions, technology enhanced learning based on the sharing of equipment between institutions is suggested for wide-scale implementation across countries. This was a breeding ground for new researchers to attempt to establish a seamless, interoperable, and shareable integrated architecture that encompasses several remote laboratories from several universities in order to span their dissemination and interinstitutional operation. Under this concept appears a new type of middleware called *Remote Laboratory Management Systems* (RLMSs), such as MIT iLabs [18], WebLab-Deusto [19], Labshare Sahara [20]), or RELATED [21]. These RLMSs provide development toolkits to incorporate remote laboratories, as well as management tools and common services. A summary of the principal characteristics of these platforms is represented at Table I. A further and more detailed review on the integration and interoperability of remote laboratories nowadays can be found at [22] and [23].

The main drawback of this approach is that the integration of remote laboratories into LMSs requires additional layers, adding complexity to labs in terms of performance. On the other hand, RLMSs do not provide by themselves all the convenient resources for distance teaching/learning of students with all the implications that this methodology involves. Specifically, students must carry out their practical activities in an autonomous way and, therefore, additional Web-based resources to the remote labs should be included into the course. For this reason, the RLMSs should not only present a description of the phenomena under study and its didactic context for remote experimentation, but also the scaffolding tasks student must follow to achieve his/her goals.

B. Extending Learning Contents Standards

A different approach to the integration of remote laboratories into learning process is based on the extension of well-known learning contents standards such as SCORM and IMS. A first approach in this direction is Library of Labs (LiLa) project [24], which has created a repository portal that includes online laboratories from distinct universities. LiLa objectives are closer to Lab2go but they offer access to the remote laboratories. Experiments are represented by SCORM packages, that can be easily integrated into Learning Management Systems. LiLa provides access control and booking systems as an inherent part of shareable content objects (SCOs) to have the same effect if the SCO is deployed out of the LiLa portal (in an LMS). The access to the experiment, either in the LiLa portal or in the LMS, is provided by a URL.

Table I: Summary of RMLS found in the literature

	Labshare	iLab	WebLab-Deusto	Related
Developed by	UTS (Sidney, Australia) [20]	MIT (Boston, USA) [18]	Deusto University (Spain) [19]	UNED (Spain) [21]
Platform	Cross-platform	Windows server	Cross-platform	Cross-platform
Authentication	Username and password and interface to federate australian universities	Username and password	Username and password, LDAP, OpenID, Oauth 2.0	Username and password, OAuth, OpenID
Authorization	Yes	Yes	Yes	Yes
Booking system	Scheduling and queue	Scheduling and queue	Queue	Scheduling and queue
Federation of laboratories	Yes	Yes	Yes	No
User monitor	Yes	Yes	Yes	Yes
Types of experiments supported	Batch and interactive (controlled and uncontrolled)	Batch and interactive	Batch and interactive (controlled and uncontrolled)	Batch and Interactive
Integration of a remote laboratory	Complex	Easy	Easy	Easy
Other characteristics			Mobile access and integration in Moodle	Mobile access and Augmented Reality

Very similar to LiLa project is Open Collaborative Environment for the Leverage of Online Instrumentation (OCELOT) [25] project. OCELOT is a open-source, collaborative online framework and middleware. In this case remote laboratories are packaged into IMS Content Packages. And a relevant feature is that it combines Web Semantic and ontologies to define the collaborative interactions.

The main drawback of this approach is that the SCORM and IMS content packages are standards oriented to package static contents. This approach must extend the existing standards to include the needed features for the management of remote laboratories. So, the LMS must be aware of the standard extension and offer support to then.

C. Integration by Using LMS Extensions

Many LMSs offers their own extension mechanism. So, a different option to integrate remote laboratories into LMSs is the creation of an extension of the corresponding LMS. This approach has been chosen by this project. The main benefits are detailed in the next section.

As an example, the MARVEL project [26] has created a booking module for the most popular open source LMS, Moodle, which is based on hour slots. Although it had been modified to facilitate the integration of remote laboratories, this approach is oriented to a fixed scheduling schema and remote laboratories only built with LabVIEW control panels. This fixed scheduling scheme does not allow different types of experiments take place. As the session slot is fixed maybe this session duration can not adapt to the students' needs. Other disadvantage of Labview control panels is the need of a web plugin in order to execute the laboratory interface.

Another Moodle approach can be found at [27] where a Moodle plugin and a dotLRN plugins are proposed to integrate remote laboratories into Learning Management System. In this work, they do not present a clear integration strategy for general laboratories which are integrated ad-hoc. On the other hand, they present a useful extension for WebLab Deusto

platform for its integration into Moodle. So, the scheduling schema is delegated to the underline middleware. The integration of a remote laboratory in this case is complex: first integrate it into WebLab Deusto, afterwards, install and configure the corresponding plugin. Our approach is a more straight forward step.

EJSapp [28] proposed a set of Moodle plugins for the integration of virtual and remote laboratories. The remote laboratories are represented by EJS applets. They offer a scheduling schema, collaborative tools for shared sessions, and a manager for the experiment resulting files. The main drawback of this approach is that two different activities can be developed on the same laboratory or equipment, and the plugin threat them as different and concurrent activities. To solve this situation, a middleware is needed.

It is also remarkable that most of the integration proposals do not pay much attention to the monitoring of the student during the performance of the experiments. This is also a key element in the development of a new proposal.

IV. DISCUSSION

The integration of remote laboratories into LMSs have several benefits. First, this integration allows the versatile use of on-demand learning laboratories as learning resources. A remote laboratory does not provide by itself all the convenient resources for distance teaching/learning of students with all the implications that this methodology involves. Specifically, students must carry out their practical activities in an autonomous way and, therefore, with complementary Web based resources to the remote labs should be included. For this reason, all the remote laboratories in this framework should not only present a description of the phenomena under study or the didactic context of the experiment for remote experimentation, but also the scaffolding process that students must follow in order to achieve the proposed goals.

Second, when integrating laboratories into LMSs, a set of experiments can be deployed depending on a particular

learning/teaching process. Therefore, it is important to define specific activities, for instance, which consists in understanding the transformation of the solar and aeolian energy sources into electric energy. Thus, a key aspect to be addressed is the development of a personal learning context into the LMS that offers to students a work-space and supports their learning process with the appropriate learning resources, including the services that the remote laboratories provides, in this case, the solar and aeolian prototypes developed in this project. The aeolian laboratory focuses on helping students to understand how wind is directly related to the generation of energy, and the solar laboratory is focused on how the solar motherboard and the angle of incidence of the solar light are correlated. According to this, students are asked to handle the obtained data in order to generate their own plots as homework, and to make some conversions of unit measurements, such as Watts and Joules.

Third, the integrated learning environment must organize the access of users to available experimentation modules and simplify the organization of user groups. It should also be able to integrate other educational services such as notification services by email, news, forums..., allowing users (students and instructors) their interaction and the collaboration among the learning community. In order to support this, some management services (like control access or current status) have been added to the renewable energy laboratories [11]. Furthermore, a remote laboratory must report instructors students' tracking including the data collected during the simulated and real.

To sum up, this type of integration makes feasible to have a scalable architecture, which provides a real and flexible interaction environment for laboratory users (students and instructors). Much functionality is added automatically by the LMS, so the laboratory's developer only has to focus on the laboratory itself.

V. CONCLUSIONS AND FURTHER WORK

The integration of remote laboratories into LMSs is of real of interest, because of the fact that instructors will be able to specify courses by using remote laboratories as an additional activity. This is even more noticeable in distance education and, what is more, it may enhance the scientific skills of students. For these reasons, this work presents the state of the art in this topic and analyses the best way to perform this task, and discusses the main benefits of this integration.

As a future work, it is planned to perform a fully-functional integration of our remote laboratories into one of the most popular LMSs, as Moodle is. Evaluations from the users' points of view (both instructors and students) will be also conducted in order to analyze their satisfaction. In addition, a study of the recolected data from the experimental sessions will be analyzed in conjunction with the students satisfaction.

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A Novel, International Masters Program to Address the Sustainable Energy Challenge

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Abstract— An education collaboration between the University of APEC (UNAPEC) in the Dominican Republic and the College of Engineering at the University of Puerto Rico-Mayagüez (UPRM) yielded a novel Masters Program completed by fifteen Dominican engineers using sustainable energy as focus. The authors proposed and executed this distance learning program with collaboration from Engineering and Social Sciences professors. The program addressed the Dominican energy problem from a technical perspective, but also considered and integrated social aspects of the problem. This education paradigm provided an integrated perspective of the local and regional energy dilemma needed to advance a sustainable energy future in countries with scarce traditional energy sources. After the courses were completed, each student presented a Masters project proposal. The proposals were reviewed by UPRM, UNAPEC faculty and in some instances by the supervisors of the students at the transmission company. All projects addressed a technical need existing in the Dominican power system. Each student defended the work before a panel composed of three to four UNAPEC faculty, and two to three UPRM faculty (using videoconference). Assessment results for the program reveal that program objectives were successfully attained.

Keywords— *Electrical engineering education, sustainable development, distance learning, graduate education.*

I. INTRODUCTION

Sustainability has been a key global issue since “Our Common Future” was published in 1987. Even though there was previous work on sustainability, the most widely-known definition remains the one proposed in 1987: “the use resources today in a way that does not compromise the ability of future generations to meet their needs” or some variation [1]. In the last ten years, a significant number of graduate and undergraduate initiatives have used sustainability either as a central theme or a key area of emphasis. For example a project-based approach is used in [2] to expose undergraduate and graduate students to interdisciplinary experiences in sustainable energy. Also a renewed power and energy program initiative has been developed with an inter-disciplinary focus including sustainability to provide a comprehensive approach to energy and the environment [3]. Another example is a PhD

program in Sustainability that includes convergence between specific disciplines and sustainability [4].

This paper presents a sustainability-based distance education program, developed at the University of Puerto Rico-Mayagüez (UPRM) and delivered through videoconference to the University of APEC (UNAPEC) in the Dominican Republic. UPRM and UNAPEC have had academic collaborations since 1994. In the early 2000’s these universities began a joint degree in Electrical Engineering, which graduated eleven Dominican engineering students with Masters degrees in the areas of communications and electronics. A second cohort of students began a Masters program in electric power engineering, with focus on sustainable energy on 2007. After visits to the Dominican Republic and meetings with university and electric industry officials, the authors proposed and executed the program with collaboration from Engineering and Social Sciences professors. The program was structured to meet the needs of the power industry, in traditional areas of power generation, and distribution as well as alternative areas related to sustainable energy. Using the definition of sustainability from “Our Common Future”, a sustainable energy framework was used to structure the program. Most courses were delivered through distance learning using videoconferencing systems, except a handful of courses that were in person. A strong component of the program was the integration of an assessment component across the curriculum to measure the effectiveness of the content delivery, educational practices, technology, and student satisfaction. This paper describes the latter part of the program, the Masters projects the students developed and the program assessment.

II. PROGRAM CURRICULUM

Since sustainability was used as a framework for the program, a sustainable energy cluster of courses was included in the curriculum: renewable energy, biomass conversion and a course on energy and society. The interdisciplinary nature of sustainable energy was presented to students not only through the topics of the curriculum, but also through the professors. Colleagues from Chemical Engineering and Social Sciences taught two of the courses in the sustainable energy cluster. The

curriculum also included the deregulated perspective in energy markets and power system economics (the Dominican power sector is deregulated on the generation level and partially in the distribution level). Finally, more traditional courses were included in the Generation and Transmission cluster: Power system operation and control, stability and reactive power. Table I shows the order and period in which the courses were taught, identifying the area for each course. All courses were worth three credits, except for a six credit introductory course that served as a refresher course.

All students worked for the state-owned transmission company, thus the program was offered at night, one course per period. All courses were delivered by faculty from UPRM to UNAPEC via videoconference, except a few courses that were offered during the summer. There was an instructor at UNAPEC to help with coordination at the Dominican side. For further description of the development and initial phases of the program, the reader is referred to [5].

TABLE I. A SUSTAINABILITY-FOCUSED ELECTRIC POWER ENGINEERING MASTERS PROGRAM

Area	Program Curriculum	
	Course	Period
Intro	Computational Tools (6 credits)	May-Aug 2007
E	Energy Markets	Sep-Dec 2007
D	Power System Protection	
GT	Power System Operation & Control	Jan-Apr 2008
GT	Power System Stability	
SE	Renewable Energy Systems	May-Aug 2008
GT	Reactive Power	
D	Power Electronics	Sep-Dec 2008
D	Distribution Systems	
SE	Energy and Society	Jan-Apr 2009
SE	Biomass Energy Conversion	
D	Power System Economics	May-Ago 2009
Final	Research Project	Sep-Dec 2010 Jan-Apr 2011

(E: Economy, D: Distribution, GT: Generation & Transmission, SE: Sustainability)

A. Course Assessment

The graduate program was supported by an assessment system for continuous improvement. The assessment system was developed to quantify the effectiveness of the videoconference modality in student learning and satisfaction. Students were involved from the beginning in the assessment and evaluation of the program and they were aware of the importance of their participation and support to improve the program. A student evaluation questionnaire was developed to understand the effectiveness of the course, validated through expert assessment and then deployed as a pilot in the first course of the program. Student responses were analyzed to

identify needs and areas of opportunity to improve the questionnaire. Expert validation and pilot testing were used to evaluate the questionnaire structure, concepts assessed and the corresponding questions. As a result of the assessment process a system of “best practices” was developed to share insights and lessons learned with the program professors.

In this particular program the assessment system, as described in Fig. 1 helped to maintain the program quality and provide opportunities for student development.

Research shows that there are several factors that impact student satisfaction in distance learning courses. We studied the student needs and preferences, and obtained student feedback about the learning environment to successfully support the design and implementation of the program [6]. Several techniques such as content validity analysis, focus group and midterm evaluations were used to analyze whereas the findings from the literature review and the questionnaire validity evaluation were aligned with the program, learning process and student needs. A novel midterm evaluation, in the form of a focus group through video conference was implemented in the program. By this time students were familiar with the equipment, technology and course dynamics. The focus group was used to gain student insights on: (1) teaching process, (2) program experiences and expectations, (3) communication strategies between students and instructors, (4) information exchange experiences, (5) faculty performance (i.e., environment, expression, dynamism and motivation). Table II presents the relevant findings collected from the focus group discussion.

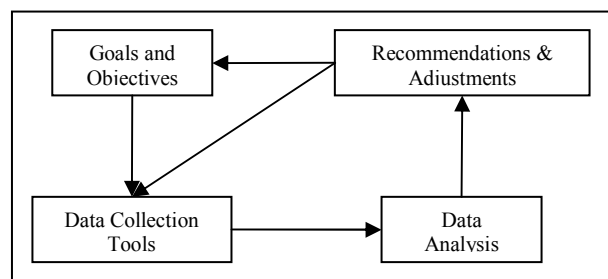


Fig. 1. Assessment process followed in the program

The results from the focus group aligned well with findings in the literature. Most of the concepts identified in the distance learning literature were part of the issues students presented in the focus group. Student insights were related to: (1) appearance and structure, (2) technical problems, (3) procedures and expectations, (4) content delivery, (5) communication and instructor presence and (6) instructor performance. The only issue that literature highlights that was not mentioned by students was knowledge and application. Table II summarizes the findings related to student insights and comments aligned with the concepts studied. The findings were used to correct problems and improve the learning experience for students in the remaining courses of the program.

TABLE II. ASSESSMENT RESULTS FROM FOCUS GROUP WITH STUDENTS IN THE MASTERS PROGRAM

Concepts	Findings
Appearance and Structure	Good use of internet page to share content and information
Technical problems	Distortion in the PowerPoint presentation when the professor moves in the camera field. The problem was avoided through the use of a laser pointer, a ruler or the computer mouse to point to items in the presentation Great quality of the sound between sites.
Procedures and expectations	Student had challenges connecting to internet during class. Some courses lacked syllabus, and appeared lack of organization with the content. There is not enough time to cover the material in some courses. There needs to be more collaboration to have books available in the library as well as journal articles discussed in class.
Content delivery	Provide an alternate system to view the professor and the course content separately during transmission. Suggestions to use multiple screens in the transmission to view the professor and course content in separate screens. Provide students with computers during class and allow students with personal computers to access internet during class to download material. Record CD's of courses during live transmission.
Communication and Instructor presence	Faculty is easy to access to answer questions. Professors are available through multiple means such as the course website, email, office phone and personal phone.
Instructor performance	Reasonable time to complete class work and activities.

Table III shows results from the course "Power System Operation & Control". Students were given the opportunity to assess all courses using the same instrument.

In the assessment process students openly expressed their concerns and ideas, and they were incorporated to improve the program. This had a positive impact in the course evaluations as well as the program final evaluation. In one of the assessment activities one student stated "thanks for allowing us an opportunity to share our suggestions and being open to use our feedback". For the most part evaluations had scores above 4 in a 5 point scale. The greatest challenge in the program was the quality of the video conference communication during classes. There were frequent problems with video delays, and audio problems that the instructor in his classroom was not able to detect on time. Constant and swift technical assistance

is thus a requirement at both ends of a distance learning program using videoconference.

TABLE III. SAMPLE ASSESSMENT RESULTS FOR ONE COURSE

Item	Average	Std. Dev.
I contact the professor and receive an answer promptly	4.7	0.47
Homework complement class material	4.5	0.52
Class material helped me attain new knowledge useful for innovative, fast and practical problem solving	4.7	0.47
The medium to receive, read and download class documents is effective	4.2	0.41
Announcements, documents and professor's notes are easily obtained	4.5	0.52
The professor creates an appropriate learning environment that encourages students to ask questions	4.9	0.30
At the beginning of class I had enough time to get familiar with relevant terminology and technical language about concepts I know that are called differently.	4.5	0.52
The Professor's teaching methods are aligned to my learning style.	4.5	0.52

III. MASTERS PROJECTS

From the initial program cohort of 27 students, 17 completed the courses with the required grades. The next program phase was the submission of a Masters project proposal for evaluation and approval. From the 17 students that completed the curriculum, 16 presented pre-proposals for Masters projects. UPRM faculty helped the students in narrowing or broadening the scope of their proposals as needed. After that, students presented the formal written proposal. The proposals were reviewed by UPRM, UNAPEC faculty and in some instances by the supervisors of the students at the transmission company. All project proposals addressed a technical need existing in the Dominican power system. Proposals included a timeline of work that usually spanned several months. Table IV summarizes the topics chosen by the 15 students who successfully completed the Masters project.

Students received guidance from faculty in Puerto Rico and the Dominican Republic during their projects. Once students had made substantial progress in their work, they registered for the course "Research Project" at UNAPEC. The course entailed three progress reports over a three-month period. After each progress report, UPRM faculty gave students feedback on what areas needed improvement. Towards the end of the course, students were informed whether they were ready or not to defend their Masters project.

The first group of students presented their projects on December 2010. Each student had to defend their work before a panel composed of three to four UNAPEC faculty, and two to

three UPRM faculty (the latter connected through videoconference). A second group of students defended their work on April 2011. The last student to present the Masters project did so in July 2011. Students received a traditional letter grade for their Masters project, based both on their oral presentation as well as on their written reports. However, a rubric was used by the authors to assess the degree of attainment of important learning objectives for the program. Table V shows the results from applying the rubric to all projects. Fig. 2 shows these results graphically, providing further evidence of the success of the program. All items assessed had a score over 70%. The lowest score (2.93 or 73%) was the inclusion of sustainable energy topics in the Masters projects. Student proposals included diverse topics, not all of them related directly to sustainable energy. Even though the program's framework was sustainability, it was not a requirement to include sustainability in their projects. Faculty did not want to force students but rather allow students to freely select if they wanted to pursue sustainable energy topics in their work. Nevertheless, even those that did not include sustainability explicitly, they did so partially through consideration of social or environmental issues in their projects. The overall goal of the program, to give students a more holistic perspective of their role as engineers, was thus met.

TABLE IV. MASTERS PROJECTS SUCCESSFULLY PRESENTED

Project	Topic
1	High Voltage Line Stability
2	High Performance Conductors to Improve Performance of High Voltage Lines
3	Economic Analysis of the Power Generation Units connected to the Dominican Power System
4	Underground transmission line design
5	Evaluation of Static VAR Compensator in a critical Bus of the Dominican Power System
6	Restoration Criteria for the Dominican Power System
7	Aggregate Value of Distribution System Services
8	Estimation and Characterization of Hazardous Waste
9	High Voltage Fuel Cells
10	Integration of Wind Parks to the Dominican Power System
11	Reactive Power supply from the Hydroelectric Power Plant at the Northern region of the Dominican Republic
12	Feasibility of Establishing the Bio-Refinery approach in the Dominican Republic
13	Interconnection Analysis for Wind Parks in the Northern region of the Dominican Republic
14	Feasibility Analysis of an Interconnection between the Dominican Republic and Haiti
15	Protection Schemes

TABLE V. RUBRIC USED TO ASSESS MASTERS PROJECTS AND AVERAGE RESULTS FOR EACH ITEM

Item	Score (1 to 4)
Significance of the project for the local electric power industry	3.80
Innovative solution for the local electric power industry	3.27
The project includes sustainable energy topics	2.93
The project considers social and environmental implications	3.40
The project includes economic analysis	3.00
The student demonstrates current knowledge and skills about the electric power industry	3.60
Application of engineering tools to solve electric energy problems	3.53

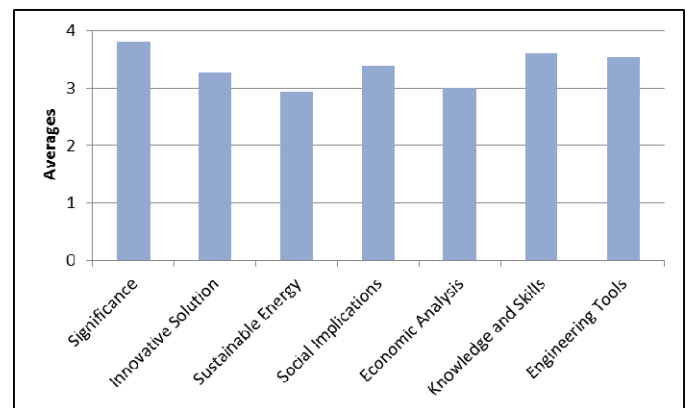


Fig. 2. Assessment results from students' Masters projects

Only one eligible student did not submit a final Masters project. Fifteen (15) Dominican engineers graduated with a Masters degree from this distance learning program. The degree was signed by the Chancellors of both UNAPEC and UPRM, as evidence of the collaboration between the institutions to provide this service to the Dominican Republic.

IV. PROGRAM ASSESSMENT

After all students defended and submitted their Masters project, and all grades were posted, they were asked to assess their experience in the program. Table VI shows the results of this program assessment. The authors knew the program was successful because of the course evaluations, the results from the oral defense of each project, and the results from the Masters project rubric. However, student perceptions of the program further evidenced success, especially the first item on Table VI, where students unanimously agreed that the program provided them an "integrated vision" that will allow them to work on "the energy challenges of the 21st century". All items were above 90%, except for "gained responsibilities as leaders or decision makers in the electric power grid" that received an 80% affirmative response, which is still high considering that this item requires an action from the employer.

TABLE VI. ASSESSMENT RESULTS FOR THE PROGRAM

Item	Average	Std. Dev.
This program helped me build an integrated vision of Power Engineering that will allow me to design innovative solutions for industry and the service sector that address the energy challenges of the 21st century.	5.00	0.00
I am prepared, with current knowledge, to respond in a practical, fast, innovative, competitive and coherent way to the challenges of unregulated electrical markets.	4.64	0.50
Through this program I was able to acquire knowledge to apply science and techniques to problems related to electrical engineering.	4.91	0.30
The program helped me deepen my knowledge in problems related to the generation, transmission and distribution of electric energy.	4.73	0.47
The program helped me build an integrated vision of the power system that will allow me adapt and face diverse.	4.73	0.47
Through this program I was able to study alternatives and possible innovative solutions for the Dominican power industry.	4.82	0.40
Through this program I was able to study alternatives and possible solutions considering social and environmental implications.	4.45	0.52
Through this program I was able to study alternatives and possible solutions considering economic implications.	4.64	0.50
The program helped me identify applied and technological innovation processes in the electric power sector.	4.82	0.40
The program helped me obtained new knowledge in the electric energy field.	4.73	0.47
The program helped me broaden my philosophical and theoretical frameworks in sustainable energy.	4.64	0.50
I look forward to carry out, in the future, responsibilities associated with direction, analysis or decision making in power system.	4.82	0.40
After completing the program I have assumed leadership or decision making positions in the electric energy system.	4.09	0.83
I have contributed solutions to specific problems that relate to the scientific, technical and economic development of my country.	4.55	0.52

As part of the final program assessment, students had an opportunity to reflect about their future professional goals. Student responses to this question show student convictions about “having the tools and skills to make better decisions in their daily work; the framework for technical discussions with higher analytical power; desire to continue pursuing scientific research to support their country”. The final project incorporating a real world problem was viewed by students as essential. Even some students reported that they want to continue developing knowledge in the area as well as feeling empowered to share what they learned with others. In particular one student was motivated to “start his career as academic faculty and in the long term, achieve a leadership position in the electric sector”.

The assessment process showed that the program strength relied on faculty knowledge; contents quality and ethical standards; the use of technology in the program; and the final project which provided an opportunity to do research and make a real contribution to their society. The comments from the participants indicated that the program helped them become better professionals through the use of different educational methods and activities as well as faculty “ethical values, commitment and quality in the execution”. Also the assessment process highlighted several areas of opportunity to strengthen the program in the future. These areas of improvement include: (1) support in research methodology as well as more mentoring during the process of the project, (2) inclusion of elective courses, (3) provide more feedback to students during the program, (4) provide online tests and practice activities to support learning using the program website, and (5) have the opportunity to select the final project topic earlier in the program.

V. CONCLUSIONS

A novel, international, distance learning graduate program was successfully completed by fifteen Dominican engineers. The program addressed the Dominican energy problem from a technical perspective, but also considered and integrated the social and environmental aspects of the problem using a sustainability framework. This education paradigm yielded an integrated vision of the local and regional energy dilemma needed to advance a sustainable energy future in countries with scarce traditional energy sources. The students unanimously agreed that the program provided them this integrated vision that will allow them to work on the energy challenges of the Dominican Republic. The assessment results for the program revealed that the program was successful in attaining its objectives.

This collaborative program between UNAPEC and UPRM also had a positive impact at UPRM. The work enriched the courses taught at UPRM in the traditional way through improved teaching materials and methods, as well as the professional development of the professors. Finally, the approach used in the conceptualization and execution of this program could be replicated elsewhere. In customized programs such as the one described in this paper, it is of paramount importance to align the needs of society (in this case the electric sector in the Dominican Republic) to the

program's academic requirements while keeping the core knowledge that needs to be mastered by the participants. A thorough assessment process is needed to ensure that this societal alignment and contents requirements are maintained throughout the program, and that the program achieves its goals.

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Self-regulated Learning in Transfer Students: A Case Study of Non-traditional Students

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Abstract – Nationwide, only 17% of community college students go on to complete a bachelor's degree within six years of enrolling at a community college and even a fewer number in the STEM fields. Community college students are more likely to be non-traditional, who are coincidentally comprised mostly of members of underrepresented groups. In this work, we examined the academic development of a cohort of non-traditional students as they transferred to an elite four-year institution from local community colleges. Drawing from educational and psychological research, we evaluated student motivation, resilience, and self-regulated learning habits throughout the first year of their transfer. The broader goal of this project is to better understand the self-regulated learning skills and motivation of non-traditional students from the point of transfer to degree completion. This in turn will foster the development of pedagogical techniques and support systems that are better suited for non-traditional students, with the ultimate goal of on-time degree completion and entrance into the STEM workforce.

Keywords – Non-traditional students; self-regulation; goal orientation, cohort models.

I. INTRODUCTION

Increasing the number of students who major in and graduate from the fields of Science, Technology, Engineering and Mathematics (STEM) has been a common discussion topic among academic and professional stakeholders. [1-2]. In recent years, there has been a sense of urgency to reform undergraduate instruction to improve STEM degree interest, retention, and graduation [3]. Meanwhile, it is estimated that about 40% of students who start off in a physical science or engineering major switch to a non-STEM field before graduation [4-5]. Lack of persistence and dropout rates are even higher for students who start their education at community colleges, many of whom also come from underrepresented groups [6]. More than other college students, these groups face hurdles entering and remaining in a STEM curriculum. Some of the major hurdles faced by these students are economic burdens and academic unpreparedness. The socioeconomic status of a student usually determines the level and rigor of

the education that the student receives at the public school system. In less affluent neighborhoods, where many non-traditional and community college students reside, the academic programs are often less rigorous. Fewer advanced science and mathematics classes are available and students have a harder time preparing for the demanding curriculum required of most STEM majors. Despite these hurdles, this population represents a potential talent pool from which to draw a more diverse and inclusive workforce in the STEM fields [7].

In Fall 2013, approximately 7.1 million students attended two-year community colleges, representing 40% of all undergraduate students in the United States [8]. However, on average, only 17% of students who start at two-year institutions finish their studies at a four-year institution within six years [9]. Many community college students are from underrepresented populations including minorities, first generation college attendees and students from low resource families. In addition, a large percentage of community college students are considered non-traditional, a demographic that includes adult-learners, low-income financially independent students of college-age, young mothers, and working professionals who never completed their post-secondary education. Recent works in the STEM education field have indicated that cohort programs, peer-based community building activities, hands-on experiences and active engagement can contribute to higher success and retention rates of non-traditional students [10-14].

In this paper we examined the development and progress of non-traditional students who transferred and enrolled at The George Washington University (GW) in Fall 2014. This work followed students who transferred from local community colleges into the cohort-based Integrated Information Science and Technology (IIST) program at GW. This two-year interdisciplinary degree completion program is specifically designed for community college graduates to finish their bachelor's degree in two academic years at GW. More details about the program and the curriculum can be found in a previous FIE conference paper [15].

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Using educational and psychological research, we measured and evaluated student motivation, resilience, and self-regulated learning habits to determine how these relate to past work experiences, age, demographics, and academic performance. Additionally, we looked at the pre-existing beliefs and goals of the incoming transfer students and evaluated their academic progress, changes in behavior, and performance throughout the first year of their studies in our program. Specifically, academic performance was tracked in a sequence of Python programming courses over the 2014-2015 academic year. Special attention was given to motivation orientation, short-term/long-term goals and computer efficacy and e-learning capabilities.

II. METHODOLOGY

This work was guided by research and theory in education and psychology; specifically, self-regulation theory. Research in this area has clearly established the intimate connection between affective (i.e., emotional) and cognitive states and resulting academic performance, with emotions such as frustration often driving behavioral decisions [16-17]. For example, there is typically a decline in student motivation over the course of the semester and a corresponding drop in key self-regulatory cognitive strategies tied to achievement [18]. Ongoing research on this issue has pointed to the need to go beyond traditional achievement/cognitive factors for predicting success and designing interventions [19]. Over the past 25 years, self-regulation theory has become the dominant approach in educational and applied psychology to understanding learner motivation [20]. The process of self-regulated learning (SRL) involves cognitive, affective, and behavioral components, and describes the continuous process of achievement striving, monitoring, and evaluation that successful learners engage in over time. SRL has proven to be a useful framework for understanding the mental processes involved in learning. With regard to college STEM education, research has demonstrated that self-regulation predicts higher grades and is associated with different facets of goals, beliefs, and emotional reactions [21]. Furthermore, students' self-regulation is associated with retention in their degree path [21-22].

In this study, we examined our student population and tried to better understand their motivation, aptitude and attitude towards STEM fields and careers. This was accomplished by analyzing the data provided in application packages, by conducting surveys to measure motivation levels and identify obstacles, and by tracking success trajectory and academic performance over the first year of studies at GW after transfer. The data collection included the following:

- *Admissions materials:* The information that was provided by the students on their application packages

was examined. This included demographic information (gender, age), past academic performance (GPA, computer and math literacy) and professional experience (number of years working). This information was used as a baseline to understand initial motivations for entering the program.

- *Surveys:* Surveys were administrated twice during the academic year (end of Fall 2014 & Spring 2015 terms) to better understand students' goal orientation, motivation, self-directed learning and short-term/long-term goals. Three different classes of goal orientation theory (learning, prove performance and avoid performance) were used to characterize our non-traditional students' intention to master challenging situations and their desire to validate competency through positive or negative judgement [23-24]. Short-term goal measurements were categorized as goals related to achievement (i.e., studying to get better grades and attain a higher GPA), learning oriented goals (studying for the sake of learning and mastering concepts), or a mix of achievement and learning oriented goals. Long-term goals were measured according to future STEM and non-STEM related academic and career endeavours.
- *Academic performance:* This was analyzed through overall GPA and performance in a sequence of CS1-CS2 type Python programming courses.

III. RESULTS

Fig. 1 provides an overview of some of the characteristics of students that were part of this study. We had an initial sample pool of 26 students during the Fall 2014 term. The average age, employment status and number of professional work experience exemplify the non-traditional aspects of our students. This graph is based on the data for all 26 students, and the first survey that was administrated during the end of Fall 2014 term.

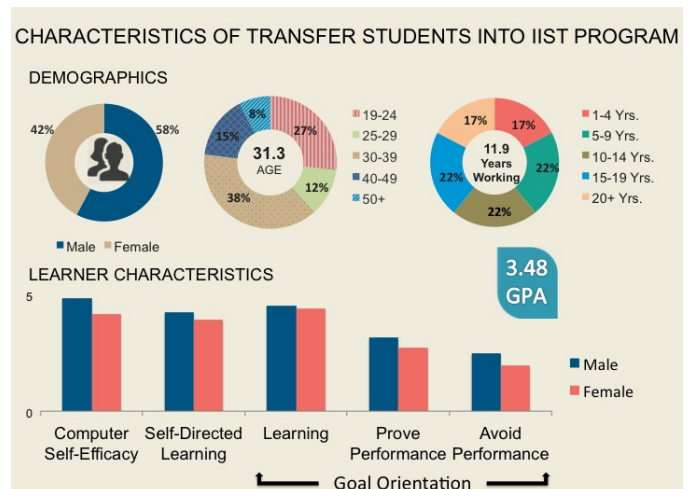


Fig. 1 Characteristics of students who entered the IIST program in the Fall 2014 term.

The data shown in Fig. 1 can be summarized as follows:

- The average age of the student sample was 31, with an average of 12 years of work experience and a 42% to 58% female-male ratio.
- Most of our students exhibited high learning goal orientation ($M = 4.46$), medium prove performance goal orientation ($M = 3.08$), and low avoid performance motivation ($M = 2.13$). Data was measured on the Likert scale of 1-5, with 1 being the strongly disagree and 5 being the strongly agree option on the survey and M representing the mean calculated value. This indicates that the dominant motivation factor for our students was the desire to learn, and that our students were more likely to take risks and try a challenging task. This result is not surprising as adult learners tend to be more self-regulated and motivated, and they are more conscious about education cost. In addition, coming back to school and entering the program is already indicative of this group's willingness to take on challenging situations, affirming their high prove performance goal orientation.
- Men showed higher level of computer self-efficacy than women, who consistently showed lower skills though not significantly lower. A follow-up survey conducted during the spring term indicated that women increased in both computer self-efficacy and performance. Men also reported a significantly higher level of prove performance orientation in the second semester.

IV. ANALYSIS

To further investigate the learning characteristics of our student population, a more in-depth analysis was conducted using the demographic information presented above, the result of both fall and spring surveys, and the academic performance of students over the course of the academic year. Subgroup analyses were conducted for three groups of interest: gender, age, and employment status. Past research has suggested that these variables are relevant to the experience of barriers to academic achievement and graduation. The result is summarized in Table 1 and is described below - note that the information provided in Table 1 is based on the 21 students who continued in the program after the first term. 5 students dropped out of the program after the end of the fall term.

A. Women vs. Men

The data collected in this study revealed a number of interesting differences related to gender, with both men and women displaying different sources of motivation and changes over time in learner characteristics. Men showed significantly higher overall academic performance compared to women as indicated by cumulative GPA.

However, women as a whole improved more over time than men, most notably in their improvement in course performance between the fall and spring terms, which was equivalent to over half a letter grade.

These differences may be tied to motivation as several indicators demonstrated the differences in the motivation or sources of motivation for men and women. Women's motivation appeared to be tied more to goal-orientation and their focus on learning as stated in their academic goals. For instance, when asked about their short-term goals, 70% of women stated goals related to learning compared to 9% for men. Additionally, for learner characteristics that were measured during each semester, learning goal orientation significantly predicted course grade in the spring for women, but not for men. For prove performance goal-orientation, men increased between the two semesters while women showed a slight decrease, resulting in a significantly higher level for men.

Women also became more confident in their abilities to use computers over time, increasing in computer self-efficacy on the second survey. Men reported higher levels than women for both surveys. Computer self-efficacy is likely an important characteristic critical to success in STEM coursework that focuses heavily on computer use, such as the Python programming courses completed by participants in this study.

	Gender		Age		Employed	
	M	W	< 30	> 30	No	Yes
N (number)	11	10	9	12	10	11
Short-term Goals						
Achievement only	41%	0	0	33%	9%	30%
Learning only	9%	70%	33%	42%	55%	20%
Mixed	50%	30%	67%	25%	36%	50%
Long-term Goals						
STEM related	80%	78%	75%	82%	78%	80%
Non-STEM related	20%	11%	13%	18%	11%	20%
None	0	11%	12%	0	11%	0
Academic Achievement						
Mean CGPA	3.86	3.58	3.78	3.69	3.73	3.73
Fall course grade (/100)	92	86	90	88	90	89
Spring course grade (/100)	93	92	93	93	93	93
%Change Spring-Fall	1.1	6.5	3.2	5.4	3.2	4.3
# Dropouts	4	1	1	4	-	-

TABLE 1. SUBGROUP ANALYSIS OF 2015 SPRING CLASS BASED ON GENDER, AGE AND EMPLOYMENT STATUS.

B. Younger than 30 years old vs. Older than 30 years old

Overall, learners across both age groups were similar on measures of motivation and learner characteristics. Surprisingly, the older-learners (30 and over) in this sample had higher computer self-efficacy than those who were under 30. However, at the time of the second survey those under 30 reported higher levels of computer self-efficacy and similar to older-learners. They were also higher in self-regulated learning, which is somewhat expected. There were no differences between the older and younger learners for goal orientation, though interestingly both groups decreased significantly in learning goal orientation over two semesters.

Older learners stated more of a range of academic goals with about a third stating goals related to achievement. Those below 30 were much more likely to state goals related to learning and achievement than those who were 30 and over. Finally, a small percentage of those under 30 stated that long-term career goals were not part of their plans as they seemed too distant, or because of a desire to focus on finishing their degree. All participants 30 and over stated long-term career goals. In expressing the barriers to their goals, those over 30 stated barriers related to time-constraints from work and family much more than those under 30. In terms of performance, both groups were similar on a range of measures such as assignment grades, exams, and GPA.

C. Employed vs. Non-employed

Those who are currently employed were higher in age, self-directed learning, avoid performance goal orientation, and showed a greater range of academic goals compared to those who were not employed. Those not working primarily stated goals related to learning or learning and achievement. Both groups performed relatively similar in terms of course performance but those who were not employed showed a greater improvement over the course of their studies.

D. Dropouts

19% of the sample dropped out after one semester (5 out of 26). Of these 5, 4 were men who were also over the age of 30. 50% of men who dropped out were between 30-49 years of age and 2 were over 50 years of age. 1 person who dropped out was female and less than 25 years of age. Only two participants who dropped out completed the survey in the fall. However, they were much higher in prove performance goal orientation (3.25 vs. 2.99 average per item) and avoid performance orientation (4.63 vs. 2.06 average per item). Reasons for dropping out tended to revolve around extenuating factors, non-traditional backgrounds, and long delays between prior coursework and enrollment in the program, leading to a more difficult adjustment. Class performance was also much lower for

those who dropped out compared to those who are still currently enrolled in the program.

V. DISCUSSION AND CONCLUSION

Throughout this preliminary study, we have found that non-traditional students have unique characteristics, goal orientations and motivation levels that should be taken into consideration. Overall, the students were characterized by high levels of motivation and academic success. However, noteworthy differences were found between men and women. Specifically, women entered the program with more learning-oriented goals, and had lower levels of academic achievement. Women also showed greater improvement between the fall and spring terms. Age did not appear to have a strong effect on motivation or performance; however older students were more likely to have STEM-related career goals.

One of the more interesting aspects of this study is in the changes over time that was observed in the performance and learner characteristics of the student sample. Students in each of these subgroups entered the program with varying levels of goal orientation, computer self-efficacy and self-directed learning, but over the course of two semesters became more similar in these measures and in course performance. These findings may also be a result of the effectiveness of the cohort model. Surprisingly, employment status also had few effects on motivation or performance, with both employed and unemployed students performing at the same level. This is noteworthy given that many students reported that employment-related barriers (e.g., lack of time) interfered with their ability to devote time to schoolwork and the success trajectory in the program over the two years.

In the follow up study, we plan to continue to observe this group of students as they enroll in their second year of studies at GW and as they continue their transfer journey in our program. We also plan to explore ways to support high-risk students who are in danger of dropping out. A better understanding of their background and motivation goals might allow us to identify indicators that could allow us to approach such situations early on. By providing just-in time support and additional resources we might be able to help such students remain in the program. A further analysis of barriers and obstacles that students face could also be taken into consideration to better serve the students.

A more general goal of this study and subsequent work is to better gauge self-regulation, goal orientation and motivation levels of non-traditional students from the point of transfer to degree completion. The end result would be a framework and pedagogical techniques that can better equip educators to support this population and to provide a supporting environment to foster the growth of these students, with the ultimate goal of on-time degree completion and entrance into the STEM workforce.

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Transfer Student Pathways to Engineering Degrees: A Multi-Institutional Study Based in Texas

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Abstract—This work in progress paper describes a mixed methods study designed to investigate transfer student pathways as a means to increase engineering degree production and broaden participation in engineering careers. The study explores the framework of transfer student capital and its relevance for engineering transfer students. In this paper, we provide an overview of a survey instrument developed to collect data from more than 6,000 students who successfully transferred to one of four 4-year institutions in Texas as new engineering students between 2007 and 2014. Our study expands the small body of literature on engineering transfer students and sheds light on specific policies and practices that impact transfer.

Keywords—*broadening participation; engineering; transfer; pathways; persistence; transfer student capital; social capital*

I. BACKGROUND

In 2015, President Obama introduced *America's College Promise*, a new proposal to make “two years of community college free for anyone who is willing to work for it” [1]. The plan to remove cost as a barrier and make higher education accessible to all Americans would require a significant investment from both federal and state governments. Current estimates indicate that the program would cost the federal government \$60 billion over the course of ten years and an

additional \$20 billion contribution from state governments. To maximize results from such a substantial investment, it is important to address and resolve existing challenges related to degree completion and upward transfer for community college students within engineering. In this paper we provide an overview of our current NSF study focused on transfer students in Texas that is aiming to meet that objective.

II. STUDY ON TRANSFER STUDENT PATHWAYS TO ENGINEERING DEGREES – WORK IN PROGRESS

A. Motivation

For more than a decade, the National Research Council (NRC) and National Academy of Engineering (NAE) have emphasized the important role that community colleges play in broadening participation and expanding pathways to engineering degrees [2, 3]. However, leaders in higher education have acknowledged that the transfer student pathway within engineering is not operating at full potential [2].

The existing body of literature on engineering transfer students is slim and fragmented [4]. Most of what we know is based on the community college literature more generally, which is limited in its application to engineering transfer students. Current literature suggests that common barriers to transfer student success in STEM includes: 1) inaccurate and/or passive transfer advising; 2) weak transfer/articulation policies; 3) lack of course transferability; 4) the sudden shift from a supportive environment to one with competitive

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classroom pedagogies; 5) unfamiliarity with academic rigor and expectations at 4-year institutions; 6) feelings of isolation; and 7) poor experiences with financial aid [5-8]. While these studies identify key challenges, Dowd [5] argues that “the body of literature focusing specifically on transfer in STEM is not robust enough to substantiate conclusions about the unique programmatic features that are necessary to design effective STEM transfer pathways” (p. 112).

New research suggests that creating transfer pathways into 4-year public/private colleges can broaden participation in engineering specifically for Hispanic students [9]. Given that more ethnic/racial minorities begin their pursuit of higher education at schools other than 4-year public/private colleges, it is critical that we create pathways into engineering from 2-year public colleges. According to the National Center for Education Statistics, 56% of Hispanic students and 48% of African American students in undergraduate education during Fall 2012 were enrolled in 2-year public colleges [10].

B. Purpose and Research Questions

The purpose of this mixed methods research is to develop a clearer understanding of transfer student pathways as a means to increase engineering degree production and broaden participation in engineering careers. The study sites for this research are 4 of the top 10 producers of U.S. Hispanic engineers, and all are based in Texas: The University of Texas at El Paso, Texas A&M University, The University of Texas at Austin, and The University of Texas-Pan American [11].

Our study expands the small body of literature on engineering transfer students and sheds light on specific policies and practices that impact transfer. Specifically, our investigation addresses the following research questions:

1. How does transfer student capital relate to academic achievement and degree attainment for transfer engineering students at 4-year institutions?
2. How do Hispanic and non-Hispanic transfer students compare on measures of transfer student capital and its relation to academic achievement and degree attainment?
3. How do students decide to transfer into engineering at a 4-year institution?

4. What institutional policies facilitate success and enable transfer pathways into engineering at 4-year universities for transfer students?
5. How do institutions hinder transfer students in their transitions to engineering at 4-year universities?

Findings from this study can inform decisions on how to allocate limited resources (i.e. financial and human) to diversify pathways and increase the number of students who transfer into and succeed in engineering at 4-year institutions. In addition, this research will help policy makers and higher education administrators (i.e., deans, department chairs, and admissions officers) understand the barriers and perceptions that prevent more students from transferring into engineering at 4-year institutions so that they can make data-informed adjustments to their existing institutional practices.

C. Theoretical Framework - Transfer Student Capital

The framework for transfer student capital serves as a guide to organize this study on engineering transfer students [12, 13]. Transfer student capital is the accumulation of knowledge about higher education that develops in a student as he or she interacts with faculty, receives academic advising/counseling, studies for coursework, navigates through university transfer policies to fulfill academic requirements, and proceeds through the transfer process from a community college to a 4-year institution [13]. This theory suggests that the students who possess larger accumulations of transfer student capital are more apt to successfully transfer from a community college to a 4-year institution [14]. Our study explores the framework of transfer student capital and its relevance for engineering transfer students.

D. Methodology

The methodology guiding this study is an explanatory sequential mixed method design; a qualitative strategy will be used to extend findings from a quantitative analysis. Data sources for each research question are summarized in Table 1. The quantitative phase consists of a cross-sectional survey-based approach that also draws on data from institutional student records to address research questions 1 and 2. The qualitative phase is an embedded case study that will include semi-structured interview data to address research question 3.

TABLE I. RESEARCH QUESTIONS, PHENOMENA, AND DATA SOURCES

Research Question and Phase	Population	Data Collection	Phenomena of Interest
RQ 1 & RQ 2 quantitative survey	6,100 students who transferred into engineering for the first time between 2007 and 2014	Cross-sectional data from an adaption of the L-TSQ survey and student academic data	Transfer Student Capital
RQ 3 qualitative embedded case study	Institutional stakeholders and students who transferred into engineering for the first time between 2007 and 2014	Semi-structured interviews with purposeful sample of stakeholders and students selected based on survey findings	Academic Adjustment
RQ 4 & RQ 5 quantitative survey & qualitative embedded case study	Combined population from RQ 1, 2, & 3	Combined data collection from RQ 1, 2, & 3	

We will use findings from the quantitative phase to form interview protocols and identify a purposeful sample of “stakeholders” at the four institutions for the interviews in the qualitative phase. Information from both the quantitative and qualitative phase will be used to address research questions 4 and 5.

III. DEVELOPING THE ENGINEERING TRANSFER STUDENT SURVEY

A. Alternate Survey Instruments

The survey for our study is an adaptation of the Laanan-transfer students' questionnaire (L-TSQ) [13-15] plus a compilation of survey items extracted from the following multi-institutional research studies that investigated transfer student experiences in STEM: Prototype to Production: P2P [16] and Measuring Constructs of STEM Student Success Literacy: Community College Students' Self-Efficacy, Social Capital, and Transfer Knowledge [17, 18]. To address validity, our survey was developed using input and feedback from content experts on the project advisory board and representatives from the participating 4-year institutions and their partner local community colleges. Representatives included a combination of administrators, faculty, and staff from 8 institutions with working knowledge of policies and practices in Texas that impact students who transfer to 4-year institutions as new engineering students.

B. Content

The final survey instrument is comprised of six sections that include a mix of multiple choice and open-ended questions. At this time, we estimate that students will need 15-20 minutes to complete the 45 question survey. Multiple survey items are embedded in 16 of the 45 questions. A high level summary for each section of the survey is provided as follows:

1) *Personal Information (19 questions)*. Part 1 of the survey captures participant background information, including: gender, race/ethnicity, citizenship, age, education attainment, future degree aspirations, parent/guardian education attainment, mode of admission at receiving institution, identification of primary sending institution, and expected/actual time to degree completion.

2) *Transfer Pathway (2 questions)*. Part 2 captures students' reasons for starting their education at a different institution and factors that influenced their decision to transfer to the receiving institution.

3) *Experience with the Transfer Process (8 questions)*. Part 3 captures students' perceptions of the transfer process and usefulness of information sources on how to transfer. This section also captures data on student experiences prior to transfer, including: experiences with academic advising at both sending and receiving institutions, and use of student resources at the receiving institution.

4) *Experience at Sending Institution (1 question)*. Part 4 captures students' perceptions of preparation received at the sending institution with respect to learning and study skills.

5) *Comparing Experiences at Each Institution (8 questions)*. Part 5 captures data that allow us to compare student experiences at the sending and receiving institutions before and after transfer, respectively. In this section, questions focus on student experiences with faculty, coursework, and time management at each institution.

6) *Experience at Receiving Institution (7 questions)*. Part 6 captures students' perspectives on transfer challenges and general perceptions of the receiving institution. This section also captures students' perceptions of the adjustment process and social support available at the receiving institution.

C. Need for Local Customization

In working with the full project team, we quickly recognized the need for local customization during our effort to develop the Engineering Transfer Student Survey because of varying terminology and practices (which is a finding in and of itself). During survey development, we defined key terms to increase clarity for study participants and stakeholders and dedicated careful attention to appropriate use of terminology. The final versions of the instrument have been customized to accommodate the following:

1) *Alternative Transfer Pathways*. The sample population in this study includes students coming from transfer pathways that may be classified as upward (e.g. from community college to 4-year institution), lateral (e.g. from one 4-year institution to another), swirl (e.g. return to original institution), or double-dipping (e.g. dual enrollment at both community college and 4-year institution) [19]. To capture unique and diverse perspectives, survey questions were further customized to address students who pursued alternative transfer pathways to engineering, such as students admitted into formal co-enrollment programs as well as students who are concurrently enrolled in two institutions.

2) *Local and Sensitive Terminology*. During our working meetings across 2-year and 4-year institutions, we identified terms that are mistakenly used interchangeably, but carry unique meaning from an institutional perspective. For example:

- *Dual enrollment* is a term used to describe high school students who are enrolled in dual credit/early college high schools; where *concurrent enrollment* is used to describe post-secondary students enrolled in multiple institutions of higher education at the same time.
- *Co-enrolled* is a term used to describe student participants in formal co-enrollment programs such as the Texas A&M Engineering Academy. Students admitted into this academy have applied to Texas A&M University and receive a coordinated admissions offer to co-enroll in both Texas A&M University and Blinn College. Unlike co-enrolled students, *concurrently enrolled* students have separate admission offers from multiple institutions.
- The terms *counselor* and *academic advisor* are used interchangeably at 2-year institutions to refer to professional staff hired to advise and assist students with

their academic plans. At four-year institutions, the more common term is *academic advisor*.

- The terms *previous institution* and *receiving institution* are used in our survey to capture and compare student experiences. For cases where students attend more than one institution prior to transferring, we define *previous institution* as the college/university where the student spent most of their time. Based on this working definition, the students is invited to identify his or her previous institution; we do not use “most recent university attended prior to transfer” as the default.

3) Unfamiliarity with Upward Transfer Policy Jargon.

Administrators on the project team agreed that engineering transfer students would not be familiar with jargon used at the state-level to advance upward transfer policies, such as *2+2 programs*, *course or program articulation agreements*, and the *Texas Voluntary Transfer Compact Program* (a finding worthy of future investigation in our study). Based on this feedback, we minimized references to *articulation agreements* and excluded the terms *2+2 program* and *Texas Voluntary Transfer Compact Program* from the final surveys. Whenever possible, we replaced the upward transfer policy jargon with local terminology (i.e. EPCC-UTEP Degree Agreements, Texas A&M Engineering Academy, Texas A&M University System Program for System Admission, UT System Coordinated Admission Program) to increase relevance for study participants.

IV. FUTURE WORK

In this paper we provide an overview of our current NSF study focused on transfer students in Texas. The purpose of the study is to develop a clearer understanding of transfer student pathways as a means to increase engineering degree production and broaden participation in engineering careers.

We launched the two year research project in October 2014 with a collective effort to develop a survey customized for transfer students in engineering. We are collecting and analyzing survey data through Fall 2015. At that time, we will launch the qualitative phase of the study to extend our findings from the quantitative phase.

We envision that our research findings on what helps and hinders transfer can be used to: 1) make improvements and revisions to existing policy; and 2) serve as a guide for states and institutions seeking to adopt new policies that promote upward transfer in engineering.

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Influence of Professional Demographics on Faculty Feedback in Asynchronous, Video-Annotated Peer Review (VAPR)

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Abstract— The use of an asynchronous video-annotated peer review system (VAPR) presents the opportunity to enhance teaching and diffuse pedagogical practice in higher education. The process involves the video recording of classroom teaching by each faculty member, which is then reviewed and annotated in real-time by faculty peers to identify specific instances of good practices, opportunities for improvement, and opportunities to incorporate research-based teaching approaches. The purpose of this study is to analyze the nature of faculty peer comments generated throughout the peer feedback process. Each peer-generated video annotation text file was coded to characterize the type of feedback given, encompassing characterizations such as: good practice, suggestions; types of teacher knowledge; and general attributes of teaching. The demographics of the peer authors, for corresponding annotations, are also classified based on highest degree, familiarity with the course as an instructor, and familiarity as a student. Findings indicate that a majority of the comments are related to the direct instruction of the course, rather than the content of the instruction. While not statistically significant, familiarity with the course as instructor is positively correlated to the number of comments pertaining to pedagogical content knowledge. These findings support the need for peer-review by faculty familiar with the course to offer context specific suggestions as well as those peers unfamiliar with the course to offer opportunities to diffuse instructional strategies from other contexts.

Keywords— *faculty peer review, professional development,*

I. INTRODUCTION

Faculty peer review has long been implemented in higher education as a form of formative feedback to support the refinement of instructional practice [1]. However, structural barriers limited the time and access required to implement this approach broadly. An alternative to the traditional form of peer review was developed to limit these issues using an asynchronous video-annotated peer review (VAPR).

This approach allows for faculty to review each other's classes in a systematic process that supports faculty reflection and shared vision to support the change and diffusion of pedagogical practices through social reflexivity [2]. While the process is systematic, the formation of the peer review pairings is less understood; commonly a pairing of convenience rather than optimally structured to encourage a deeper reflection that

will facilitate faculty change. As a first step to this optimization, this study seeks to characterize the type of comments faculty make in peer review based on professional demographics that may affect the type of feedback provided.

II. PEER REVIEW OF FACULTY TEACHING

In her review of peer review via teaching observation in higher education, Blackmore [1] summarizes the application of peer review as a tool for change that provides a method of assessing performances in order to help faculty peers improve so that good practice can be identified and shared [1, 3, 4]. Peer review is increasingly used within organizations to measure, evaluate and improve job performance by providing feedback to the individual on performance [4].

In their report of collaborative peer review for improving college teaching, Keig and Waggoner [5] note that faculty should play a role in instructional improvement through peer review because they are especially well qualified to identify events specific to the classroom [7]. These events include factors affecting the instruction, classroom procedures, and use of language to engage students, and components related to the discipline and curriculum in general. In addition, faculty possess insight into vital components of teaching that cannot be adequately assessed by students and administrators [6, 8-12].

In their review of literature, Keig and Waggoner also note that problems can persist from pairings due to too congratulatory and inaccurate assessments [1, 13]. There is often a fear of being too critical in the review of peers, however Cole [13] identified that a "culture of criticism is essential to the reviewing of ideas that can lead to improvements in the quality of a product. Because of this potential to be too congratulatory or critical, it was noted that checks and balances are needed [13].

Blackmore [1] notes that peer review has strength in its ease of establishment, being more inclusive for all faculty, and opportunity for greater dissemination. The selection of the reviewers is dependent on the purpose of the observation, expectations for the process, and which aspects of teaching are in need of improvement [6]. When the focus is on course content and level of complexity, adequate peer review may require input from reviewers with a considerable amount of expertise in that field of study. However if the focus is on more

general pedagogical techniques including presentation skills, instructor enthusiasm, and organization, familiarity may not be required.

Nonetheless, there may be less of a focus on subject and discipline as a result of pairings that include self-selected pairs, pairing with coordination, and groups with external input [1]. Peer reviewers do not have to be from the same subject disciplines. Good practice can be shared among the various subject specialists. Involving reviewers from other non-related fields can provide an advantage to the peer review [1, 15-17]. The use of non-familiar users may also limit “the perpetuation of conformity of teaching” noted by Cox and Ingleby [17], and may also reduce conflicts of interest [6]. In addition, periodic change in pairing ensures that more experienced teachers are paired with less experienced [19].

While there has been substantial insight into the process of peer review, there is less insight into the specifics of those reviews, including what events that might be observed by the reviewers [6].

Peer Review Comments

In examining faculty peer review of teaching implementation, Bernstein, Jonson, and Smith [19] make suggestions based on observations of an American Association for Higher Education derivation of a peer review system. Pairs of faculty interacted on three topics of discourse: course intellectual content and goals, teaching practice, and student learning (p. 74). Participating faculty cited beneficial, high-quality discussions and were “extraordinarily positive” (p. 79) about the experience. Faculty also altered class practices, generally by reducing lecture-based, passive instruction and replacing it with more active methods.

Peer review commentary on observations made by fellow faculty in the classroom of the observed should lead to teaching reflection and change [20]. Arreola’s [21] form-driven faculty peer review feedback system calls for establishing teaching role parameters including content knowledge, curriculum, and instructional practices, each with an assigned weight and rating. However, these are not just sourced from observations, but conferences and course material.

Ratings from reviewers of those faculty being observed in the classroom should be reliable and valid, despite the fact that they, “...are not as well established as they are for student ratings” [22]. Nonetheless, Paulsen found several studies showing reliability in peer review of teaching. Again, Paulsen’s review of the literature found unanimously that reviews should be comprised of content knowledge, teaching effectiveness feedback, with Cashin [23] adding curriculum and course design. There should be consistency in required peer review contents to encourage reliability across faculty peer review portfolios. Effective formative evaluation should identify areas for improvement and pathways to success. Teaching should be more similar in its subjection to the rigor of review as research traditionally is.

Gosling [24] calls for a peer review model in which both parties, the observed and observer, benefit and learn from the

peer review process. The mutually beneficial aspect of this preferred peer review model is coupled with shared responsibility; there is a “collective responsibility for teaching” (p. 3). Teaching observation should include observation and interplay of student evaluation, assessment, outcomes, and curricula.

Yin’s [25] case study on the implementation of a formative, developmental peer review process was summarized [26], with leadership championing the process as a necessary professional development component. The observations involved annual events that included pre-observation conferences, classroom observation with standardized forms retained by the observed faculty, and a private post-observation discussion regarding the observation and relevant institutional criteria. Again, the observation activities are intended to be mutually beneficial. Summaries are collected by the coordinating personnel and integrated good practices are circulated, supporting diffusion. Confidentiality is maintained. The university overall improved significantly and faculty participant feedback was positive.

Chism [27] calls for the use of standard checklists and worksheets based on the teaching entity’s protocol concerning the peer review process, its purpose, and its goals, with observations reviewed by those both familiar and unfamiliar with content. The classroom observation form provided by Felder and Brent [28] provides for ten ratings to be given by two reviewers to allow for reconciliation and reliability in the areas of instructor preparedness, content knowledge, enthusiasm, clarity of speech, use of examples, visual aids, questions posed, attention of class, student involvement, and respect to students. There is also space provided for providing open-ended descriptions of strengths and areas of improvement. Berk [29] generally provides for similar areas for scaled ratings.

Peer review participants should gain experience and apply an observation and reflection conceptual framework resulting in a video portfolio that includes classroom teaching videos accompanied by instructor-provided self-assessments and context [30]. Video portfolios must feature content that stimulates reflection and faculty discourse on teaching practice per situated cognition and social constructivism theories. The authors recommend use of “functional criteria” that cite evidence from the videos to support teaching evaluation such as student responses or behaviors in the classroom resulting from the instruction, environment, and so forth. Both the reviewer and the observed benefit from scoring and being scored while citing functional criteria in videos as both parties reflect on practice.

Video portfolio commentary featured callouts of practice deemed noteworthy by research assistants that had corresponding times in footage, which were later rated 1 (basic) through 5 (masterful) [30]. Each callout was categorized in a hierarchical model the investigators developed. Top-level criteria were: pedagogy, climate, mathematical thinking, and classroom management. At the next level, 18 aspects of teaching fell under these criteria, listed in the Appendix (pp. 291-293). Pairing of scorers was used for consistency in ratings. In analysis for consistency among scorers, “...scorers may have been applying a theoretical

standard of ‘best practice’ to the observed actions of the teacher, rather than evaluating how functions of teaching are being accomplished within the class as a whole”. There was a significant difference in scorers’ scores in the criteria when examining scorer professional demographics as educational research-oriented individuals versus teachers. An important caveat is that the demographics of individuals categorized as educational researchers were graduate researchers, thus may not have the combination of research AND teaching practice that full-time academic faculty may have. Think-aloud monitoring of scorers showed some deviation from the intended approach to scoring for which scorers had been trained, collecting and recording data supporting each criterion then assessing based on collection. Participation in assessment of practice via video taping showed increases in teaching reflection and awareness of changes in practice in their classrooms. Results also showed that reliability in scoring and consistency in language of practice can be maintained through social moderation.

Kavas and Ozdener [31] used an online version of a teaching practice assessment form to gauge pre-service teachers on the criteria of content knowledge, teaching, assessment and communication skills. Wu and Kao [32] used asynchronous, video-annotated streaming video review of teaching for pre-service teachers in Taiwan, featuring ratings in 10 areas (objectives, contents, examples, inspiring learning, organization, provoking thinking, awareness of students, wording, incident handling, and time management) and accompanying comments. The observed were required to reply to peer comments to promote reflection on practice. Pre-service teachers’ attitudes were overwhelmingly positive about the feedback system. Reviews averaged 7.6 comments each per teacher, with two-thirds commenting with a timestamp pertaining to a particular event in the video. The greatest number of comments (35%) pertained to interactions with students. Miyata’s [33] approach to streaming on-demand video also encouraged self-reflection. Pre-service teachers rate themselves on similar aspects as literature already discussed, then have conferences with mentors to evaluate and stimulate their self-reflection.

III. VAPR PROCESS

The video-annotated peer review (VAPR) process was developed to support the diffusion of research-based instructional practices and create a formative feedback process that will serve to enhance faculty development and teaching improvement. The process was crafted using the guidelines specified by Chism [34] for peer review and video-based cases for faculty development by Marx, Blumenfeld, Krajcik, and Soloway [35]. This process of peer review was determined to enhance diffusion of research-based practices given the shared classroom experience of the reviewers and instructors and the shared critical evaluation of those experiences [36].

The VAPR process requires faculty to select which of their class sessions to record for peer review. The videos are then reviewed using software capable of video annotation. The video annotation software reads and displays the video file and stores any comments or tags created by the reviewer in the annotation file at specific time-stamps.

The sessions are first recorded using a high definition digital recorder. After the class session is recorded, the instructor is given the video file and is asked to reflect and summarize the perceived execution of the course. The instructor creates the annotation file, linked to the video file, and uploads the pre-observation summary and pre-reflection as the first comment (associated to timestamp 00:00). This initiation of video-annotated commentary by the observed faculty allows the instructor to consider the course goals and learning objectives while situating the reviewer in the context of the class. The pre-observation summary also provides the reviewers an opportunity to familiarize themselves with the course outcomes, concerns, and rationale for pedagogical techniques.

The instructor then shares the files with a representative from the local Center for Teaching and Learning Excellence and two other faculty to review the video. The reviewers may pause the video and insert their comments at the appropriate timestamp. This comment-video timestamp association alleviates decontextualized statements. The review of the video by two faculty provides an opportunity for the sharing of practices and the reviews thereof to engage in social reflexivity that will support the reflection of their own instructional practice [2].

To aid in the review process, the reviewers are provided a table of attributes that was defined to comprise effective teaching by a university committee. This table provides several examples for each main attribute, of which there are five (Table I). The simplicity of the form is similar to the evaluation form suggested by Felder and Brent [28]; it also reflects many common attributes that have been deemed important and shown to have direct impact on student learning [34].

The table of attributes, adapted from the model described by Bergquist and Phillips [37] illustrated by Keig and Waggoner [5], guides the reviewers to provide feedback on the instructor’s organization, knowledge of subject matter, clarity and pace, atmosphere of the classroom, and professionalism. It is void of numerical ratings and lacks an emphasis on summative evaluations to encourage participants to share an open and honest exchange of thoughts and feedback, without fear of a potentially negative impact on their promotion and tenure [38].

Finally, the subject of the review watches their own video and annotated comments provided by the reviewers at the specified timestamps, and is asked to create a post-observation reflection summary that provides them the opportunity to reflect on the intent of the class and how their peers perceived the class session and use of pedagogical techniques. The process is then repeated with different faculty reviewers, with the intention of changing and sharing practice.

TABLE I. PEER REVIEW ATTRIBUTES GUIDE

Instructor's Organization (<i>The instructor...</i>) <ul style="list-style-type: none"> presented the material in an effective, organized manner. presented the material at an appropriate level for the course and students. provided clear, concise examples and visual aids to clarify the material. used technology, to improve course delivery or facilitate activities.
Instructor's Knowledge of Subject Matter (<i>The instructor...</i>) <ul style="list-style-type: none"> illustrated command of the subject matter. presented material that was important and current.
Clarity and Pace of Instruction (<i>The instructor...</i>) <ul style="list-style-type: none"> defined new terms or concepts. elaborated or repeated complex information. made explicit statements drawing student attention to certain ideas. spoke in a voice in an audible voice with clear enunciation. avoided distracting mannerisms. spoke at a pace that allowed students to take notes, if applicable (PowerPoint or notes may be available) paused during explanations and after asking questions. provided explicit directions for assignments.
Instructional Atmosphere (<i>The instructor...</i>) <ul style="list-style-type: none"> conveyed enthusiasm for the subject and appeared engaged in the instruction. conducted the class so that students felt comfortable to ask questions. varied the tone and pitch of voice for emphasis and interest.
Instructor's Professionalism (<i>The instructor...</i>) <ul style="list-style-type: none"> arrived to class on time. answered questions respectfully, avoiding condescension, treating students with respect. dressed in a professional manner commensurate with the subject matter profession. appeared confident, demonstrated command of the classroom

IV. PROBLEM STATEMENT & RESEARCH QUESTIONS

The purpose of this study is to examine the trends of faculty peer comments generated throughout VAPR with respect to characteristic attributes of teaching and Shulman's types of teacher knowledge. Specifically, this study seeks to explore the following research questions:

- 1) *How does familiarity with course content, context, and purpose being reviewed relate to the comments made throughout the video feedback?*
- 2) *How does educational and professional background relate to the comments made throughout the video feedback?*
- 3) *What are the prominent faculty professional and educational demographics that relate to the type of feedback provided?*

V. METHODOLOGY

This study employs an exploratory quantitative analysis to classify the peer-review comments annotated during the first implementation of a peer review process. The review followed the standard implementation of the VAPR process in the Spring 2014 semester with observation, selection, and recording a class session, providing a pre-observation

reflection, review by the institution's Center for Teaching and Learning Excellence, review by two consecutive faculty, followed by completion of a post-observation analysis.

A. Participants

Nine faculty, within the same engineering department, all participated in VAPR for the first time acting as both observed on one session and reviewing participants on two of the other eight observations. The course covered first-year through junior level course work including: introduction to engineering design, introduction to programming, graphical communications, fluids, and advanced modeling. These courses varied in time from a one to two hour duration for the observation commitment. The participants classified these courses as being representative of a typical class session without any anomalies, quizzes, or tests.

Participants were comprised of both tenure-track and non-tenure track faculty at academic ranks ranging from instructor to associate professor. Non-tenure track faculty are primarily responsible for teaching 12-15 credits per semester while tenured and tenure-track faculty are to teach 8-9 credits per semester while also being involved in research, which includes engineering education research. Participants' full time teaching experience ranged from 3 to 14 years with an average of 9 years.

B. Data Collection

Following the review process, each of the nine observations included a peer-generated video annotation text file that was imported into Excel. Each entry was categorized for the type of feedback given, encompassing characterizations such as: suggestions or identification of good practices, attributes of the instruction from Table I (instructor's organization, knowledge of subject matter, clarity and pace, atmosphere of the classroom, and professionalism), and Shulman's seven types of teacher knowledge.

Shulman's categories of teacher knowledge include subject matter knowledge, pedagogical knowledge, pedagogical content knowledge, curricular knowledge, knowledge of the learners, knowledge of educational context, and knowledge of educational ends, purposes, and values [11]. Subject matter knowledge, also referred to as content knowledge, is related to the depth and breadth of knowledge that a faculty member has with respect to the topic that faculty member is teaching. Pedagogical knowledge pertains to basic principles of class management and organization of materials, often learned through propositions and case knowledge [11, 39]. Pedagogical content knowledge combines the subject matter knowledge with appropriate pedagogical knowledge to advance understanding in that area. Pedagogical content knowledge reflects what experts know about how subjects can be taught effectively, what misconceptions are likely to arise, and how to help students achieve the specific learning goals of the domain [11]. Knowledge of the educational context define the teacher's understanding of the classroom and the physical limitations and accessibility of the classroom, whereas knowledge of the curriculum represents the broader understanding of the course outcomes, assignments, and access to books and other resources. Knowledge of the learner reflects the faculty's

conceptions of the students' cognitive and affective characteristics that include prior requisite knowledge and motivation. Knowledge of educational ends, purposes, and values refers to the degree to which teachers align with the purpose of their course and how it fits into the overall curriculum.

The peer authors' backgrounds of corresponding annotations are also classified as familiarity (having taught the course in the past or not) and experience (taken a similar course as a student or not, tenure or non-tenure track, years of academic career experience, and highest degree attained).

TABLE II. CHI-SQUARE ANALYSIS CATEGORIES

Categories	Groups
Attributes	Familiarity
Instructor's Organization (<i>IO</i>)	(Yes, No)
Knowledge of Subject Matter (<i>KoSM</i>)	Course Taken
Clarity and Pace (<i>C&P</i>)	(Yes, No)
Classroom Atmosphere (<i>CA</i>)	Highest Degree
Professionalism (<i>P</i>)	(MS, PhD)
	Years Experience
	(Low, Mid, High)
Teacher Knowledge	
Subject Matter Knowledge (<i>SMK</i>)	
Pedagogical Knowledge (<i>PK</i>)	
Pedagogical Content Knowledge (<i>PCK</i>)	
Curricular Knowledge (<i>CK</i>)	
Knowledge of the Learners (<i>KoL</i>)	
Knowledge of Educational Context (<i>KoC</i>)	
Knowledge of Educational Ends, Purposes, and Values (<i>KoEPIV</i>)	

C. Data Analysis

The data were primarily analyzed through descriptive statistics to determine the frequency of types of comments made and the relative percentage of comments that fit into each category based on the faculty demographics.

A Pearson chi-squared analysis was also conducted to determine if there is a statistically significant association between the types of peer review comments and faculty demographics. The chi-square test was run for each comparison of categories and groups listed in Table II.

VI. FINDINGS

Through a comparison of relative percentages of comments (Table III), when categorizing for attributes of the instruction 52% of the comments were related to clarity and pace with 35% focusing on the classroom atmosphere. When looking at these comments, it appears that clarity and pace were identified as separate categories. Those commenting on clarity frequently identified good practices or suggestions with respect to making sure that the students understood the content of the course. They often made suggestions for alternative forms of instruction that included on-line videos and physical demonstrations of the problems that related the intent of the

course back to real-world applications. In comparison, comments addressing pace were focused on maintaining involvement in the class and ensuring that students were keeping up with the structure of the class. This included, but was not limited to, providing time for students to think about a problem when asked before requesting an answer and providing them additional time to work out in-class problems. These types of comments were aligned with notes when the same student was answering the questions. In classes with a computer lab format, several comments drew attention to keeping the students at the same step as the instructor.

TABLE III. FREQUENCY OF COMMENT TYPES FOR INSTRUCTIONAL ATTRIBUTES

Attribute of Teaching	
Instructor's Organization	6%
Subject Matter	0%
Clarity & Pace	52%
Classroom Atmosphere	35%
Professionalism	7%
Teacher Knowledge	
Subject Matter Knowledge (<i>SMK</i>)	8%
Pedagogical Knowledge (<i>PK</i>)	43%
Pedagogical Content Knowledge (<i>PCK</i>)	21%
Curricular Knowledge (<i>CK</i>)	0%
Knowledge of the Learners (<i>KoL</i>)	6%
Knowledge of Educational Context (<i>KoC</i>)	16%
Knowledge of Educational Ends, Purposes, Value (<i>KoEPV</i>)	6%

Comments pertaining to instructional atmosphere were directly related to ensuring an optimal learning environment with high participation. Comments of this category included providing suggestions for where to stand during the lecture, encouraging faculty to move away from the podium, and phrasing of statements that may deter or decrease student self-efficacy. For example:

"Be careful about 'so that's easy'. Yes, it should be easy, but if somebody is struggling to understand what you did (and as quick as that was, it could be many students), you don't want to turn them off to the rest of the material because you said 'well this is easy'."

When examining the distribution of comments categorized by type of teacher knowledge, the highest was focused on pedagogical knowledge at 43% of annotations, followed by 21% for pedagogical content knowledge, and 16% for knowledge of the educational context. Pedagogical knowledge comments were represented in the form of what Shulman [39] classifies as principles, maxims, and norms. Principles typically derive from empirical research about practices. In these instances, one common principle that was referenced by several participants addressed the use of peer instruction through polling students in class. A maxim provides practical

claims, such as involving humor in class, offering insight into when questions should be asked, and the structure of the classroom. One example of this involves a recommendation about encouraging student participation:

“What about making students who are working on specific problems sit near each other. This way if they have common questions they can all listen in. This will also incorporate a small level of cooperative learning.”

“You might consider taking a break or giving students something to work on or answer every 15-30 minutes.”

Fewer pedagogical knowledge comments were focused on norms, which express a philosophy or value with respect to teaching. Several of these comments addressed the role of the student in higher education and that the instruction should make the student ask and answer why, rather than blindly receiving the knowledge.

Pedagogical content knowledge comments pertained to the specific instruction techniques related to the topic being addressed. Many of these pedagogical content knowledge comments offered suggestions to the practice, rather than identification of good practices, by adding specific examples to the demonstrations of the phenomenon or practice as seen below:

“Mixture of lecture and questions posed to students on section views, general purpose, different types, and nuances between 6 common types of sections views and their construction -- could spend a bit more time on applications unless covered later (why one type vs. another type could apply) and also infuse some real world everyday examples (apples, engine cutaways at a science and technology museum for children, swiss cheese - what part of slice you hatch vs. don't hatch, etc.).”

Other pedagogical content knowledge comments addressed the ordering of topics to offer clarifications to student understanding. Without an in-depth understanding of the subject matter and an understanding of the students many of these comments would not have been possible.

As noted by Bingham and Ottewill [12] and Cole [13] there exists the potential for reviewers to be either too congratulatory or too critical, either of which have the potential to decrease the effectiveness of the peer review. In this single case 29% of the comments offered suggestions, 66% identified a good practice, and the remaining 5% of comments identified a good practice, but then built on the practice by providing an additional suggestion on the pedagogical implementation.

A. Comparison of Faculty Demographics and Peer Review Comments

The chi-square analysis of dependence identified that there was no statistically significant identification that the number of comments made was related to the groupings identified in Table III. The only values close to significance was familiarity teaching the course and experience as a student in the course.

Since the chi-square failed to identify any statistical significance between the categories and dependency on the grouping, descriptive statistics have been used to explore

general trends between the two groups for both the frequency of teaching attribute comments and teacher knowledge comments (Tables IV and V). The largest variance in frequency of comments among the teaching attributes occurred with the respect to the differences in highest degree and tenure status, where a higher percentage (9%) of comments on clarity and pace came from faculty with a Master's degree and non-tenure track. In comparison there was a variation of 8% between the same groups when looking at classroom atmosphere. In this category of comments, 8-9% more comments came from faculty holding a PhD and those that were tenure track.

TABLE IV. PERCENTAGE OF TEACHER ATTRIBUTE COMMENTS BY GROUP

	Teaching Attribute				
	IO	KoSM	C&P	CA	P
Familiarity					
<i>Taught</i>	7%	1%	51%	36%	6%
<i>Not Taught</i>	5%	0%	57%	32%	7%
Experience					
Student	6%	1%	54%	35%	5%
Not Student	8%	0%	50%	35%	8%
Highest Degree					
<i>MS</i>	7%	0%	58%	29%	6%
<i>PhD</i>	6%	1%	49%	38%	7%

When examining the descriptive differences between groups with respect to the teacher knowledge comments, there is a larger difference for familiarity with respect to the frequency of pedagogical knowledge comments and pedagogical content knowledge comments. In comparison all other grouping and categories had an absolute difference of 7% or less with an average difference of 2.5%. In this scenario, faculty who taught the course previously offered 12% more pedagogical content knowledge comments than those who never taught the course. In comparison, those who had never taught the course made 15% more pedagogical knowledge comments.

TABLE V. PERCENTAGE OF TEACHER KNOWLEDGE COMMENTS BY GROUP

	Teacher Knowledge						
	SMK	PK	PCK	CK	KoC	KoL	KoEPV
Familiarity							
<i>Taught</i>	9%	39%	25%	0%	5%	17%	5%
<i>Not Taught</i>	7%	54%	13%	0%	3%	15%	8%
Experience							
Student	9%	42%	22%	0%	5%	18%	5%
Not Student	8%	46%	19%	0%	4%	13%	10%
Degree							
<i>MS</i>	6%	48%	21%	0%	3%	15%	7%
<i>PhD</i>	9%	40%	21%	0%	7%	17%	5%

VII. CONCLUSIONS AND DISCUSSION

The approach to evaluating peer review comments discussed here represents a cursory examination of general comments made in one implementation of the review. It comes

as no surprise that a majority of comments were related to the direct instruction occurring in the class. Due to the limitations of the peer-review system, faculty are significantly removed from the immediate atmosphere of the classroom creating the potential for unfamiliarity with the course context. The guiding parameters of the peer-review, in this study the prescribed Table of Attributes, may also provide a significant impact on the characterization of comments being made. Therefore, adoption of peer-review can be tailored to the community of practice to yield the desired results of pedagogical change.

The findings from this study begin to provide insight into the design of the faculty community involved in the peer-review process. Since familiarity with the course has more of a relationship to the types of comments made rather than any of the other groupings explored, faculty have the opportunity to diffuse more content-specific instructional techniques. However, the inclusion of reviewers unfamiliar with a course being reviewed has the potential to diffuse general pedagogical techniques from other disciplines and course contexts. This illustrates the need for a mixed-approach when formulating faculty groups to engage in the peer-review.

While this study observed a high percentage of positive comments in comparison to suggestions for instructional improvement, this is not a result of self-congratulatory practice among the participants. Upon closer examination of the comments, it appears that the positive comments reflect an affirmation of cultural norms to teaching practices utilized by the community of practice. An excessive amount of negative comments and suggestions has the potential to disengage participants in the community to change their practice, while the positive comments can reinforce practices valued by the community involved in the peer-review. Therefore VAPR has the potential to establish cultural norms of teaching within a community thus enhancing the inclusion of innovative and evidence-based instructional techniques provided they are valued by the community. Additional work will explore this cultural norm of teaching approaches within a community of practice and how categorizations of peer-review comments change over time.

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Pathway, Choice of Major, and Peer Economic Status of Nontraditional Students in Engineering

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Abstract—Research on nontraditional students in engineering is sparse. We use longitudinal data from eleven public, research universities in the United States to investigate nontraditional (NTS) and traditional (TRS) students who ever declared engineering as a major. Nontraditional students could help fill the national call for more science, technology, engineering, and mathematics (STEM) degrees in the United States. The researchers focus specifically on engineering students because it has been found that they are different from the other disciplines under the STEM umbrella. The research questions addressed in this paper were: Is the peer socioeconomic status different for nontraditional students compared to traditional students? What choices are nontraditional students making for their major, and are these different from or the same as those made by traditional students? Is the pathway different for nontraditional students compared to traditional students? This paper shows that socioeconomic status of nontraditional students in engineering is lower than traditional students in engineering. We show some different choices that nontraditional students make for their engineering major. This research also shows that nontraditional students who start in engineering are less likely to switch to and graduate in other majors than traditional students—non-traditional outcomes are more binary, resulting in either graduation in engineering or leaving the university without a degree, so non-traditional students lead traditional students in both of those outcomes.

Keywords—nontraditional; socioeconomic status; pathway

I. INTRODUCTION

This study focused on pathway, choice of major and socioeconomic status of nontraditional students compared to traditional students in undergraduate engineering majors. There are misperceptions about what engineering is within the United States that is preventing students from majoring in it. Many institutions are having a hard time recruiting and graduating enough engineers to meet the demand. Nontraditional students could be an avenue to fill this unmet demand.

Higher education has the challenge of educating students, controlling costs, and maintaining equity. The issues of equal access, retention, and degree completion have not gone away partly due to the escalating costs in higher education. Higher education has shifted their financial aid policies towards self-

help aid from gift aid, regardless of students' financial need. This change in policy makes it harder for low socioeconomic students to attend college.

This paper was focused on understanding nontraditional students' pathways for degree completion, what choices are they making for a degree, and whether their socioeconomic status plays a role in their decision to stay. We used quantitative data in this study to see large overarching patterns in many different institutions.

There is not much data on nontraditional students in engineering. This study explored pathways, choice in major and socioeconomic status to gain a better understanding of nontraditional students in engineering.

A. Defining a “nontraditional” student

There are numerous ways to define a student as “nontraditional” because a “traditional” student definition is defined by attending a 4-year university in the fall preceding high school graduation. They are not married nor have any dependents, attending part-time, working a full-time job while enrolled, and are not financially independent [1]. Some researchers have defined commuter students as nontraditional because they do not live on campus and therefore have a different college experience because they are living off campus [2, 3]. A nontraditional student is one who follows a path that is different in one or more ways from the traditional path.

The National Center for Educational Statistics (NCES) has shown that public, four-year institutions have 43% of their students are traditional, and the other 57% have at least one or more characteristics that would define them as nontraditional [1]. MIDFIELD is comprised of public, four year institutions from which the data for this study comes from. These institutions have 20% of their students with one nontraditional characteristic, 23% have between two and three, 14% have at least four [1]. It has been shown that the more nontraditional characteristics then the more likely chance of the student leaving higher education institutions [1]. It is common for researchers to use age as a determining factor for nontraditional students, specifically being over the age of 24 [1, 4, 5, 6, 7, 8, 9, 10]. The researchers in this study use being over the age of 24 as the determining characteristic for being nontraditional.

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MIDFIELD does not have access to other data to be able to use other nontraditional characteristics to analyze. We are currently working on expanding the database to be able to look at different aspects of nontraditional students.

B. Why Peer Economic Status?

The NCES has shown that if students have more nontraditional attributes, then they are less likely to graduate [1]. For students that are already considered nontraditional by age, does their socioeconomic status set them apart even more? Other research has shown that lower socioeconomic status can be an even bigger factor for student attrition in higher education [11].

Higher education costs are escalating every year, and many institutions are raising the cost of tuition to help manage their school's budget [12]. It was found that students with the highest departure rates within science, engineering, or mathematics (SEM) majors had financial need or were underrepresented minorities [12]. One-third of students with financial need leave the institution after one year of college. This study also showed that male students in SEM received a larger proportion of gift aid than non-SEM majors and all females [12].

Tones, Fraser, Elder, and White researched the support services for low socioeconomic mature-aged students in Australia. They found that mature-aged students had additional barriers in higher education including disabilities, commuting issues, and family and friends did not value educational goals [13]. It was reported that low socioeconomic mature-age students had limited resources of financial assets, health, study skills, and a home computer. They used the financial assistance department more often, and used the counseling services less often than middle and higher socioeconomic students.

MIDFIELD researchers have Peer Economic Status (PES) which uses high school free lunch eligibility as a proxy for the economic conditions of the high school a student attended before enrolling in the university [11]. PES is defined as 100 percent less the free-lunch percentage of a student's high school so that a school with a higher PES has a lower fraction of students eligible for free lunch and likely better resources. Orr, Ramirez, Ohland, and Lundy-Wagner researched the variables in MIDFIELD for students' free lunch participation in their high schools prior to attendance at the university and found that school level variable is a better predictor than district-level variables for six-year degree completion [14]. Engineering degrees have hope for lower socioeconomic status students to have steady income and stable job prospects, and this research informs the community of how well or not-so-well, this information is reaching lower socioeconomic students and whether they are choosing engineering degrees.

Privacy laws make it nearly impossible to find out individual's financial information. Thus, researchers are using other means, such as first-generation status, parent education level, parent occupation, parent income level, or Federal Pell grant eligibility [14]. Unfortunately, MIDFIELD does not have any of those variables, which is why there was the creation of the PES variable. PES does not measure an individual's level of poverty, but the abundance of poverty at high schools.

School-level poverty is correlated with individual-level poverty, academic achievement, postsecondary matriculation, and school resources [14].

Understanding the socioeconomic background of nontraditional students that pursue engineering degrees will help all the stakeholders have more relevant understanding for increasing nontraditional enrollment in engineering degree programs.

II. METHODS

A. The MIDFIELD Database and its Characteristics

This research utilizes Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD), which consists of a dataset with 1,014,984 students, whereas 210,736 of those students ever declared engineering as a major, at eleven U.S. institutions with nine of these in the Southeastern U.S [15]. One-tenth of the engineering degrees awarded in the United States were by MIDFIELD institutions. MIDFIELD includes seven of the 50 largest U.S. engineering institutions by engineering enrollment (institutions in which over 20 percent of students major in engineering, versus the nine percent national average) [16]. MIDFIELD was designed to have engineering students overrepresented. Results from this research are anticipated to generalize to the same type of institutions, which are large public universities with above average enrollment of engineering students, and therefore are relevant to institutions producing most engineering graduates nationally. Since this dataset includes whole population data, statistical inference is unnecessary—all reported differences are true differences for the institutions and subpopulations studied for the time period.

B. The Population Studied in This Work

Of the total MIDFIELD population, this work focuses on the 141,125 students who ever declared engineering as a major and have sufficient data in MIDFIELD to calculate six-year graduation rates. Nontraditional students (NTS) make up 3.2% (4,500) of the group studied. In this paper, nontraditional students are defined as students who have surpassed their 24th birthday at first matriculation to the institution. Traditional students (TRS) are defined as being younger than 24 at first matriculation. In this paper, graduation is defined as having graduated by the sixth year from matriculation, following a standard of reporting by the Integrated Postsecondary Education Data System (IPEDS) [17].

III. RESULTS AND DISCUSSION

Table I shows the terms and definitions that are used throughout the rest of the paper. These definitions separate the majors that are offered at the institutions that were used in this study. The researchers generalized the majors into groups of majors because there were too many different majors to be able to get any useful results when looking at each major from each university.

This study compared each grouping of majors of traditional and nontraditional students.

TABLE I: DEFINITIONS OF TERMS USED IN ANALYSES

Term	Definition
A&H	Arts and Humanities
AGR	Agriculture
BUS	Business; Economics, Management, Marketing and Related Support
CON	Continuing (enrolled, but not graduated at the sixth year)
ENG	Engineering
HSI	Health Sciences
ITD	Interdisciplinary
ONS	Other Non-Science
S&M	Science and Mathematics
SOC	Social Sciences
TEC	Technology
TOLEDO	Trajectory of Leaving Education, Destination Obscure. Used to describe a student who no longer appears in the database, but never received a degree.

A. Where are nontraditional students after six years?

Table II shows the sixth-year destination for nontraditional and traditional students. All of these students had engineering as their major at one point during their undergraduate experience. Nontraditional students are more likely to graduate in engineering, but they are also more likely to leave the institution (TOLEDO) than traditional students. Thus, nontraditional students were less likely to switch to non-engineering majors and they were less likely to still be enrolled at the sixth year (CON). The higher incidence of TOLEDO as a destination for nontraditional students may indicate that they have stopped out of education for a while, transferred to another school, or dropped out of higher education for good—the MIDFIELD dataset cannot distinguish among these pathways. While this finding generates hypotheses, further research is needed to explain why nontraditional students are less likely to switch to non-engineering majors.

Students that choose engineering as a major at some point in their college career have good chance to graduate with an engineering degree, NTS had 43.5 percent and TRS had 41.8 percent graduation in six years. This means that nontraditional (NTS) students have a higher rate of graduating with an engineering degree within 6 years than traditional students. Both NTS and TRS have the same overall pattern of choice of major, as shown in Table II, where neither group chooses interdisciplinary or health sciences at a high rate, but both groups have a higher rate in science and mathematics degrees. NTS did not go into mathematics or science, business, technology, or social sciences degrees as often as TRS. NTS do not see these other degrees as alternatives to an engineering degree as much as TRS. NTS chooses other non-science degrees, agriculture, interdisciplinary, or health sciences almost never.

TABLE II. SIX-YEAR OUTCOME FOR NONTRADITIONAL AND TRADITIONAL STUDENTS STARTING IN ENGINEERING.

Major	Six-year Outcomes		
	NTS	TRS	Total
ENG	43.5%	41.8%	41.8%
S&M	3.6%	4.9%	4.8%
BUS	0.6%	3.4%	3.3%
TEC	0.2%	1.6%	1.5%
SOC	0.4%	1.1%	1.1%
A&H	0.6%	0.8%	0.8%
ONS	0.2%	0.8%	0.7%
AGR	0.2%	0.6%	0.6%
ITD	0.0%	0.4%	0.4%
HSI	0.0%	0.2%	0.2%
CON	9.1%	10.7%	10.7%
TOLEDO	41.6%	33.8%	34.2%

We broke down the choice in major into specific engineering majors in Table III. Table III shows that NTS are choosing different engineering majors compared to TRS. Nontraditional students are not choosing BIE, EOE, ISE, TXE by over half compared to traditional students choosing that same major.

TABLE III: NONTRADITIONAL AND TRADITIONAL STUDENTS' CHOICES OF ENGINEERING MAJORS THAT GRADUATED.

Graduate Group		Engineering Choices	
		NTS	TRS
MCE	Mechanical	21.3%	20.0%
ELE	Electrical	28.5%	17.1%
CVE	Civil	16.7%	13.6%
ISE	Industrial/Systems	4.2%	10.6%
CHE	Chemical	7.6%	9.7%
CPE	Computer	8.5%	8.5%
ASE	Aerospace	3.5%	6.7%
EGE	General	2.6%	3.3%
MTE	Materials	1.5%	2.3%
BIE	Bioengineering / Biomedical	0.7%	2.0%
EOE	Other Engineering	0.7%	2.0%
TXE	Textile	0.6%	1.4%
ARE	Architectural	1.2%	1.0%
ESE	Engineering Science and Mechanics	0.3%	0.6%
NCE	Nuclear	0.5%	0.5%

Nontraditional students are choosing CVE, ELE, MCE more than traditional students, although they are the top choices for both groups, TRS students are choosing other engineering majors at a higher rate than NTS. The majors that nontraditional students are choosing are more widely known as traditional engineering than the other more nontraditional engineering majors. It may be that the nontraditional students are choosing ‘safe’ degrees that they have heard of and know other people with those degrees. They may feel that they cannot risk getting an engineering degree that is not as well known or may have more trouble getting a job.

B. Nontraditional student PES

First, we looked at nontraditional and traditional students by gender. The larger difference is between nontraditional and traditional students. Both female and male nontraditional students have lower PES than traditional students, but the effect size is not large, as shown in Table IV.

Nontraditional males have the lowest PES at 84.91, and traditional males have the highest at 88.7. Females are not the highest and lowest but have a spread of 2.83 PES percentage points.

In Table V, we show that the average PES of traditional and nontraditional students by institution. MIDFIELD institutions are comprised of large, public research institutions mostly in the southeastern U.S. but there is a variety of different average PES values for traditional and nontraditional students. Table V shows that traditional students have a higher PES across all institutions except nontraditional females at institution F. TRS males have the highest PES scores at each institution. Traditional female students consistently have a slightly lower PES than traditional male students, but higher than both male and female NTS. There are two institutions, C and D, where NTS females have the lowest PES value, but all the other institutions lowest PES values with NTS males.

Students that come from high schools with fewer resources are bringing in more diversity than their nontraditional status. These students are consistently showing a lower PES than traditional students. Nontraditional students are, on average, from a lower socioeconomic background, and have more barriers to graduating associated with low socioeconomic status.

Table VI shows the PES for students with various sixth-year outcomes. There is some evidence that economic factors play a role in students leaving the institution, since students at TOLEDO have a lower average PES. TOL (TOLEDO) PES for nontraditional and traditional students is 84.46 and 87.46. Among those students who switch majors, PES does not seem to be a factor, since engineering has an average PES of the disciplines shown, and students switch into majors with both lower and higher PES averages.

TABLE IV: AVERAGE PES FOR NONTRADITIONAL AND TRADITIONAL STUDENTS BY GENDER.

Type of Student	Average PES	
	Female	Male
NTS	84.95	84.91
TRS	87.78	88.7

TABLE V: AVERAGE PES BY INSTITUTION AND GENDER

Institution	TRS		NTS	
	Female	Male	Female	Male
A	89.77	90.46	86.65	85.38
B	91.56	91.73	87.18	86.21
C	86.74	87.79	85.06	86.57
D	90.51	90.99	86.24	88.02
E	86.41	86.64	83.65	83.46
F	87.31	87.89	96.61	85.65
G	81.49	82.08	XX	72.37

TABLE VI: PES OF NONTRADITIONAL AND TRADITIONAL STUDENTS WITH VARIOUS SIXTH-YEAR OUTCOMES.

Major	Average PES	
	NTS	TRS
HSI	96.14	87.18
ONS	90.61	90.37
TEC	88.82	90.33
BUS	88.68	89.44
S&M	87.73	90.59
ENG	85.74	89.91
AGR	84.52	87.63
TOL	84.46	87.46
CON	82.07	86.53
SOC	80.2	88.84
A&H	76.75	88.92
ITD	XX	90.85

In Table VI, HSI for nontraditional students had the highest PES overall. ONS was the only other major that nontraditional students have a higher PES than traditional students and this was the major where the students were the most similar. A&H was the lowest PES for nontraditional students. The lowest PES for traditional students was CON at 86.53. Traditional students have a higher PES in ENG than nontraditional students, 89.91 vs. 85.74. Nontraditional students have a high graduation rate that suggests that they

have more circumstances that they overcome, although the effect size is not large, which they may make up for with maturity and determination.

IV. CONCLUSIONS

This research focused on nontraditional students pathways, choice of major, and peer economic status because these all matter in the success of nontraditional students graduating with engineering degrees. The results from this work show that nontraditional students enrolling in engineering are more likely than traditional students to graduate in engineering, but are also more likely to leave the institution without a degree. Both might be explained by a higher level of commitment to the engineering degree—empowering a higher graduation rate, but leaving those students blind to other options where they might change majors and graduate. It may also be that if nontraditional students cannot complete the engineering degree, they do not have the resources (financial, time, etc.) to change majors and continue. There is some support for the latter conclusion in studying economic indicators from the PES values at high schools that students attended.

Nontraditional students are more likely to choose and graduate in mainstream engineering majors such as civil, electrical, and mechanical while avoiding more specialized engineering majors. This may be because they are less likely to have heard of those majors and are concerned about getting a job.

More research is needed to investigate how nontraditional students choose a major, their motivation to persist, their lack of interest in switching to non-engineering majors, and the impact of high school economic background on their educational experience. This work reveals some fundamental findings and generates valuable hypotheses for future research.

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Culturally Situated Survey of Engineering Identity for Latina/o Undergraduates

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Abstract—Measures of engineering identity have been designed for an aggregate group of engineering students leaving the ways that students of color develop their engineering identities unexplored. This work in progress paper presents a culturally situated survey of engineering identity for Latina/o undergraduates. The survey was built using data from 20 interviews and observations with engineering Latina/o students. This study took an asset-based approach through the use of the Community Cultural Wealth framework. The survey was administered to 75 students. Using the survey responses of 33 engineering identity items, exploratory factor analysis was performed to examine the structural validity of the survey.

Keywords—*engineering identity; Latinas/os; retention; underrepresentation*

I. INTRODUCTION

One way to address retention of undergraduates in engineering is through a study of engineering identity development. Research has shown that college students who identify as engineers are more likely to persist in engineering than those who do not identify as engineers [1], [2]. Current measures of engineering identity have been designed for an aggregate group of engineers [3], [4], [5] leaving the experiences of engineering students of color unexplored. Moreover, because these measures were not designed for students of color, they may not be culturally situated in the experiences of these students.

This study presents a culturally situated understanding of the way students of color develop an engineering identity in order to affirm, incorporate, and acknowledge students' cultures and cultural values. A study of engineering identity development for Latinas/os is warranted not only because such study has not been previously studied, but also because studies of identity development specific to students of color can help schools of engineering address retention in engineering. The purpose of this paper is to present the construction and validation of the survey of engineering identity development.

II. RESEARCH METHODS

The research question posed in this study was in what ways and to what extent does membership in the Society of Hispanic Professional Engineers (SHPE) influence the

engineering identity development of Latina/o students? This research question was answered using a two-phase mixed methods design. The mixed methods study was designed with a developmental purpose [6] – that is, with the goal of using the results from the first phase to develop the second phase. The first phase of the study [7] was composed of 20 semi-structured interviews with Latina/o undergraduates and observations. In the second phase of the study, I created and piloted a web survey of engineering identity using results from the first phase. Using the pilot survey data, I ran exploratory factor analysis to examine the structural validity of the survey. This paper focuses on the second phase of the study.

III. THEORETICAL FRAMEWORK

This study was guided by Yosso's Community Cultural Wealth (CCW) theoretical framework [8]. The CCW framework was created to study and acknowledge the wealth in the lived experience of students of color. This framework posits six forms of capital: aspirational, linguistic, familial, social, navigational, and resistant. Aspirational capital "refers to the ability to maintain hopes and dreams" even in the face of barriers. Linguistic capital "includes the intellectual and social skills attained through communication experiences in more than one language and/or style." Familial capital "refers to those cultural knowledges nurtured among *familia* (kin) that carry a sense of community history, memory and cultural intuition." Familial capital also "engages a commitment to community well being." Social capital refers to the "networks of people and community of resources." Navigational capital "refers to skills of maneuvering through social institutions." Resistant capital "refers those knowledges and skills fostered through oppositional behavior that challenges inequality." This framework enables researchers to identify and document wealth "to transform education and empower People of Color to utilize assets already abundant in their communities" (p. 89).

Through the use of the CCW framework, I investigated the Latina/o engineering student experience by focusing on the knowledges these students bring to their engineering programs and schools rather than focusing on deficiencies. Additionally, the use of CCW allowed me to explore the students' experiences and engineering identity development

from an asset-based framework.

IV. SURVEY DEVELOPMENT

Interviews with 20 Latina/o student members of SHPE and observation of events at a SHPE chapter and at the 2014 national SHPE conference revealed three new dimensions of engineering identity development [8]. These new dimensions were engineering role modeling, having a commitment to the community, and being part of an engineering *familia*. The results from the first phase of the larger study also confirmed the following, previously found dimensions of engineering identity: intrinsic and psychological motivation to pursue engineering [9], professional skills development [3], [9], [10], and leadership skills development [3], [10].

Using primarily the results from the first phase of this study, I constructed a survey that was situated in the experiences of Latina/o engineering undergraduates. The survey consisted of 48 questions including 33 items of engineering identity.

A. Survey Constructs

The survey constructs, developed using results from the first phase, were **commitment to community**, **developing as a professional**, **developing as a leader**, **engineering role modeling**, and **having an engineering familia**. **Commitment to community** referred to the students' ties to the local (university) and home community via outreach and service. **Developing as a professional** referred to students' gaining non-technical professional skills through local, regional, and national SHPE workshops. Similarly, **developing as a leader** referred to students' gaining leadership skills through local, regional, and national SHPE workshops and by serving in SHPE committees and SHPE executive boards. **Engineering role modeling** referred to having a Latina/o engineering role model and being an engineering role model to other Latina/o students. Finally, **having an engineering familia** referred to the family-like support that students provided and received within SHPE. In addition to these five survey constructs, the already-developed construct of intrinsic and psychological motivation [9] to study engineering was added to the survey. Though the interview protocol did not directly address motivation for studying engineering, aspects of intrinsic motivation to study engineering were present in the ways students talked about their engineering journeys in their interviews.

B. Survey Items

In total, there were 33 engineering identity items for the six survey constructs. For the motivation construct, I used 5 previously developed survey items to measure intrinsic and psychological motivation to pursue engineering [9].

For the remaining five survey constructs, I used the interview and observation data to develop items. For the **commitment to community** construct, there were 4 items including involvement in the community and STEM outreach. For the **developing as a professional** construct, there were 5 items including gains of non-technical professional skills, and participation in workshops to address professional skills. For

the **developing as a leader** construct, there were 5 items including ability to take on leadership roles and participation in workshops to address leadership skills. For the **engineering role modeling** construct, there were 8 items including the importance of being and having engineering role models and Latina/o engineering role models. Finally, for the **having an engineering familia** construct, there were 6 items including importance of having peer support from other Latina/o engineering students.

Guided by the goal of creating a culturally situated survey of engineering identity development for Latina and Latino students, I used participant language and specific experiences to create survey items. As examples of participant language, I used the terms *familia* and SHPE *familia*, instead of only asking about peers or support, to honor the terminology that students used in the interviews. As an example of specific experiences, to explore the construct of commitment to community, I asked about involvement with *noche de ciencias* ("science night" – an outreach science program for kids and parents) as a specific experiential example of commitment to community.

C. Survey Standards

After the survey items were constructed, I followed content, cognitive, and usability survey standards to minimize measurement error [11].

To address content standards, whether the survey items were asking what they were intended to ask, I sought feedback on the survey items from content area experts. Experts included two scholars in the fields of higher education and engineering education and potential survey takers. These experts were familiar with the content of the survey. Through this review process, I ensured that the survey items mapped to the constructs and that they were aligned with the overall research question.

To address usability and cognitive standards, I consulted with a survey expert to ensure the survey items were appropriate in wording, structure, and formatting. After the survey expert consultation, I made the following changes to the survey. First, I changed leading questions to balanced questions. Leading questions, such as some yes or no questions, are unbalanced and could lead to acquiescence bias [12]. Instead of asking the survey respondents, "Do you consider yourself an engineer?" with yes or no answer options, I asked them, "Which of these statements best describes you?" and provided item-specific response options. Second, instead of presenting a matrix of questions in one page, I opted for one question per page. When each page has only one question, survey respondents concentrate on each question at a time. Conversely, a matrix or grid of questions can overwhelm the survey respondent and cause survey breakoffs, item missing data, and respondent dissatisfaction [13]. Another reason for presenting one survey question at a time is that questions that are positioned higher up on the screen are rated more favorably than questions that are positioned at a lower location on the screen [13]. Third, I reworded and restructured agree/disagree questions. Agree/disagree scales have been shown to have more acquiescence bias from survey takers

because survey takers more often agree with the statement regardless of the question [14], [15], [16]. Finally, I used a unipolar scale (with four to five items) for maximum validity and reliability [17].

To address cognitive and content standards, I conducted two separate cognitive interviews with content area experts. These interviews helped to address the understanding of each survey item. The content area experts were undergraduate engineering students who were members of SHPE at the time of the cognitive interview. During the interview, I asked the content area experts to take the survey as if they had received it via email. After they took the survey, I asked the content area experts to do retrospective think-alouds [11] for every item. In a retrospective think-aloud, the respondent is asked a series of questions about how they answered the survey items. These questions probe about the cognitive process of answering a survey item. Through feedback from the retrospective think-aloud, a researcher can also optimize wording and formatting of the survey items. The content area experts provided wording and format changes to the survey. After the changes were made, I pilot tested the web survey with three more content area experts; they had minimal formatting changes.

D. Procedure and Participants

The final web survey consisted of 48 questions, which included the 33 engineering identity items, and demographic questions. On average, the survey took about 13 minutes to complete. The final survey was distributed using SurveyMonkey® to SHPE undergraduates who intended to graduate in 2015. A link to the survey was sent to 1,629 students via email. After two weeks, 105 people responded to the survey. After data cleaning, there were 75 cases that were used for exploratory factor analysis.

The gender breakdown for survey participants was 47% female, 52% male, and 1% who did not respond. About 77% of the participants were fourth or fifth year undergraduates. The majority of participants were non-transfer students (64%). They represented a range of engineering majors; the top five majors were mechanical engineering, civil engineering, aerospace engineering, chemical engineering, and industrial engineering. Almost all participants identified as Latina/o, Chicana/o, or Hispanic (92%), 8% of the participants identified as Latina/o, Chicano/o, or Hispanic sometimes, and one participant was unsure. With regard to ethnicity, the top four ethnic backgrounds that participants identified with were Mexican, Puerto Rican, Ecuadorian, and Colombian. Nineteen participants had family members, other than their parents or siblings, who were engineers. Eight of the participants knew engineers through their high school teachers. With regard to the highest level of a parent's education, 19% of the participants responded that the highest level of education for a parent was a High School Diploma or GED followed by a 16% for Bachelor's degree. With regard to SHPE, about 41% of the participants were involved with SHPE for 3-4 years. The majority (56%) were executive board members.

V. RESULTS AND DISCUSSION

A. Exploratory Factor Analysis

I ran Exploratory Factor Analysis (EFA) using R Studio with five factors retained. I chose Principal Axis Factoring (PAF) in order to maximize the variance extracted by the factors [18]. Practically, PAF was also chosen in order to examine the shared variance among variables in the dataset through a small number of factors [19]. Oblique rotation was chosen to rotate the factors for two reasons. First, inspection of the factor correlation matrix revealed that two factors were highly correlated (.76). Second, oblique rotation is recommended for social science research where factors are more likely to be correlated in practice [20]. I chose oblimin rotation to simplify the factor structure by minimizing cross products of loadings [18].

The final simple factor structure (shown in Table I) consisted of five factors and twenty-six items. The final five factors explained 57% of the variance in the data. Factor 1, motivation, consisted of five items and had a Cronbach's alpha reliability coefficient of $\alpha = 0.74$. Factor 2, community, consisted of five items and $\alpha = 0.77$. Factor 3, professional and leadership, consisted of nine items and $\alpha = 0.94$. Factor 4, role modeling, consisted of three items and $\alpha = 0.75$. Factor 5, engineering *familia*, consisted of four items and $\alpha = 0.85$. The final simple factor structure had a Cronbach's alpha reliability coefficient of $\alpha = 0.91$.

B. Item Reliability Analysis

All of the factors had acceptable reliability coefficients of 0.74 and above as shown in Table II.

TABLE II
DESCRIPTIVE STATISTICS FOR FACTORS

Factor	No. of items	Mean (SD)	Skew	Kurtosis	Alpha
Motivation	5	4.40 (0.46)	-0.50	-0.36	0.74
Community	5	4.42 (0.51)	-0.59	0.40	0.77
Professional & Leadership	9	3.89 (0.88)	-0.92	0.55	0.94
Role Modeling	3	4.31 (0.64)	-0.92	0.85	0.75
Engineering <i>Familia</i>	4	4.28 (0.72)	-0.75	-0.44	0.85

VI. IMPLICATIONS

This study proposed three new dimensions of engineering identity; namely, community, role modeling, and engineering *familia*. These dimensions encapsulate ways that Latina/o student members of SHPE identified and developed as engineers. The results from this study have at least three implications for schools of engineering. First, engineering courses can incorporate in the curriculum ways to foster and nurture these dimensions of engineering identity. For example, to foster the community dimension, students could have the option of working with a community organization on an engineering design project that meets a need for the organization. Second, engineering administrators can incorporate these dimensions in their programmatic retention efforts. For example, role modeling could be incorporated

organically into already-existing student development programs, such as first-year programs that have an engineering introductory course for student success. Third, one of the ways that schools of engineering could adapt these dimensions is by using the survey for evaluation and assessment of identity development of students. Using these results, schools of engineering can assess academic opportunities that may be available for students to develop as engineers.

VII. FUTURE WORK

We plan to build on this survey in at least three ways. First, to further address construct validity, future work will compare the measures of engineering identity examined in this survey with other measures of engineering identity. Second, we plan to distribute to a national sample of SHPE undergraduates. Using those results, we will investigate the relationships between identity development and student and university characteristics and context. For example, we will look at within group differences with regards to race, ethnic background, gender, type of institution, and first generation status. Finally, we plan on expanding on this survey to make it applicable to non-SHPE, Latina/o students.

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TABLE I
ITEM AND FACTOR LOADINGS FOR FINAL FACTOR STRUCTURE

Survey Items	Factor 1 (Motivation)	Factor 2 (Community)	Factor 3 (Professional & Leadership)	Factor 4 (Role Modeling)	Factor 5 (Engineering <i>Familia</i>)
How good do you feel when you are doing engineering?	0.66				
How fun do you think engineering is?	0.71				
How interesting do you think engineering is?	0.71				
To what extent do you like to build stuff?	0.43				
To what extent do you like to figure out how things work?	0.35				
As an engineer, how important is giving back to the community through outreach such as Noche de Ciencias (Science Night)?		0.79			
How important are STEM outreach programs for kids?		0.38			
As an engineer, how important is being involved in your community to you?		0.71			
As an engineer, how committed are you to the well being of your community?		0.64			
In your journey as an engineer, how important is being an engineering role model to middle school and high school students?		0.36			
To what extent has your participation in SHPE helped you develop as a professional?			0.75		
To what extent have you acquired nontechnical, professional skills from SHPE that you need to become an engineer?			0.72		
To what extent have you attended SHPE workshops to learn about nontechnical, professional skills that you need to become an engineer?			0.74		
To what extent have you developed your nontechnical, professional skills through your SHPE involvement?			0.93		
To what extent has your participation in SHPE helped you develop communication skills to network with other professionals?			0.84		
To what extent has your participation in SHPE helped you develop as a leader?			0.91		
To what extent has your participation in SHPE helped you acquire leadership skills that you need to be an engineer?			0.86		
To what extent have you attended SHPE workshops to learn about leadership skills that you need to be an engineer?			0.76		
To what extent have you been able to take on leadership roles in SHPE that you need to be an engineer?			0.58		
In your journey as an engineer, how important is finding engineering role models within SHPE?				0.34	
In your journey as an engineer, how important is being able to find engineering role models?				0.77	
In your journey as an engineer, how important is having an engineer role model?				0.75	
How important is to have a SHPE <i>familia</i> (family) of engineers to you?					0.56
How important is having support from other Latina/o engineers to you?					0.99
To what extent do you feel like you are part of a <i>familia</i> (family) when you are around Latina and Latino engineers?					0.45
To what extent does seeing other Latina/o engineers succeed make you feel like you can succeed in engineering?				0.32	0.63

Note: loadings < 0.32 are suppressed

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Technological Tools to Learn Calculus

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Summary— Online learning tools have allowed professors to carry out their classes in an interactive way, synchronic as well as asynchronic, giving them the opportunity to explore from different points of view specific themes or concepts, achieving greater dynamism in their classes through the active participation of students. This article presents the results of the implementation of a software tool for massive use designed with the objective of allowing Engineering students to strengthen their basic mathematical knowledge as well as to improve their results in courses such as Calculus I and Mathematics I. These courses are part of the first semesters of the syllabus for all undergraduate programs of the School of Engineering, and are basic courses in the formation of an engineer at Universidad EAFIT (Medellín, Colombia).

This software tool for massive use allows students to self-diagnose, to solve exercises with different levels of complexity and difficulty, to visualize academic contents such as video classes and virtual resources, and to know their evolution in the understanding of basic concepts in calculus. On one hand, this facilitates the beginning of their studies at the university. On the other, it gives the professor an initial diagnose of the level students have to start the course so that continuous analytics can be performed based on the learning process of the student.

Furthermore, this article shows the results of a comparative analysis done to two groups of students, a Control group and an Experimental group, that took Calculus I as part of their undergraduate studies. The experiment lasted two months with testing done at the beginning and at the end of the course. The objective was to register the level of knowledge acquired by the students and compare the differences between the two groups, control and experimental. The testing also allowed the progress of the student between tests to be measured, taking into account that the experimental group had the opportunity to explore the platform during this two-month period. Therefore, the analysis performed served to gather information useful for evaluating the effectiveness of the proposed system in the learning process of the students at the University.

Keywords— Calculus, e-Learning, Practice, Evaluation, Calculus Teaching, Tools

INTRODUCTION

The Calculus course offered as part of the curriculum for undergraduate students at Universidad EAFIT's School of Engineering is considered one of the courses with the highest dropout ratio in all programs in the University. Faced with this issue, the University conceived an educational innovation project with the goal of developing a Software Tool to determine the starting level of competency in calculus for each student attending the Calculus I course, and provide an effective leveling tool for the concepts that are prerequisite to obtain a good performance in that course.

In the next sections we will (a) describe the fundamentals that served as framework for the development of the Software Tool for massive use that allows students to self-diagnose and level their knowledge of pre-calculus before the commencement of their studies at the University; (b) the process carried out for the development of the tool; and (c) the results of the first pilot test with students.

I. THE LEARNING OF CALCULUS AND THE DIGITAL SOLUTIONS FOR LEARNING

It is of the outmost importance for students the acquisition of a good mathematical ability in the first stages of schooling [1]. Likewise, “the difficulties in the understanding of numerical concepts and problems in calculus during the first years may interfere with the acquisition of mathematical abilities in the future” [2] as well as in the formation of engineers.

It is required, for the understanding of Calculus, that students have an adequate mental attitude so that

they are willing to complete every single one of the activities suggested by the professor or by the textbook to reinforce the theory of the course. At the same time, it is fundamental to practice and link concepts with real life situations because. This way, students can acquire a better understanding that allows them to apply, justify, support, and defend their solutions and solving processes in front of their classmates.

Traditionally, professors help students understand what prerequisites are needed for Calculus as part of the course. This allows students to exercise their reasoning capacity, and allows new students to identify which concepts they have as baseline to approach the course and what concepts they can't grasp and why.

Another technique used in the Calculus course is the interaction between students to create questions and to answers them. This technique, called collaborative construction, enables the understanding of the concepts. Additionally, professors use strategies that allow them to catch the attention of students by highlighting important concepts making them easier to identify and understand. This way, for example, the student can go over his/her notes without any problem to identify concepts and procedures.

Nowadays, learning environments must take into account the framework of constructivism. [3] This approach sustains that the process of teaching and learning can be understood better if the observer is able to see the professor as the facilitator and students as the main characters responsible for building their own knowledge through their own experiences or those proposed by the professor, their own reflections, readings, and the sharing of ideas with their classmates and professors. These theories are also seen in the approaches presented by Vico, Kant, Mark, and Darwin. [4] Thus, the goal is for students to enjoy learning and to be committed to learn for the rest of their life.

Applying this approach to teaching and learning in Basic Sciences, such as Math and Calculus, poses challenges that have been identified by several authors. For example, Vrancken, Gregorini, Engler [5] pose that "teaching Calculus is one of the

biggest challenges of modern education because its learning has numerous difficulties related to high level thinking, where processes such as abstraction, analysis, and demonstration are implicated. [6]

During the past couple of years, some successful experiences have been reported in the implementation of online mathematical courses platforms. Some examples are: ALEKS [7], from McGraw-Hill publishers, offers courses in diverse topics categorized for all levels of education; the IXL web platform [8], through interactive interfaces, supports the learning of many topics such as pre-calculus; and the Khan Academy¹ platform, a repository of short videos that teach complex mathematical concepts in a very simple way.

Subsequently, the evolution of Technological Tools for learning have made possible that today we can configure learning solutions that support formal, collaborative, and experiential processes. Some solutions are: the so called MOOC² (Massive Online Open Course); immediate answering systems that activate student participation in the classroom by allowing students to answer to quiz, surveys, and discussions through their smartphones; tools that allow the creation of animated and interactive web content; eLearning platforms that allow the user to learn in a fun way by gaming; and tools that allow the automatic creation of dynamic and interactive presentations and allow the user to save them in standard formats recognized by Learning Management Systems (LMS).

All these elements inspired the creation of the Software Tool for the teaching of Calculus. This tool integrates multiple different solutions for learning while allowing the collection of data needed for using analytic tools to inquire about the learning process of students.

¹ Khan Academy: A non-profit organization with the mission of providing free world class education to anyone, anywhere in the world. <https://es.khanacademy.org/>

² MOOC: (Massive Online Open Course) Is a distance learning course found online to which anyone can register, doesn't have a limit of participants, and students work at their own pace.

II. DEVELOPMENT PROCESS OF THE ONLINE COURSE

After researching and exploring existent tools, the development process of the pre-Calculus course –which houses the Software Tool- started with the instructional design using the ADDIE (Analysis, Design, Development, Implementation, Evaluation) methodology [9]. The result of the analysis was the specification of competencies, methodologies, activities, contents, rubrics, and evaluations needed in the tool.

Based on the learning objectives of the course and the pedagogical structure of the contents proposed in the analysis and design stage, the resources for the course were developed. This was achieved by carefully completing digitalization, graphic design, proofreading, audiovisual production, and integration processes through IMS [10] standards such as VDEX [11], LTI, QTI2 and SCORM [12], as well as other formats that allow the export and import of contents such as MBZ for courses, and GIFT and AIKEN for workshops. Likewise, eLearning standards to guarantee the durability, interoperability, accessibility, and reusability of all learning resources were incorporated.

The content development included the creation of digital audiovisual resources that were dynamic and interactive and the generation of workshops through algorithms in Java to obtain multiple versions of the same document. Figure 1 shows the content architecture of one of the eleven modules of the course.

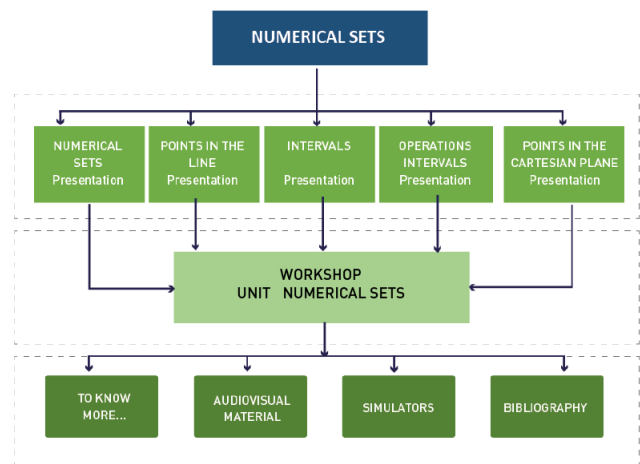


Figure 1. Navigation Map

The interaction model for tracking the learning process was designed under principles that could guarantee a good user experience. This experience relates to the whole range of activities that can make a student to learn, [13] as some people process concepts through practical experience, reflective observation, which leads them to be able to solve a problem.

Figure 2 shows the cycle for tracking learning processes.

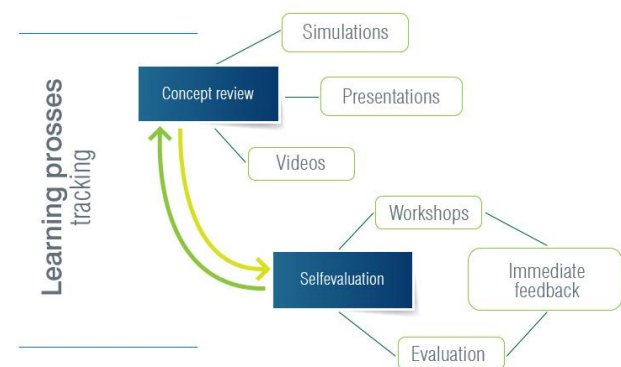


Figure 2. Interaction model for the internal organization of contents

For the implementation of the course, a framework Figure 3 capable of supporting the required services was designed. It integrated different systems to manage learning activities, course material, evaluation/assessment, and LaTeX language [14] for the treatment of the mathematical content.

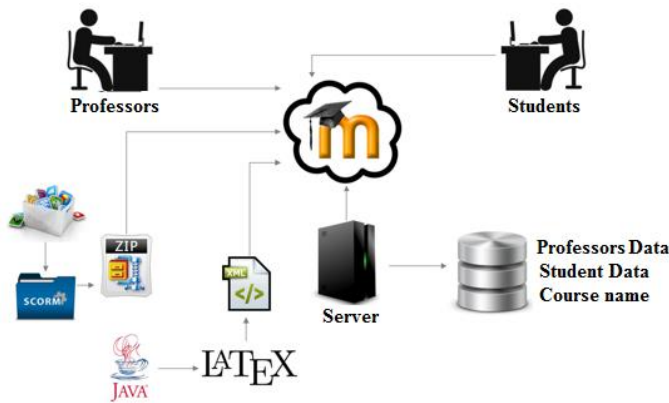


Figure 3. Tools for the development of the contents of the course

The technological architecture used in the project is shown in figure 4. This architecture includes a server where the Moodle platform runs along with a database (where all data and interactions of students is saved). All contents from the course are also stored in that server. This entire infrastructure is hosted in the Cloud so professors and students can access the platform in a safe way from anywhere as long as they have their usernames and passwords.

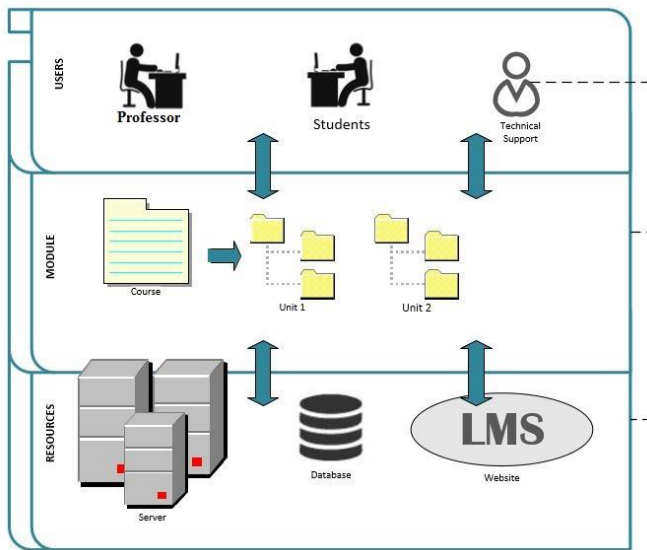


Figure 4. Technological Architecture

The Pre-Calculus course used, as the base for its module of training and evaluation, the system developed by the project “Evaluation System for the Statistics Course”. This project proposed the use of a system integrated with the LMS that generates automatic questions [15]. All the work structure for question generation is integrated with the LMS

using Java programming language and using IMS academic standards [16] based on XML [17] such as QTI1 [18], QTI2, and XML-MOODLE [19]. The results are questions in different formats like multiple-choice, true or false, and pairing.

Different examples of questions used in unit workshops are presented in figures 5, 6 and 7.

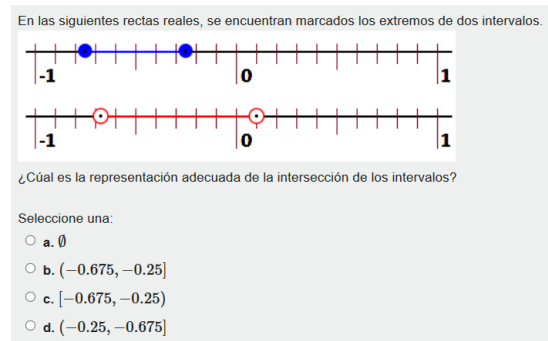


Figure 5. Example question in the unit for “Operations with Intervals”

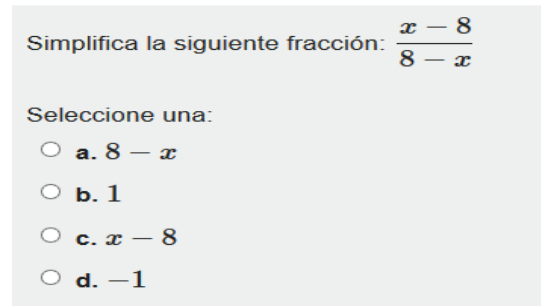


Figure 6. Example question in the unit for “Algebraic Fractions”

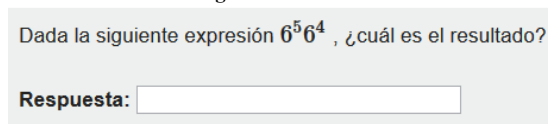


Figure 7. Example question in the unit for “Exponentiation”

Once the course was fully developed, different tests and necessary modifications were done before running a pilot test.

III. PILOT TEST

Description of the Pilot Test

The approach applied to measure the effectiveness of the Tool in terms of students' results, was the comparison of two groups coursing Calculus I. The first group was denominated Control, and the second group was denominated Experimental. Both groups were evaluated the same way. Each group executed two short tests in printed format (a diagnostic test and a final test). The only difference between both groups was that the first group, the Control group, didn't have access to the Tool and the other did. The tests were carried out during the first and last day of the two-month period designated for this pilot.

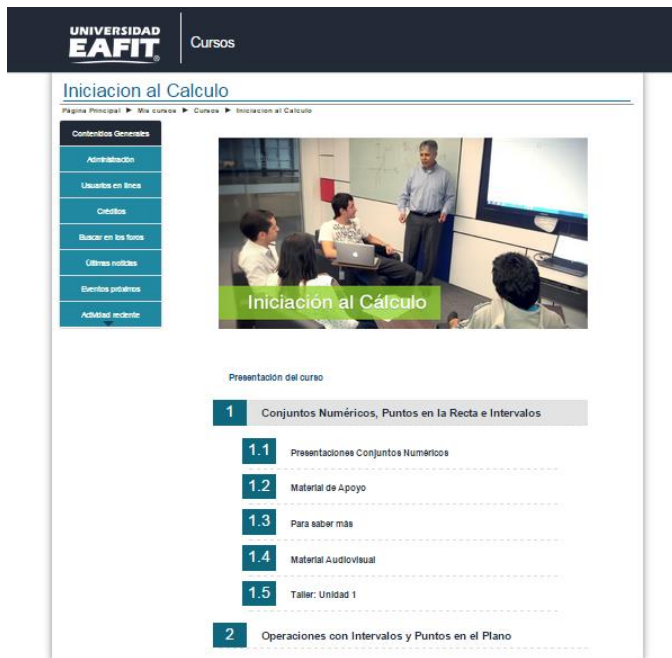


Figure 8. Snapshot of the Pre-Calculus Course

The first test was carried out in printed format at the beginning of the course for both the control group (26 students) and the experimental group (25 students). The test included three topics: numerical sets, intervals, and regions in a plane; for a total of 13 questions. Both groups had a very high percentage of first time students (close to 90%) and a remaining 10% of recurring students. Regarding the duration of the test, 90 minutes were set as the time limit. This test was done in order to have an

initial diagnose and register the mathematical concepts that the student is clear on the point of Calculus I course.

Once the initial testing was complete, both groups continued with their classes. The experimental group had access to the course module on the Software Tool, giving students access to different materials and academic resources among which they could find workshops and audiovisual content. The access was enabled for a period of two months so students could explore the platform to its fullest, identify their mistakes, and improve their mastery of the course's concepts.

The second test was carried out at the end of the two-month trial period for both the control group (26 students) and the experimental group (25 students). This one tried to resemble the conditions of the first test as much as possible. The objective was to obtain a register of the variation of the acquired knowledge of the students to compare it with the results of the first test on themselves (to look for signs of improvement) and between the two groups to see the effects of the platform on the results of the experimental group (that had access to the Tool for two months) against the results of the control group.

IV. EVALUATION OF RESULTS

A. Analysis of the Results Achieved in the Control Group

Figure 9 shows the results in the two tests carried out in the control group. The table shows the topic evaluated, the level of difficulty in a scale from 1 to 5, the specific competence, and the average score that students achieved in the topic.

Topic	Difficulty level (1-5)	Competences	Control Group 26 Students Test 1	Control Group 26 Students Test 2
Numeric al sets	1	Locate decimal numbers on the real line and converts decimal values to fractions	57%	79%
	2	Solve simple problems with a fraction applied to a context		
	3	Performs complex operations with fractional applied to a context		
	3	Locate decimal numbers on the real line and converts decimal values to fractions		
intervals	2	Recognize the conventions used in the representation of intervals	71%	77%
	3	Operations with intervals (Union)		
	3	Operations with intervals (Intersection)		
	3	Operations with intervals (Difference)		
Points and Regions	3	Locate points in the Cartesian plane	94%	77%
	2	Distinguish between quadrants of a Cartesian plane		
	4	Operates between points on a Cartesian plane		
Average Rating %			71,89%	77,51%
Average Rating 0-5			3,59	3,88

Figure 9. Control Group's Results

The results of the first test show that students in the control group have a good level of understanding of the topics evaluated. According to the results of the second test, there was increase in the average grade, which went from 3.59 (on a 0 to 5 scale) to 3.88. This can be interpreted as an improvement in the level of understanding of the students of the topics evaluated in the tests.

It is important to say that this group decreased their results in the last part of the second test, this could be because the questions varied between both tests, for example, in the first test the students had to calculate the distance between two points and in the second test they have to calculate slope of a line segment, despite that this questions are part of the same section, they could have different difficulty level for the students.

On the first test of the subject of points and regions they obtained a 94% yield, while in the second was 77%, this can be explained by the fact that the observation period the students did not entered to the Software Tool, as well as in regular classes the professor did not carried out reinforced understanding activities of these concepts.

B. Analysis of the Results Achieved in the Experimental Group

Figure 10 shows the results in the two tests carried out in the experimental group. The table shows the topic evaluated, the level of difficulty in a scale from 1 to 5, the specific competence, and the average score that students achieved in the topic. The results of the first test show that the students in the experimental group have a lower initial level of understanding than students in the control group (3.28 compared to 3.59 on a 0 to 5 scale).

Topic	Difficulty level (1-5)	Competences	Experimental Group 25 Students Test 1	Experimental Group 25 Students Test 2
Numeric al sets	1	Locate decimal numbers on the real line and converts decimal values to fractions	61%	69%
	2	Solve simple problems with a fraction applied to a context		
	3	Performs complex operations with fractional applied to a context		
	3	Locate decimal numbers on the real line and converts decimal values to fractions		
intervals	2	Recognize the conventions used in the representation of intervals	65%	78%
	3	Operations with intervals (Union)		
	3	Operations with intervals (Intersection)		
	3	Operations with intervals (Difference)		
Points and Regions	3	Locate points in the Cartesian plane	72%	81%
	2	Distinguish between quadrants of a Cartesian plane		
	4	Operates between points on a Cartesian plane		
Average Rating %			65,54%	76,07%
Average Rating 0-5			3,28%	3,80

Figure 10. Experimental Group's Results

According to the results of the second test, there was increase in the average grade, which went from 3.28 (on a 0 to 5 scale) to 3.80. This can be interpreted as an improvement in the level of understanding of the students of the topics evaluated in the tests.

C. Percentage Improvement from Test 1 to Test 2

Figures 11 and 12 show how much students in the control and the experimental groups, respectively, improved from the first test to the second. The net improvement was 5.6% for the control group whilst the experimental group improved by 10.5%. It is

important to point out that both groups had traditional classes with their respective professors.

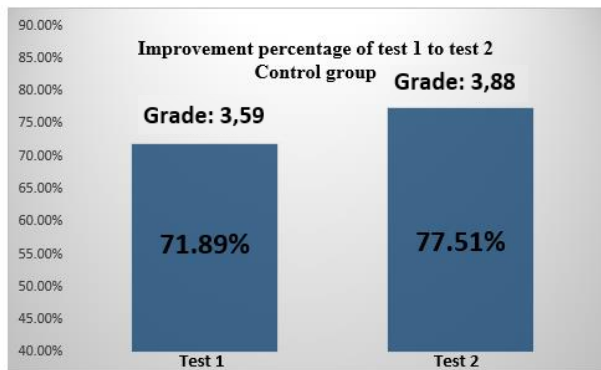


Figure 11. Improvement from test 1 to test 2 for the Control Group (in %)

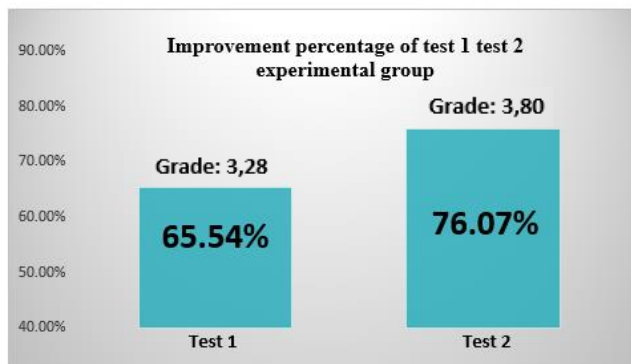


Figure 12. Improvement from test 1 to test 2 for the Experimental Group (in %)

This analysis highlights that, although the difference is not significant between the average score in the second test for both groups, the experimental group achieved the highest percentage change (10.5% vs. 5.6%) of both groups from test 1 to test 2. A priori, the increment could be attributed to the use of the platform by students in the experimental group, but further research and new tests must be completed to support this hypothesis.

V. CONCLUSIONS AND FUTURE WORK

- The Software Tool achieved the integration of different solutions in an ecosystem dedicated to learn Calculus. This allowed, along with practice processes, to complement the learning process with videos, digital resources, evaluations, and learning analytics.

- The architecture designed can be replicated for other courses that require leveling out the learning of basic concepts such as concepts to improve processes of reading and writing.
- Integrating the Software Tool with other solutions that can be adapted to the students' learning styles can enrich it.
- The online Pre-Calculus program has had very good results during its course. Today it has 11 modules that cover: numerical sets, points in a straight line and intervals, operations with intervals, points in a plane, exponentiation, factorization, algebraic and arithmetic fractions, radicals, rationalization, trigonometry, problem solution, straight lines, and circumferences. This allows students to strengthen their learning process.
- To stimulate active participation from students, it is important to offer stimuli or incentives to them. For example, awarding bonus points to students that affect the grade of the first midterm exam of the course.
- The Software Tool proved to be a resource that facilitates the leveling out in the learning of basic Calculus and mathematical concepts. After this study, the University institutionalized in 2015 the use of this tool with all freshmen.
- In the analysis of results obtained in the different tests, we observed that students have frequent difficulties with topics such as numerical sets and intervals when they first start their undergraduate program. More specifically in competencies such as locating decimal numbers or fractions in a real straight line, converting decimal values into fractions, and completing operations with intervals. The good news is that their level of understanding of the subject increases exponentially once it is reviewed in the Software Tool.

- From 2014 to 2015 more than 2000 students were registered in the platform for the leveling out previous to the Calculus I course.
- Since 2015, a new experimental pilot is being completed with middle school students of different public schools in the city of Itagüí, Colombia with the objective of measuring the effectiveness of the tool and converting it into a MOOC.

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Construct Peer Assessment Instrument Using Existing E-learning Tools

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Abstract—Work in Progress: This paper reports the study on how peer review instruments based on existing e-learning tools can affect the quality of peer review process and how this type of tools can benefit the reviewers. The study starts from a pilot study on constructing peer assessment instruments for an assignment in a Master course by using PeerMark and Moodle workshop. A comparison of these two tools has been given. Moodle workshop is more robotic, provide more options, but not very easy to use. Turnitin PeerMark is easy to use, more effective, but provides less options. Moodle workshop seems to have the potentials to facilitate guidance to the reviewers, feedback to the reviewers, peer interaction and knowledge construction better. A combination of the features of both tools should make a better peer assessment tool. Further investigation is required on how these tools can be improved or combined to organize a complex peer assessment marking criteria properly and to benefit the reviewers better. A plan for the next step research has been given, including further evaluation, software implementation and formal evaluation framework development.

Keywords—Work in Progress; peer assessment; e-learning; Turnitin PeerMark; peer review; peer review tools; Moodle Workshop.

I. INTRODUCTION

Peer assessment has been widely used in tertiary education due to that it facilitates student involvement, student engagement and student centered learning, thus enhance student learning, and it also allows students practice their professional skills and social skills [1].

A latest research [2] indicated that the prior research on the peer assessment has primarily examined the learning benefits that result from the receipt of peer reviews, with few studies specifically exploring the merits of producing feedback reviews or the learning mechanisms. Most of the researches are focusing on the peer review process, rather than the quality and the necessary functions of a peer assessment instrument.

In order to support peer assessment in large classes, computer support can be regarded as a necessity to manage the whole process of assignment submission and grading [3]. To make the peer review process efficient and effective, a number of commercial or free software have

been used. These include Turnitin PeerMark and Moodle Workshop and Moodle Forum.

PeerMark is a built-in peer review tool of Turnitin which is a web based e-learning system particularly good at plagiarism-prevention. Moodle is a free, open-source PHP web application for producing modular internet-based courses. It is a popular e-learning system. Moodle workshop is the peer assessment module of Moodle.

Turnitin has been widely used and the experiences of using Turnitin PeerMark have been reported in research publications [2, 3 and 4]. However the marking criteria used in these practices are usually simple and short in the range of 4 to 10 items, it's hard to find a report on using PeerMark for complex marking criteria. This raises questions, if a software tool like Turnitin PeerMark or Moodle workshop is suitable for a peer review assessment with complex marking criteria? What are the necessary features of these software tools? The focus of the peer assessment is usually on the collaborative learning and the opportunity to practice professional skills and social skills. The effectiveness of the peer assessment tool was not given sufficient attention.

This research takes the two widely used peer assessment tools, Turnitin PeerMark and Moodle workshop, as the starting point to explore how the peer review instruments can affect the quality of the peer review process and how this type of tools can benefit the reviewers.

There are many aspects related to the quality of the peer review process. According to reference [5], peer evaluation reliability and validity are concerned by both of the instructor and the students, in particularly, the students have very low confidence in their peers. One of the reasons is that peer reviewers are novices in their disciplines, to overcome this drawback, various functions such as calculating individual reviewer's review accuracy and authors' back-evaluations about the helpfulness of reviewer feedback would be helpful [6]. If peer review instruments can facilitate guidance to the reviewers and facilitate feedback to the reviewers, it would improve the reviewers' skills and thus improve the quality of the peer assessment.

Vague feedback and misinterpretation of writers' intentions on the reviewers' part have been found to be two major reasons why most of the reviewers' comments are not effective. Four characteristics of comments were identified to facilitate student's revisions: clarifying writers' intentions, identifying problems, explaining the nature of problems, and making specific suggestions [7]. This also confirms that if guidelines like the four characteristics can be implemented in the peer review instrument, it would improve the quality of the peer review and benefit the reviewers.

A web based peer review system can play multiple roles: an information distribution channel and management center; a forum for peer interaction and knowledge construction; and storage for knowledge construction procedures [8]. The most effective individual appears to be the strategic adapter who effectively constructs a project, adjusts to peers' comments, and serves as a critical reviewer as well. This suggests that if a peer review system can facilitate peer interaction and knowledge construction, it would make the participants more effective.

This paper reports the study on how peer review instruments based on existing e-learning tools can affect the quality of peer review process and how this type of tools can benefit the reviewers. The study starts from a pilot study on constructing peer assessment instruments for a summative assignment in one of our Master courses by using PeerMark and Moodle workshop. The tools are then compared and discussed based on the experiments.

In addition to the general factors such as fairness, effectiveness and reliability, the discussion also includes the following issues related to the benefits of the reviewers for a peer assessment tool:

- Guidance to the reviewers.
- Feedback to the reviewers.
- Peer interaction.
- Knowledge construction.

The experiments from the pilot study provide better understanding of the features and capability of these peer assessment tools. To have a complete understanding on these tools, more experiments are required. It is expected to develop a formal evaluation framework for this type of e-learning peer assessment tools.

In the following sections, the pilot study is discussed first, and then a comparison of PeerMark and Moodle workshop is given, finally a summary.

II. THE PILOT STUDY

The pilot study includes the experiments on constructing peer assessment instruments for a Master course assignment by using PeerMark and Moodle workshop. The assignment is a study report on an existing web based system. Accumulative grading has been used in the marking criteria. The marking criteria consist of four categories: technique part (consists of 10 items),

architecture part (consists of 8 items), industry policies (consists of 6 items) and overview of the report (consists of 7 items). To facilitate guidance to the reviewer, five dimensions, **Description**, **Investigation**, **Analysis**, **Critique** and **Literature**, were defined for the items. These dimensions are electively linked to each item. Table I shows a simplified version of the marking criteria to demonstrate the pattern required when constructing the assessment instruments, where D=Description, I=Investigation, A=Analysis, C=Critique, L=Literature and M=Marks. A dimension is checked if it should be considered for that particular item.

Two experiments had been conducted on PeerMark: three students and each reviewed two assignments; four students and each reviewed two assignments.

For the review options, PeerMark supports anonymous review and non-anonymous review. For anonymous review, it allows single blind review and double blind review. Double blind review was used in the experiment for fairness. The condition for this option is no student name on the report. For the reviewer assigning, it supports system randomly distribution, teacher pairing students up and self-assessment. The students' reviews will be assessed by the teacher. The system randomly distribution was used in the two experiments. In the experiment for three students, each student was allocated two papers, and each paper received two reviews, it was fair and balanced. In the experiment for four students, each student still was allocated two papers, so the student work load was balanced; however, one paper only received one review and another paper received three reviews, this was not fair. This should be adjusted by the teacher pairing students up option.

As a result, the proposed marking criteria in Table I can be implemented in the PeerMark and the assignment can be marked. However, it seems difficult to create categories in the marking criteria, so it could not be organized properly. And also, there seems no space to attach the selected dimensions to each item. This leaves less guidance to the reviewers.

TABLE I. ASSESSMENT CRITERIA PATTERN

Categories	Items	Dimensions					M
		D	I	A	C	L	
Technique	Purpose	X		X			2
	History	X	X	X			2
	Domain	X	X				2
	Popularity	X	X	X	X	X	3
Architecture	Design	X	X	X	X	X	3
	Database	X	X	X			3
	Roles	X	X	X		X	2
	Software	X	X	X		X	2
Industry	Brief	X					5
	Security	X	X	X	X	X	5
Overview	Consistency						4
	Presentation						4

The similar experiments had been done on Moodle workshop, where five students had been involved. A few things need to be highlighted for these experiments.

For the reviewer assigning, scheduled random allocation, manual controlled random allocation and manual allocation are supported. The manual controlled random allocation was used in the experiments. Two options are supported by Moodle in this case: the first option is two reviewer per submission; the second option is two reviews per reviewer. Both options were used in the experiments.

For the first option, two reviewers were allocated to each submission, as a result, each of the five students received two reviews. This was fair and balanced. For the second option, two reviews were allocated to each reviewer, this was done twice. For the first time, each submission received two reviewers and it was fair and balanced. For the second time, one submission received one reviewer, one submission received three reviewers, and all the other submissions received two reviewers. This was easily adjusted by switching to the manual allocation model.

Moodle work shop provides four grading strategies: **Rubric**, **Accumulative grading**, **Comments** and **Number of errors**. Among these, **Rubric** matches the marking criteria pattern in Table I most closely. It allows categorizing the items and allows attachment of the selected dimensions for each item. However, it does not allow partial credit for each item, only allows overall comments and not for each item. **Accumulative grading** allows partial credit and item comments, but it does not allow categorizing the items. **Number of errors** provides YES/NO options and comments for each item. This could be used to provide feedback to the reviewers.

Both PeerMark and Moodle workshop can implement the marking criteria pattern in Table I, however, none of them can implement it perfectly. Moodle workshop seems to facilitate the guidance and feedback to the reviewers better.

III. COMPARING TURNITIN PEERMARK AND MOODLE

To gain a deeper understanding, Turnitin PeerMark and Moodle workshop are compared in the following aspects:

- **Comment** – PeerMark supports a comment tool which allows students comment on the paper they are reviewing. A comment is equivalent to the notes that a student may write in the margins of a paper. A comment might be: "I like this idea. Think you could develop it further in this paragraph." A comment may be up to one thousand characters in length. PeerMark also supports text boxes for entering comments. On the other hand, Moodle workshop only supports text boxes.
- **Configuration workflow** – When create a new peer assessment, both PeerMark and Moodle workshop support a wizard style configuration workflow which is easy to flow. In Moodle workshop, it seems easy to

switch backward and forward between the workflow phases. This may provide more opportunities for the reviewers to revise their comments according to the feedbacks of their peers and the instructor, thus facilitate peer interaction and knowledge construction.

- **Marking criteria** – PeerMark support marking criteria library which allows marking criteria reuse; Moodle workshop supports assessment form which allows editing the marking criteria for one assessment. Both PeerMark and Moodle workshop are not perfect for complex marking criteria. When the marking criteria are getting longer, they cannot be organized properly. However, Moodle workshop provides four grading strategies, one of them allows categorizing the items, these make Moodle workshop to facilitate marking items organization, the guidance and feedback to the reviewers better.
- **Grading schema** – In Moodle work shop, the grade for one assessment consists of two portions: grade for submission, this sets the maximum grade a student can attain from a teacher for a given submission; grade for assessment, sets the maximum grade a student can receive for assessing other students' work. The grade can be calculated automatically. In PeerMark, some manual processes seem to be involved. This definitely facilitates feedback to the reviewers.
- **Pre-event learning** – Moodle workshop allows a teacher upload an example assessment for practice, this certainly facilitates knowledge construction; PeerMark seems does not support this.
- **Review allocation** – Both PeerMark and Moodle workshop support random allocation, manual allocation and self-assessment. Moodle workshop provided two options for random allocation, this could improve the fairness of the workload.
- **User Interface (UI)** – PeerMark UI is simple and easy to use. Moodle workshop provides more options and not easy to follow. How it does provide many instructions to help the users.

From the above, we can see that the two tools share common features such as configuration workflow, review allocation and feedback to the reviewer. The two tools share shortcomings as well, such as marking criteria management. Turnitin PeerMark owns some effective features such as the comment tool and the criteria library. Moodle workshop owns some robotic feature such as grade intelligent calculation. Moodle works seems to have the potentials to facilitate guidance to the reviewers, feedback to the reviewers, peer interaction and knowledge construction better. A combination of the features of both tools should make a better peer assessment tool.

IV. SUMMARY AND FUTURE WORK

In summary, Moodle workshop is more robotic, provide more options, but not very easy to use. Turnitin PeerMark is easy to use, more effective, but provides less options.

Moodle works seems to have the potentials to facilitate guidance to the reviewers, feedback to the reviewers, peer interaction and knowledge construction better. A combination of the features of both tools should make a better peer assessment tool. Further investigation is required on how these tools can be improved or combined to organize a complex peer assessment marking criteria properly and to benefit the reviewers better.

Further experiments and studies are required to get deeper understanding of these tools.

The plan for next step research includes:

- Split the students in the Master course used for experiments into two groups: one group will use Turnitin PeerMark, another will use Moodle workshop for peer review. Then we will evaluate the fairness, effectiveness, reliability and the benefits to the reviewers for both cases. Students' opinion regarding these aspects will be solicited.
- Repeat the above process for another course by making possible improvements identified from the first process.
- Consider other existing e-learning peer assessment tools.
- Identify the useful features for all the tools studied. Identify the features should be improved for all the tools. Identify the necessary features should be added to these tools. Implement an improved peer assessment tool on Moodle.
- Develop a formal evaluation framework for e-learning peer assessment tools.

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Use of Operational Amplifiers and Discrete Off-the-Shelf Components to Teach Fuzzy Logic Controller Concepts

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Abstract— This paper presents the realization of Fuzzy Logic Controller concepts using operational amplifiers as a tool to teach students about design and modeling. Design of a FLC is performed because this path provides a good background for the student to experience a complete process approach that goes from verbal description of a problem throughout the final practical implementation, passing through the process of mathematical modeling and the understanding of what a realization of a function means. All the basic blocks consist of operational amplifier circuits that are taught in a first circuit course, just pushing the application a little beyond but still within the reach of the already acquired background.

Keywords—practical implementation; fuzzy logic; operational amplifiers; membership function; teaching circuits and control.

I. INTRODUCTION

In educational technology related areas, students are motivated with the validation of theories with practical implementations [1], because then the functionality of what is learned in the classroom takes real form in a tangible form [2].

In our department, in addition to regular classes, mentoring students for later work in design or research is done regularly on this context, teaching skills must include hands on experience that could help them integrate knowledge from different courses. This paper offers a tool that has been used by the authors to help students understand some concepts and relationship that many don't see until senior courses, or even after graduating.

In particular, students find it difficult to associate mathematical functions and algorithms to physical realizations. For many, the closest they get to this relationship is using the computer to realize mathematical algorithms. But very few consider this an experience of realizing a mathematical algorithm with an electronic physical system.

Starting with an idea previously developed with similar purposes [3], this work presents the construction of a Fuzzy Logic Controller (FLC) with simpler circuits so practically a first course in circuits with additional skills learned in precalculus, and enhanced with some help, is enough to provide students valuable help to overcome the above mentioned mental barrier. Although FLC are usually realized

with IC's [4] the implementation presented here uses discrete Operational Amplifiers (OA) and resistors. Students also learn the importance of interpreting results with this experience, since the circuits used are the same that appear in courses for quite different applications.

II. WHY A FUZZY LOGIC CONTROLLER?

FLC provides a tool to develop skills covering different “abstract” stages in the physical realization of a project. In short, the proposed experience has provided students with a complete experience as an example of the chain:

Language Description → Mathematical Model → Physical Realization

The process goes through the following stages:

- It starts with a set of rules provided by an expert using “plain” human language [4, 5].
- These rules are then modeled using Fuzzy methods.
- Students can go through the mathematical work of validating the model; software tools such as MATLAB® can be used at this stage to facilitate these tasks.
- Students “realize” physically with circuits the mathematical functions needed.
- Validation follows through simulation and experimental activities, measuring responses for example in oscilloscopes.
- The system is finally assembled and validated connecting the different blocks.

Once the FLC has been built, it can be further used in different applications.

III. FUNDAMENTAL CONCEPTS OF FUZZY LOGIC

A. FL Principles

The basic principles of FL can be introduced early to students and are simple enough to use almost immediately. For

this reason, it can be fast used by undergraduates in projects, and is also easy to understand the applications.

FL is in short a mathematical model for human reasoning where expressions are not totally true nor completely false, and applies logic rules such as modus ponens or modus tollens using such expressions. Examples abound to illustrate how humans make decisions with this type of reasoning.

Also, FL is used to model systems which are difficult to deal with mathematically, some of which do not have mathematical model available [5].

To model the human reasoning, FL utilizes definitions such as membership functions (MF) to provide a “truth value” to expressions, and mathematical operations such as minimum, maximum, weighted sum and others, to deal with the reasoning rules [5, 6].

B. Typical Membership Functions (MF) Used in FL

Fig. 1 shows common membership functions: “S”, “Z”, “Trapezoidal” and “Triangular”. Using only these functions it is possible to model almost all problems.

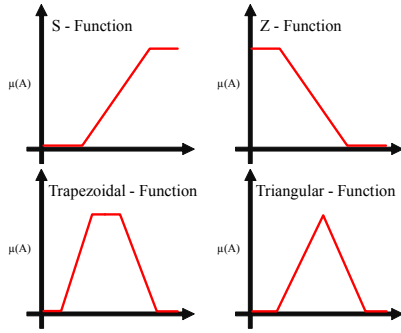


Fig. 1. Membership Function Types

The OA is the most popular electronic low cost device available and used in applications. The fundamentals are included in basic circuit texts [7] and OA's are included in early laboratory courses. Thus, it is a candidate to use for different projects and applications in early courses.

C. Membership Functions

Looking at Fig. 1, we should focus on OA circuits that allow a) positive or negative slope, and b) Saturation. Fig. 2 shows a circuit which happens to be the backbone of the configurations used to introduce OA to students: the inverting and non-inverting amplifiers [7]. The first one is obtained by connecting V_n to ground, while the second one grounding V_m .

Here, we use it to generate the membership functions by controlling the slope and position of the function, as well as pushing the OA into saturation region.

The slope sign and position depend on which voltage V_m or V_n is used as *INPUT* to receive data, and which one as *OFFSET* to position the curve. The slope, measured in the Output-Input plane, is obtained with the OA working in linear operation, that is, when V_{out} falls in the range $(0, +V_s)$.

Otherwise, the OA is saturated, yielding the desired slope in the “S” and “Z” functions.

Unlike many basic circuits, where dual power supply is used, we work here connecting the $-V_s$ terminal to ground, i.e. $-V_s = 0V$. This has the additional advantage of using only one power supply.

D. Analysis of the Circuit

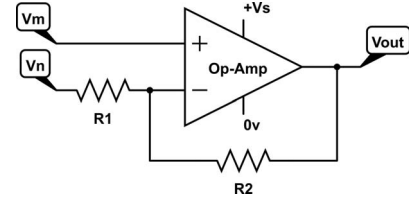


Fig. 2. Non-Inverting Amplifier Mode Fundamental block

If we define $K = R2/R1$ and assume that the OA would never saturate, then applying the usual analysis for ideal OA [7], we arrive at

$$V_{out} = (K + 1)V_m - KV_n \quad (1)$$

The result (1), however, is valid if and only if the condition $0 \leq V_{out} \leq +V_s$ is fulfilled. We use these considerations for generating the slope in “S” and “Z” functions. Outside this range we go to the saturation regions of the functions.

E. Generating the “S” Function

From Fig. 1, the “S” function requires a positive slope. From (1), we see that V_m should be used as input, and V_n used for offset. Taking into consideration the conditions for V_{out} , we can obtain (2).

$$V_{out} = \begin{cases} 0 & \text{if } V_{in} \leq V_a \\ (1 + K)V_{in} - KV_{offset} & \text{if } V_a \leq V_{in} \leq V_b \\ +V_s & \text{if } V_{in} \geq V_b \end{cases} \quad (2)$$

Here, $V_a = K V_{offset}/(K+1)$ and $V_b = V_a + V_s/(K+1)$.

Fig. 3 shows the behavior of the output voltage with respect to the input voltage for different changes in slope described by the dotted lines.

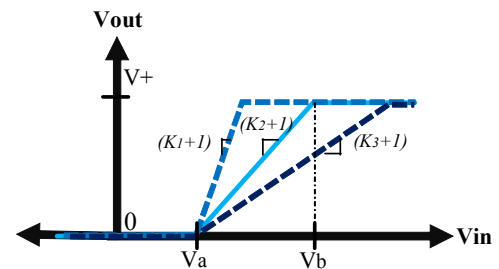


Fig. 3. Generation of “S” Function ($K_1 > K_2 > K_3$)

F. Generation of “Z” Function

For the “Z” function, we exchange the input and offset roles. That is, now V_m is used as offset and V_n as input. In the linear region, equation (3) applies.

$$V_{out} = V_{offset}(1 + K) - V_{in}(K) \quad (3)$$

The condition $0 \leq V_{out} \leq +V_s$ determines the V_{in} constraints. Fig. 4. Shows the results for different values of K .

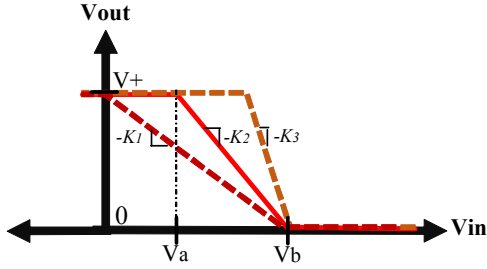


Fig. 4. Response for “Z” Function ($-K_1 < -K_2 < -K_3$)

G. Generating the Trapezoidal Function

We obtain a “Trapezoidal” or “Triangular” MF by subtracting “S” functions as illustrated in Fig. 6, the subtractor of Fig. 7. An analysis of this circuit yields (4). The block symbol in Fig. 7 is introduced for easier explanation later.

$$V_{out} = \begin{cases} 0 & \text{if } (V_2 - V_1) \leq 0 \\ \frac{R_b}{R_a}(V_2 - V_1) & \text{if } 0 \leq \frac{R_b}{R_a}(V_2 - V_1) \leq +V_s \\ +V_s & \text{if otherwise} \end{cases} \quad (4)$$

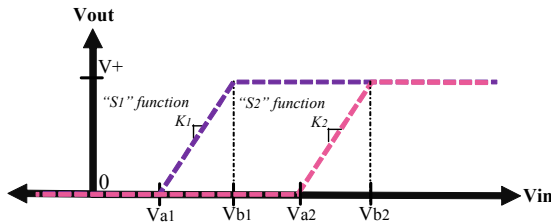


Fig. 5. Two “S” Functions with Different Slope and Offset

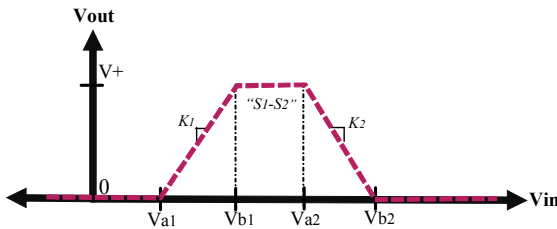


Fig. 6. “Trapezoidal” or “Triangular” MF Subtracting two “S” Functions

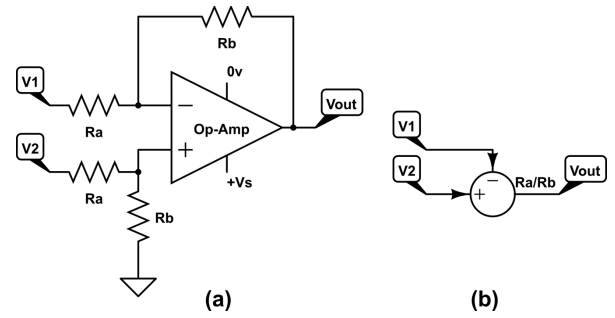


Fig. 7. Subtractor (a) Circuit; (b) Functional Block Representation

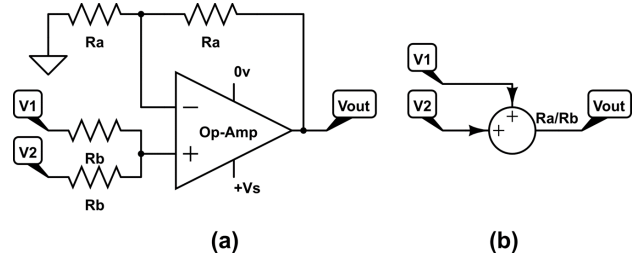


Fig. 8. Adder (a) Circuit; (b) Functional Block Representation

H. Minimum and Maximum functions

For classical logic, the operations of disjunction (*OR*), conjunction (*AND*) and negation (*NOT*) on propositions, are defined as the union, the intersection and complement [8]. Popular definitions in FL are (5).

$$\begin{aligned} X \text{ AND } Y &= \min(X, Y) \\ X \text{ OR } Y &= \max(X, Y) \\ \text{NOT } X &= 1 - X \end{aligned} \quad (5)$$

Here, “1” is physically understood as the saturation voltage. The minimum operation is realized combining the subtractor of Fig. 7 together with an adder of Fig. 8. The block diagram for a minimum realization is shown in Fig. 9.

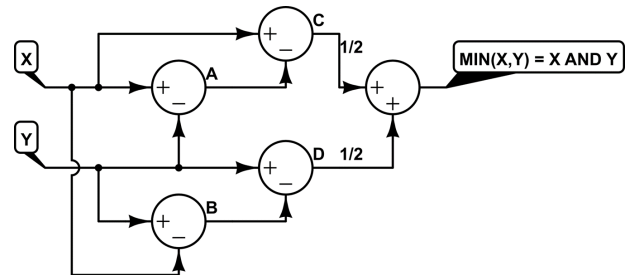


Fig. 9. Realization for a Minimum Function

Here, if $X \geq Y$ then $A = (X - Y)$ and $C = Y/2$. Also, Because of (4), $B = 0$, so $D = Y/2$. These are added, and the output is Y . Similar reasoning applies if $Y \geq X$, producing X as output.

Adders and subtractors can also be used to produce the maximum function. One last stage is defuzzification, which can be realized using a weighted sum or the maximum circuit.

I. Experimental Verifications

The above theoretical analyses were first validated through simulations. Fig. 10 shows curves obtained at this stage.

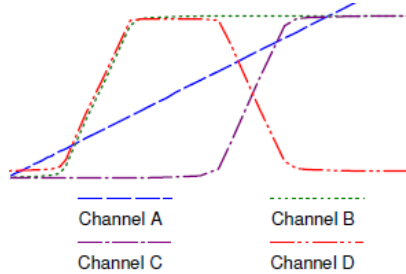


Fig. 10. Responses on the Simulator Oscilloscope

Having verified that simulation performed as expected, electronic circuits were built so results could be verified experimentally. Fig. 11 shows the oscilloscope printout of membership “Z” and “Trapezoidal” functions.

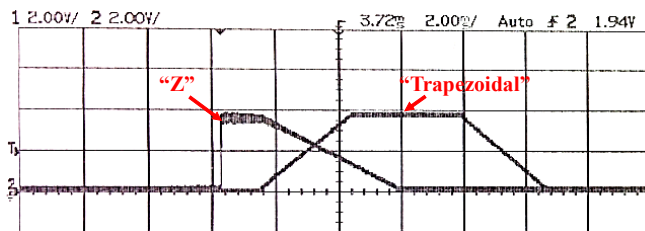


Fig. 11. Printout with Inputs MF for a Ramp Function Entry

Fig. 12, on the other hand shows the minimum output response after the two memberships of Fig. 11 are used as inputs.

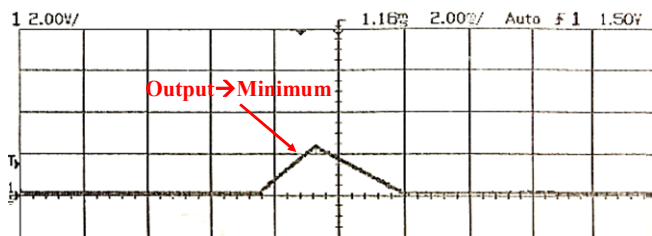


Fig. 12. Printout with Minimum Rule Response

IV. FL SYSTEM SIMULATION AND CONSTRUCTION

To culminate the process, we need to use the designed blocks setting up a FLC. With this in mind, we start by the mathematical description of a system. MATLAB® Fuzzy Logic Tool provides us with a user friendly package to do this [9]. Fig. 13 shows the first screenshot to configure the system consisting of two inputs and one output. The student did the complete mathematical analysis and hardware simulation before proceeding to construct the system, which worked as expected.

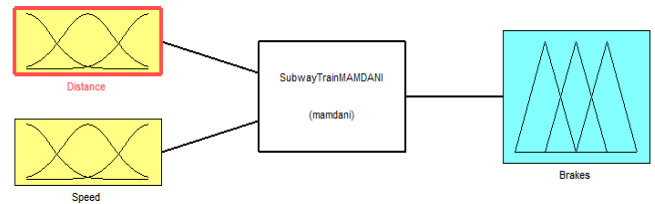


Fig. 13. FL System with Subway Train MATLAB® Example

V. CONCLUSIONS AND WORK EXTENSIONS

Although it may be argued that building nowadays a fuzzy system with operational amplifiers is not convenient, there are many practical consequences of this exercise. Among them, we can mention

- Construction as a proof of concept for analog designed systems. Do not forget that analog offers advantages in many practical situations over digital realizations, or else that it can be used as a subsystem in a mixed signal system.
- Help in learning FL Concepts and the electronics associated to it.

On the other hand, this experience has provided an excellent tool to introduce EE students at early stages to the process of system design through a practical hands-on exercise where the complete cycle:

Language Description → Mathematical Model → Physical Realization

For this experiment, only first circuit course knowledge using operational amplifiers is needed. Furthermore, it provides student with the unique experience of looking at one circuit from different points of view. This is essential for a good engineering practice, where similar, or even the same, physical systems are applied to very different fields. All depends on practical interpretation.

This work needs to be extended with a full application to a control systems problem. This is left for future work.

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Using Audio Amplifier Distortion Characteristics as a Pedagogical Tool to Explain Signal Processing Theory

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Abstract—This paper will describe how audio amplifiers specifications can be used as a pedagogical tool to help explain distortion concepts in signal processing theory. Audio entertainment systems are an ideal and practical vehicle for this subject since these are ubiquitous among students, and audio quality or lack thereof is readily perceived. We will consider various distortion types including amplitude, phase, and nonlinear. In the nonlinear distortion category we present harmonic, and intermodulation. Also discussed are distortions due to limits of dynamic range, and quantization errors. We then present how distortion concepts can be integrated into a signals and systems course.

Keywords—distortion; fidelity; signal processing; audio engineering

I. INTRODUCTION

The topic of signals and systems is a major component of electrical engineering (EE) curricula. However, this area tends to be mathematical, and thus for some students, may be perceived as being somewhat abstract as compared to other EE topics. Many EEs ask how the content in their signal processing course relates to what is encountered in their everyday world – which often consists of devices such as audio entertainment systems. An important segment of a signal processing course is system distortion – specifically, to what degree is the output a facsimile of the input. These distortion types include, amplitude, phase and nonlinear. While the standard signal processing course covers theory of distortion, many undergraduate electrical engineering students often cannot relate this theory to real world phenomena. For example, an electrical engineer should be able to understand and articulate why a CD player, even though quantization noise is added during the recording process, is inherently superior to reproducing a concert as compared to analog magnetic (cassette) tape.

II. SIGNAL DISTORTION

A. Distortionless Systems

The assumed goal for an audio amplifier is that it accurately replicates the original input*. In other words, it has *high fidelity* or is *distortionless*. More formally a *distortionless system* is where the output is a scaled and delayed version of the input. This is expressed as $y(t) = Kx(t - t_d)$ with $x(t)$ and $y(t)$ the input and output, respectively, K is a constant gain factor, and t_d is a constant time delay. The system function would therefore be $H(j\omega) = Ke^{-j\omega t_d}$, where ωt_d is the system's phase term. Because K is constant, we say the system has a *flat* response over all frequencies. The types of distortion typically encountered are amplitude, phase, and nonlinear. System distortion will affect the shape of the output signal; in addition, nonlinearity can also add artifacts to the output and/or affect the relative amplitudes of the various input components.

B. Amplitude Distortion

Amplitude distortion occurs when the K term varies with frequency. The degree of amplitude distortion is often called *magnitude response*. Thus a high quality system will have a “flat response.” For example, it is desirable for an audio amplifier to have a response that is constant from 20 Hz to 20 kHz, the range of the human ear. In practice, flat means the response can vary as much as 3 dB. An example of amplitude distortion would be the telephone system where the frequency range is 300 to 3000 Hz; adequate for voice, but not music. An extreme example is a system where the input is a square wave, “rich” in harmonics, and the output is a single sinusoid. System bandwidth is a measure of amplitude distortion.

C. Phase or delay distortion

Phase or delay distortion occurs when the phase term, ωt_d is not a linear function of frequency. However, most human ears, with the exception of a musician, or the mastering engineer, are relatively insensitive to phase distortion. Therefore, phase distortion is usually not of significant concern in music systems.

* To be sure, some desire a system where distortion and/or other artifacts are intentionally added into the output. The vacuum tube amplifier is one example where the unintended distortion is pleasant to the ear.

We present a brief example of phase distortion. Consider a system with flat frequency response and linear phase with an input of $x(t) = 10 \cos \frac{\pi}{2}(t-2) + 2 \cos \frac{\pi}{6}(t-2)$ and transfer function of $H(j\omega) = 5e^{-j3\omega}$, yields an output of $y(t) = 50 \cos \frac{\pi}{2}(t-5) + 10 \cos \frac{\pi}{6}(t-5)$. Note the two components have equal time delays and thus meets our non-distortion criteria. The same input to a system with nonlinear phase where $H(j\omega) = 5e^{-j\omega^2}$, yields $y(t) = 50 \cos \frac{\pi}{2}(t-5.61) + 10 \cos \frac{\pi}{6}(t-1.32)$.

Note there is no amplitude distortion, but the uneven relative time delays indicate phase distortion. An example of a system whose input is a square wave and whose output response has minimal amplitude distortion, but phase distortion is shown in Fig. 1. References [1]-[4] contain additional information on amplitude and phase distortion.

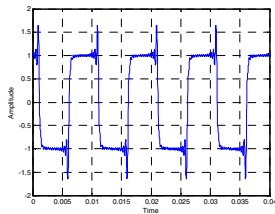


Fig. 1. Output waveform from a system with negligible amplitude distortion, but nonlinear phase distortion. The system's input is a square wave.

D. Nonlinear distortion

A *linear* system is one where proportional changes in the input result in the same proportional changes in the output. Consider the classic operational amplifier circuit where the voltage gain is $A_v = 10$, and power supply $V_{ss} = \pm 12$ V. The circuit will operate linearly if the input voltage, $|v_{in}| \leq 1.2$ volts, otherwise the output flattops to the power supply rails and hence the amplifier is no longer linear. In fact, when the input is large enough such that the amplifier exceeds its linear dynamic range; it becomes *overloaded* causing the output to have additional frequency components or artifacts. Thus the system is *nonlinear* and thus exhibits nonlinear distortion. Not only can a nonlinear system cause these spurious outputs, but in the case of multiple inputs, the weaker input may be drowned out by the stronger one. As we will see later, the range of input magnitude such that the amplifier does not overload is referred to as *dynamic range*.

Nonlinear distortion can be modeled in the following manner: $y(t) = a_1x(t) + a_2x^2(t) + a_3x^3(t) + \dots$ [1] where one or more coefficients are significant relative to a_1 . This nonlinear system may produce spurious output artifacts. Harmonic and

intermodulation are two types of nonlinear distortion and are described below.

Harmonic distortion is where a single tone sinusoidal input generates harmonics. Consider a system with $y(t) = x(t) + 0.1x^2(t)$ and input $x(t) = \cos 2\pi f_m t$. The resulting output is $y(t) = \cos 2\pi f_m t + 0.05 + 0.05 \cos 4\pi f_m t$. Neglecting the DC term, the output spectral magnitude, $|Y(f)|$, is shown in Fig. 2. Note the spurious harmonic at $2f_m$.

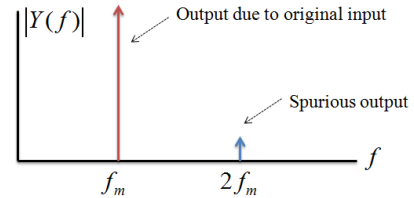


Fig. 2. Harmonic distortion example for a system with a single tone input.

Intermodulation distortion is the result when the nonlinear elements in the system cause the multiplication or modulation of the input components to generate additional, but spurious output terms. Recall that the product of two cosines results in two new cosine functions whose angles are the sum and difference of the original functions. Consider the above nonlinear system, except that instead of a single input, we have two inputs at different frequencies. If the input were $x(t) = \cos 2\pi f_1 t + \cos 2\pi f_2 t$, the output becomes $y(t) = (\cos 2\pi f_1 t + \cos 2\pi f_2 t) + 0.1(\cos 2\pi f_1 t + \cos 2\pi f_2 t)^2$. If we carry out the math, we observe four additional and spurious sinusoidal outputs at frequencies $2f_1$, $2f_2$, $(f_1 + f_2)$, and $(f_1 - f_2)$. If $f_1 = 2$ kHz, and $f_2 = 5$ kHz, then in addition to an output of 2 and 5 kHz signals, the output would also yield tones at 4, 10, 7 and 3 kHz. This is illustrated in Fig. 3. Going beyond this simple example, imagine the level of intermodulation distortion if the input was music with its many harmonics. Initially it may appear that a level of 0.1 in the squared term of x doesn't seem significant, but 0.1 is only -20 db. The human ear can perceive sounds that are 30 dB down from the average signal level.

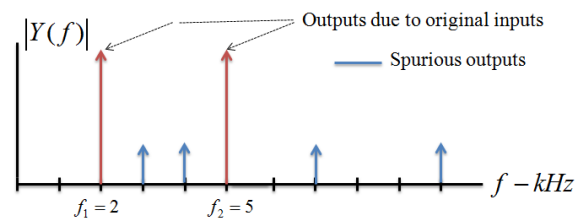


Fig. 3. Intermodulation distortion example with 2 tone input.

In published specifications of some commercial audio systems, all distortion products are lumped together and constitute *total harmonic distortion* (THD). THD can vary from -38 to -137 dB (0.013% to 0.000013%. Cabot [5]

provides an excellent discussion on the theory and measurement of these types of distortion.

E. Dynamic Range

Dynamic range is the difference (for dB) between the loudest and weakest sounds, an example being an orchestra's brass versus woodwind sections. Dynamic range is a limitation on a system's linearity. The ability of an audio amplifier to preserve the relative powers of these sections is a measure of its dynamic range. Dynamic range is defined as $DR_{db} = 20 \log_{10} (V_{max} / V_{min})$ with an orchestra having a DR of 120 dB. It should be noted that DR may be limited by the recording system. For example, a cassette tape's DR is 70 dB, whereas a CD ROM's DR is 96 dB [1]. Thus for digital plus analog systems, the DR is dictated by the number of quantization levels, the media, and the analog electronics. This is illustrated in Figure 4. In observing Figure 4, consider the following example. Let's say we are interested in recording an orchestra with the full range of instruments. In order to "fit" the orchestra's range of 120 dB inside the CD's 96 dB dynamic range we have to limit the amplitude of the brass section and/or slightly increase the amplitude of the woodwind section. Therefore, in systems where the recording and/or sound system has less dynamic range than the original input, we must employ some type of amplitude compression (e.g. logarithmic compressor) so the recorded sound will fit inside the amplitude limits. In another example, to tape record a live performance, we have to compress the 120 dB input so it will fit inside the tape's 70 dB range. Note that this amplitude compression introduces a different sort of nonlinear distortion whereby we sacrifice output signal shape fidelity in order to minimize overload and spurious output components. A manifestation of the increased dynamic range is in the transition from tape to CD players inside automobiles, where there is an increased tendency for users to adjust the sound volume.

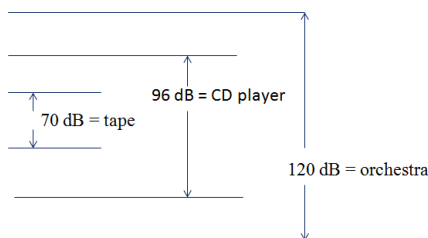


Fig. 4. Graph to illustrate dynamic ranges for various music sources.

F. Desirable distortion

To give the devil his due, we conclude this section with a brief commentary of vacuum tube amplifiers. The vacuum tube, like a transistor is an amplifying device. The vacuum tube inherently has a relatively wide dynamic range as compared to the bipolar transistor. When a tube amplifier is overdriven so the output is clipped, the clipping is less abrupt than its transistor counterpart, hence more pleasant to the ear (i.e. a softer manifestation of nonlinearity). However, since the 70s, the vacuum tube amplifier has been obsolete since with today's technology, a solid state amplifier will meet any realistic

fidelity specification. Power wise the tube amp is much less efficient than its solid state counterpart, and many tube amplifiers have some residual 60 Hz background hum. These and other practicalities, suggest there are no technical reasons to use vacuum tubes in audio systems. On the other hand, many audiophiles prefer the sound from vacuum tube amplifiers since they observe that the tube amplifier *introduces a degree of warmth to the listening experience*, and as previously stated, clipping with tube systems is less obnoxious than solid state systems. Finally, many believe the sound quality of the tube-speaker combination is superior to that of its transistor-speaker counterpart.

III. PEDAGOGY

The use of audio systems as a pedagogical tool to enhance learning in the signals and systems area began several years ago when an invited speaker at an IEEE student branch meeting made a presentation on audio amplifier quality. The talk, while mostly qualitative, piqued the students' interest in signals and system theory and gave them an appreciation that abstract signals and system theory can readily explain real world phenomenon. We initially incorporated audio amplifier specification examples into the lecture material of an existing signals and systems course. In the future, it is envisioned that new laboratory projects will be developed where students can audibly experience the various types of distortions as well as observe these on an oscilloscope and dynamic signal analyzer (DSA). Examples would include the effects of overdriving an amplifier, reducing the number of quantization levels when digitizing a signal, and observing and measuring the outputs of various audio amplifiers that have various degrees of total harmonic distortion. While we could offer a separate course on audio distortion, our intent is to integrate this topic into an existing signals and systems course.

Distortion and signal overload is extremely relevant to communications systems and thus was also incorporated into our communication systems course. For example, the *near-far problem* whereby the receiver front end is required to have wide dynamic range in order to be able to simultaneously capture and process both weak and strong signals; a design challenge in any receiver technology, but particularly in today's CDMA wireless phones where multiple signals are all at the same frequency.

A learning objective is that engineering students will better understand the specifications of an audio system and thus be able to make meaningful comparisons between competing systems and go beyond many of the existing electronics and signals and systems courses that assume linearity and primarily focus on maximizing bandwidth. Another objective is that by incorporating audio applications into the signals and systems courses, students are forced to confront the non-ideal behavior of real systems, and understand how this type of behavior affects the listening experience. In any case, audio systems present an interesting case study and thus are an alternative to the usual academic and theoretical black box systems encountered in the undergraduate signals and systems curriculum.

IV. CONCLUSIONS

This paper has presented a perspective on system response that goes beyond the traditional pedagogical undergraduate electrical engineering topics of amplitude distortion, step response, and even phase distortion. Using the audio amplifier example, we have introduced another set of system specifications that characterize system fidelity and

performance. We have also shown that nonlinear distortion affects response by either introducing new artifacts in the output, or because of dynamic range limitations requires the input signals fall within certain signal strengths so as prevent additional output artifacts from being introduced.

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A Mixed Pedagogical Method to Improve Teaching and Learning in Brazilian Computing Area Undergraduate Courses

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Abstract—In this paper, we present an innovative mixed pedagogical method to improve teaching and learning in undergraduate courses related to computer area. The method proposes learning multi-criteria assessments and pedagogical strategies, such as problem-based learning, that should be carried out during the activities. This research was performed in a three-year case study in courses undertaken at the Federal University of Ceará (UFC), Brazil. The main contribution of this work is the mixed pedagogical method that uses the combination of important pedagogical strategies, with promising results. There was observed an improvement in student results and professor evaluations in four of the five cases. In these four courses, researchers used the method with all requirements being met.

Keywords— *pedagogical practices, innovation, teaching undergraduate, professor's evaluation*

I. INTRODUCTION

Professors face difficulties related to teaching and learning activities results in Brazilian computing area undergraduate courses, such as low student motivation, difficulty to link the subjects to labor market, only theoretical focus, among others [1, 2]. These problems are still increasing, because there are difficulties when the students execute text-reading activities, and there is a low turnout of student presence in the classroom during the courses.

There are difficulties inherent to the pedagogical vision of being a professor and analysis of teaching and learning activities results in computing area undergraduate courses. It is important to know what professors that have been successful in the classroom use in terms of pedagogical practices, to mitigate these difficulties.

We proceeded with a survey and subsequently identified some of the difficulties faced by Brazilian professors when teaching in computing area undergraduate courses:

- Difficulties in motivating students in complementary courses when facing competition from other technical courses;
- Bad initial results that decrease the student motivation at the beginning of the courses;

- Difficulty encountered by students in linking the knowledge and skills acquired in courses with their future professional work;
- Theoretical traditional focus related to some courses in computer undergraduate;
- Deficient basic formation of some students in relation to the course requirements;
- Difficult relationships between professors and students.

These problems are increased with the difficulties of students when involved in text reading activities and the low turnout of student presence in the classroom during the courses.

We proceeded with an empirical observation and analysis of courses results in computing area undergraduate during the period 2007 to 2013. This was coupled with the researchers' experience as professors (undergraduate and postgraduate) in the computing and education areas. Our first research results were presented in [13].

In this work, we presented and evaluated from a student prospective view, our classroom practice. We evaluated five courses within two programs at the Federal University of Ceará (UFC), Brazil. The main objective was to experience a mixed innovative pedagogical method, trying to get better student learning results and minimize the presented difficulties when teaching undergraduate in courses within the computing area. We observed the reduction of disaffection in classes, improving the relationship between professor and students, and also the establishment of a link between the acquired knowledge of the course and the market. The planning activities were considered very well in the students' assessment. The students preferred the proposed practice in relation to traditional practices experienced by them so far in the courses. The multi-criteria evaluation was cited by students as being fairer and more motivating than just simply tests and theoretical work.

II. LITERATURE REVIEW AND RELATED WORKS

At a high conceptual level, this work deals with education evaluation and performance, and as such, it derives ideas from several other researchers working in pedagogical innovative practices to improve professor and student performance.

The efficiency of instructional strategies in the student learning has been presented by [3, 8], in the courses of science, engineering and mathematics.

The process of developing an instrument to assess a professor's teaching practice in Brazilian university education was shown in [16], where the work result analysis revealed the existence of important factors that influence professor performance, such as "teacher-student relationship" and "teaching practice". The presented instrument has proven to be a promising element to improve teaching quality in the classroom. Our method uses the professor's teaching practice evaluation by students as an instrument to improve teaching performance in a continual monitoring cycle.

The difficulties inherent to the pedagogical training vision of being a professor and analysis of teaching activities among others, were presented in [4], whereby the authors proceeded with a study evaluating Brazilian professors in the communication area. Thus, the key attributes and practices of accounting for professors that have been successful in the classroom, from the standpoint of students in Brazilian public and private universities, were presented in [5].

The school and classroom contexts with pedagogical innovations employing technology were successfully sustained as presented in Owston [14]. The author cited that the essential conditions for the sustainability of classroom innovation were professor and student support of the innovation, the perceived value of the innovation by professors, professor professional development, and principal approval.

There was a project-oriented framework proposal for engineering schools in [18], which combined pedagogical methods, such as: project-based learning, active pedagogy and traditional teaching paradigms. The authors cited that although comparisons between various pedagogical methods are difficult and sensitive, numerous internal signals confirm the validity of several aspects of their mixed pedagogical proposal.

To meet the needs of engineering graduates who can function comfortably in an increasingly distributed team context, which crosses country and cultural boundaries, the work shown in Daniels et al. [7] evaluated an Open Ended Group Project Framework (OEGP) as a pedagogical strategy, whereby using collaboration.

The feedback concerning the pedagogical practices of graduate teaching assistants was proposed in [6]. The evaluation tool called G-RATE allowed various stakeholders, such as: classroom observers, administrators, graduate teaching assistants, undergraduates, and students, to provide feedback about their pedagogical practices within a laboratory session.

Constructivism has lately been the more theoretical approach when used to guide teaching materials development, especially for multimedia learning environments [17]. The fact that the constructivist approach is predominant means not only a trend reflected in textbooks, because even the idea of constructing knowledge is present in the work of various authors, and depending on which one is the elected benchmark, sets up a pedagogical practice somewhat differently.

There are fundamental common elements, despite the differences between the theoretical concepts of constructivism research. The consideration of the individual as an active agent of his own knowledge displaces concern from the education process (traditional view) to the learning process. In the constructivist view, the students build representations through their interaction with reality, which will constitute their knowledge, an irreplaceable process, and incompatible with the idea that knowledge can be acquired or transmitted. Taking these assumptions means changing some core aspects of the teaching-learning process in relation to the traditional view [17]. Table 1 shows a comparison between traditional and constructivist approaches.

The Problem-based learning (PBL) is a well-referenced method in literature. In PBL, students work in small collaborative groups and learn what they deem necessary to solve a problem. The professor acts as a facilitator to guide the student through the learning cycle [13].

In the PBL learning cycle (see Figure 1), also known as the PBL tutorial process, students are introduced to the problem scenario. The problem is formulated and analyzed through the identification of scenario relevant facts, helping students to represent the problem [10]. To the extent that, students best understand the problem, the possible solution hypotheses are generated. An important point in the cycle is to identify the knowledge gaps in relation to the problem of learning issues that will be studied during their self-directed learning (SDL). Students then use their newly gained knowledge by assessing their hypotheses based upon what was learned. At the end of each solved problem, students reflect on the acquired knowledge. The professor helps students learn the cognitive profile needed for problem solving and collaboration. One of the cited limitations for this method used, is the amount of people necessary to facilitate learning in large classes [10, 13].

TABLE I. TRADITIONAL AND CONSTRUCTIVIST LEARNING APPROACHES

Traditional Approach	Constructivist Approach
Focus on professor	Focus on student
Focus on course programme	Focus on individual significance construction
Student mind is a blank paper	Learning is construction upon previous knowledge
Student is a passive knowledge receptor	Student controls the learning process
Memorization of knowledge	Skills and knowledge will be developed in the context where they will be used

The use of PBL to improve the curriculum of an undergraduate mechanical engineering course was addressed in [9]. The authors stated that a new course was proposed, which was based more upon troubleshooting than topics. Problems were solved by small groups of students with the facilitators help. The paper describes the impressions and experiences of the students in the course, and how the final problem was solved. Our work differs from this prior work, because the use of PBL was just one component of our mixed pedagogical method. The effectiveness of using a management simulation as the PBL "problem" in a strategic planning course was presented in [21]. Strand *et. al.* [22] proposed a course based in the guiding principles of trauma theory and problem-based learning. The article described the course objectives, structure,

and format and reports on an evaluation based on 7 (total) offerings of the course by 4 different schools of social work.

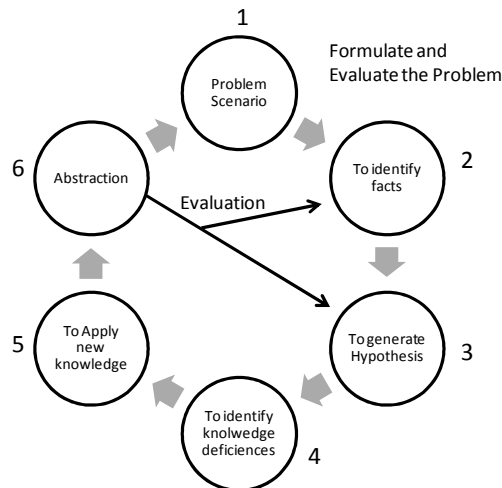


Figure 1. Problem-based learning cycle [13]

It is important to know the problems faced by professors when teaching in their daily lives, when addressing the need for new pedagogical practices. University professors in the communication area said that they faced the pedagogical problems as soon as they appeared. Table 2 illustrates the identified main problems and pedagogical solutions encountered by professors [4].

TABLE II. PEDAGOGICAL PROBLEMS AND SOLUTIONS ENCOUNTERED BY PROFESSORS

Pedagogical problems faced by professors	Solutions encountered by professors
Student unmotivated and listless to continue the course. When the student starts the course he/she will already be getting discouraged. They are such a quick gratification generation.	We're professors, we need to be there giving them motivation to continue. I talk about their future profession, and show some texts about it.
Disinterest, academic failures.	I try to motivate students through case studies and practical projects.
Very heterogeneous student profiles in the classroom. Lack of student motivation. Lack of integration with other courses in undergraduate.	-
Relatively rapid and radical change of the students profile and interests, perhaps due to the ongoing technological transition.	I try to confront the issue by talking with students and avoiding hasty conclusions, whilst maintaining a commitment to ethics and critique education.
Students' disinterested in reading area texts and papers.	Each semester I seek creative ways to attract the interest of students.
Keep relationships with students as subjects and not as teaching objects.	Read specialized books and talk with others professors.
Lack of time to hone skills and implement educational updates.	Read books, search internet and talk with others professors.
Pedagogical issues are not discussed in the course coordination meetings of the professors.	I make my own self-assessments with students, including the issue of course.

In the same work, when asked about the activities development by professors, students in the two evaluated universities answered in the manner as summarized in Table 3. From presented information, we found that some professors searched for innovative classroom teaching practices, but this

activity is not usual. The authors observed that there is often a difference between what was planned and what is implemented in practice by professors. During the evaluated lesson study, the following observations were made: purely expository presentations, indifference, inattention, lack of interaction between professors and students, and sometimes the difference between what was presented and the real world.

TABLE III. STUDENT ANSWERS ABOUT PROFESSOR'S CLASSROOM ACTIVITIES

How the activities should be executed by professors	How the activities are executed by professors
Knowing how to align the market with academics. Respecting the student. Following the course content.	They make presentations using powerpoint. He has pleasure with the execution of activities. He motivates the students. He brings the market to students.
Being more relaxed. Being dynamic. Promoting debates.	We feel like we're at home. We invent products. He does not use alternative strategies. We have to read a text and discuss it in the classroom. He asks the question and tells us what we need to research. However, the lesson is always the same subject.

Research on learning with computing has been a major focus in the learning sciences. In our method execution, students should use computers during the classes. A pedagogical training strategy has been evaluated into the student's undergraduate experience in biology, with good results [19]. A course-based computing approach was tested in Magana et al. [15] and the work results indicated that students performed proficiently in applying computing methods, procedures, and concepts to the solution of well-structured engineering problems. The student self-perceptions of their overall computing abilities and their abilities to specifically solve engineering problems shifted from low to high confidence. The authors' philosophy was based in two premises: computational thinking is best realized in domain-specific, personally relevant contexts; the transfer of learning is better promoted when emphasizing understanding rather than memorization and providing learners with enough time to develop patterns of recognition, and providing students deliberate practice in authentic contexts in which feedback is provided [15]. In a related way, our proposed method includes problems solution as a strategy to be used by professors when planning the courses. Professors should plan the courses to prioritize the transfer of learning between the actors.

Concept mapping is an effective knowledge construction tool for helping learners organize important concepts related to a core issue. An integrated concept mapping and web-based problem-solving environment was developed in [11]. The researchers conducted an experiment to evaluate the effectiveness of the approach on students learning performance, learning satisfaction and cognitive load in an elementary school social studies course. Their results showed that the concept map-integrated approach could enhance the students' web-based problem-solving performance, although the students showed lower degrees of technology acceptance and learning satisfaction in comparison with the conventional web-based problem-solving approach. Using our pedagogical method, the professor can use a concept mapping strategy to plan some classes in a course.

Implementing optional hands-on practice (HOP) activities could prepare the students for the actual hardware manipulation in an introduction to computer science (ICS) course and also to enhance their performance in the future advanced practice courses [20]. The research results showed that HOP participants not only had higher academic scores, but were also less stressed toward the ICS course than the non-participants.

Augmented Reality (AR) is a technology with great potential to impact affective and cognitive learning outcomes. The research presented in [12] assessed to which extent an AR learning application affects learners, level of enjoyment and learning effectiveness. The results indicated that augmented reality can be exploited as an effective learning environment for learning the basic principles of electromagnetism at high school provided that learning designers strike a careful balance between AR support and task difficulty. We consider that depending on the course topics, AR is a possible technology that can be used by professors when planning classes in the courses, using our pedagogical method. Artificial information about the environment and its objects can be overlaid on the real world.

III. PROPOSED METHOD

As basic requirements for the method application, the professor should have an available classroom with Internet access or computer laboratory for use in all planned activities of a course.

The amount and distribution of activities for each course must be balanced between those presented in the proposed method description, grouped and distributed in the lessons, according to the content specificities of the course.

Figure 2 illustrates our proposed method overview, where the professor should plan which resources will be used and in what classes during the planning phase of the course.

The initial course content plan shall be presented and discussed with students, thus enabling the sharing of ideas and possible changes. From the implementation of classes, the teacher will place in sequence, the planned class types according to the content to be followed, always looking to boost its formatting and use of teaching resources, such as: videos, pictures, texts, internet access, among others.

Learning multi-criteria assessments should be carried out during the activities, whereby seeking to generate feedback and discussion results with the students whenever possible. The professor evaluation process by students should be seen as an everyday life tool, whereby the professors will receive online feedback, allowing changes in content planning, both during the course and for the next subjects.

Our mixed pedagogical method consists of the set of activities described as follows:

i. Identification of knowledge and skills that need to be developed by the students

The information concerning the knowledge and skills that will be developed during the course is the guiding elements for all method actions, so it should be identified during the course content planning.

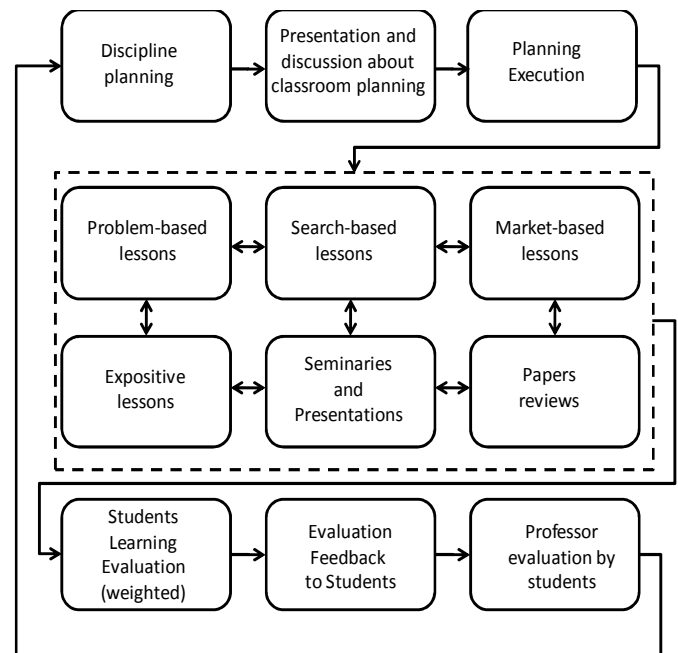


Figure 2. Proposed method overview

ii. Selection of academic papers related to the content of the courses for review

The professor should select a group of journals and conferences in the course area, which may be revised by the students in activities, both in the classroom and at home during the course.

iii. Selection of problems to be solved using problem-based learning strategies in the classroom

Select from books, public tenders tests, certification exams or other events that may arouse greater student interest in relation to the course, a group of problems that can be solved by student groups for specific PBL classes. The problems should have a limited scope, in order to be solved, preferably by up to three classes. Sometimes, depending on course scope, students can use computers and software to help them in activities.

iv. Research and identify market related topics to the subject content practical application

The taught content market applicability in a course is one of highly valued factors by students and can be used as a motivating factor for their participation in course activities.

Professors should seek to identify ways to use the acquired knowledge during courses in business activities, preparing lessons to show this specific purpose. If by chance these applied topics do not exist, they must then move to the next step. It is possible that the professor adopts a set of activities based upon Internet research or other research sources for classroom work. Students can use computers and some software in this activity, depending on course planning.

v. Present and discuss course planning

The information concerning the course's content and lesson plan should be shared with students as early as possible. Professors should discuss the lesson plan with students, adapting it when there are relevant suggestions. Thus, with the active participation of students in project execution, professors can get a greater student commitment.

vi. Adopting a weighted assessment practice

Good students were found to be dissatisfied with unfair evaluation practices [17]. The basis of the proposed method consists in defining a multi-criteria evaluation for courses. The professor can use the following evaluation criteria (objective and subjective):

- Presence in classroom activities (percentage of presence);
- Participation and interest in the process of knowledge collective construction (subjective grade in accordance with the observations during classrooms);
- Development of work/activities in the classroom that can include tests resolution, problem simulations and other activities. Individually and/or in groups (professors must obtain an average grade of executed activities);
- Preparation of paper summaries or other issues at home (to obtain an average grade of completed work);
- Troubleshooting classrooms (Problem-based learning) (professors must seek an average grade for problem solutions executed during the course);
- Students' participate as an author and/or lecturer, developing a paper on a relevant topic of the course. The activity should be planned for the end of the course period (professors must average the grades of the written and presentation work);
- Set the weights of each evaluation criteria (total of weights should equal 1);
- Provide feedback on each activity evaluation carried out by students.

The final result of the course (E_w) should be calculated as the weighted average of all evaluation criteria M_i averages, as shown:

$$E_w = \frac{\sum_{i=1}^n (M_i \cdot w_i)}{\sum_{i=1}^n (w_i)} \quad (1)$$

IV. METHODOLOGY

The research was conducted during the years of 2011, 2012 and 2013. This case study involved five courses in the Information Systems Program and Computer Networks Program at the Federal University of Ceará, Brazil. The case study involved the following steps:

1. Problem validation through interviews with professors and Information Technology professionals;
2. Literature review;
3. Development of the pedagogical proposal;

4. Implementation and evaluation of the proposal in one undergraduate course;
5. Refinement and organization of the method;
6. Implementation and evaluation of the proposal in four undergraduate courses;
7. Tabulation and result analysis;
8. Results publishing.

A. Instrument

Professors are periodically evaluated by students in undergraduate programs at UFC, Ceará, Brazil. We used an institutional assessment system, currently under test at the institution, called SAVI. We applied a questionnaire with 29 items designed to assess a professor in four dimensions: management of teaching activities, development of teaching activities, communication and interaction with students, use of results from students learning evaluation.

The 29 questions answered by students to evaluate the professor in their relative course are shown in Table 4. Professors can view results of their evaluations by students at the end of an evaluation process, either generally or tabulated by course. The system also allows partial assessments that can be made during the course, allowing the teacher to identify problems during the planning execution, and to correct them as required.

TABLE IV. QUESTIONS ANSWERED BY STUDENTS IN PROFESSOR EVALUATION AT UFC

Q1) Professor presented the course-teaching plan upon commencement of course?
Q2) Professor discussed the course-teaching plan upon commencement of course?
Q3) Professor clarified the meaning and importance of course for the program?
Q4) Does the course teaching plan show the content planning?
Q5) Does the course teaching plan contain the general and specific objectives?
Q6) Does the course teaching plan contain a description of the contents / units?
Q7) Does the course teaching plan contain the teaching methodology?
Q8) Does the course teaching plan contain the forms and rules of learning assessment?
Q9) Does the course teaching plan contain the basic and complementary bibliography?
Q10) Professor demonstrates organization and logical sequence to teach the course content.
Q11) Professor uses plain language to improve content understanding by students.
Q12) Professor utilizes appropriate didactic procedures to meet the course objectives.
Q13) Professor streamlines the classroom, promoting activities that encourage student participation.
Q14) Professor clearly guides the requested work solution.
Q15) Professor establishes the relationship between theory and practice, respecting the specific course.
Q16) Professor encourages student's critical thinking.
Q17) Professor knows the course content components area.
Q18) Professor highlights crosscutting issues (social, environmental, cultural, ethical, scientific, etc.), related to course content.
Q19) Professor maintained adequate ethical and professional attitude in the classroom.
Q20) Professor encourages students to obtain high performances.
Q21) Professor respects any student's limitations or failures.
Q22) Professor arrives punctually in class.
Q23) Professor is assiduous.
Q24) Professor maintains good relationship with students.
Q25) Professor establishes clearly, the criteria for assessment of student learning.

Q26) Professor uses assessment practices that value reflection and problem solving issues.
 Q27) Professor uses evaluation forms compatible with the goals and teaching content.
 Q28) Professor uses evaluation forms that capture effectively, the actual student learning.
 Q29) Professor uses evaluation results for feedback and consolidates student learning.

Besides the use of the evaluation questionnaire in the system, the researchers still proceeded with semi-structured interviews with all of the students enrolled in the course, in order to know their preference concerning the adopted practice in relation to traditional practices experienced so far in the undergraduate courses, aiming to identify the strengths and weaknesses of the teaching method and their learning results.

B. Population and Sample

The target population included the professors and students enrolled in each course ($N_1 = 15$, $N_2 = 51$, $N_3 = 18$, $N_4 = 23$, $N_5 = 19$). Thus, the student sample was formed by 107 students enrolled in the evaluated courses during the two years of study, whereby they responded to the questionnaire for evaluating their professors, and also participated in an interview about the specific impact of pedagogical practice adopted on their results in each course.

V. CASE STUDY AND RESULT ANALYSIS

There was the evaluation of five undergraduate courses: Information Systems Advanced Topics, IT governance, Entrepreneurship, Information Systems Management, all within the Information Systems Program, and the Information and Communication Technology Management course within the Computer Networks Program.

We used a PBL-based strategy [10] in some specific classes for this purpose in all evaluated courses. The PBL classes were performed and programmed to follow the course's content. The problems were proposed and solved by small groups of students with teacher facilitation. The students had access to the Internet during the PBL sessions.

In addition to classes using PBL, the proposed method allows the professor to schedule classes where the student will carry out research aimed at solving real cases as applied or even mentioned in books or papers. There were dynamic classes to improve student participation and involvement. Whenever possible, there was a market topic insertion related to what was being presented. In a complementary manner, some works were executed in the classroom and others at home. These studies consisted of: studies on important topics, presentation of summary papers, resolution of public tender tests, and study of best guidance practices adapted for each course topic, whereby trying to consider the current industry standards.

With these integrated actions, researchers established a link between the courses and the market, whereby there was a large increase in student interest. The research strategy in the classroom proposes linking teaching with the research faculty, thus becoming student partners in the search for knowledge, combining theory and practice as partners in the educational process. Aiming to meet the research goal in the course, professors developed research on the identification and

assessment of the course's related problems, which took place during classes and as an external activity.

It is important to emphasize that students evaluated these points in a positive manner, as can be seen from some reports by students obtained during the interview taken after a course lesson:

- "The professor was able to associate course content with topics of the market";
- "Troubleshooting evidence procurement motivated me to deepen my knowledge [...]";
- "Each class had a goal and a different motivation for the course";
- "I am motivated and also thinking about a new business";
- "I want to get a management certificate."

Complementary works were carried out in the classroom and at home, including studies on important topics, presentation of articles summaries, proofs resolution, as well as monitoring of industry standards and the state of the art related to each course.

The proposed method consists of a major advantage, whereby it allows the professor to use creativity in order to plan classroom and home activities, which can improve aspects related to the courses.

A. Some Results

The first case study involved the evaluation of the proposed pedagogical practice in the *Information Systems Advanced Topics* course (*Information Systems Program*). This case was presented in our previous work [13]. The course had fifteen students, which facilitated the implementation of our strategy. This is because we didn't have facilitators involved in the experience (to minimize limitations of many students in class). The university lecturer's function does not exist in Brazilian universities. Importantly, the UFC campus at Quixadá has multimedia features in sufficient quantity for all courses, thus enabling the planning of lessons based on the use of software tools with additional Internet access in the classroom. Our objective was to improve student motivation in relation to course, to create an effective link between the course and the computing profession, and to acquire knowledge of collective construction. The pedagogical course planning was presented and discussed with students throughout the rest of the course, adapting it as necessary. We listened to students' suggestions and adapted the class planning during the whole experience.

The innovative teaching methodology was also one of the strengths indicated in interviews related to this course. The professor implemented oriented works, PBL-based lessons, research presentations, reading books and journal reviews. To improve final results in the course, the professor established a workshop that was totally organized and presented by the students. The course studies consisted of: studies on advanced topics, presentation of summary papers, resolution of public tender tests, and study of best IT governance guidance practices (ITIL and COBIT), which are considered to be the current industry standards.

The professor evaluation by students in this course is shown in Figure 3. Positive indicators were verified in all evaluation dimensions, with percentages greater than or equal to 90% on all questions (evaluation performed by 53.33% of the students in the course). We observed that students issued

and shared information about IT governance importance through means of social networks (i.e. Facebook). Final course results and our innovative strategy were announced in a positive manner among students, which in turn, generated a demand by a new offer for this specific course in other undergraduate programs. An empirical result that strengthens the researchers argument is the fact that our strategy improved the student evaluation mean (8.9 in course), which indicates a very good result. Student evaluation mean in previous courses during last two years was around 7.6.

We continued our study and the proposed method was applied in the year 2012 in two courses. We worked with two scenarios: One course with as few as 18 enrolled Information and Communication Technology Management students and the other course consisting of 51 enrolled Information Systems Management students.

There was a need to evaluate this phase of the study because a vast amount of enrolled students would hinder the process of applying the method, a fact that was expected by the researchers. The context of each course in program and the impact of using the results of the method at the end of each course were evaluated. In some activities during two course evaluation (2012-2013), the professor used as a communication channel for all students, the blog called Simplifying IT Governance. This blog was created based on students' suggestion, after the first evaluated course in 2011.

It was observed that the profile of the students enrolled in the two courses was very heterogeneous, whereby the *Information and Communication Technology Management* course had been formed by mature students with a tendency to be more engaged, they had providing and executing activities in the classroom. Heterogeneous students, some of which were in the second year of their program and others in their first year in program, also formed the other evaluated course.

A large number of the 51 enrolled students in the Information Systems Management course class had great difficulty in achieving interaction between themselves, the professor and the planned activities implementation. The researchers identified a certain lack of student motivation, especially among the students undergoing their first year in program.

These identified aspects and difficulties had a negative impact on the method application and on the overall result of professor evaluation by students in this course. Figure 5 shows the course evaluation scatter highlighted in red. 44% of students enrolled in the course evaluated the professor. There was a downward trend in the average of professor evaluation. The poor final results of these students in the course may have had an impact on professor evaluation by students of this group and may have influenced the overall result.

We refined the method to the following two courses, which were evaluated in 2013, discarding the worst grade in each group of classroom activities; in order to minimize the impact of students justified absences on the student's final grades. We obtained promising professor evaluation results in the most evaluated courses during this study. Figure 4 shows the

professor evaluation by students during IT Governance course in 2013.

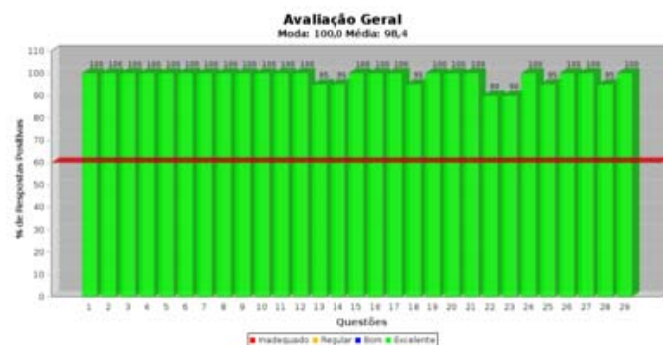


Figure 3. System general results of professor evaluation by students in first evaluated case [13]

Professors executed some classroom activities in these courses during our study, following our method guidance. The research strategy in the classroom proposes linking teaching with the research faculty, becoming student partners in the search for knowledge, whereby combining theory and practice as partners in the educational process. Aiming to meet the research goal in the IT governance course, we developed research on the identification and assessment of managing IT service problems, taking place during classes and as an external activity.

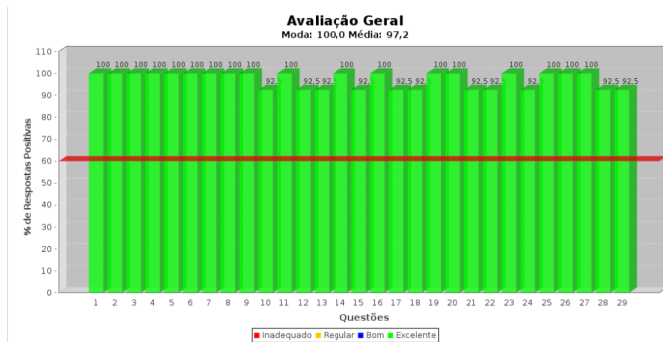


Figure 4. System general results of professor evaluation by students in IT governance course - 2013

Interviews results indicated that the most students liked our method activities, executed during the five evaluated courses (87%).

B. Discussion

The overall results of the proposed method were promising, as can be seen in Figure 5 and Figure 6, whereby only one evaluated course obtained a poor professor result. This happened because the student's profile, high level of classroom absence, too many enrolled students, among many other identified reasons.

The results average (Figure 6) for each professor evaluation question was good and researchers could observe that the method interested the majority of the students. The only course where researchers didn't obtain similar results was Information Systems Management (2012). As showed, we identified the reasons that caused this result.

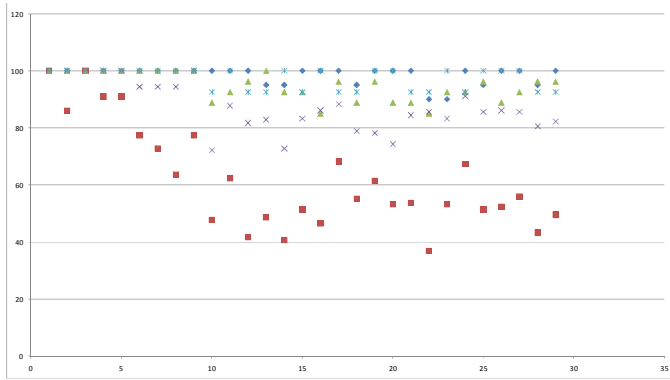


Figure 5. Course's professor evaluation results scatter graph

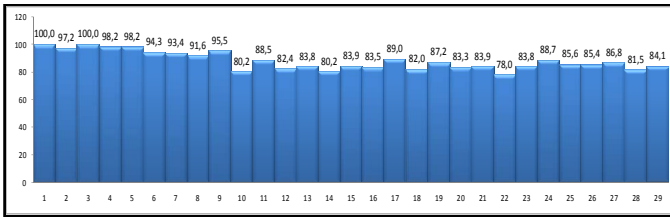


Figure 6. Professor evaluation average results by questions in all courses

TABLE V. AVERAGE INCREASE OF STUDENTS' GRADES

Course	Increase Percentage
Advanced Topics in Information Systems	17%
Information and Communication Technology Management	20%
Information Systems Management	5%
Entrepreneurship	28%
IT Governance	23%

Is there evidence that students have learned the subject being taught? In interviews, 87% of the students answered yes. Some students enrolled in *Information Systems Management* course related some learning problems, because they had missed several classes, and thus no longer participated in many activities. Table 5 shows the increase percent of the average students grades in the five evaluated courses. Researchers used the previous student average grades in the same courses to calculate these percent. The student's results in four courses were promising, indicating that the proposed method can increase the students' performance, at least in the evaluated cases.

VI. CONCLUSION AND FUTURE WORKS

This paper presented a mixed pedagogical method in the classroom, which was applied in two undergraduate programs held at a Brazilian university.

The researchers obtained important results that can be used by professors in similar experiences. The strategy generated positive results in terms of increasing student motivation in evaluated courses, with an improvement of final student results and a disclosure of the importance of courses between the other students.

Our mixed pedagogical method used the combination of important pedagogical strategies, with promising results. The professor evaluation by students was promising, whereby the researchers observed the reduction of disaffection in classes, improvement in the relationship between professor and students, and also the establishment of a link between the acquired knowledge of the course with the market. The planning activities were considered very good in the students' assessment, whereby classroom planning presentation and discussion clarified the course importance, content information, objectives and bibliography. The students preferred the proposed practice in relation to traditional practices experienced by them so far in the courses.

The multi-criteria evaluation based upon student participation during the courses in various activities, both theoretical and practical, at home and in the classroom, was cited by students as being fairer and more motivating than just simply tests and theoretical work. There was observed an improvement in student results and professor evaluations in four of the five cases. In these four courses, researchers used the method with all requirements being met. The proposed method needs a scenario to a favorable application. In a single course assessment, where the results were not promising, the professor tried to apply the method presented in a course with 51 enrolled students, without the help of facilitators, whilst still facing other restrictive factors already presented in the results analysis.

Professors need to customize assessment activities, according to each course nature in the proposed method. There is a difficulty in applying the method in classes with large numbers of students, where it is essential that the professor require the assistance of a facilitator, in order to implement the method, especially during the PBL activities in the classroom. Researchers suggest the help of a facilitator for each group of 18 students in a class. Classes with low attendance of students can hinder the method application. There was a great difficulty with the evaluation of students who had missed several classes, and thus no longer participated in many activities. Excluding some notes related to these activities was a possible solution to this problem.

Results showed that a differentiation innovative method in the classroom could improve course results. The overall results of the professor evaluation by students were solid and reliable.

In future work, professors can use some facilitators in order to help them in courses. The use of different learning strategies proposed in literature is a possible way to improve our method results in further studies. Other possible work would be to evaluate these practices in other knowledge areas and undergraduate courses.

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Modeling Student Perceived Costs and Benefits to Cooperative Education Programs (Co-ops) and Pathways to Participation

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Abstract— Cooperative education programs alternate education and practice, resulting in increased grade point averages, greater confidence in choice of career, and relatively higher post-graduation salaries. This study examines perceived benefits and barriers for students who choose not to participate in co-ops. Since students who participate in co-ops are more likely to persist in STEM fields, and there are differences in participation rates by race/ethnicity (i.e. Black and Hispanic students participate at lower rates), it is critical to understand the reasons for non-participation. Co-op and non-co-op students from a large Midwestern U.S. research university were surveyed and the responses are disaggregated by gender and race/ethnicity. Choice Theory provides a theoretical framework to model perceived benefits and costs of co-op participation. Decision tree modeling is used to describe the different pathways to co-op participation and examine relationships between student backgrounds and pathways. Constant comparative analysis is used to study open-response questions. Future work will include follow up interviews with students from this survey to gain a more nuanced understanding. Findings have implications for the diversification for the engineering labor force.

Keywords— cooperative education, pathways to participation, Choice Theory, cost benefit analysis, barriers to participation

I. INTRODUCTION

Co-op students gain industry experience before graduation, developing relevant job skills through application of classroom learning. These experiences may enhance students' self-efficacy and increase their confidence in choice of major [1]. Furthermore, co-op students often receive job offers from their employers, and studies show they receive higher starting salaries as well [2]. Additional benefits of co-op are well established in existing literature. However, reasons that some students do not participate in co-op is not well understood. This work will contribute to the body of knowledge by examining perceived costs and benefits of co-op participation for co-op and non-co-op students.

Different pathways exist for students to pursue or not pursue co-op opportunities. This study identifies critical points that students choose to exit or proceed along the pathway to co-op participation. Identification of these critical points will help stakeholders improve policies and communication with students to increase interest and participation in co-op. The

pathways analysis identifies common pathways to co-op participation, and highlights critical points where students choose not to participate in co-op. Stakeholders can use these findings in conjunction with findings about perceived costs and benefits to strategically reach students and address barriers to co-op participation. This study provides key findings about different pathways to co-op participation and increases knowledge about how students perceive co-op costs and benefits.

II. BACKGROUND

A. Benefits to Co-op Participation

Benefits of co-op participation have been well explored in literature. Cooperative education provides work experience prior to graduation as students alternate semesters between work and school, usually completing three or five school/work rotations. Reference [3] found that co-op participation provides experiential learning opportunities that increase student engagement and enhance student learning. Evidence indicates that students involved in these "educationally meaningful activities," such as co-op, demonstrate higher levels of persistence and higher rates of completion in education. Additionally, reference [4] found that co-op students earn higher cumulative grade point averages (GPA) than non-coop students in engineering majors. Beyond graduation co-op students have higher starting salaries, in agreement with research by reference [2]. Reference [2] also found that co-op students are more likely to be employed after graduation. Reference [5] confirmed that co-op students have increased job market prospects, providing strong evidence that co-op participation rate for low ability students increases dramatically in times of low average wage growth.

Furthermore, co-op students exhibit greater certainty about career choice [6]. These students were more likely to have first jobs related to their major and overall career plans. Reference [6] noted that co-op students showed enhanced self-efficacy, which is beneficial in sustaining academic performance and persistence to graduation. Reference [7] also explored student perceptions of learning in the classroom and experiential learning in industry. Benefits of experiential learning include increased ability to view career expectations realistically, increased network of professional contacts, and increased

leadership skills. These experiences provide greater career clarity for co-op students [8].

B. Co-op Program Challenges

Few studies research why some students do not participate in co-op. Reference [9] explored challenges facing cooperative education in the twenty-first century since its launch in 1906 at University of Cincinnati. Reference [9] noted that the term co-op is used to describe various types of work-based learning, suggesting that defining features of co-op include exposure to professional workplaces, socialization in the workplace, development of professional identity, and integration of knowledge into on-campus learning. Reference [9] identified integration between work and school as a fundamental component of co-op and an area that could be improved. Reference [10] also researched experiences of co-op students and noted that participants found their co-op experience worthwhile overall, but individual work experiences had some disadvantages, such as quantity of work during terms, range of work term choices, and support from employers. Understanding students' reasons for not participating in co-ops will help programs improve policies and the co-op experience, and increase interest in co-op participation.

C. Theoretical Framework: Choice Theory in Educational Decision Making

Researchers have used Choice Theory as a theoretical framework to model educational decision making. For example, reference [11] used Choice Theory as a theoretical framework to model educational decisions made by students and their families. Reference [11] explained model choices as decisions made by evaluating costs and benefits of different educational options. This model explained how gender differentials in levels of education have decreased, while class differentials in educational attainment persist. The model was based on secondary effects, defined as choices made by the individuals, rather than primary effects, which encompass levels of ability. Reference [11] aimed to explain differences in educational attainment through differences in choices made by individuals, assuming that choices are influenced by students' expectations about likelihood of succeeding in respective options.

Researchers can apply this framework to analyze survey data. Reference [12] analyzed how European researchers apply rational choice theory in research using survey data. Key concepts of this theory include available alternatives, expectations, and costs and benefits. Rational choice theory assumes that individuals consider the costs and benefits of available options when making a decision and form expectations about the consequences of these actions. For example, a student considering cooperative education would evaluate the costs and benefits of participating in co-op and also consider possible results of participation compared to possible results of participation in alternative activities. Reference [12] explained that researchers can evaluate choices in two ways – 1) directly, by surveying individuals about expectations and perceived costs and benefits, or 2) indirectly, by measuring individuals' actions. Continuing the above example, a researcher could ask a student about perceived costs and benefits of co-op or could record the student's decision to

co-op or not to co-op. Reference [12] advocated applying both strategies in research.

Reference [13] furthered research on social class and educational decision-making of students through rational choice theory. Reference [13] analyzed decision-making within French schools in choosing secondary school tracks, suggesting that students and families evaluate the costs and benefits of an educational track and the likelihood of succeeding in completing that track. Reference [13] postulated that students analyze benefits of each track in the context of maintaining social class position, in line with the model of "relative risk aversion" described by [11]. Reference [13] used bivariate analysis to explore potential association between social class and selected variables related to decision-making. We use the above methods to understand how students perceive costs and benefits of co-op participation in this research.

III. METHODS

The study includes a large Midwestern research university with a voluntary co-op program that offers 3-session and 5-session plans. Co-op students alternate session of academic study with sessions of work with a qualified employer and are expected to stay with the same company throughout the program. Formally initiated in 1954, the program now serves over 1,100 students and more than 300 active employers from private industry and government agencies. While the program serves students in eight different colleges across the university, the College of Engineering has the largest enrollment.

We developed the survey based on input from co-op program coordinators and pilot interviews from Spring 2014 [14]. Co-op program coordinators identified several different ways in which students can enter the program and the pilot interviews informed the questions regarding perceptions. We also collected demographic information such as gender, race/ethnicity, citizenship, and major. Using Qualtrics, we created one survey with several logic steps that categorized students into three groups:

1. Current co-op participants
2. Students who are interested in the program, but not participating
3. Students are not interested in co-op

We used both a quantitative and qualitative approach to analyze survey results. The survey contained both closed- and open-ended response questions about perceptions of co-op, experiences in the process of obtaining co-op placement, and demographic information.

We emailed the survey, developed with input from co-op program coordinators, to 1,938 students who completed the second course of the foundational engineering sequence. Of these students, 286 students responded to the survey for a response rate of 14.8%, which is consistent with the expected response rate for an electronic survey [15]. 136 of these students are co-op participants, and 1,802 students are non-participants. These students were eligible to apply for co-op in Spring 2014. The sample consisted of 69.4% male, 30.6%

female; 72.3% White, 20.2% Asian, 4.5% Hispanic, 0.4% Black, 2.5% other; 86.3% domestic, 13.7% international.

We analyzed responses using descriptive and bivariate statistics of survey questions. Additionally, open-ended responses were coded to analyze perceived costs and benefits of the co-op program. We analyzed open ended responses with constant comparative analysis [16].

IV. RESULTS

We identified students in three categories – 1) current co-op participants, 2) students who are interested in co-op, but not participants, and 3) students who are not interested in co-op. Table I shows the proportion of students in each category. Composition of respondents when disaggregated by gender, US citizenship, and race/ethnicity is comparable to the overall undergraduate engineering population at this large Midwestern research university.

TABLE I. FREQUENCIES OF STUDENTS IN CO-OP INTEREST LEVEL CATEGORIES

<i>Category</i>	<i>Frequency</i>	<i>Percentage of Total (n=286)</i>
Not Interested	143	50.0
Interested, but non-participant	59	20.6
Current co-op participant	59	20.6

^a. Total is not 100%, because the remainder of students did not know about the program or preferred not to answer

A. Pathways to Co-op Participation

Survey results indicate multiple pathways to co-op participation and non-participation. From the survey, five critical points were identified in the path analysis – 1) interest, 2) information, 3) application, 4) interview, and 5) participation. Not all respondents were aware of the program. In fact, about 8.7% of all respondents were unfamiliar with co-op programs. Of the students who knew about co-ops, approximately half indicated they were not interested in co-ops (see Table I). Of non-participants, only 29.2% indicated they were interested in the program (see Table II). Critical points along the pathway to co-op are summarized in Table II. The percentages are calculated within each group of students, co-op and non-co-op.

TABLE II. CRITICAL POINTS ALONG PATHWAY TO CO-OP AWARENESS AND PARTICIPATION

<i>Pathway to Co-op</i>	<i>% of Co-op Students</i>	<i>% of Non-Co-op Students</i>
Aware of Co-op	100.0	89.0
Heard About Co-op from Family	23.7	13.7
Heard About Co-op from Class	40.7	61.7
Heard About Co-op from Promotion	64.4	51.5
Interested in Co-op	100.0	29.2
Applied through Co-op Program	78.0	10.5
Interviewed through Co-op Program	27.1	8.4

A potentially influential piece of awareness and interest in the co-op program is how students learn about the co-op program. We asked students how they heard about the co-op program – from class/professor, from friend, from family, from promotional material, or other. Students could select more than one option. A greater proportion of co-op students indicated they heard about co-op from family (23.7%) compared to their non-co-op peers (13.7%). A greater portion of non-co-op students heard about the program in class (61.7%) compared to co-op students (40.7%). However, a greater proportion of co-op students indicated they heard about the program from promotional materials (64.4%) compared to non-co-op students (51.5%). Follow up interviews with students will explore the influence of each of these information sources on students' decision to choose co-op or not.

Interested students have the opportunity to attend an informational session about co-op to learn more about the program. In the aggregate, including co-ops and non-co-ops, 71.2% of all students interested in co-ops attended an information session about co-op, and 53.6% of these students who attended the information session ultimately participated in co-op. Of the interested students who did not attend the information session, 41.2% participated in co-op. The results suggest that informational sessions are a critical point in which students decide to participate in co-op.

Students who complete an application through the co-op program may then interview through the co-op program. Table II shows that 78.0% of co-op students indicate that they completed an application through the co-op program. Of those students who completed an application, 58.0% of them indicated they interviewed with companies through the co-op program, while 37.7% indicate they interviewed either through a career fair or directly with a company. Of the students who indicated they interviewed through the co-op program, 50.0% participated in co-op. Overall, 33.9% of co-op participants indicate that they obtained their co-op placement by interviewing through the co-op program. Alternative paths include interviewing through a career fair or interviewing directly with a company.

We asked students to rate their experiences with the co-op program on a scale of very satisfied to very dissatisfied in four areas – application process, interview process, company matching, and responsiveness to questions/concerns. On average, co-op students indicate they are satisfied to very satisfied in all four areas. Non-co-op students are, on average, slightly satisfied with the application process, interview process, and question response. However, non-co-op students are, on average, slightly dissatisfied with the company matching. These are students who may have completed the application, but did not continue the process after being dissatisfied with the company match.

Co-op students may participate in a three-session or five-session co-op. The majority (63%) of co-op students in this survey are participating in a five-session co-op. About 43% of these five-session co-op students obtained their placement by an application through the co-op program. In contrast, 4.8% of three-session co-op students obtained their placement by an application through the co-op program. The remaining co-op

students obtained their placement through a career fair or through direct interview with a company.

B. Co-op Students' Perceived Benefits of Co-op

Using Choice Theory as a framework to understand student's decision making processes, we asked students directly about perceived costs and benefits of the program. Co-op students' perceptions of the program's benefits are comparable to the existing literature. While these students list advantages of co-op similar to those found in literature, they speak about these benefits in different ways. Table III lists perceived advantages in ranking order (1 being the most common). 80.0% of co-op students list work experience as a benefit of co-op, and 28.8% of these students list having a competitive edge in the job market as a benefit. Students respond that participating in co-op provides a competitive edge before their first job, leading to "easy placement" and increased job prospects. Co-op students say that they build their resume and will be able to advance in their career more quickly. Furthermore, 49.2% of students list money as a benefit to the co-op program. Students indicate that they "become financially stable" since the salary is better than that of a campus job and that participating in co-op helps pay off loans.

TABLE III. PERCEIVED BENEFITS BY CO-OP STUDENTS

Co-op Participants	1.	Work Experience
	2.	Money
	3.	Competitive edge in job market
	4.	Job training
	5.	Networking
	6.	Career exploration

Co-op students emphasize the career benefits to participating in co-op. They are either less interested or not aware of additional benefits surrounding improved academic performance and confidence in major choice. Some students do refer to gaining "practical knowledge in the field," increasing "awareness of tools and practices in the related industries for my major," and "applying things learned in the classroom." 25.4% of co-op students list job training as a benefit of co-op, while 5.1% view application of classroom learning as a benefit.

C. Perceived Disadvantages of Co-op Participation

Perceived costs of co-op participation differ for co-op students and non-co-op students. Table IV compares perceived cost by both groups of students listed by ranking order (1 being the most common). Co-op students most often list disconnect with peers on campus as a disadvantage to co-op, whereas non-co-op students list increased time to graduation and preference of internships over co-op. 33.9% of co-op students list disconnect with peers on campus as a cost of co-op. Co-op students describe "falling behind friends in classes," "becoming disconnected with friends established in first two years of school," being "difficult to build relationships with people not co-oping," and having "personal disadvantages like difficulty holding relationships and friendships with people at [school]."

TABLE IV. PERCEIVED DISADVANTAGES BY CO-OP AND NON-PARTICIPANTS

Co-op Participants	1.	Disconnect with peers on campus
	2.	Time to Graduation
	3.	Missed Opportunities on Campus
	4.	Off schedule in classes
Non-co-op Students	1.	Time to graduation
	2.	Prefer Internship over Co-op
	3.	Missed Opportunities on Campus
	4.	Commitment to 1 company/industry

In contrast to academic benefits cited in literature to co-op participation, co-op students describe costs of co-op participation surrounding their academic studies, including "making planning for future academic endeavors quite difficult," "significant gaps between challenging coursework," "spending so much time away from school makes it more difficult," and "getting off track with your major."

Non-co-op students list concerns about extending time to graduation and missing opportunities on campus. These students mention desires to participate in other programs, such as study abroad, graduate school, and leadership opportunities within campus organizations. They believe that internships will better fill their needs by "not putting off my graduation date," "not missing any semesters of school," having "the ability to change companies," not "being limited to one company for all terms," and "gaining experience at several different companies (large and small)."

V. DISCUSSION

Both co-op students and non-co-op students list time to graduation and missed opportunities on campus as disadvantages of co-op. That perceived inflexibility of the program has been mentioned by co-op and non-co-op students as a reason for pursuing other experiences than co-op. Literature cites academic advantages of co-op, yet co-op students list being off schedule in classes as a disadvantage of co-op. As reference [9] suggested, co-op programs could improve in integration between school and work. Increased integration could also assist in lessening the perceived disadvantage of disconnect with peers on campus and inability to enjoy other aspects of college for co-op students.

Understanding the decision processes for not pursuing co-ops and the different pathways to co-op participation is useful because co-op programs and employers can use this information to understand how students utilize their programs. Knowing the pathways various students enter the program, schools have the ability to better market their programs and services to students. Employers can also use this information to help them create environments that are more likely to draw in students wanting a co-op. Further, to the extent that barriers to minority participation can be addressed, co-op program staff can recruit a more diverse group of participants.

Based on our analysis of the pathways, we identified several critical points that have implications for potential changes and improvements for different stakeholders interested in increasing and diversifying co-op participation. For example, at the awareness stage, we found co-op participants are more likely to have learned about co-op through family and

promotional materials. This leads to the importance of everyone having correct information. If parents or peers are misinformed early, they may pass on incorrect, discouraging information to potential co-op students. Also, providing more information for students whose parents/peers have not encouraged them to participate may help improve awareness of the benefits of co-op participation to those that did not have family or peer influence. At the interest stage, presentation of co-op benefits can be improved by addressing perceived disadvantages listed by non-co-op students. Co-op administrators, educators, and employers can explain to students how the co-op program provides opportunities for career exploration and professional development. Stakeholders can also provide more information about how co-op students can transition smoothly between school and work. Additionally, at the application stage, non-co-op students indicate they are least satisfied with company matching. Increased communication and clarity around this process could improve students' satisfaction and interest in co-op participation. Additionally, the discrepancy between five-session and three-session application pathways identifies a need for further investigation of co-op program policies.

Non-co-op students express preference for internships over co-op positions. Future research will clarify reasons for this preference. Clarification of what a co-op entails and its flexibility may address this perceived disadvantage and also alleviate concerns about committing to one company/industry. It is interesting to note the difference in perception between co-op students and non-co-op students about the commitment of co-op. Non-co-op students express concern about committing to one company/industry, while co-op students embrace commitment to a company in which they are interested to gain a competitive edge. Co-op students view career exploration as a benefit to co-op, while non-co-op students fear that co-op will limit their opportunities for career exploration by committing to one company/industry. These non-co-op students say that internships will better fill this desire.

VI. IMPLICATIONS AND FUTURE WORK

Future work includes conducting interviews with survey respondents to gain a more nuanced understanding of perceived costs and benefits. Additional insight can be gained by understanding if and how co-op students' perceptions change when they begin the program. Interviews will also increase understanding of non-co-op students' reasons for being less satisfied with the company matching process and why they chose not to participate.

Understanding of critical points in the path to co-op participation will help both co-op programs and employers present the benefits of co-op and possibly increase interest and participation in co-op while lessening concerns some may have about the program. Knowledge of student perceptions of costs and benefits to co-op participation will help co-op programs and institutions convey benefits of co-op participation to students to increase awareness and interest. These programs should consider the influence of family and promotional materials when communicating information about the co-op program. Employers can also gain insight about the interview process and how to convey information about their co-op

programs. For instance, they can focus on highlighting the flexibility of co-ops and opportunities for career exploration. Additionally, they can emphasize opportunities for career development and gaining practical knowledge for the workplace.

This work will also help to further the engineering education field as a whole. Understanding the costs and benefits students consider when making decisions regarding their professional training will help schools develop programs to fit those needs. Students will then be able to choose from programs more suited to fit their needs and desires allowing engineering students to graduate with the knowledge and experience needed to excel in an area they know will be of interest to them.

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Mapping Career Success Competencies to Engineering Leadership Capabilities

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Abstract—Societal expectations of twenty-first century engineers have dramatically changed over the past few decades. There is a need to educate engineers not just in technical subjects, but also in many non-technical areas including globalization, communication, and leadership. There has been a growth of engineering leadership education programs offered by postsecondary engineering institutions. The effectiveness of these programs is often measured by the student's acquisition of skills, without considering the benefit of these skills on the students' careers. Using the career success competencies model, this paper seeks to determine if engineering leadership education impacts career success. The theoretical mapping analysis indicated a positive relationship between engineering leadership education and career success. The most significant competencies related to an engineer's career success were career insight, proactive personality, openness to experience, and lifelong learning.

Keywords—boundaryless career; career success; engineering leadership; engineering leadership education

I. INTRODUCTION

Engineering education has had an increasing focus on outcomes-based education. National organizations, such as ABET and CEAB (Canadian Engineering Accreditation Board) now mandate the attributes that students graduating from engineering institutions will have achieved. These attributes are designed to be the skills required for engineers to succeed in today's society, including essential technical knowledge and skills, as well as nontechnical skills, attitudes and character traits.

Over the past decade, there has been a growth of teaching and learning activities focused on the professional skills in engineering. Often to measure the success of these activities, students are assessed before and after. If the appropriate skills are gained, the activities are concluded to be successful in producing a more competent engineer. However, a key element missing in this assessment process is the measurement of whether or not possessing these professional skills is beneficial to an engineer's career.

This paper will focus specifically on the skill of engineering leadership. Leadership education programs have recently had a high rate of growth and development in post-secondary engineering institutions. A 2009 summary of engineering leadership education found that the majority of the 70 programs reviewed were less than 5 years old [1]. The

question then follows, does engineering leadership education have an impact on career success?

To analyze the relationship between engineering leadership and career success, first there must be a clear method of how to measure career success in engineering. General career success measurement instruments have been researched for decades [2], and a widely accepted model of career success will be presented. The model will be analyzed for inclusion of specific requirements of career success within the engineering industry. Then, the model of career success competencies will be mapped to engineering leadership capabilities. This mapping will provide a basic foundation for the link between career success and engineering leadership.

II. CAREER SUCCESS COMPETENCIES

A. Boundaryless Career

At the end of the 20th century, traditional assumptions about employment had changed, and people were able to obtain sequences of experiences across both organizations and employers [3]. It was apparent that employees were no longer restricted to a single organization throughout their career.

The term boundaryless career was introduced in 1993 [4]. Boundaryless careers are simply defined as "sequences of job opportunities that go beyond the boundaries of single employment settings" [5]. Hierarchical relationships are broken down, and there is increased an ability to move across occupational careers and employers [4].

B. Measurement of Career Success

There are two types of career success typically discussed in literature: objective and subjective. Objective career success includes extrinsic measures such as salary, upward mobility, and managerial level [3]. Subjective career success includes intrinsic measures, where individuals are able to evaluate their own career success through "self-defined aspirations, values, needs, standards and career stages" [6].

In the past, career success was commonly associated with extrinsic measures such as increased salary and upwards progression within an organizational hierarchy. However, modern boundaryless careers often have lateral movement within organizations, and these extrinsic measures of career success are no longer valid measurements.

Subjective career success represents a judgement on career accomplishments and a sense of progress towards career goals [3]. These intrinsic measures are more suitable for the boundaryless career. Common examples of intrinsic measures include career satisfaction surveys [7], career commitment [8], wage satisfaction [3], and marketability [9].

C. Career Competencies Model

To cope with the complexity and change of a boundaryless career, three required career competencies were identified by DeFillippi and Arthur in 1994: knowing-why, knowing-whom and knowing-how [5]. Career literature has focused considerable effort on defining, verifying, and conceptually explaining these competencies [10]. The extensive research and verification available is the reason these three career competencies were chosen for the analysis in this paper.

Firstly, the knowing-why competency focuses on the individual's career motivation, personal meaning and identification [5]. It considers the individual's willingness to explore different possibilities, and ability to adapt to change in one's work environment [9]. This competency is associated with awareness of one's needs, abilities, interests, and aspirations related to work-experiences, as well as one's self-concept and self-identity [10].

Next, knowing-whom refers to an individual's career-related connections, both within and outside the organization. It is characterized not only by development of relationships, but also in how these relationships are utilized [10]. An extensive network is beneficial to the individual as a resource, a new source of learning, and an attained reputation [5].

The final career competency, knowing-how, emphasizes an individual's broad and flexible knowledge. This includes the portfolio of career skills and job skills that are useful across organizational boundaries. Knowing-how also includes the aptitudes of continuous learning and opportunity development, which can be defined as one's career identity [9].

Eby, Butts, and Lockwood used these three competencies as the basis for developing a model to measure career success [9]. In their model, each career competency is associated with two or three intrinsic variables for career success. Table 1 provides a summary of the instruments used to measure each variable. Many of these instruments were developed by others. The original source of each instrument and the number of items used in the model is also indicated in Table 1.

This model uses different instruments that have been verified and validated. It provides an excellent overview of the variables required to measure subjective career success and will be used for the analysis in this paper. However, it is widely accepted that subjective career success is a multi-dimensional construct, and the instruments used in Eby, Butts, and Lockwood's model are all single-dimensional [11]. Although this is a recognized limitation of the model, multidimensional career success criteria has only recently been developed, and there is not yet a well validated model.

TABLE I. SUMMARY OF INSTRUMENTS USED BY EBY ET AL. [9] TO MEASURE VARIABLES OF CAREER SUCCESS.

Career Success (CS) Variable	Original Source (as cited in [11])	No. of Items
CS1. Knowing-Why		
- Career Insight	[12]	3
- Proactive Personality	[13]	10
- Openness to Experience	[14]	8
CS2. Knowing-Whom		
- Mentorship	[9]	1
- Internal Networks	[9]	3
- External Networks	[9]	4
CS3. Knowing-How		
- Career / Job Skills	[9]	5
- Career Identity	[15]	4
Perception of Career Success	[7]	5

III. ENGINEERING CAREER SUCCESS

An individual's own importance level of the career satisfaction elements can be influenced by their occupational context. It has been shown that people from diverse occupational backgrounds will interpret the measures of career success differently [16]. It is therefore important to consider career success within an engineering context. Limited literature exists in the field of measuring engineering career success. However, three contextual aspects of engineering career success were determined based on the available resources.

Firstly, lifelong learning is fundamental for success in the 21st century engineering career [17]. Staying abreast with the most recent technological advancements is essential for being innovative and creative. In the career competency model, lifelong learning is included in the variable "career identity".

Secondly, a study in the engineering construction industry found the most critical aspect to fostering a successful career path was developing a professional network [18]. This includes networking, mentorship, training, and constructive feedback, and is covered in the knowing-whom competency.

The same study found that young engineers were aware that they were primarily responsible for their own career development and self-improvement [18]. Further studies have shown that students desire to participate in their learning process and to be proactive players in improving their learning [19]. This third aspect of engineering career success relates to the model's "proactive personality" variable.

All three of these aspects are included in the model, thus the career competency model recommended in Table 1 is appropriate for measuring engineering career success. However, the relative importance of these three aspects may be different in an engineering context and should therefore be given special consideration.

Overall, there is a dearth of literature on measurement of career success in an engineering context. Further research in this area would be beneficial for a more concrete understanding of engineering career success.

IV. ENGINEERING LEADERSHIP CAPABILITIES

Engineering leadership has been highlighted as an important skill for engineers to be able to succeed in their 21st century careers by many, including in the National Academy of Engineering's publication *The Engineer of 2020* [20] and in the recent CDIO syllabus update [21].

It is important to note that leadership skills are beneficial to all engineers, regardless if they plan to pursue leadership roles. Professional skills such as communication, time management and self-reflection are valuable across every engineering discipline. All engineers must be prepared to work in a team environment when solving technical problems [22].

The Gordon-MIT Leadership Program (GLP) was launched in 2007 and aims to develop the next generation of technical leaders [23]. GLP customized a model for engineering leadership, which contains six central capabilities of effective engineering leaders, as shown in Table 2 [24]. The full list of individual skills is provided later in Fig. 1, and full descriptions can be found on the GLP program website [23].

The GLP model was chosen for the mapping analysis. This model was initially designed based on the definition of leadership from the MIT Sloan School of Management. Over the years, the GLP model has been continuously refined and updated. It is highly reputable within the field of engineering leadership, and was used as reference for the extension to the CDIO syllabus, *Leading Engineering Endeavors* [21].

V. MAPPING CAREER SUCCESS COMPETENCIES TO ENGINEERING LEADERSHIP CAPABILITIES

The analysis seeks to map the career success competencies (Table 1) to the capabilities of effective engineering leaders (Table 2). The scope of this paper will discuss only the one-way mapping procedure, and will not address the relationship in the opposite sense. Although each individual engineering leadership capability is important to be an effective engineering leader, each capability may not be required for a successful career. The paper seeks to understand which variables of career success are taught in engineering leadership programs, and this can be achieved through the one-way mapping analysis.

Each career competency variable definition was compared with the individual leadership capabilities to determine if there was a link. Links were classified as "Strong", "Medium", or "Weak". A strong link showed a high level of similarity, often with synonymous words and phrases being used. Medium links had similar concepts that were being applied in a different context. A weak link showed little similarity in the meaning, even though the broad topic may have been the same.

The classification process was done following a constant comparative method. After each variable was classified, it was compared with the other variables classified at that level to ensure consistency. At the end, each variable was compared with the variables that had been classified at different levels. This ensured the difference between strong, medium, and weak links was clear and consistent.

TABLE II. SUMMARY OF CAPABILITIES OF EFFECTIVE ENGINEERING LEADERS DETERMINED BY [24].

Engineering Leadership (EL) Capability	Description
<i>EL1. Attitudes of Leadership</i>	Reflection on beliefs and attitudes; sense of responsibility; foundational leadership skills
<i>EL2. Relating</i>	Develop relationships; listen to others; understand diverse viewpoints; advocate for your position
<i>EL3. Making Sense of Context</i>	Understand the context of leadership; comprehend and explain complex environment simply to others
<i>EL4. Visioning</i>	Create purposeful images of the future; identify what could and should be
<i>EL5. Delivering on the Vision</i>	Move from abstraction to innovation, invention, and implementation
<i>EL6. Technical Knowledge and Reasoning</i>	Deep working knowledge of discipline; understand, decompose, and recombine elements of technical problems

A summary of the mapping is shown in Fig. 1, and the remainder of this section details the reasoning for each link and classification of strength.

A. Knowing-Why (CS1)

The three variables associated with knowing-why were career insight, proactive personality and openness to experience. Each of these mapped to skills in EL1, "attitudes of leadership".

1) *Career Insight*: Career insight is defined as having realistic career expectations, and an understanding of one's strengths and weaknesses [9]. An individual skill included in EL1 is "self-awareness and self-improvement". This includes awareness of one's own personal, interpersonal, and professional skills [24], strongly linking with the definition provided previously of career insight.

2) *Proactive Personality*: The tendencies to identify opportunities, to take action, to demonstrate initiative and to persevere are elements of a proactive personality. An individual skill listed in EL1 is "initiative". This skill is described as the willingness to create a vision and take action, and teaching students the importance of being proactive, which shows a strong link to a proactive personality.

3) *Openness to Experience*: This is defined as individuals who are "imaginative, curious, broadminded and active" [9]. In EL1, the skill "resourcefulness, flexibility and change" includes the ability to be adaptable, and willingness to take alternative courses of action. Both of these skill definitions show an openness to experience and have a strong link.

B. Knowing-Who (CS2)

The three variables associated with knowing-who were mentorship, internal networks and external networks. These variables each had a medium link to skills in EL2, "relating".

1) *Mentorship*: Developing a mentoring relationship was described in CL2 as important for developmental experiences, visibility and exposure, as well as a valuable source of learning [9]. One of the individual skills in EL2 is

“interpersonal skills”, which includes “coaching and teaching, and providing and receiving evaluation and feedback” [24]. A medium link is shown, as mentorship is not directly mentioned, however similar elements are emphasized as those in the provided career competency definition.

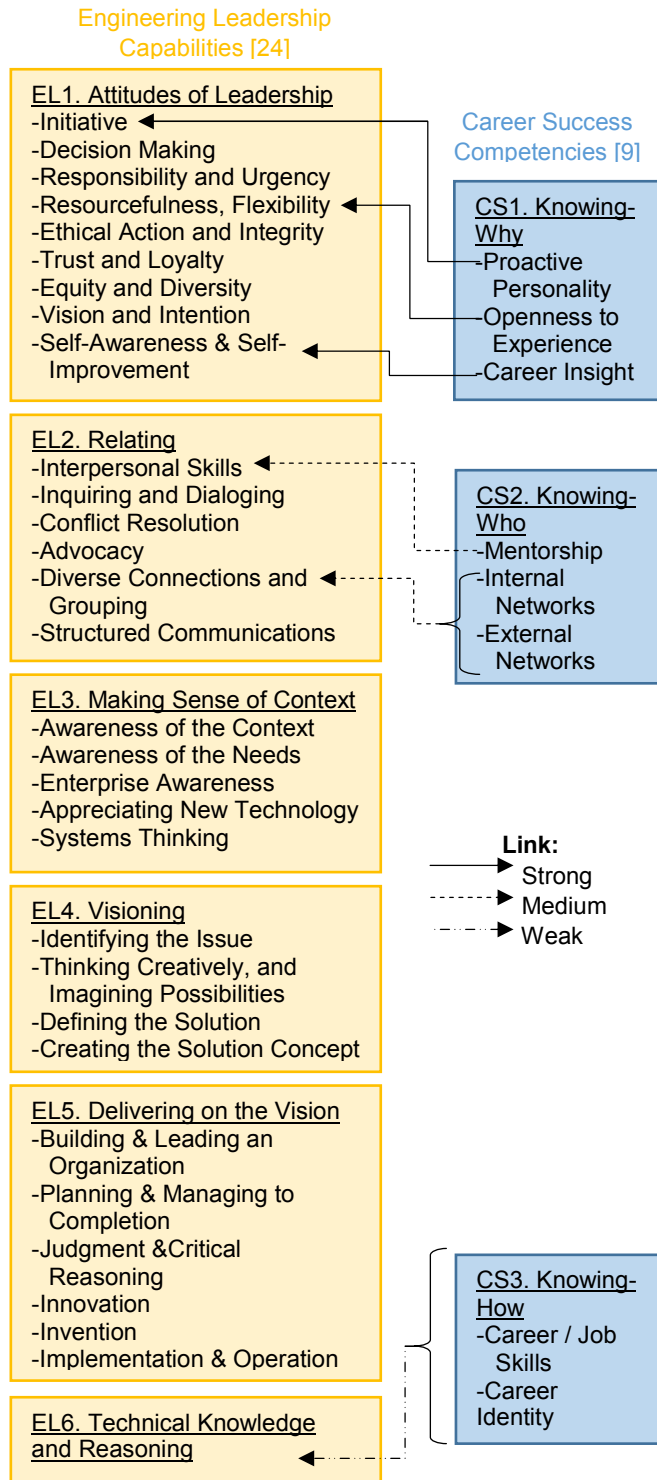


Fig. 1. Mapping between career success competencies [9] and engineering leadership capabilities [24].

2) *Internal and External Networks*: These two CS2 variables were defined as individuals being well connected for support and development within their company, as well as outside of the company. They do not map to separate skills of EL2, but rather to one individual skill called “Diverse Connections and Grouping”. This skill emphasizes connecting with diverse groups of people who have different backgrounds, skills and experiences to “help achieve the goals and technical solutions” [24]. The slightly different meaning of the two definitions shows a medium link.

C. Knowing-How (CS3)

The two variables associated with knowing-how were career / job skills and career identity. This career success competency had the weakest link to engineering leadership capabilities, however it mapped to skills mostly within EL6, “technical knowledge and reasoning”.

1) *Career / Job Skills*: The emphasis of this competency is on the transferability and flexibility of one’s career skills, rather than just the career-related skills themselves. EL6 only discusses the importance of discipline specific technical engineering skills, without mentioning that the skills should be portable. However, EL5 discusses the need for leaders to be able to manage change, which could be interpreted indirectly as a need for flexible skills. Although these engineering leadership skills have some similarity, the link is weak.

2) *Career Identity*: Career identity also has a slight link to EL6, “technical knowledge and reasoning”, however career identity was defined as continuous improvement and opportunity development. Continuous improvement is mentioned in the leadership capability EL1, where it discusses proactive planning for continuing education and future careers. Opportunity development is included in EL5, “develop approaches to incorporating competence outside of one’s enterprise” [24]. Overall, only a weak link is observed.

VI. DISCUSSIONS

All of the career competencies mapped to engineering leadership capabilities, with varied levels of strength. The career competency with the highest link strength was knowing-why, which mapped strongly to EL1, “attitudes of leadership”. Additionally, it has been shown that knowing-why is the greatest predictor of career success [10]. Therefore, if engineering leadership education programs are able to foster “attitudes of leadership” in their students, this is a good indication that there would be an improved level of career success.

Knowing-how has been shown to be the second most influential career competency on career success [10]. A skill included in knowing-how, lifelong learning, was also emphasized as a critically important skills in the engineering literature [17]. However, knowing-how was the competency with the weakest link to engineering leadership capabilities.

Lifelong learning is also not mentioned in the definitions of leadership provided by the CDIO Syllabus extension “Leading Engineering Endeavours” [21] and the National Academy of Engineering [20]. Although both organizations include lifelong

learning skills in their general engineering attributes, they are not specifically mentioned in the skills of engineering leaders. This skills is essential for all engineers to succeed in the fast paced technological innovation of the 21st century, particularly those interested in leadership activities [17]. To improve the success of graduating engineering leaders, it would be beneficial to include lifelong learning in leadership programs.

There is a common maxim, “it’s not what you know, it’s who you know,” and this often is the case. The engineering career success literature supported this where professional networks were determined to be an important aspect of an engineer’s career success [18].

However, in the general literature, networking has been shown to have little impact on career success [10], [25]. This contradiction could be due to the style of networking. Supervisor-focussed networking (i.e. championing) can increase career success, whereas self-promotion can tend to decrease career success [26]. The type of career success being measured (objective vs. subjective) may also effect the correlation observed with networking. Regardless, networking, mentorship and building relationships is important for students for many reasons other than career success (e.g. visibility, exposure, improved learning experiences, and guidance) and should continue to be a part of engineering leadership education programs.

The importance that different elements of leadership have on success in the engineering industry should also be considered. One study showed socio-emotional intelligence (including verbal expression through assertion, emotive availability, and inspiration) had the strongest correlation to successful leadership compared to personality and mathematical-logical intelligence [27]. It is notable that again, this emphasizes the importance of knowing-why (emotional intelligence), over knowing-who (personality) and knowing-how (math-logic intelligence).

It is also important to consider how engineers perceive themselves as leaders. As stated by Rottman, Sacks and Reeve, “engineering leadership depends on engineers recognizing themselves as leaders” [28]. One of the largest barriers to engineering leadership at postsecondary institutions is that leadership activities supported by engineering faculties are primarily through optional extracurricular involvement. Students may view these experiences as exterior to their essential learning experiences, and thus decide not to participate. However, the results from this analysis show that participation in engineering leadership education programs could improve a student’s career success.

Lastly, postsecondary institutions are often expected to produce an extremely well-rounded graduate with a wide variety of skills and abilities. The divide between academia’s responsibility and industry’s responsibility is not well defined. Are there variables within the career competency model that should be the responsibility of industry to develop and foster within their employees? For example, perhaps lifelong learning should be considered a skill that is expected to be taught outside the context of engineering education.

VII. CONCLUSION

Based on the theoretical analysis, all of the career success competencies mapped to engineering leadership capabilities. The skills with the strongest link were those that mapped to the knowing-why competency. The most significant variables related to an engineer’s career success were career insight, proactive personality, openness to experience, and lifelong learning.

Overall, the theoretical results suggest that teaching engineering students skills in leadership would have a positive impact on their career success. These results are valuable to all engineering students, not just those who plan to pursue a career path in leadership.

The analysis performed for this paper was entirely theoretical and the conclusions should be taken with care. Further verification and validation is required to fully understand the relationship between engineering leadership education and career success. Also, the classification procedure was based on the author’s interpretations of the competencies, capabilities, and the strength of their relationship. The potential bias should be taken into consideration.

VIII. FUTURE RESEARCH

Literature on engineering career success is very minimal. This area requires further exploration to provide insight on the contextual importance of the career success competencies in engineering [16]. Investigation of the bias of an individual’s perspective in engineering could also help to gain a more clear view of the field.

The career success model recommended in this paper could be used as a measure for engineering institutions doing curricular development. Using the model would allow institutions to determine the influence their efforts are having on students’ career success. Concrete data such as this would improve the validity of the conclusions made from the theoretical analysis.

Future research could conduct a similar analysis, instead comparing the career competency model to the graduate attributes provided by national accreditation bodies, such as ABET or CEAB. This would provide theoretical insight to the engineering attributes that most enhance career success.

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Professional Engineering Pathways Study

A longitudinal study of early career preparedness and decision-making

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Abstract—This paper introduces the Professional Engineering Pathways Study (PEPS), a three-year study aimed at developing new understandings of early career engineering career preparedness and decision-making. The project takes a national perspective, drawing on data from six partner institutions across the U.S., and focuses specifically on engineering students' experiences, perceptions, and plans as they look toward their initial career steps. The project involves two critical elements. The research element uses a longitudinal, mixed-method approach to examine how engineering students explore, select, and prepare for their chosen careers. The community of practice element focuses on bridging research-to-practice by engaging administrators, faculty, and staff at the six partner institutions in data interpretation and dissemination activities. This research will help drive continuous improvement in engineering programs and universities. Preliminary results of the study will be presented at the conference.

Keywords—college-career transition; preparedness; decision-making; expectancy value theory; cognitive information processing theory; longitudinal; mixed-methods; community of practice

I. INTRODUCTION

U.S. economy needs a diverse and highly qualified engineering workforce, and yet the engineering profession still struggles to attract and retain talent. Fewer than 10 percent of incoming college students in the U.S. pursue engineering as a major [1], and according to data from the National Science Foundation [2], less than half of graduates with engineering as their highest degree pursue careers related to engineering. Concerns about a future shortage of engineers have led to many calls to increase engineering retention, e.g., [3-4]. Yet, these calls often focus on retention in the major or among experienced workers and fail to consider the 30 percent of men and 40 percent of women who leave the field almost immediately after earning undergraduate engineering degrees [5]. To increase retention during the college-career transition, we must learn more about the factors contributing to early

career engineering attrition [6], and particularly, “problematic attrition”. Margolis & Kotys-Schwartz [7] define attrition as problematic if an individual is “pushed away” from engineering by negative experiences and beliefs as opposed to being “pulled away” by other interests or circumstances.

Although literature on the college-career transition of engineers is limited, we can draw on existing literature to inform our inquiry. Several studies have focused on undergraduate students' plans to pursue engineering or non-engineering career options after graduation. For example, Margolis & Kotys-Schwartz [7] explored the decisions of mechanical engineering seniors at a western U.S. institution to pursue engineering careers at graduation and in the future. Ro [8] investigated the plans of engineering sophomores, juniors, and seniors at 31 institutions to pursue six different engineering and non-engineering career options within three years of graduation. Amelink & Creamer [9] identified correlates of long-term engineering career interest among engineering undergraduates at nine institutions. This collective body of research identifies groups of education-related variables that seem to differentiate engineering focused plans from non-engineering plans. These variables include participation in curricular and extracurricular activities such as senior capstone design, co-op/internships, and student organizations for underrepresented groups [7,8], exposure to active/collaborative learning and professional and core engineering skills [8], and positive interactions with engineering instructors, faculty members, and other students [7,9]. Drawing on these findings, we can directly examine how these activities inform students' career decision-making processes.

Our inquiry is also informed by the results of two NSF-funded research studies: the Academic Pathways Study (APS) and the Engineering Pathways Study (EPS). APS was sponsored by the NSF Center for the Advancement of Engineering Education (NSF-ESI-0227558) from 2003 to 2008 for the purposes of studying the undergraduate engineering learning experience. APS was a longitudinal study that

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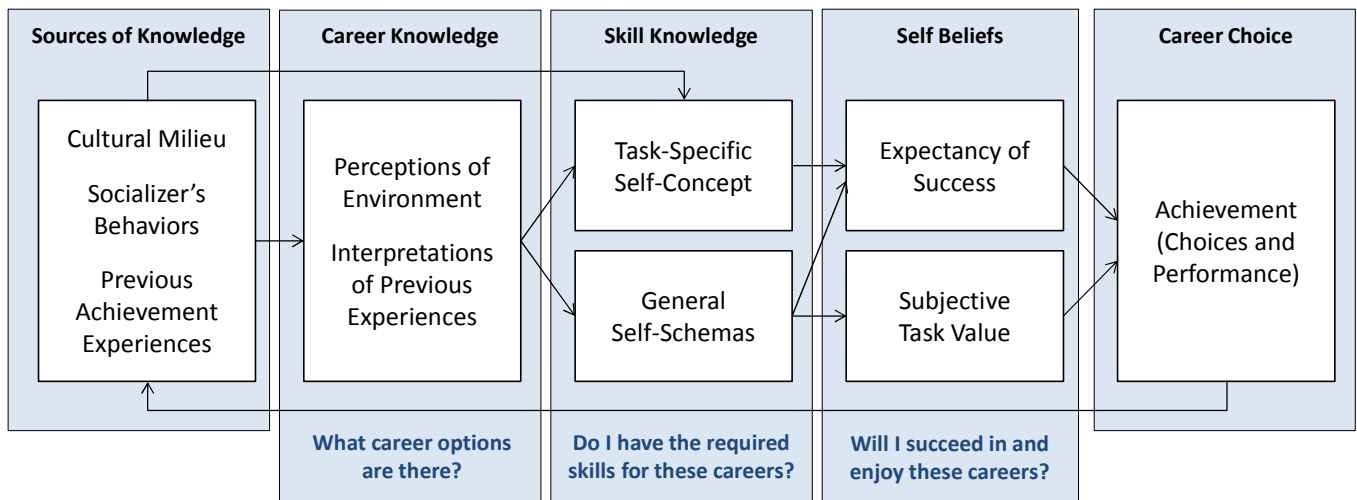


Fig. 1: Professional Pathways Model: Cognitive Information Processing (CIP) Theory [22] as a Lens for Expectancy Value Theory (EVT) [23]

followed cohorts of students across their undergraduate years using qualitative and quantitative data collection [10-11]. EPS was then a continuation study (NSF-DUE-1020678, 1021893, 1022024, 1022090, and 1022644) that examined a sub-set of some of these same participants 4-5 years into their careers [12-14]. Surveys of engineering students and alumni were also conducted as a part of APS and EPS, respectively, for broader sampling [15-16]. Results from EPS showed that 80 percent of early career engineering graduates reported first positions in engineering work [17]. However, results from APS indicate that less than 30 percent of engineering juniors and seniors plan to stay exclusively within engineering fields long-term [18-19]. Within APS and EPS, participation in an engineering co-op/internship and majoring in certain fields differentiated engineering and non-engineering first positions and engineering and non-engineering student plans [17-19]. We also learned through EPS that family, the economy, and other non-school factors can contribute heavily to post-college career plans [20-21].

The APS and EPS studies allowed us to examine experiences broadly across the college-career trajectory. At the same time, we found that a closer look at the college-career transition (college to first job or graduate school) was needed as participants had made significant decisions and changes in careers between college and 4-5 years post-college. Our study follows students directly from college into the postgraduate world enabling us to study how students' first career decisions unfold and which factors become more or less salient to their career decision-making over time. Our study focuses on the three-year period from students' junior year to 1-2 years after earning their bachelor's degrees, as this enables us to explore what happens before and after they graduate. The study takes on a national perspective, drawing on data from six partner institutions across the U.S., and has a specific objective of bridging research findings to practice. To achieve this goal, we designed a two-tiered, mixed-method study with the following sub-goals:

- To investigate how engineering students develop beliefs about their career options and abilities, and how these

beliefs influence their career plans and preparation over time, and

- To engage university administrators, faculty, and staff in using insights into early career decision pathways to improve undergraduate engineering programs and career services.

Anticipated outcomes of our study include a qualitatively rich and quantitatively broad data set on the engineering college-career transition, communities of practice dedicated to improving educational practice at each partner school, and a model for using longitudinal data to inform continuous improvement within engineering schools.

II. THEORETICAL FRAMEWORKS

While several school-related factors (e.g., choice of institution, choice of major, participation in on-campus and off-campus activities) have been linked to engineering students' plans, how these and other factors actively work to influence plans remains largely understudied. Using the Professional Pathways Model (see Figure 1), our goal is to explain how engineering students' experiences and beliefs serve to shape their career goals and actions.

We created the Professional Pathways Model by adapting cognitive information processing (CIP) theory [22] as a lens for expectancy value theory (EVT) [23]. CIP theory describes categories of knowledge that individuals need to make career choices, such as knowledge about what career options exist and what skills these careers require. EVT illustrates how this knowledge is formed (e.g., from cultural representations such as the media, family members and friends, past experiences, etc.) and how it influences individuals' career decision-making (i.e., through expectancies and values). Both theories have shown good results when applied to engineering students, e.g., [24-26].

In parallel with our research effort, we purposefully utilize a community of practice framework [27] to navigate the research-to-practice cycle and disseminate our findings. We will characterize the career "ecosystem" at each of our partner

sites, and then leverage these existing infrastructures to build communities both locally and across schools.

III. STUDY DESIGN

The overall study design is illustrated in Figure 2. The project involves two critical and inter-connected elements, the research element and the community of practice element, each of which are driven by a separate set of questions.

Research Element—For the first time, longitudinal data connecting engineering students’ experiences, beliefs, and career choices will be collected. Through annual surveys and in-depth interviews, we will follow engineering students at six

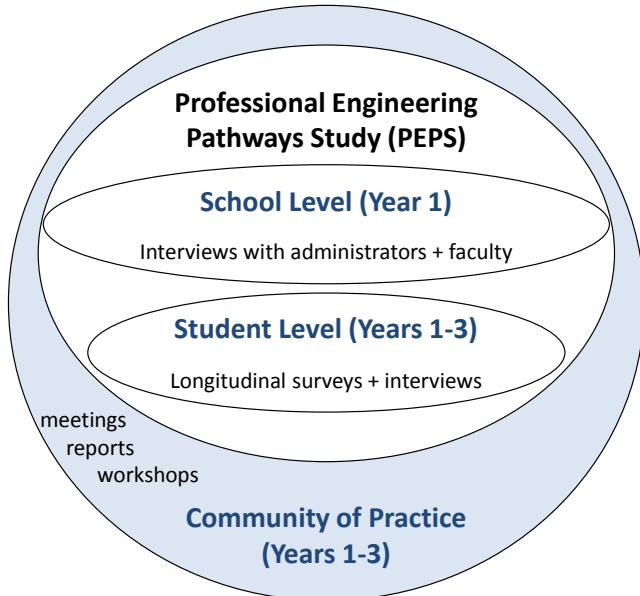


Fig. 2: PEPS Study Design

partner schools, from their junior year to their first 1-2 years post-graduation. These surveys and interviews will be grounded in the Professional Pathways Model and will answer these research questions:

- Career Knowledge: What career options are available to engineering students? How do students develop knowledge of these options?
- Skills Knowledge: What skills and abilities do engineering students need to prepare for, choose, and succeed in their careers? How do students develop knowledge and proficiency in these skills and abilities?
- Career Decision Making: What career goals, values, and expectancies do engineering students have? How do these develop and change over time? What career choices do engineering students make after graduation, and how does their career and skills knowledge affect their decisions?

Data collection at the school level will focus on developing a more complete picture of the career “ecosystems” in which our longitudinal student participants are embedded. This will help us to understand not only what career resources and opportunities are available to students at each partner school,

but also the greater institutional and regional culture in which students are making their career choices. In the first year of the study, we will collect interviews with career services related staff and faculty at each partner institution. These interviews will be supplemented by content analyses of each school’s career services and advising websites.

Community of Practice Element—Findings from the research element of the study will feed directly into the community of practice element. Project results and recommendations will be disseminated back to the partner institutions through annual reports and meetings with our school liaisons, and we will regularly solicit their feedback to support future directions of the project. Working with our partner institutions, we will also determine best practices for broader dissemination and community-building. Using Wenger et al.’s [27] community of practice model as a guide, we will answer the question:

- Educational Impact: How can findings gathered from the research element be used to strengthen the career advising and preparation of engineering students?

Partner Schools—A major aim of our study is to explicate both the personal and the contextual factors which influence engineering students’ career decision-making. The six partner schools in our study were therefore selected for their geographic, institutional, and student diversity. We have two schools each from three different regions in the U.S. (the east coast, the Midwest, and the west coast). We have a mix of public and private schools, as well as predominantly white institutions (PWIs) and schools that serve historically underrepresented groups.

Participants—Table 1 lists the cohorts of participants that will make up PEPS. Also shown are the descriptions, anticipated numbers of participants, and data to be collected for each cohort.

TABLE 1: PEPS STUDY COHORTS

Level	Cohort	Description	Estimated # participants	Data collection
Student	1	Engineering class of 2016	800	longitudinal surveys
	2	Subset of Cohort 1	90	longitudinal interviews
School	3	Career services staff and faculty	18	interviews

In 2014, our six partner schools awarded approximately four thousand undergraduate engineering degrees [28]. Based on this number and our retention rates in the APS and EPS studies, we expect at least 800 engineering students to participate in our survey, from their junior year to 1-2 years post-graduation.

We will also choose 15 students from each school to participate in a longitudinal semi-structured interview. These students will be chosen based on their demographic information and baseline survey responses. We are particularly interested in capturing the stories of underrepresented individuals (e.g., underrepresented racial/ethnic minorities, women, transfer students), for which our institutional sample is particularly well-suited. In addition, we are targeting three

different engineering majors to allow for direct comparability between disciplines: mechanical engineering (ME), electrical engineering (EE), and bio-X (i.e., biological, biomedical) engineering. These majors were selected because students in these majors tend, on average, to pursue different career paths, with ME and EE students among the most likely to pursue engineering focused careers after college and bio-X engineering students among the least likely to [17-19].

Lastly, our third cohort will consist of at least three administrators, faculty, and staff from each partner institution, for a total of 18 across the six schools. These participants will come from university career services, engineering career services, or one of the three majors that we are targeting for this study (i.e., ME, EE, or bio-X engineering). We will interview this cohort as a part of our school-level data collection efforts in Year 1 of the study. We will also invite them to participate in data interpretation and dissemination activities later in the project as part of our community of practice element.

IV. CURRENT STATUS

Interviews of career services related staff and faculty across all six participating schools are in progress. The selection and recruitment of participants were guided by both our web content analyses and recommendations from our school liaisons. All interviews are being audio recorded and transcribed. Transcript analysis will use common qualitative analysis approaches [29-30] to identify pertinent themes by school, by role (e.g., head of career services, faculty, etc.), and by level (e.g., at the institution level, in the major, etc.). These results will be shared with our partner institutions later this year. Design of longitudinal student surveys and interviews will also be underway later this year, aiming for deployment at the six schools in early 2016.

V. PRELIMINARY FINDINGS

Our preliminary findings are based on interviews with faculty and administrators at two of our partner sites. We found that the focus of the career services and advising offered to students can vary across institutions which has necessitated having a nimble and reactive data collection protocol. For example, one site uses high student contact means (e.g., seminars, career fairs, and one-on-one meetings) to support student career search goals at an institutional-level, while career services at another site consists mainly of individual departments directing students to resources if and when students request help. Preliminary findings support our intended plan of using six institutions of various types and sizes so that we can compare and contrast across cases.

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Assessment of a Cooperative Training Course using Faculty Course Assessment Report in an ABET Accredited Engineering Technology Program

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Abstract—The electrical and electronics engineering technology (EEET) associate degree program at Hafr Al-Batin Community College (HBCC) located in the Kingdom of Saudi Arabia (KSA) got accredited recently by the engineering technology accreditation commission (ETAC) of ABET. In this paper, we have described in detail our experiences of using the faculty course assessment report (FCAR) methodology for the direct and indirect assessment of both course learning outcomes (CLO's) and ABET student outcomes (SO's) supported by the cooperative (co-op) training (EEET 290) course in the EEET unit at HBCC. Furthermore, the paper demonstrates how the student's evaluation by his supervisor is also taken into account while assessing both the EEET 290 CLO's and its respective ABET SO's using the FCAR tool. In addition, we have also analyzed the student's self-evaluation of his co-op training experience. Moreover, we have also compared the co-op training given to our students by Saudi Aramco, Saudi Electricity Company (SEC), and Saudi Telecom Company (STC). In this comparison, we have highlighted some strengths and weaknesses of the co-op training offered by these companies. Finally, the results of our analysis are used to propose actions for the continuous improvement of co-op training course in the EEET program at HBCC.

Keywords—ABET accreditation, assessment, cooperative (co-op) training, course learning outcomes (CLO's), engineering technology program, faculty course assessment report (FCAR), student outcomes (SO's).

I. INTRODUCTION

The faculty course assessment report (FCAR) [1]–[3] is a streamlined assessment methodology that allows course instructors to write assessment reports in a concise and standardized format conducive for use in both ABET General Criteria 3 & 4 for accrediting engineering technology programs [4]. The electrical and electronics engineering technology (EEET) associate degree program at Hafr Al-Batin Community College (HBCC) passed the ABET accreditation process [5] by adopting the FCAR as the primary tool for the assessment of both course learning outcomes (CLO's) and ABET student outcomes (SO's). Implementation of the FCAR tool in the

EEET unit at HBCC has served as an effective way for the continuous improvement of all the courses offered by the unit.

The cooperative (co-op) training course is an integral part of the EEET program at HBCC and has the highest number of credit hours as compared to other courses in the EEET program. The co-op training course contributes to 6 credit hours and is coded as EEET 290. The current requirement for enrollment in the co-op training course is that students must have completed at least 48 credit hours and must have maintained a cumulative major grade point average (GPA) of at least 2 [6]. The EEET students at HBCC undergo their co-op training in companies such as Saudi Electricity Company (SEC), Saudi Telecom Company (STC), Saudi Aramco, Saudi Basic Industries Corporation (SABIC), Ma'aden, Schlumberger, Halliburton, etc. Co-op students get trained for a period of one semester (15 weeks) in the industry working in any of the fields of electrical and electronics. The students are required to submit progress reports, final report, and make a presentation at the end of their co-op training.

In our previous paper [7], we had discussed the usage of the FCAR tool for the assessment of both CLO's and ABET SO's supported by the microcontroller applications (EEET 209) course. We had also demonstrated “closing the loop” process for the EEET 209 course using the FCAR tool. In this paper, we discuss how the FCAR tool was customized to analyze the sample data of 3 co-op students from the EEET unit during the spring semester of the academic year 2013–2014 at HBCC. We have also analyzed supervisors' evaluations of co-op students during their training period. This paper also presents a comparison of the co-op training given to our students by Saudi Aramco, SEC, and STC.

The rest of this paper is organized as follows. The CLO's of the EEET 290 course and their assessment methods are discussed in Section II. The grade distribution for the EEET 290 course is presented in Section III. The direct and indirect assessment of both the EEET 290 CLO's and its respective ABET SO's are described in Sections IV & V, respectively. Modifications made to the EEET 290 course and proposed

actions for the EEET 290 course improvement are discussed in Sections VI & VII, respectively. A comparison of co-op training programs of 3 companies is presented in Section VIII. Finally, we conclude our paper in Section IX.

II. EEET 290 CLO'S AND THEIR ASSESSMENT METHODS

We have analyzed the assessments of 3 co-op students for the EEET 290 course during the spring semester (Semester 132) of the academic year 2013–2014 at HBCC. Students 1 & 2 underwent their co-op training at SEC branch in Hafr Al-Batin city under the same supervisor, while student 3 underwent his co-op training at STC branch in Hafr Al-Batin city. All 3 students were assigned different faculty advisors. The co-op students received an orientation session from their respective faculty advisors before the commencement of their training period. During the orientation session, co-op students were advised to spend 40 hours per week (8 hours per day for 5 working days) during their training period. The students were also informed about the due dates to turn in their progress reports, final report, etc. Moreover, the students were also provided with sample copies of all the assessment activities, formatting guidelines, etc. The faculty advisors were also encouraged by the college to arrange company visits. These visits enabled the faculty advisors to check the progress of their students and also meet with their respective supervisors. Furthermore, the co-op students data for different assessment activities such as progress reports, final report, and PowerPoint presentation was collected and graded by their respective faculty advisors. This data together with supervisors' evaluations was then used for the direct assessment of both the EEET 290 CLO's and its respective ABET SO's as described in Section IV.

The CLO's of the co-op training course are listed in Table I. As can be seen from this table, the EEET 290 CLO's focus on the communication, presentation, surveying, technical, and writing skills acquired by the co-op students. CLO's focusing on other skills can be added in the future as a part of the continuous improvement process.

TABLE I. EEET 290 CLO's.

CLO #	Course Learning Outcome
CLO 1	Survey the literature related to your co-op training program.
CLO 2	Develop an ability to communicate clearly and effectively.
CLO 3	Prepare your co-op reports clearly and concisely.
CLO 4	Prepare and explain your co-op PowerPoint presentation.

The mapping of EEET 290 CLO's to ABET SO's is shown in Table II. As can be seen from this table, the EEET 290 CLO's have been mapped to two ABET SO's, namely, (d) & (f). We notice that a majority of the EEET 290 CLO's assess ABET SO (f). ABET SO's (d) & (f) are defined in [4].

TABLE II. MAPPING OF THE EEET 290 CLO's To ABET SO's.

CLO #	a	b	c	d	e	f	g	h	i
CLO 1						✓			
CLO 2				✓					
CLO 3						✓			
CLO 4						✓			

Tables III & IV show the distribution of marks for supervisors' evaluations of co-op students during the first and second

halves of their training periods, respectively. These marks are kept confidential from the students by their respective supervisors and are mailed directly to the co-op coordinator at the college. The co-op coordinator hands over the supervisors' evaluations to the respective faculty advisors. As can be seen from these tables, the supervisors evaluate their respective co-op students based on a list of 10 professional traits. These professional traits are selected by the faculty advisors. It is likely that these supervisors' evaluations may not be reliable and may be affected by a leniency bias [8].

TABLE III. DISTRIBUTION OF MARKS FOR SUPERVISORS' EVALUATIONS OF CO-OP STUDENTS DURING THE FIRST HALF OF THEIR TRAINING PERIOD (SE 1).

Trait	Student 1	Student 2	Student 3
Attendance and Punctuality	1	0.5	1
Attitude	1	1	1
Communication Skills	1	0.5	1
Dedicated	1	1	1
Dependable	1	1	1
Diligent	1	1	1
Motivated	1	1	1
Reliable	1	1	1
Responsible	1	1	1
Self-Disciplined	1	1	1
Total Marks Scored	10	9	10

TABLE IV. DISTRIBUTION OF MARKS FOR SUPERVISORS' EVALUATIONS OF CO-OP STUDENTS DURING THE SECOND HALF OF THEIR TRAINING PERIOD (SE 2).

Trait	Student 1	Student 2	Student 3
Attendance and Punctuality	0.5	0.5	1
Attitude	1	1	1
Communication Skills	1	0.5	1
Dedicated	0.5	1	1
Dependable	1	1	1
Diligent	1	1	1
Motivated	1	1	1
Reliable	1	1	1
Responsible	1	1	1
Self-Disciplined	1	1	1
Total Marks Scored	9	9	10

The abbreviations used in Tables III–XIV are as follows: PR 1 is progress report 1, SE 1 is supervisor evaluation 1, max. is maximum, avg. is average, intro. is introduction, concl. is conclusion, FR is final report, Q&A is questions and answers, and PPT is PowerPoint presentation. In Tables V–VIII, the EAMU is a performance vector with the following four categories [3], [9]: E is for exemplary with a point value of 3, A is for adequate with a point value of 2, M is for minimal with a point value of 1, and U is for unsatisfactory with a point value of 0. Based on the feedback received from the previous FCAR's and depending on the quality of co-op students in the EEET unit, we have set a uniform metric goal of 2 for all the CLO's of the EEET 290 course. In other words, during Semester 132, we were aiming to achieve an adequate level of performance by the co-op students in each of the CLO's of the EEET 290 course.

Table V shows the marks obtained by each of the 3 co-op students in the progress reports and supervisors' evaluations. Tables VI & VII show the marks obtained by each of the 3 co-op students in the final report and PowerPoint presentation, respectively. The maximum marks row vector in Tables V–VII and Table X contains the maximum marks for the corresponding item in the respective column. For example, in Table V,

PR 1 & 2 in the maximum marks row vector are for 10 marks each, while PR Total in the maximum marks row vector shows the combined maximum marks for both the progress reports.

TABLE V. DISTRIBUTION OF MARKS FOR PROGRESS REPORTS AND SUPERVISORS' EVALUATIONS.

Student #	PR 1	PR 2	SE 1	SE 2	PR Total	SE Total
Student 1	7	9	10	9	16	19
Student 2	6	7.5	9	9	13.5	18
Student 3	6	8	10	10	14	20
Max. Marks	10	10	10	10	20	20
E	0	0	2	1	0	2
A	0	2	1	2	1	1
M	3	1	0	0	2	0
U	0	0	0	0	0	0
Avg.	1	1.67	2.67	2.33	1.33	2.67

TABLE VI. DISTRIBUTION OF MARKS FOR FINAL REPORT.

Student #	Intro.	Relevancy	Format	Concl.	FR Total
Student 1	10	8.5	8.5	8	35
Student 2	9	8	10	7	34
Student 3	10	10	8	9	37
Max. Marks	10	10	10	10	40
E	2	1	1	0	1
A	1	2	2	2	2
M	0	0	0	1	0
U	0	0	0	0	0
Avg.	2.67	2.33	2.33	1.67	2.33

TABLE VII. DISTRIBUTION OF MARKS FOR POWERPOINT PRESENTATION.

Student #	Intro.	Clarity	Depth	Concl.	Q&A	PPT Total
Student 1	5	4	3	4	4	20
Student 2	4	4	3.5	4	3.5	19
Student 3	5	5	4.5	3.5	4	22
Max. Marks	5	5	5	5	5	25
E	2	1	0	0	0	0
A	1	2	1	2	2	3
M	0	0	2	1	1	0
U	0	0	0	0	0	0
Avg.	2.67	2.33	1.33	1.67	1.67	2

In Table VIII, the EAMU vector ranges are shown for progress reports, supervisors' evaluations, final report, and PowerPoint presentation. The EAMU vector ranges are decided by the faculty advisors. In Table VIII, range 1 is for the different components of PowerPoint presentation like intro., clarity, etc., range 2 is for PR 1 & 2, SE 1 & 2, and the different components of final report like intro., relevancy, etc., range 3 is for PR Total and SE Total, range 4 is for PPT Total, and range 5 is for FR Total. The EAMU vectors in Tables V–VII are determined by counting the number of students whose assessment marks fall in the respective range category shown in Table VIII. For example, in PR 1 column (see Table V) the marks scored by all 3 students fall in the range we have set for M (see range 2 column in Table VIII). Therefore, the EAMU vector for PR 1 is (0, 0, 3, 0), respectively. Now, the average of the EAMU vector for PR 1 is calculated as shown below:

$$\text{Average} = \frac{0 * 3 + 0 * 2 + 3 * 1 + 0 * 0}{\text{Total number of students}} = 1, \quad (1)$$

where 3, 2, 1, & 0 are the point values of E, A, M, & U, respectively.

III. EEET 290 COURSE GRADE DISTRIBUTION

In this section, we discuss the distribution of grades and the calculation of GPA for the EEET 290 course. The weightage

TABLE VIII. EAMU VECTOR RANGES FOR THE EEET 290 COURSE ASSESSMENTS.

Vector	Range 1	Range 2	Range 3	Range 4	Range 5
E	4.6 to 5	9.1 to 10	18.6 to 20	22.6 to 25	35.1 to 40
A	3.6 to 4.5	7.6 to 9	15.1 to 18.5	17.6 to 22.5	27.6 to 35
M	2.6 to 3.5	5.1 to 7.5	10.1 to 15	12.6 to 17.5	20.1 to 27.5
U	0 to 2.5	0 to 5	0 to 10	0 to 12.5	0 to 20

assigned to each assessment of the EEET 290 course, as shown in Table IX, is decided by all the faculty advisors and is subjected to revision on a timely basis. The lower and upper ranges for each letter grade are the same for all the EEET courses and are shown in Table XIV in [7].

TABLE IX. ASSESSMENT POLICY FOR THE EEET 290 COURSE.

Assessment	Weightage
PR 1	10%
PR 2	10%
SE 1	7.5%
SE 2	7.5%
FR	40%
PPT	25%
Total	100%

The weighted total marks in Table X are obtained by calculating the total marks scored by each student in different assessment activities such as progress reports, supervisors' evaluations, etc., and then scaling down by their respective weightages as shown in Table IX. Note that the maximum marks for SE 1 & 2 in Table V are not the same as those in Table X. This is not a discrepancy. The maximum marks for SE 1 & 2 in Table X are the actual maximum marks assigned by the faculty advisors for supervisors' evaluations as shown in Table IX. Marks obtained by the students for SE 1 & 2 in Table V have been scaled down to 7.5 and then entered in Table X for determining their respective letter grades.

TABLE X. WEIGHTED TOTAL MARKS FOR EACH ASSESSMENT OF THE EEET 290 COURSE.

Student #	PR 1	PR 2	SE 1	SE 2	FR	PPT	Total
Student 1	7	9	7.5	6.75	35	20	85.25
Student 2	6	7.5	6.75	6.75	34	19	80
Student 3	6	8	7.5	7.5	37	22	88
Max. Marks	10	10	7.5	7.5	40	25	100

The distribution of grades for the EEET 290 course is shown in Table XI. As can be seen from Tables X–XI & Table XIV in [7], students 1 & 3 got B+, and student 2 got B. Finally, the GPA for the EEET 290 course is calculated as shown below:

$$\text{GPA} = \frac{Q}{N} = \frac{10}{3} = 3.33, \quad (2)$$

where Q denotes the quality points as defined in [7] and N is the total number of students in Table XI.

IV. DIRECT ASSESSMENT OF BOTH THE EEET 290 CLO'S AND ITS RESPECTIVE ABET SO'S

In this section, we describe how the average EAMU scores obtained from Tables V–VII in Section II were utilized for the direct assessment of both the EEET 290 CLO's and its respective ABET SO's.

TABLE XI. DISTRIBUTION OF GRADES FOR THE EEET 290 COURSE.

Grade	Number of Students
A+	0
A	0
B+	2
B	1
C+	0
C	0
D+	0
D	0
F	0
Total (N)	3

Table XII shows the mapping of EEET 290 CLO's to ABET SO's using the average EAMU scores obtained from Tables V–VII in Section II. For the sake of simplicity, we have used any one assessment for each CLO except CLO 2, wherein, we have considered both the evaluations by the supervisor as can be seen from Table XII. For example, we have selected SE Total, which is found to assess CLO 2. The average EAMU score for SE Total (2.67) obtained from Table V is entered for CLO 2 in Table XII.

TABLE XII. MAPPING OF THE EEET 290 CLO's TO ABET SO's USING AVERAGE EAMU SCORES (DIRECT ASSESSMENT).

CLO #	a	b	c	d	e	f	g	h	i
CLO 1						PR 1: 1			
CLO 2				SE Total: 2.67					
CLO 3						FR Total: 2.33			
CLO 4						PPT Total: 2			
Avg. EPAN	0	0	0	2.67	0	1.78	0	0	0

In Tables XII & XIV, the EPAN is a performance vector with the following four categories [3], [9]: E is for excellent with a point value of 3, P is for proficient with a point value of 2, A is for apprentice with a point value of 1, and N is for novice with a point value of 0. Based on the feedback received from the previous FCAR's and depending on the quality of co-op students in the EEET unit, we have set a uniform metric goal of 2 for all the ABET SO's supported by the EEET 290 course. In other words, during Semester 132, we were aiming to achieve a proficient level of performance by the co-op students in each of the ABET SO's supported by the EEET 290 course. The average EPAN scores in Table XII are calculated by taking the average of all EAMU scores in the respective columns.

Figures 1–4 illustrate the direct assessment of both the EEET 290 CLO's and its respective ABET SO's. Figure 1 shows a plot of the average EAMU scores obtained from Table XII with respect to the EEET 290 CLO's. As can be seen from Figure 1, we have achieved an adequate level of performance by the co-op students in all the EEET 290 CLO's except CLO 1. Figures 2 & 3 show the plots of the average EAMU scores obtained from Table XII with respect to the EEET 290 CLO's supporting ABET SO's (d) & (f), respectively. Figure 4 shows a plot of the average EPAN scores obtained from Table XII with respect to the ABET SO's supported by the EEET 290 course. As can be seen from Figure 4, we have achieved a proficient level of performance by the co-op students in only ABET SO (d) supported by the EEET 290 course.

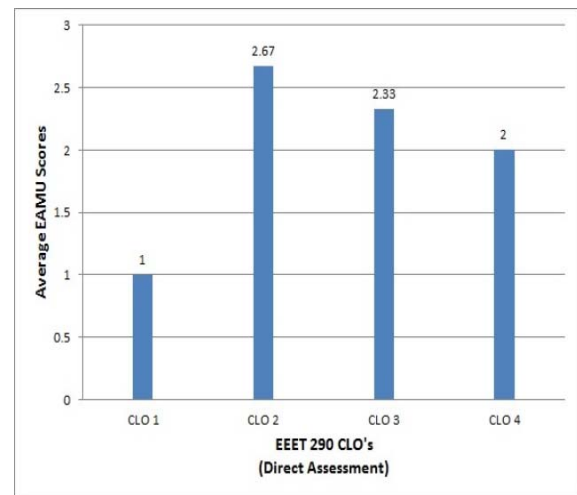


Fig. 1. Average EAMU Scores For All The CLO's Of The EEET 290 Course Obtained From Direct Assessment.

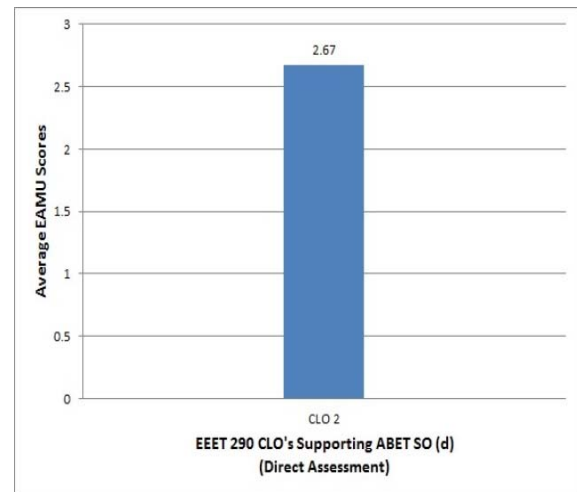


Fig. 2. Average EAMU Scores For The EEET 290 CLO's Mapped To ABET SO (d) Obtained From Direct Assessment.

V. INDIRECT ASSESSMENT OF BOTH THE EEET 290 CLO'S AND ITS RESPECTIVE ABET SO's

In this section, we describe how the data obtained from the co-op students self-evaluations of the EEET 290 CLO's as shown in Table XIII was utilized for the indirect assessment of both the EEET 290 CLO's and its respective ABET SO's.

The co-op students self-evaluations of the EEET 290 CLO's as shown in Table XIII was conducted at the end of their co-op training by their respective faculty advisors. A self-evaluation of the EEET 290 CLO's provides an opportunity for the co-op students to evaluate their level of accomplishment of CLO's. In Table XIII,

- 4 is strongly agree,
- 3 is agree,
- 2 is neutral,
- 1 is disagree, and
- 0 is strongly disagree.

The scaled averages in Table XIII are calculated as described in

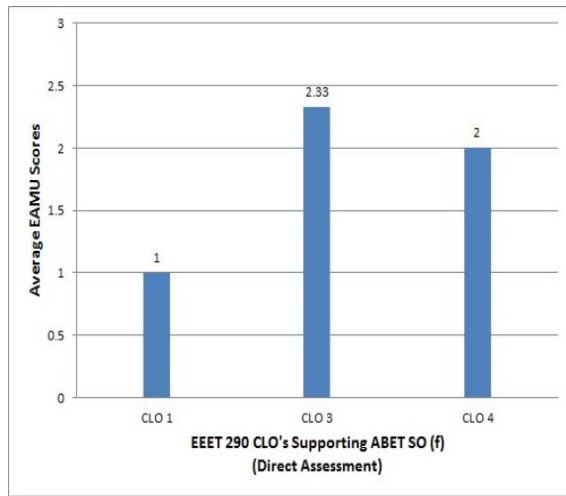


Fig. 3. Average EAMU Scores For The EEET 290 CLO's Mapped To ABET SO (f) Obtained From Direct Assessment.

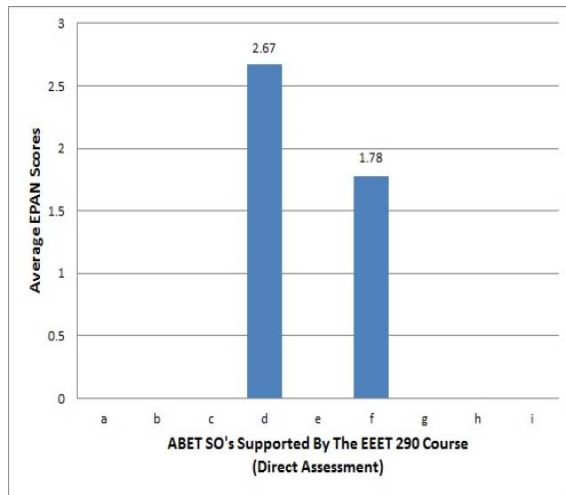


Fig. 4. Average EPAN Scores For The ABET SO's Supported By The EEET 290 Course Obtained From Direct Assessment.

[7]. As expected, the indirect assessment of both the EEET 290 CLO's and its respective ABET SO's is not reliable because all students tend to either agree or strongly agree that they have accomplished the CLO's, as can be seen from Table XIII.

TABLE XIII. CO-OP STUDENTS SELF-EVALUATIONS OF THE EEET 290 CLO's.

CLO #	4	3	2	1	0	Scaled Avg.
CLO 1	1	2	0	0	0	2.49
CLO 2	2	1	0	0	0	2.75
CLO 3	3	0	0	0	0	3.00
CLO 4	2	1	0	0	0	2.75

Table XIV shows the mapping of the EEET 290 CLO's to ABET SO's using the scaled averages obtained from Table XIII. Figure 5 shows a plot of the average EPAN scores obtained from Table XIV with respect to the ABET SO's supported by the EEET 290 course. As can be seen from Figure 5, we have achieved a proficient level of performance by the co-op students in both the ABET SO's supported by the EEET 290 course. As can be seen from Figures 4 & 5, the average

EPAN scores for ABET SO (f) do not match.

TABLE XIV. MAPPING OF THE EEET 290 CLO's TO ABET SO's USING SCALED AVERAGES OBTAINED FROM TABLE XIII (INDIRECT ASSESSMENT).

CLO #	a	b	c	d	e	f	g	h	i
CLO 1						2.49			
CLO 2				2.75					
CLO 3						3.00			
CLO 4						2.75			
Avg. EPAN	0	0	0	2.75	0	2.74	0	0	0

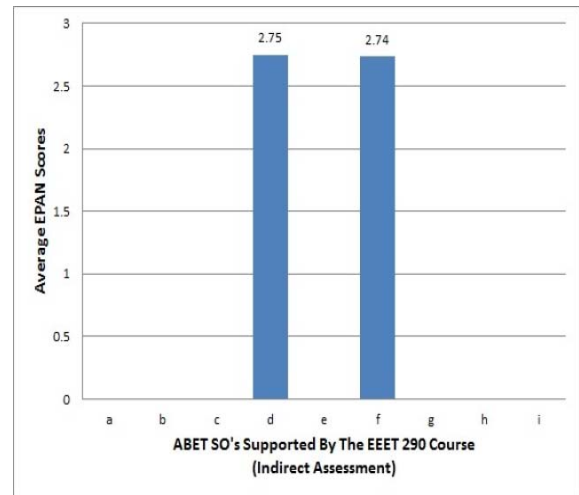


Fig. 5. Average EPAN Scores For The ABET SO's Supported By The EEET 290 Course Obtained From Indirect Assessment.

Finally, the co-op students evaluations of academic preparation, faculty advisors, supervisors, co-op trainings, and co-op organizations are shown in Table XV and Figure 6. From Figure 6, it is easy to determine the ratings for academic preparation, faculty advisors, etc., for each student. This determination of rating for each item of each student was not possible from Table XV.

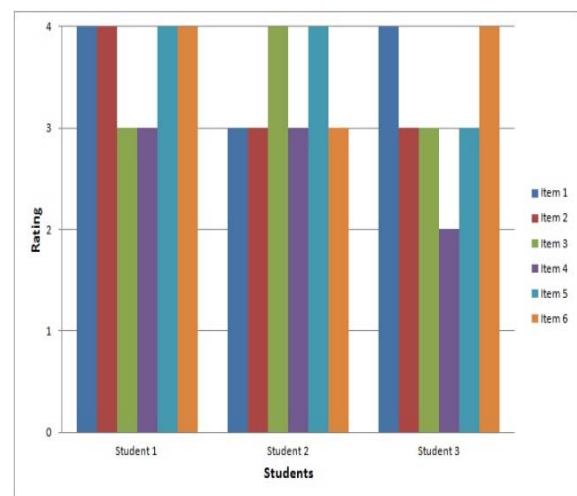


Fig. 6. Co-op Students Evaluations Of Academic Preparation, Faculty Advisors, Supervisors, Co-op Trainings, And Co-op Organizations.

TABLE XV. CO-OP STUDENTS EVALUATIONS OF ACADEMIC PREPARATION, FACULTY ADVISORS, SUPERVISORS, CO-OP TRAININGS, AND CO-OP ORGANIZATIONS.

Sl. #	Item	4	3	2	1	0
1.	The academic preparation for my co-op training was adequate.	2	1	0	0	0
2.	I received adequate communication from my co-op faculty advisor.	1	2	0	0	0
3.	My supervisor adequately explained my responsibilities.	1	2	0	0	0
4.	My supervisor was always available when I needed assistance.	0	2	1	0	0
5.	My co-op training was closely related to my career interests.	2	1	0	0	0
6.	I would like to recommend this organization for future co-op students.	2	1	0	0	0

VI. MODIFICATIONS MADE TO THE EEET 290 COURSE

The below modifications were made to the EEET 290 course during the spring semester of the academic year 2013–2014 after reviewing the proposed actions section of its FCAR from the fall semester of the same academic year. This demonstrates “closing the loop” process for the EEET 290 course.

- CLO 1 focusing on the surveying skills acquired by the co-op students was introduced and assessed.
- The weightages assigned for the final report and PowerPoint presentation assessments were swapped.
- Indirect assessment of both the EEET 290 CLO's and its respective ABET SO's was done by utilizing the data obtained from the co-op students self-evaluations of the EEET 290 CLO's.

VII. PROPOSED ACTIONS FOR THE EEET 290 COURSE IMPROVEMENT

First, it is proposed to reduce the number of credit hours of the EEET 290 course from 6 to 3. This proposal is made because the number of credit hours for the co-op training course in five other similar ABET accredited programs in the Kingdom's colleges is 3. For the remaining 3 credit hours, the EEET unit at HBCC can consider introducing a project work course, thus keeping the same number of total credit hours required for the EEET associate degree program.

Second, it is proposed to conduct only one evaluation by the supervisor with a weightage of 7.5% for the entire co-op training period. This proposal is made because the supervisors' evaluations may not be reliable.

Third, it is proposed that the students turn in weekly reports for all 15 weeks of their training period. In these weekly reports, the students will be advised to briefly list all of the co-op training related activities carried out by them during their training weeks. Also, all the weekly reports must be reviewed, signed, and stamped by their respective supervisors. The students will be advised to e-mail their given weekly report during the subsequent week to their respective faculty advisors. These weekly reports will be assigned a weightage of 7.5% in the assessment policy for the EEET 290 course.

Fourth, it is proposed to share the co-op students evaluations of academic preparation, faculty advisors, supervisors, co-op trainings, and co-op organizations from Table XV and Figure 6 with their respective supervisors. This will help the supervisors to continuously improve themselves.

Finally, it is proposed to organize an orientation seminar focusing on CLO 1 for the next batch of co-op students. This

proposal is made as we did not achieve an adequate level of performance in CLO 1 by the co-op students we have analyzed in this paper.

VIII. COMPARISON OF CO-OP TRAINING PROGRAMS

In this section, we present a comparison of the co-op training given to our students by Saudi Aramco, SEC, and STC. Note that no HBCC EEET students underwent their co-op trainings at Saudi Aramco during the spring semester of the academic year 2013–2014. However, the co-op training program of Saudi Aramco is compared with that of SEC and STC based on our prior experiences.

A. Saudi Aramco

1) Strengths:

- The co-op training program is well planned and organized.
- The co-op training program matches well with the academic preparation.
- The co-op students are under close supervision throughout their training period.

2) Weaknesses:

- There are no case studies included in the co-op training program for associate degree EEET students.
- There are not many employment opportunities available for HBCC EEET graduates.

B. SEC

1) Strengths:

- There is an excellent match between the co-op training program and academic preparation.
- Employment opportunities are available for HBCC EEET graduates.

2) Weaknesses:

- The co-op training program is not well planned and organized.
- The co-op students are not under close supervision throughout their training period.
- There are no case studies included in the co-op training program for associate degree EEET students.

C. STC

1) Strengths:

- Employment opportunities are available for HBCC EEET graduates.

2) Weaknesses:

- The co-op training program is not well planned and organized.
- The co-op training program does not match well with the academic preparation.
- The co-op students are not under close supervision throughout their training period.
- There are no case studies included in the co-op training program for associate degree EEET students.

IX. CONCLUSIONS

As a result of this study, the following conclusions can be drawn:

- In the direct assessment of the EEET 290 CLO's we observed that the co-op students performed at an adequate level in all the EEET 290 CLO's except CLO 1.
- In the direct assessment of the ABET SO's supported by the EEET 290 course we observed that the co-op students performed at the proficient level in only ABET SO (d).
- As expected, the indirect assessment of both the EEET 290 CLO's and its respective ABET SO's is not reliable.
- Proposed actions from the FCAR of the fall semester of the academic year 2013–2014 were implemented during the spring semester of the same academic year, thus demonstrating “closing the loop” process for the EEET 290 course.
- It is recommended that the companies operating in Saudi Arabia design their co-op training programs in consultation with the respective faculty advisors in the Saudi universities and colleges.
- It is recommended that the co-op supervisors in companies operating in Saudi Arabia undergo training on co-op supervision.
- It is recommended that at least one case study is included in the co-op training program for each associate degree EEET student.
- Finally, we propose not to send our future students for co-op training at STC because of a mismatch between their co-op training program and EEET associate degree program at HBCC.

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Is this thing on? Determining Comfort Level with Communication Skills in a Technical Discipline

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Abstract— Students with a technology focus often express and demonstrate that they find it difficult to communicate their ideas and designs. Students in the Rochester Institute of Technology's School of Interactive Games and Media are further challenged in that in order to be successful in their pursuit of a career in game design and development, they need to effectively convey their game ideas and design specifications while expressing the passion for the ideas that will convince others to climb on board and work on their projects. In this paper, we discuss the way we help our students develop these skills within a course structure. Through several course offerings, the faculty and students anecdotally noted that the students communication skills improved and their comfort in communication improved as well. In order to more accurately determine if this observed improvement was measurable, a survey of comfort with communication skills was created. The paper will present the results of an exploratory study using the instrument, which involved administering the survey to the students in the course as well as students in another course without a focus in development of these skills. The results from both sets of students were analyzed to determine if there was an increase in comfort with communication skills and to begin a process of validating this new instrument.

Keywords— *communication skills; professional skills; game production*

I. INTRODUCTION

Today's students in technical fields must navigate several challenges to be successful within the workplace. Along with a command of technical skills and the ability to be adaptable as technology changes, students of the technical discipline must also be adept at skills such as verbal and written communication. Although this statement is not revolutionary, technical disciplines are becoming increasingly reliant upon collaboration and teamwork. In the past, employees with extreme technical skill could sometimes be considered "exempt" from interacting with their colleagues. Today's reality is that most employers can no longer tolerate a mindset of isolated productivity. Employees must be able to present their ideas in a convincing manner, and must be skilled in the arts of presentation, persuasion, critique, and mediation.

Although this has been a pervasive problem, educators are still challenged in the classroom to provide learning experiences that focus upon communication skills in a convincing context. However, we often make such exercises

peripheral to the technical content, often separating the technical creation and the essential communication tasks such as ideation, presentation, and documentation. Such tasks are only a minor component of technical assignments, with the occasional course requiring a culminating communications-based project, such as an end-of-term report or a final presentation. Even in such cases, these tasks are a portion of the assessment and often have a marginal impact on the overall assignment assessment.

Today's challenge addresses the question of how to we actually create authentic technical and educational processes and practices that allow faculty to explore successful and even unsuccessful communication and interaction patterns with students. Furthermore, how do we move beyond treating communication skills as an extra and separate component to the technical work?

To help frame this exploration, there are two basic levels: finding means to determine levels of communication comfort in learners and finding means to link technical and communication educational outcomes in course design. This paper addresses our initial results in exploring the first task – comfort level with communication skills in a technical discipline.

II. BACKGROUND

Communication skills in general have been recognized as important for some time. ABET gives specific focus for such skills in applied science, computing and engineering programs as a desired course and program outcome [1][2][3]. Given the importance, there are several approaches to including these skills in the curriculum. Institutions readily recognize the importance and have developed approaches that best work for them and their curriculum and students.

A. Integrating Communication throughout the Curriculum

The PITCH program [4] aimed to integrate communication skills for engineering and computer science undergraduate students throughout the entire curriculum. This program focused on multiple aspects of communication that include written documents, poster presentations, oral presentations, and design reports. The students were given various types of assignments throughout their four years. The faculty focused on making rubrics and samples available to the students ahead

of time as a means of instruction on proper communication techniques.

At SUNY Oswego, communication skills were integrated in the curriculum by adding a required technical writing course and adding elements to other courses (e.g. reports, presentations) as well as adding a multi-disciplinary team aspect to some team projects [5].

In Australia, Falkner and Falkner also touted the advantages of integration across the curriculum and actually propose a methodology by which others can design communication skills curricula [6].

B. Taking outside courses

Although not as popular, some institutions require one or more additional outside courses for their students. For the Information Technology department at University of Cincinnati, the students are required to complete specific communication courses. The senior design capstone for these students is viewed as a culminating experience where they bring the communication pieces and their IT curricula together [7].

C. Communications Course within Curriculum

Still another approach is to create a stand-alone communications course inside the technical curriculum. University of Toronto did this with their "Communication Skills for Computer Scientists" course [8]. This course focused on writing, speaking, and interpersonal communication. Students were asked to deliver a number of speeches throughout the term ranging in duration from 60 seconds to 5 minutes. Within these assignments, they were asked to describe information from a graph or chart, participate in a mock interview, and to present a topic of interest. They were coached through this process; videos of the speeches were posted online for comment and critique by instructor and student alike.

In [9], we see another instance of a course within the department created for introducing communication skills that focused on writing and oral skills through the use of lab sessions. At the end of his paper, Lawrence argues that one course is simply not enough and that integration of communication skills throughout the curriculum is better.

D. Specific component within a course

Some institutions have yet to find ways to integrate communication skills fully throughout their curriculum. Instead, they find success integrating one or two aspects into an already existing course, rather than creating an entire course devoted to the topic.

At Andrews University, technical writing and oral communication practice are integrated in the entire first year of engineering courses. Tasks include the writing of reports and giving of multiple presentations with feedback [10].

At Denison University, computer science and mathematics students focus on communication skills in their sophomore year. While enrolled in specific courses within their major, the

two groups are brought together once a week for a lab. During the course of the term in this lab session, students presented three talks on topics in math or computer science which are peer reviewed by other students. They are also asked to self-critique their presentations and to critique talks outside the course (departmental talks or campus-wide talks). Survey results indicated that they are now more at ease presenting math or computer science material in front of an audience and have increased willingness to present their talks at the department, regional, or national level [11].

At Roger Williams University, they focused on enhancing oral communication skills by asking students to extemporaneously talk about a random topic for three minutes once a week. The talk stops at the end of three minutes or when the presenter uses a distractor ('um', 'ah', or long pauses without speech). Though these talks are not formally assessed, it is noted that there is improvement in student performance in presentations within other courses [12].

A multi-institutional effort was described in [13] for integrating communication skills into a data structures and algorithms class. This course was typically taught in the second year of the curriculum. Writing, speaking, reading, listening, and teaming were focused on through various assignments. Students were asked before and after to rate their ability in reading, writing, speaking, and teaming. Students rated themselves more positively at the end than at the beginning, but the authors do not indicate whether those increases are of statistical significance.

Bennett and Urness describe a CS1 course that used daily student presentations as a way to address communication skills at the introductory level [14]. Students select topics for these presentations, which allowed for greater coverage of breadth of computing topics than a typically programming-focused CS1 course. The presentations were only a few minutes in length and generally students provided interesting presentations. The authors studied student change in attitude toward computing, but not communication skills. Anecdotally, the instructors indicate that they see improvement in student's skills.

For a junior-level course in object-oriented programming at King's College, peer evaluated oral presentations have been added [15]. Michael observed that the student participation (in the peer evaluation process) made them more invested in the presentations as a whole. He notes, however, the interesting range of opinions (across the spectrum of positive and negative feedback) about certain presentations that were collected from the peer evaluation forms.

In [16], we see the use of a student-centered model with problem-based learning and peer assessment to tackle the problem of developing communication skills. The students developed writing skills through the use of wikis and oral presentation skills via poster presentations. The authors of the study report that students enjoyed the wiki assignments. The authors believe this is because they were not traditional writing assignments (e.g. reports). For the poster presentations, the authors discuss how they provided feedback and allowed students to improve by asking them to present multiple times, iterating on their ideas each time.

E. Assessment of communication skills

In [17], a focus group study was employed to look at engineering students' beliefs about their learning of communication skills. While the focus group asked about communication in general, the participants focused on writing as the main form of communication in their responses. The participants in this study indicated that they learned communication skills better when they received more examples of good communication on which to model. They also indicated that they wanted examples grounded in the real world as to how communication would fit into their future.

III. OUR COURSE

In the School of Interactive Games and Media at Rochester Institute of Technology, all of the graduate students are required to enroll in the Game Development Processes course. This course has been focusing on aspects of communication as it directly relates to the art of game concept pitch process [18]. Development of communication skills is not a direct learning outcome of the course, but rather of our graduate program as a whole.

At first, we explored many of the approaches outlined in the previous section as a means to enhance communication skills throughout the course. However, we quickly noted that these techniques did not map well with the needs of the course. The pitch process is more than just communication, but instead lends itself more into the format of limited dialogue with an audience under constraints of time and succinct information presentation, all while adjusting to the needs of the audience. As such, prior discussed methods do not focus upon the richness of such a dialogue and do not address the nuances and adjustments needed as part of the practice of this format.

This course and its content lend itself to the inclusion of assignments that can potentially help to increase student comfort and ability with communication skills, but it is not the only place these skills are integrated. So our model for integrating communication skills maps most closely onto the models that integrate different aspects of communication skills within various courses.

While more details about the course can be found in [18], we will recap the structure of the course as it relates to communication and pitch and detail how the latest version of the course (Fall 2014) changed from the previous structure mentioned. The communication skills that this course is focused on increasing are oral communication skills (presentation, ideation, pitch, critique). In Fall 2014, the class met three times a week for fifty minutes each class period. Within the class, there were various group activities employed. The instructor for the course assigned the students to groups ensuring that through the semester, the students were required to work with as many of the other students as possible with minimal overlap.

A. Ice-Breaking and First Assignment

Within the first three weeks of the course, we provide the students with an overview of many aspects of the game industry through interactive experiences. In the third class of

the semester, we discuss aspects of the industry as seen in the Entertainment Software Association's 2014 Industry Report [19]. To do this, we use a variation of the game Wits & Wagers [20] in which the students are divided into four teams that compete against each other. In the next class, we use a variant of Pictionary [21] to get students to describe to their classmates, through drawings on the board, the various roles one could have in the games industry. For class 7, the students are challenged to a competition using three unique games, a synonym-based word puzzle game (a "word rebus" where instead of pictures standing in for words, words stood in for other words), Taboo [22], and Charades [23]. These three are used to illustrate the various types of communication that are useful in a team setting: written, verbal, and non-verbal.

For each of these games, someone in the class is required to give clues or present in some fashion to the class. Then, the rest of the class must participate in some way if they want to get the answer and/or earn points for their team. From observations in the last several course offerings, including the Fall 2014 offering, the students were very eager to interact and the atmosphere in the room was light and fun. The students seemingly had a good time playing the games and interacting with their classmates.

Within the first two weeks, the first assignment for the course requires the students to complete a deliverable is assigned and collected. This assignment asks the students to forecast the future by looking at current trends in the field and putting together a presentation (a set of slides) about the trends that they find the most interesting, appealing, and/or promising. The slides are submitted to the faculty, but there is no presentation of the assignment. The grading for the assignment, however, is based on how well they expressed the trend through visual storytelling and minimal textual explanation. Slides that are "walls of text" are not sufficient for the exercise, and are not accepted as a deliverable.

At the beginning of class 6, the start of the third week of classes, several examples are pulled from the submitted assignments and critiqued as a group for aesthetics, ability to convey information, and ability to hold interest. Both strong and weak examples from student submissions are critiqued. At this stage in the course, the submissions are critiqued anonymously. We discuss as a group and through critique how the information was effectively or not effectively conveyed. We discuss ideas of how to convey information visually. As part of the critique process, the students are also taught techniques for critique. They learn how to separate out their personal biases from subjective analysis and learn how to present feedback in constructive ways.

B. Ideation and Presentation of Ideas

Starting in the fourth week of class, we move into the topic of ideation. Coming up with good ideas is not an easy task and if we want our students to succeed in a fast-paced industry, we need to make sure they have some techniques for rapid generation, exploration, and evaluation of novel ideas. We introduce them to three techniques during weeks four and five that will give them some tools for ideating in the future, blue sky [24], brainstorming [25], and mind mapping [26].

Each technique is given approximately two class periods broken up with the following structure: present the technique, students work in small groups and perform the technique, students informally present the ideas generated. For each of these techniques, it is helpful to “seed” the session with a theme or idea as well as a goal. We have had the instructor give a theme (thought about before class). We used the game Name 5 [27] to generate lists of “things” and choose from those lists to ideate around, and we have also used the Grow a Game website [28]. The goal is for the students to come up with a game idea.

After the students have been given the “seed” and performed the technique for a short time (10-25 minutes depending on the technique), the teams are instructed to focus on the best of the ideas generated and flesh out their group’s game idea for 5 more minutes. After that time, one person tells the entire class what the game idea was and how the technique got them to that idea. During these informal presentations, we tell the other groups that questions are appropriate, positive comments are welcome, negative comments are not, and constructive suggestions are actually the best.

C. Pitch

After an idea is hatched, we need to form a cohesive game concept around it and present that concept to the stakeholders that will eventually decide if it will be moved into production as a game. This pitch process is one that we spend significant effort on during the class. The students are led through a series of discussions and lectures about what the important parts of a pitch are and what makes a good pitch [18]. Then, we ask them to perform the task of pitching, many times.

For the Fall 2014 semester, the students were first asked to pitch their ideas for their semester-long project to the course instructor. This was done during class 11. This pitch needed to be done early to facilitate the progress of the project and make sure students were on the right track early or risk an unsuccessful project by the end. These pitches were limited to 10 minutes in length. After the teams presented their pitch, there was a short time for questions from the audience. Feedback was then given to each team by the instructor about their project as well as their pitch.

In what would become a theme for the semester, they were told they were going to do it again for class 17. This time for only 8 minutes and that they would need to ensure all group members spoke, and that they would be presenting their ideas to another instructor who had not heard the first pitches. Therefore, they could not rely on previous knowledge of the audience. At least one person would have never heard about their game before, and that was the person that was ultimately grading them and giving them feedback on their second attempt.

A few weeks later (in class 24), the students were surprised with an in-class exercise in which they were asked to pitch another group’s semester-long project. In what we call “minute-pitch swap” the groups were allowed 5 minutes to introduce the other group to the games and then 8 minutes to prepare a maximum 2-minute pitch about the other team’s game. The purpose of the exercise is two-fold; first, it gets the

original team talking about their project again, and second, it allows the other team to put their spin on the project and present it in a different way than the project’s “owner”. In some cases, this caused the groups to re-think or enhance certain aspects of their project based on what the other group found important and/or focused on for these short presentations.

On class 30, the groups were told that they would have to prepare another pitch for class 34 (in a little over a week). They were assigned groups and given 8 minutes to pitch a new game idea picking at least two elements from the following list of themes: gangsters, gardening, fire, turtles, an attic, and airplanes. After the pitches from class 34 were complete, the groups were instructed to go back and do the same pitch again for class 36 focusing on polish of the pitch.

The last pitch of the semester was in the form of the final project presentations. While not a pitch, per say, the students were instructed to treat it more like a longer, product pitch. The product was done, they were now selling it to their target audience and related stakeholders. Basically, we did not want them to perceive the final presentation like a presentation, but to keep the lessons learned from pitch as they described to us their final product.

D. Other Presentations

There were other presentations required of the students throughout the semester. Some presentations were more traditional. The semester-long project ended with a postmortem presentation in which the members of the group reflected back on what worked and what did not for their project and within their group structure and work patterns. The final for the course was a presentation on business and legal concerns as they relate to starting an independent game studio.

In the middle of the semester, groups were formed to present to the class about various software design methodologies (e.g. Scrum, Agile, Waterfall, etc.). For this presentation, the groups were tasked with creating an interactive exercise for the students as part of their presentation. This exercise was to be designed to illustrate the methodology that they were presenting to the class.

As you can see, we utilize a number of different techniques to encourage our students to communicate with each other in teams and to the class as a whole that are both formal and structured as well as casual and semi-structured. Throughout the semester, in conjunction with these activities, the students are asked questions by their peers and by their instructors. In other words, they participate in and are subject to critique of their ideas and presentations. As described in [18], the instructors feel that these exercises have a positive benefit to the students and their communication abilities. A question that remained unclear is whether or not the students felt any difference in their communication skills and abilities.

IV. METHODOLOGY

Due to the amount of focus on oral communication skills and the observation of the course instructors that by the end of

the course that students seemed to be better at communicating, we wondered whether or not the students perceived a difference in their comfort with their communication skills by the end of the semester. Our main research question was: For students enrolled in the Processes class, would there be an increase in comfort level with communication skills at the end of the semester when compared to the beginning of the semester?

In order to determine whether or not this was the case, we created a study that used a quantitative methodology that followed a quasi-experimental design approach [29]. The Comfort with Communication and Critique survey was created (Appendix). This 5-point Likert-scale survey, (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree), consisted of 23 statements. Within the survey, participants were asked their level of agreement with statements about their oral communication skills and ability to give and receive critique.

The survey was created with a mix of positively worded and negatively worded statements to avoid the problem of a student simply picking “5” for all statements. The same score for all statements does not make sense given the nature of the statements and therefore, any data with the same answer for all statements would be removed from the analysis.

This survey was administered at the beginning (during class 3) and at the end (at the final exam) of the Game Development Processes Course. It was delivered as a “quiz” through the university’s learning management system. The quiz format was chosen because it provides a way to track the responses back to an individual student. The students were told that even though this survey was under the “Quiz” tab for the course, it was not a quiz, and was not a graded component for the course. Therefore, participation was voluntary.

In order to provide a contrast to the results from the Processes class, the same survey was administered during week 1 (class 3) and the final week of the semester to a class called Production Studio. The purpose of production studio is to allow upper-division undergraduate students a chance to work on projects of their choosing under the direction of a faculty member. In this course, there is not an emphasis on ideation, pitch, or process, and students were not exposed to the range of presentation and critique activities as they were in the Processes class. In fact, the students were expected to receive instruction in production processes in prior coursework, with the focus of the course being a simulation of the Kickstarter process. Presentations and communications were critiqued by the instructor and by the class, and although there were recommendations for improvement, there is no learning outcome for this course for exploring process models directly.

As a secondary research question, we wanted to see that there was no difference in comfort level with communication skills in the Production Studio group.

After the two surveys were administered, the data was exported from the learning management system by the individual course instructors and the participant’s survey from the beginning of the semester was paired with their survey from the end of the semester. Following the pairing,

information about which student completed which survey was removed. The data was saved in Microsoft Excel format and Analyse-It was used to analyze the results of both groups.

V. RESULTS

There were 15 students enrolled in the Game Development Processes course for the Fall 2014 semester. Of those 15, 14 completed both administrations of the survey, giving a response rate of 93%. For the remainder of this section, this group will be referred to as the experimental group.

There were 19 students enrolled in the Production Studio course in the Fall 2014 semester. All of the 19 students completed both administrations of the survey, giving a response rate of 100%. For the remainder of this section, this group will be referred to as the control group.

We will call the survey given at the beginning of the semester the pre-survey and the survey given at the end of the semester the post-survey. The mean for each statement for both the pre-survey and the post-survey is shown in Table 1, and is categorized by each statement. Results are shown for pre- and post- results by the control and experimental groups. A mapping of statement identifiers to the actual statement text is shown in the Appendix of this paper.

TABLE I. SURVEY AVERAGES PER STATEMENT
(* INDICATES SIGNIFICANCE, $p < 0.05$)

	Survey Average			
	Control Group (n=19)		Experimental Group (n=14)	
	Pre-Survey	Post-Survey	Pre-Survey	Post-Survey
S01	4.53	4.21	4.43	4.43
S02	2.42	2.84	2.57	2.43*
S03	3.89	4.00	4.57	4.64
S04	3.26	3.37	3.36	2.79
S05	3.37	3.53	3.86	4.21
S06	2.32	2.63	2.14	1.93*
S07	3.63	3.74	3.71	4.07
S08	4.16	3.89	4.36	4.50
S09	3.79	4.00	4.00	3.93
S10	4.37	4.16	4.00	4.07
S11	4.00	4.00	4.07	4.07
S12	4.16	4.16	3.79	4.14
S13	3.74	4.00	3.93	4.29
S14	3.37	3.53	3.71	4.00
S15	3.89	3.84	3.93	4.21
S16	3.74	3.84	3.36	3.36
S17	4.05	4.32	3.57	4.00
S18	2.37	2.63	2.14	2.00

	Survey Average			
	Control Group (n=19)		Experimental Group (n=14)	
	Pre-Survey	Post-Survey	Pre-Survey	Post-Survey
S19	3.89	4.21	3.86	4.00*
S20	3.89	4.16	3.79	3.86
S21	3.58	4.00	3.29	3.50*
S22	3.37	3.58	3.43	3.79
S23	3.16	3.37	2.79	3.14

A. Comparisons between pre-survey and post-survey results in experimental group

Our main research question was concerned with a difference in pre-survey to post-survey scores in the experimental group. We performed a pair-wise analysis of results by statement. Due to the low number of samples, we used the Wilcoxon rank-sum test for non-parametric analysis. For the experimental group, we did not find significant differences from pre-survey to post-survey responses.

B. Comparisons between pre-survey and post-survey results in the control group

Our second research question asked whether there was a difference in pre-survey to post-survey scores within the control group. Due to the same constraints as the first analysis, we used the Wilcoxon rank-sum test for non-parametric analysis.

For the control group, some of the statements revealed significant differences from pre-survey to post-survey results in statements related to speaking, critique, and mediation.

The first category where we notice some significant difference in score is in statements related to oral communication. Statement 2, "I feel unsure of myself when I speak to a person of authority (e.g. Professor, Boss)" demonstrated a significant difference between pre-survey and post-survey results ($W(7) = 0.0, p < .05$). Furthermore, statement 6, "I become less confident if someone asks a question during my formal presentation" showed significant difference between the surveys ($W(6) = 0.0, p < .05$).

For critique, statement 19 asked, "I feel confident in my ability to give useful critique of other's ideas". This statement also showed a significant difference between pre-survey and post-survey as well ($W(6) = 0.0, p < .05$).

Finally, for the category of mediation, statement 21, "I feel that through my writing, I can mediate problems or differences between team members" presented a significant difference in score ($W(7) = 0.0, p < .05$). The remainder of the statements did not demonstrate any significant difference.

VI. DISCUSSION

The results from the survey for our main research question were disappointing. There was not a statistically significant change in the responses of the students from the beginning to the end of the semester.

One possible explanation for this is the fact that the students were already fairly comfortable with their communication skills when they entered the course. The course is made up of graduate students. It is possible that they were exposed to activities before coming into the graduate program either in an undergraduate program or a professional setting that prepared them for communicated and they felt comfortable doing it.

Although we did not find statistically significant differences in responses, we did notice some trends that point to areas of further investigation, based upon confidence interval differences in individual statements between the pre- and post- survey [30, 31].

The statement where answers changed in the less desirable direction was statement 9, "I am confident in my ability to convey ideas orally", pre-survey mean was 4.0 and post survey mean was 3.93 showing a decrease in agreement of 0.07. While also not significant, it did cause us to ponder another question that would require further observation. We question as to whether prior to coming into the class, students may have been over-confident in their abilities in oral presentation and throughout the various activities, they realized that they were not as prepared as they had thought and it changed their views by the end of the semester.

A. Control Group

The results from the control group were surprising. We hypothesized that there would not be a change in the comfort level for the control group due to the lack of interventions and lack of focus on communication skills within their course. However, we did find statistically significant differences for some of their responses.

They became more confident in their ability to give critique (statement 19) and mediate problems or differences between team members in writing (statement 21). They became less confident in their ability to speak to a person of authority (statement 2) and in their ability to remain confident if someone asks a question during a formal presentation (statement 6).

We do not know why this is the case. As with the Processes class, the perspective of the instructor is that the students improved in their communication skills over the course of the semester. The fact that they had such a positive jump in their perceived ability to give critique and mediate differences through writing could be a side effect of the nature of the course which was project based and involved teams.

Their decreased confidence with regards to speaking to authority and being asked questions during a presentation is puzzling and there does not seem to be a reason given the course structure as to why this would be the case.

Looking at the non-statistically significant responses for this group, we see that for statements where the students should disagree more (4 and 18), they in fact, agree more. For statement 4 "I am not very confident when I perform in front of a large group of people", the pre-survey mean was 3.26 and the post-survey mean was 3.37, showing an increased agreement with this statement and a difference of 0.11. For statement 18,

"I cannot take criticism from others well", the pre-survey mean was 2.37 and the post-survey mean was 2.63, showing an increased agreement and a difference of 0.26.

We see the same "opposite" results for three of the statements where the students should agree. In statements 1, 8, and 10, their mean score for agreement dropped by the end of the semester. For statement 1 "I am confident when I speak one-on-one with a fellow classmate", the pre-survey mean was 4.53 and the post-survey mean was 4.21 showing a decrease in agreement by 0.32. For statement 8 "I am confident in my beliefs as I present my viewpoint", the pre-survey mean was 4.16 and the post-survey mean was 3.89 showing a decrease in agreement by 0.27. For statement 10 "I am confident in my ability to convey ideas in a written form", the pre-survey mean was 4.37 and the post-survey mean was 4.16 showing a decrease in agreement by 0.21.

Overall, it seems that this group became less confident of their communication abilities as the semester came to a close, but we don't have any explanations as to why this may have occurred.

VII. LIMITATIONS AND FUTURE WORK

Even though we tried to design this study with as much rigor as possible, we viewed this strictly as a first step and exploratory in nature. We wanted to more systematically investigate the impact the various interventions in the Processes course were having on the students comfort with communication. To that end, we created a new instrument that was administered to two groups of students. We are limited by the fact that the instrument is in fact new and had not been used before. We are also limited by the number of participants we had in the study. Further, the control group was not a complete control as there were aspects of the course that required them to use communication skills.

For the instrument, we need to work to ensure reliability and validity. This can only be done by administering the survey to more participants and we are actively working on ways in which this can be done both within the Processes course and outside.

For our Processes course, we did not receive the intended results we wanted from the study. We did not see a statistically significant increase in the student's comfort level with their communication skills. However, we have noted previously and again with the Fall 2014 semester offering, the instructor observation that the students' communication and presentation skills did improve throughout the semester. Therefore, our next step is to determine if our observations are flawed about the increased ability in communication skills, if our belief that this is partially caused by an increase in comfort with those skills is flawed, or if our instrument needs to be adjusted to better detect comfort with communication skills.

The surprising results came from what we considered our control group. For this group, it appears that their confidence in their communication abilities actually decreased during the semester. Nothing that was in the course or its expectations gives us an idea as to why this may have occurred. In order to

determine why this may be occurring in this course, further investigations are needed.

APPENDIX

COMFORT WITH COMMUNICATION AND CRITIQUE SURVEY

1. I am confident when I speak one-on-one with a fellow classmate.
2. I feel unsure of myself when I speak to a person of authority (e.g. Professor, Boss).
3. I am confident when I speak to a casual gathering of friends (e.g. telling about my weekend plans).
4. I am not very confident when I perform in front of a large group of people (e.g. talent show, play, musical performance).
5. I am confident when I have to give a formal presentation to a group.
6. I become less confident if someone asks a question during my formal presentation.
7. I am confident I can express a given viewpoint that is not my own in a formal presentation.
8. I am confident in my beliefs as I present my viewpoint.
9. I am confident in my ability to convey ideas orally.
10. I am confident in my ability to convey ideas in a written form.
11. I am confident in my ability to convey ideas in an email.
12. I am confident in my ability to convey ideas in a formal document, design document, or written report.
13. I am confident in my ability to create an effective presentation (e.g. Powerpoint).
14. I am confident in my ability to create an engaging presentation (e.g. keep the audience interested).
15. I feel more comfortable telling someone my thoughts face to face.
16. I feel more comfortable telling someone my thoughts in written form (email, text, etc.).
17. I understand how to critique others.
18. I cannot take criticism from others well.
19. I feel confident in my ability to give useful critique of other's ideas.
20. I feel that I am able to mediate differences between different viewpoints.
21. I feel that through my writing, I can mediate problems or differences between team members.
22. I feel that I am capable of making a convincing presentation that can change someone's mind.
23. As people critique my presentation, I find myself swayed to their viewpoint.

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Formulating the Problem: Digital storytelling and the development of engineering process skills

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Abstract— We are exploring whether and how “Digital-Storytelling” can be used to a) attract and engage student apprentices otherwise estranged from STEM-linked career or education pathways b) help student apprentices address the complexities of ill-formed or “wicked” design problems typical of sustainable engineering. Building on preliminary evidence from a pilot 2014 study we hypothesize that apprentices who engage in digital storytelling can gain proficiency in key reasoning skills related to scientific argumentation including: 1. formulating and articulating problem statements 2. anticipating and understanding tradeoffs, limitations and contingencies of proposed solutions and 3. justifying solutions relative to requirements/specifications articulated in the problem statement. Our continuing work is in the development and validation of evaluation and assessment instruments appropriate for evaluating these skills among apprentices focused on digital storytelling and for drawing comparisons against apprentices engaged in “hands-on” sustainable design projects. Our overarching objective is to offer evidence validating digital storytelling as an alternative pedagogy for introducing and teaching STEM reasoning skills to newcomers or “outsiders”.

Keywords—*apprenticeship learning; scientific argumentation, problem-solving, digital media; media-rich learning environments, systems engineering; sustainability engineering.*

I. INTRODUCTION

This work is motivated by our interest in developing and refining pedagogic models that can be used to improve and encourage broader participation in engineering education focused on sustainable development. More specifically, we are interested in learning whether and how *digital storytelling* can be leveraged to draw learners from diverse backgrounds and disciplines into STEM-linked problem-solving activities and coursework and then to enrich and sustain their involvement. Another goal is to counterbalance those occasions when newcomers to STEM education must passively “internalize” new and unfamiliar material by providing more occasions for learners to “externalize” their emerging understanding.

Theories of “situated cognition” [1] in the learning sciences emphasize that learning is a fundamentally social

endeavor [2] that cannot be separated from the context in which it takes place [3] [4]. Theories of situated cognition posit that skills and knowledge develop interdependently through increased degrees of “intent participation” [5] in different learning communities [6], and are reinforced through responsive facilitation [7] or devices that function as learning scaffolds [8] [9] [10]. We see digital storytelling as not only a powerful way to create inclusive learning communities [11] focused on STEM topics but, perhaps more importantly, as a means of providing learners with critical opportunities to participate in *active* knowledge-building as they work to develop creative representation(s) of their *own* emerging understanding of sophisticated STEM topics and practices.

Additionally, in social psychology, “Self Determination Theory” [12] explains why learners benefit when teachers support self-directed learning or learners’ sense of autonomy. Research in this area began thirty years ago with empirical experiments looking at the effects of extrinsic rewards on intrinsic motivation but has evolved to emphasize self-regulation through internalization and integration [13]. Despite widespread and growing respect among engineering educators for pedagogical approaches that support student autonomy such as Inquiry-based Learning, Active Learning, Project-based Learning, Problem-based Learning, Critical Thinking, Academic Service Learning, etc., educational researchers exploring the “disconnect” between rich empirical evidence for the success of “student-centered” pedagogies and the actual characteristics typical of engineering classroom environments found that many faculty continue to fall back to their usual routines of traditional instructional methods. One study found that faculty who were well-informed and motivated to teach classes aligned with a learner-centered pedagogy still required more access to feasible models and need support in finding/implementing specific strategies they can use to re-design their courses [14]. We believe that many of the proven pedagogical strategies developed to support other forms of “hands-on” apprenticeship learning [15] [16]

can be adapted to structure learning environments that successfully use digital media to promote self-directed learning and thereby greater understanding of STEM knowledge and practices among newcomers.

As a *design-experiment* [17] [18] **Apprenticeships in Sustainability Science and Engineering Design (ASCEND)** iteratively implements, investigates, evaluates and refines a pedagogic model of apprenticeship learning (also called problem-based learning) in sustainability engineering through digital storytelling. Through our own preliminary research, we have seen how digital media can help to engage newcomers to STEM with content, processes, and technology involved in sustainable engineering projects. This is especially applicable to youth already immersed in the increasing ubiquity of our now digital age. Digital storytelling can help newcomers express or “externalize” their emerging understanding of sophisticated STEM content and/or practice by engaging students’ creativity and personalities in ways that writing about science might not. Digital storytelling can also afford participants a sense of “ownership” or “self-determination” to an equal or greater degree than some laboratory-based activities or other models of “hands-on” or “experiential” learning [19]. Digital storytelling may also prove instrumental in supporting and promoting active “learning communities” that provide context for STEM-learners connecting real-world problems to knowledge and skills prioritized in the formal learning context of higher education. Finally, as we will argue throughout the remainder of this paper, digital storytelling can be used to engage newcomers and experts alike in the specialized practice of *scientific argumentation*. Assessments of learners participating in this model can be compared to learning among participants engaged in “hands-on” aspects of sustainable engineering projects.

A. Innovative Practice

As access to digital media, digital production and editing tools increases, educators are increasingly turning to digital media as a way to empower and motivate learners to explore and engage with a range of topics. However a review of the literature [20] shows that attempts to revitalize STEM education through digital media largely rely on digital content supplied or created by *experts* and then conveyed to learners through media rich environments. These approaches should be distinguished from any that employ digital media as a means of fostering *learner-generated* content.

Digital storytelling differs notably from documentary filmmaking [21] as it is a highly reflexive activity that leads participants through powerful forms of self-discovery in relation to the topic, their place in society and their intellectual and creative abilities, allowing them to engage in rigorous meaning-making [22] [23]. Hughes [24] observes that the multimodal design of digital storytelling offers multiple entry points of creativity providing greater potential for storytellers to claim ownership of their story without fundamentally changing the content. Building on this premise, digital storytelling has been proposed as a “multimodal” pedagogical tool that can “create new forms of signification” to connect

personal history, voice and identity with the broader public issues faced by concerned communities and science [25]. Researchers in the the learning sciences have demonstrated a number of educational benefits for students who engage in this increasingly popular practice: for example, learners who do not identify with dominant socio-cultural groups [26] can employ multiple modes of representation to “push back” against powerful “master narratives” [27]. However, while educators working outside of STEM are increasingly using digital storytelling as a means to support students’ identities yet foster motivation to learn, autonomy and self-efficacy this potential is not being fully realized by engineering educators or others working in formal and informal STEM education contexts.

B. Research Focus and Hypothesis

Our research focuses on how digital storytelling can be employed to help newcomers to STEM gain proficiency in engineering-specific reasoning skills. For example, one essential skill for engineers is the ability to formulate and articulate well-defined problem statements that entail specifications/requirements for a desired solution [27]. This can prove especially difficult in learning contexts focused on engineering for sustainable development due to the nature of the problems under examination. As two researchers from Chalmers University of Technology recently emphasized: “Environmental and sustainability problems are not purely technical problems. Many of the most pressing issues, such as climate change, resource scarcity, and pollution, require holistic approaches that go beyond technical systems analysis and optimization. Such problems have been called *wicked sustainability problems* (WSPs) because they are highly complex, contested, and lack definite solutions” [28].

Preliminary results from our own pilot study with teenage apprentices at an alternative education vocational training center indicate that apprentices focused on digital storytelling were able to articulate more sophisticated problem statements than their counterparts – apprentices who were focused on more traditional “hands-on” or “design-and-build” tasks. Specifically, when asked about the issues motivating the construction of a rainwater catchment and smart irrigation system, digital storytelling apprentices were able to articulate statements that connected multiple issues including energy, pollution /storm water runoff, and water conservation while the apprentices working on building and installing the system itself were more likely to provide statements that focused only on one issue: water conservation [29]. Our continuing work is to develop and validate methods to assess how well learners are able to formulate and articulate problem statements, anticipate tradeoffs, limitations and contingencies on solutions and justify solutions relative to specifications in problem statements.

B. Expected Significance

Our assumption is not that learners engaged in digital storytelling will gain the same skills and knowledge as learners engaged in other “active learning” approaches. Rather, we recognize that there will be tradeoffs when the learning outcomes associated with any one approach are compared to any other. Neither do we assume that assessment of any particular set of skills or knowledge should be used to make claims about overall efficacy of any teaching model. We do

assume that the ability to formulate and articulate valid problem statements is an engineering process skill of sufficient importance (and more so when sustainable development agendas are implicated) as to warrant investigations of pedagogy designed to support this particular learning outcome. We also argue that evidence of improvement among digital storytellers in their ability to engage in scientific argumentation - to an equal or greater degree than apprentices focused on design-and-build tasks - can be used to validate digital storytelling as an appropriate pedagogical strategy for engineering education. Especially when the larger goal is to introduce and teach STEM process skills to newcomers or outsiders or to work with collaborators from other disciplines.

The **significance** of ASCEND is that, if successful, it will demonstrate a new pedagogical model that can be used to expand and diversify participation in STEM by providing incentives to non-STEM students, in particular, to engage with STEM-linked knowledge, research and activities. We expect that ASCEND's storytelling approach will attract those women and underserved minorities whom may otherwise be reluctant to pursue STEM-related fields in higher education or in the workplace. The model can also be used to introduce and promote development of STEM content knowledge and process skills.

II. METHODOLOGY

A. Scientific Argumentation: Engineering vs. Science

The majority of the literature on scientific argumentation as a formal practice (e.g. [30] [31]) traces its heritage back to a seminal article [32] that maps out an idealized microstructure for legitimate (i.e. scientific) explanation. A major caveat however, is that this literature focuses on arguments that use evidence resulting from scientific investigations to make claims that answer questions, while we are focused now on a type of argument that is slightly different (if no less "scientific"). Arguments that use evidence to justify working solutions with respect to the requirements and constraints laid out in an initial problem statement are characteristic of engineering. While "problem definition" is widely recognized as a critical step in any engineering design process, and repeatedly identified as a target learning outcome for engineering educators, literature that includes specific criteria for evaluating the quality or validity of a particular problem statement (a.k.a. the Toulmin model for evaluating scientific explanations) is scant. One exception is the recent dissertation work by Arnberg [33] which included a study of undergraduate interns engaged with design problems for their research with the Akamai Workforce Initiative (AWI). AWI partners with high-tech industry, astronomical observatories, cutting-edge research, and inventive education to meet needs in astronomy, remote sensing, and other technology industries in Hawai'i. This study found articulating measurable solution-requirements was a more challenging aspect of articulating a problem statement than identifying constraints.

B. Engineering Design Problems

Stojcevski [34] distinguishes "design problems" from other problem solving such as "story problems" (identifying patterns or breaks in patterns), "troubleshooting" (identifying

faults in a functional system or domain) or "case/system analysis" (stating attributes of ill-structured or complex problems rather than on hypotheses for generating actual solutions). Design problems are "more than just story problems", and they are not "restricted to troubleshooting". Rather design problems "incorporate new designs [while remaining practical and achievable in a way that many case studies are not]". Problem-design statements must specify and meet the needs and desires of people, function within defined constraints, and define minimum requirements for anticipated solutions. The problems encountered by apprentices in our study fit Stojcevski's description of design problems in so far as all projects elected for the ASCEND apprenticeship program are defined in consultation with sponsors/clients expecting highly tangible deliverables.

C. Evaluating Problem Statements for Sustainable Designs

In order to determine the degree to which apprentices can demonstrate their ability to formulate/articulate valid problem statements for the sustainable engineering projects they get involved with, we need to establish scoring criteria to evaluate their statements. This is no small undertaking and there are several considerations that must first be addressed:

1. **Wicked Design Problems:** Sustainable design projects are multifaceted and multimodal [35] and so dubbed "wicked problems" because they involve complex systems and must tackle added challenges like emergent behavior (a system behaves differently than the sum of its parts). To avoid reductionism, systems engineering requires decision-making that other brands of engineering can avoid [36]. For example, in systems engineering making strides in one direction (e.g. energy conservation) can result in setbacks in other directions (e.g. pollution). Overall, the challenge is to formulate statements that maintain technical accuracy on specifics while also accounting for the emergent properties of system relations.
2. **Multi-media:** Participants in our research will use multiple different kinds of media on different occasions to express their evolving understanding of the problems/issues motivating the wicked design project they are most involved with. Our challenge will be to decide which media should be prioritized for our formal evaluations or alternatively how to balance out or account for the differences we expect to see in the way problems are framed across media.
3. **Addressing Multiple Audiences:** Digital storytelling apprentices will be trained to pay attention to the needs and context of their viewing audiences during production. Creating media that is palpable and relevant to the everyday lives of non-expert viewing audiences will impact the way a problem is explained and therefore conceived. Assessment efforts will need to account for the ways in which these influences play into participants' thinking about a problem definition.
4. **Change Over Time:** Our interest is in tracking and understanding how an apprentice's understanding of the problem and ability to formulate/articulate problem

statements is changing over time. Unlike creating an “answer key” for a final exam where learner responses are benchmarked against a “correct” or “best” response, we need to create flexible scoring criteria sensitive to, and representative of incremental changes.

Despite the challenges identified above, we maintain that some basic elements of problem statements for (sustainable) design problems can be readily identified and presumed as necessary to support achievable solutions.

- *(why) Needs assessment:* Describes why a solution is needed based on current, predicted or unforeseen conditions. Includes data on baseline conditions.
- *(what) Functional Specifications:* Identifies tradeoffs across domains and boundary conditions for what a solution must minimally accomplish in multiple domains.
- *(how) Design Constraints:* Specifies procedural constraints that govern system commitments, design, construction, and implementation. May include criteria for decision making among multiple constraints. For example, to what degree do time constraints trump other considerations?
- *(who) Stakeholder Interests:* Who will use and (directly or indirectly) benefit or be impacted by the resolution of this problem, on what terms and to what degree? Identifies implications for the design process.

D. Strategy and Scoring Mechanism.

We expect that as an apprentice becomes more deeply involved with a project (whether through digital storytelling or design-and-build activities), the ways in which an individual comes to understand the issues or problem underpinning that project will evolve. We are committed to evaluation strategies that prove sensitive to changes over time in participants’ thinking rather than work as summative evaluations of one-time statements. In order to document these changes it is imperative to schedule sequential data collection sessions. On a weekly basis, a moderator will prompt participants to respond to questions about the problem their project is meant to solve and record their responses as “audio diary” entries using Sound Cloud freeware. Over time the moderator’s role should become less crucial as participants learn how to record audio diary entries. A challenge will be to make sure that participants do not repeat themselves from one week to the next, but articulate subtle changes in their perspective and understanding.

For this initial study we will be working with a population of 18 digital storytelling apprentices and 12 design-build apprentices over a 10 week period March 23, 2015 – May 29, 2015. Initially we expect to collect only 10-12 entries per week in the first 1-4 weeks, but anticipate closer to 20 entries per week by the final 12-15 weeks. Overall we hope to collect a minimum of 120 entries averaging 4 entries per participant.

We will analyze each audio diary entry for evidence of the basic elements of a problem statement described earlier. The following scores will be marked for each element:

N/A – Not Applicable

0 – Missing altogether but needed

1 – Available but barely evident

2 – Available but minimal, unclear or inappropriate

3 – Available and appropriate but could be stronger/clearer

4 – Available, clear and appropriate

5 – Exemplary, robust and comprehensive

We expect to find evidence of these different elements distributed across multiple audio diary entries. For example, in one session a participant might speak intelligently about design constraints and in another session focus more on the implications of different stakeholder interests. A score of 3 or more for each element would be considered evidence of proficiency, however it would not be necessary to score 3 or higher for *each* element on *each* occasion. Proficiency will be acknowledged as long as a score of 3 or higher is recorded on at least one occasion for each element.

It will be interesting to compare scores for audio diary entries completed by apprentices involved in digital storytelling with the way the problem is represented in the final digital production they submit for public screening. This comparison could help us understand to what degree and how a participant’s anticipation of the reception by a viewing audience can impact their own understanding of the problem.

E. Inter-rater agreement

The data will be reviewed and scored by the lead ASCEND evaluator as well as an assistant. Distinct from inter-rater reliability, inter-rater agreement is a measurement of the consistency between the absolute value of evaluators’ ratings. It represents the number of times each rating (e.g. 1, 2, ... 5) is assigned by each rater divided by the total number of ratings. After scoring the sample independently the lead evaluator and assistant will reconvene to discuss any discrepancies. A new sample set of data will be recorded after these discussions. A joint probability of agreement of 85% will be established before independent scoring continues.

III. RESULTS AND TIMELINE

Data collection will be completed in late May, 2015 and all data will be compiled and archived. Analysis will begin in June 2015 and completed in August, 2015. Given this timeline, the results of this study will not be available in time to be included in this WIP paper but will be available for presentation at the FIE conference October 21-24.

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Is Information Technology General Education Effective for Non-Engineering Major Students?

An Exploratory Study on Ethnically Chinese Classrooms

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Abstract— The role of computer and information literacy in the contemporary digital society is as important as language proficiency. This is widely exemplified in the graduate requirements in many tertiary institutions: students must pass the compulsory IT subject(s), often as a mandatory General Education (GE) course, before graduation irrespective of majors. Challenges arise to the computer science faculty as students are from different academic backgrounds with diversified level of IT background, and are often less motivated than taking a course in the major program. In this paper, we attempt to explore the reasons fostering students to devote efforts (i.e., persistence) in the GE IT course in tradition confucian examination-orientated educational settings. Student behavior and perceptions in two major groups of ethnically Chinese students (Mainland China and Hong Kong) are analyzed, revealing that mastery is the main reason leading to persistence in the mandatory IT course. Theoretically, we address the paucity on GE IT related research on ethnically Chinese students through validation and comparison of findings from the literature, leading to new directions of research. Practically, we generalize our experience from practitioner's view and propose different suggestions to effectively deliver GE IT courses under the confucian culture.

Keywords—General Education, Confucian Culture, Ethnically Chinese Student, Computer and Information Literacy, Persistence

I. INTRODUCTION

While computer and information literacy becomes the necessity to survive in the 21st century, scholars have been stressing the importance of including computer literacy in the syllabus e.g., Molnar [1]. This is exemplified in a variety of reformation in the educational system across different disciplines, e.g., the integration of computer and information literacy into K-12 teacher education [2]; the extensive use of computer technology in medical education [3]; and the integration of information technology syllabus in nursing education [4].

Computer and information literacy syllabus is now integrated across different disciplines and often included in the curriculum as credit-bearing courses in the tertiary institutions, with equal importance as language training in the curriculum. In many institutions, at least one fundamental information and communication technology subject is included in the syllabus

across all undergraduate majors, often in the form of a mandatory semester-wide credit-bearing course in the General Education (GE) domain for the Year 1 students. This ascertains that all graduates are in possession of sufficient computer literacy, so that they will have the knowledge and computer operation skills to use the digital educational resources e.g., the open education resources [5] and well equipped for lifelong education.

Successful delivery of the mandatory IT GE course to junior undergraduate students, however, is often challenging to the teachers. Kinnunen and Malmi [6] highlight an institutional “culture” issue that can demotivate students from devoting efforts in the mandatory IT GE course: a belief that failing in the mandatory IT GE course would not affect the performance in the major courses. False perception on the “disconnection” between major subjects and the mandatory IT GE course further discourages students to take up an active learning attitude in the mandatory IT GE course. Thus, increasing university students’ motivation the mandatory IT GE courses becomes one of the concerns of the front line faculty members.

Traditionally, research on computer education tends to focus on the junior computer science students on year-1 foundation subjects, e.g., the effective teaching and learning of entry level programming courses. Until recently efforts have been made to promote “kids programming”, i.e., to develop the logical thinking and problem solving ability of young children [7][8]. There is paucity in research on effective teaching and learning of compulsory foundation IT courses to non-IT major students. Our research questions are: 1) What factors, i.e., persistence, can motivate students to actively participate in a mandatory IT course for non-engineering majors? 2) How do students view the relationship between the major subjects and the mandatory IT subject? and 3) How does the curriculum arrangements affect students’ attitude on a mandatory GE IT course?

Addressing the research gap in the effective delivery of mandatory IT GE course to junior undergraduate students, this paper reports an exploratory study on year 1 students’ perceptions with respect to mandatory IT GE courses in two ethnically Chinese university classrooms at the Hong Kong Special Administrative Region and the Guangdong Province of

China. With the ethnically Chinese student population, our research also provides an insight on how Chinese students perceive the value of mandatory courses outside the major of studies.

Next section presents the related works on the research of undergraduate IT courses for non-engineering major students.

II. RELATED WORKS

A. Values and Expectations of Mandatory GE IT Course

Computer and information literacy has a great impact on interdisciplinary learning in the contemporary world. More than a decade ago, Rockman [9] has already stressed that solid information literacy foundation as the basis for “connection” between courses by enabling students to achieve the learning outcomes through problem-based learning activities that require extensive information searching. Some years later, Laird and Kuh [10] confirm that use of information technology for educational purposes would have a positive effect on student engagement especially in active and collaborative learning. Recent work by Benson & Filippaios [11] further explore the difference in workplace productivity between generations who have higher and lower computer and information literacy levels, asserting that the younger IT savvy generation is more advantageous in identifying new business opportunities than the elder generation.

Educators have well acknowledged the impact of computer and information literacy in academic and workplace productivity. Wong and Cheung [12] present an extensive discussion on a mandatory IT course delivered at the Hong Kong Baptist University, emphasizing that the course is a joint effort between the Computer Science Department, Library and the Office of the Information Technology. The 8 intended learning outcomes cover different aspects of computer and information literacy (p.59):

- Describe the importance of information technology and information literacy;
- Describe and explain fundamental concepts of different areas of information technology;
- Describe and explain the fundamental concepts of information management cycle;
- Use IT tools to search, store, organize, process and maintain information;
- Evaluate sources of information;
- Communicate and present information effectively in electronic formats;
- Describe and explain the issues of legality and ethics in searching, sharing and using information;
- Describe the major trends in and social impacts of information technology

Next section extends the discussion with an outline of the research and evaluation on students’ perceptions of the mandatory IT GE courses.

B. Research and Evaluation on Mandatory IT GE Courses

A variety of domains are evaluated on students’ perception on mandatory IT GE courses. Wong and Cheung [12] adopted an institutional-wide teaching and learning questionnaire to solicit feedback from students enrolled in the mandatory IT GE course. Items in the survey include six aspects: 1) Improvement of other courses; 2) Usefulness of the IT GE course; 3) Intellectual stimulation; 4) Course experience; 5) Student satisfaction; and 6) Course workload. A 7-point likert scale was adopted in the survey: 1 represents strongly disagree; 4 represents neutral and 7 represents strongly agree. Average scores of the six items ranges from 3.21 to 5.13, indicating students generally have a slightly positive (meaning from “somewhat disagree” to “somewhat agree”) perception on the items.

Further interpretation of the results reveals that delivery of the mandatory IT GE course as challenging to the faculty and support staff in terms of student motivation and infrastructural support. Gasiewski et al. [13] report similar findings on introductory science, technology, engineering, and mathematics (STEM) courses in junior undergraduate students, asserting that student engagement is the most important issue in student retention in the compulsory STEM foundation courses. Learning will only be effectively when students are motivated, resourceful, and engaged.

C. Design of Computer and Information Literacy Courses

Information literacy has become an important topic in the Library Science discipline. While computer literacy provides the necessity foundations to operate effectively for information retrieval and analysis, it should be integrated into interdisciplinary domains [2]. The computer and information literacy course should have a mission to diminish the gap of IT knowledge between different student groups, e.g., male and female students [14]. While the computer literacy, i.e., skills for operating a computer, remains the primary focus of the course, properly designed mandatory IT GE course can also improve creativity and collaborative skills of the learners [15].

Stephens and O’hara [16] identify five main areas of mandatory IT courses in 84 business school programmes: 1) fundamentals of IT infrastructure; 2) systems development process; 3) types of business information systems; 4) strategic applications of IT; and 5) managing the information age organization (p.184). While the first topic is the foundation of IT development emphasizing more on the technical aspects, the remaining four themes are more focused on the management aspects. In other words, the application of information technology (systems) in the business context is considered more important than the technical operational skills in the business schools. Acknowledging the requirements of the intended learners and teachers (i.e., outside the computer science department) would be necessary to design “servicing” courses that are targeted at the non-engineering (computing) majors.

D. Summary of Lesson Learnt from the Related Works

The above related works provide useful clues in the design and evaluation of mandatory IT GE courses for non-

engineering major junior undergraduate students. Table 1 summarizes the findings from the related works that form the basis of our exploratory research.

TABLE I. BASIC CONCEPTS OF EXPLORATORY RESEARCH

Domain	Description	Reference
Student engagement	Most important factor for student retention in mandatory course	[13]
Connection to the real world activities	Course only perceived as useful when it help to improve the productivity in the workplace/ major area of studies	[2], [12], [16]
Mastery	Leaners can master the materials in the course irrespective of the IT knowledge gap prior to course enrollment	[14]
Personal Best (PB) Goals	Influent to student engagement and satisfaction	[12], [13]

E. Research Gaps and Directions

In the engineering education research domain, emphasis has traditionally been put on the teaching and learning of technical subjects by engineering students. Until recently, researchers and practitioners advocate the importance of a new pedagogical solution for technology education that can pay attention to the diversity e.g., individual differences and capabilities; gender; social, economic, cultural or political differences; and even differences among countries [17]. There is a paucity of research looking from non-engineering major students' perceptions towards the mandatory IT GE course, especially how students perceive the value of the IT course and how to make the IT course "connected" to the real life experience. Moreover, cultural differences are rarely addressed in the related research findings.

Our exploratory work attempts to fill in the above research gaps on non-IT students' views on a mandatory IT course, as well as comparing ethnically Chinese students' perceptions with the findings in the literature. Next section follows with the research approach and methodology, outlining the research design and data collection methods.

III. RESEARCH APPROACH

To evaluate students' perceptions on the mandatory GE IT courses, self-administered survey was administered during the semester (i.e., before the end of the teaching weeks) to students who were taking the mandatory GE IT courses. Data were collected from two groups of junior undergraduate students: one group is from the Guangdong Province of China (the mainland China) majoring in business and the other group is from Hong Kong majoring in education, representing two different groups of ethnical Chinese students with different cultural backgrounds.

The self-administered questionnaire contains 16 multiple choice questions with 7-point Likert Scale covering the

domains as identified in Table 1. Instruments used in the survey are adopted from the existing literature:

A. Student Engagement [10]

- [ENGAGEMENT1] I discussed ideas from my readings or classes with the subject teacher outside of class
- [ENGAGEMENT2] I discussed grades or assignments with the subject teachers
- [ENGAGEMENT3] I asked questions in class or contributed to class discussions, either online or face to face.

B. Connection to the Real World Activities [18]

- [REAL1] I found the content of the IT course reflects the activities I have done at school, work or home.
- [REAL2] The practice in the tutorial/ lab sessions are related to the activities I have done at school, work or home.
- [REAL3] My performance in this course accurately reflects my ability to solve problems using computers and the Internet

C. Mastery [19]

- [MASTERY1] I want to learn as much as possible in this class
- [MASTERY2] I desire to completely master the material presented in this class.
- [MASTERY3] I hope to have gained a broader and deeper knowledge when I am done with this class.

D. PB Goals [19]

- [PB1] It is important to me to do better than the other students in the IT Course
- [PB2] I am motivated by the thought of outperforming my peers.
- [PB3] It is important to me to do well compare to others in the class.
- [PB4] I am striving to demonstrate my ability relative to others in this class.

After soliciting students' behavior and perceptions in the mandatory IT GE course, evaluating the persistence of students in the IT GE course, although mandatory, would provide some insights to researchers and practitioners on designing better "servicing" IT courses. Therefore, an extra construct, persistence, is added to the survey.

E. Persistence [20]

- [PERS1] If I can't understand my schoolwork at first, I keep going over it until I understand it

- [PERS2] If I can't complete my tutorial/ laboratory exercise at first, I keep going over it until I can complete it
- [PERS3] Overall speaking, I keep trying to work out an answer to the problem in this subject.

IV. RESULTS AND ANALYSIS

Anonymous survey was administered to two cohorts of students taking the mandatory IT GE courses in the Mainland and Hong Kong. Online survey was set up in the Moodle sites of the courses respectively, and was announced to the students through email broadcast and face to face during the lecture time. Response rate from mainland is 43.53%, while that from Hong Kong is 42.37%. Table 2 shows the descriptive statistics from the two groups of students.

TABLE II. DESCRIPTIVE STATISTICS

Item	Mean values			Difference
	Mainland (N=37)	Hong Kong (N=25)	Overall (N=62)	
ENGAGEMENT1	4.92	4.60	4.79	0.32
ENGAGEMENT2	5.03	4.52	4.82	0.51
ENGAGEMENT3	5.22	5.12	5.18	0.1
REAL1	5.81	5.52	5.69	0.29
REAL2	5.81	5.36	5.63	0.45
REAL3	5.76	5.08	5.48	0.68 *
MASTERY1	6.35	5.80	6.13	0.55 *
MASTERY2	5.73	5.12	5.48	0.61 *
MASTERY3	6.05	5.88	5.98	0.17
PB1	5.11	5.12	5.11	0.01
PB2	5.14	5.08	5.11	0.06
PB3	4.92	5.00	4.95	0.08
PB4	5.16	4.76	5.00	0.4
PERS1	5.59	5.16	5.42	0.43
PERS2	5.73	5.20	5.52	0.53
PERS3	5.86	5.64	5.77	0.22

“Difference” refers to the absolute value of difference between the means of Mainland and Hong Kong students. * denotes the 3 most significant differences in the mean value between Mainland and Hong Kong students.

The internal consistency (reliability) of the constructs is assessed with Cronbach's Alpha, ascertaining that all instruments are reliable in this exploratory study. Table 3 shows the Cronbach's Alpha values of the constructs. All values are above the 0.7 level which indicates that the survey items are reliable.

TABLE III. CRONBACH'S ALPHA

Construct	Cronbach's Alpha
Engagement in the subject	0.705
Connection to the real world activities	0.805
Mastery	0.863
Personal Best Goals	0.894
Persistence	0.797

Partial Least Square (PLS) modelling [21] is adopted to assess the relationship between different constructs and persistence, i.e., the dependent variable in our proposed model. R^2 of our model is 0.329, indicating that the model explains 32.9% of persistence behavior of the students taking the mandatory IT GE course. Figure 1 shows the path analysis of the research model (*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$).

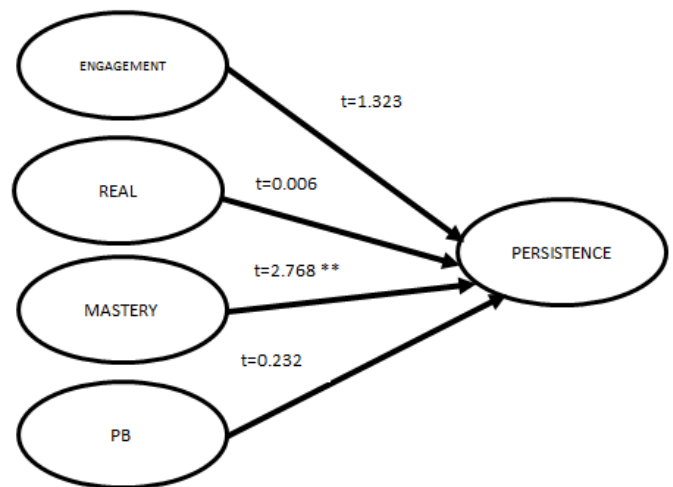


Fig. 1. Path analysis of the research model

V. DISCUSSIONS

This is one of the early exploratory works to study the perceptions of non-engineering undergraduate students' views towards a mandatory IT GE course. Findings in our research model provide some insights for researchers and educational practitioners (e.g., teachers and instructional designers) on designing the teaching and learning activities for better student retention. Next presents our further elaborations on the findings.

A. Student Engagement and Persistence

Although student engagement is believed to be a predictive indicator of persistence (i.e., retention to the course), our study shows that student engagement only exhibits a weak relationship ($p=0.173$) with persistence. This can possibly be explained with the syllabus and graduation requirements.

In the context under our study, the IT course is one of the mandatory graduation requirements. Generally speaking, students do not have any alternative options, e.g., an elective course, to replace or substitute the mandatory IT GE course to fulfill the graduation requirements. Whether the learning experience is engaging or not does rarely have any impacts on students' attitude on this course: students must pass this course in order to graduate. Graduation can be considered as the strongest extrinsic motivation factor leading to persistence in the mandatory IT GE course.

It is worth exploring the relationship between student engagement and persistence because it shows somewhat a weak relationship. Further investigation into the research model with a data driven approach provides some clues on the weak relationship by including a mediator between the two

constructs. Figure 2 shows the mediating relationship between student engagement, mastery and persistence (*: $p<0.05$; **: $p<0.01$; ***: $p<0.001$).



Fig. 2. Path analysis of the mediating relationship

PLS analysis reveals that student engagement indirectly influence persistence on the IT GE course through the mediating effect of mastery. Further investigation into this observation warrants attention from researchers as it may explain whether the same behavioral factors can explain students' behavior in mandatory or elective courses.

B. Connection to the Real World Activities and Persistence

The relationship between the connection to the real world activities and persistence cannot be supported statistically ($p=0.995$). Further analysis of the descriptive statistics would be able to explain the findings.

The greatest difference between the mean values by Mainland and Hong Kong groups of students in this survey is recorded on [REAL3] (My performance in this course accurately reflects my ability to solve problems using computers and the Internet.) Mainland students tend to agree more in this statement while Hong Kong students have a much lower level of agreement.

A possible explanation is the pedagogical model adopted in the Mainland and Hong Kong. The Outcome Based Teaching and Learning (OBTL) approach [22] has been widely adopted in Hong Kong, emphasizing that the Course Intended Learning Outcomes, Teaching and Learning Activities, and the Assessment Tasks should be constructively aligned. Assessment Tasks, however, still tend to focus on written examinations at the end of the semester that may not be able to assess the problem solving skills with computers and the Internet. Consequently, Hong Kong students expressed disagreement with [REAL3]. On the other side, OBTL is not widely practiced in the Mainland, which means that the teaching and learning activities could be examination-driven. It is natural that students perceive the examination results could reflect the computer and information literacy due to the practice for examination without extensive exposure outside the classroom.

C. Mastery and Persistence

Our path analysis shows that mastery has a strong and direct relationship with persistence ($p<0.01$). Generally speaking ethnically Chinese students tend to be afraid of making mistakes (also known as "loss of face") [23]. It is definitely not a pleasant learning experience if a student was asked by someone (either teacher or student peers) but could not give the "right" answer.

In such Chinese Confucian cultural background, mastery becomes the intrinsic motivation to drive persistence. Chinese students tend to be very diligent to understand the subject

matter discussed in the class in order not to "lose the face". This is not due to any penalties given by the teachers in the classroom but is mostly due to the unpleasant feeling when feeling a "failure". From our descriptive statistics, the influence of mastery on Mainland students is much stronger than that of Hong Kong students.

D. Personal Best Goals and Persistence

Statistically personal best goals do not have a significant relationship with persistence ($p=0.809$). Personal best goals are driven by competition between student peers so that one aims to outperform the others.

In China, competition among peers would be the norm to secure limited educational resources (e.g., admission to university, award of scholarship etc.). Often, examination results (summative assessment) determine the access to the limited resources, this exerting a pressure for students to outperform the others.

Adopting a data driven approach, we similarly explore the mediating effects between Personal Best Goals and Persistence. Surprisingly, mastery plays a very strong mediating effect between personal best goals and persistence. Figure 3 shows the mediating relationship between personal best goals, mastery and persistence (*: $p<0.05$; **: $p<0.01$; ***: $p<0.001$).



Fig. 3. Path analysis of the strong mediating relationship

PLS analysis shows that personal best influence persistence on the IT GE course through the mediating effect of mastery, with an exceptionally strong relationship between personal best goals and mastery ($p=0.000$). A promising research direction would be looking at the additional mediating and moderating effects between personal best goals and persistence.

VI. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

We admit that this exploratory study has some limitations that may affect the generalizability of the results. First, the small sample size ($N=62$) and low response rate (around 40%) would not be sufficient to claim a generalized conclusion. However, this limitation can be justified by the nature of the research settings. While most of the students consider the mandatory IT GE course as less important than the major courses, it is unavoidable that they do not put the tasks of IT course as the first priority. As this self-administered survey is anonymous and was conducted outside the classroom, it is natural that many students did not respond to the survey. Secondly, the path modelling is mainly data driven at this exploratory stage. An extensive interdisciplinary review on related works would be helpful in building a more extensive model in the next steps.

Next steps of this research include an extensive review of the path model by incorporating suitable constructs as the mediators or moderators on the path model. As we have

already observed differences in students' perceptions between the Mainland and Hong Kong ethnically Chinese student groups, future research may also compare perceptions from other ethnically Chinese student populations, e.g., Singapore and Taiwan student groups. This would be practically useful of International educators to identify and address the behavior and needs of the increasing number of ethnically Chinese students who are studying abroad.

VII. CONCLUSIONS

With the needs to provide computer and information literacy education to serve the non-engineering major undergraduate students, this exploratory research attempts to evaluate non-engineering students' perceptions on mandatory IT GE courses. Specific research questions are: 1) What factors, i.e., persistence, can motivate students to actively participate in a mandatory IT course for non-engineering majors? 2) How do students view the relationship between the major subjects and the mandatory IT subject? and 3) How does the curriculum arrangements affect students' attitude on a mandatory GE IT course?. A survey was conducted to two groups of ethnically Chinese students from the Mainland China and Hong Kong. Our findings indicate that 1) Mastery is the factor that directly leads to persistence in the mandatory IT courses, while personal best goals and student engagement influence persistence through the mediating effect of mastery. 2) Although connection to real world activities was believed to be directly related to persistence but statistically does not show a strong relationship in our study. Instead, the personal belief that one must master all course contents has a more dominant impact on students' persistence in the IT GE course. 3) The compulsory nature of our IT course that students have no choice but to pass the IT course for graduation, thus often the learning remains at the surface level to complete the course requirements. Whether the course is engaging or not does not have a direct relationship for persistence.

The findings from this exploratory study provide insights to educators on designing mandatory GE IT courses for ethnically Chinese students. Notably, giving students a sense of mastery in the subject matter would lead to high level of persistence. Next steps of the research would be interdisciplinary review of the research model, as well as to extend the study across groups of ethnically Chinese students.

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Lecture, Narrated Slides, or First Person View? Impact of Presentation on Learning Outcomes

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Abstract—We are experimentally conducting a fine-grain comparative analysis of two different methods of producing pre-recorded lectures versus a traditional live lecture. The two different pre-recorded lecture production methods do not require assistance from university staff members and therefore represent a low-cost approach. The first method is generating narrated slides using PowerPoint during a live lecture and the second method is the recording of a live lecture from the instructor's point of view using a head mounted camera such as Google's Glass. We present some of our preliminary results of this comparative analysis, which indicate that little interactions exist overall between the implemented modus of presenting instructional materials and the observed student learning gains within the study configuration. Thus, as a preliminary indicator within our study confines, instructors are enabled to select the most convenient fashion of lecture presentation. We are presently expanding our set of experiments (different cohorts, different specific subject matter, etc.) to obtain broader conclusions.

Index Terms—Educational technology; instructional media; content generation; multimedia

I. INTRODUCTION

The production of pre-recorded lecture materials is poised to become part of the standard practice of teaching. The increasing use of pre-recorded lecture materials for instruction is being driven by two factors: (i) the expansion of access to course materials for students via online courses, and (ii) the utilization of classroom time for non-lecture activities (i.e., flipping the classroom [1]). Recording classroom lectures can become a high-cost endeavor involving several video recorders and one or two staff members to oversee the recording process. Is it possible to use a low-cost production method that only involves the instructor that can be nearly as effective as the original live lecture? Answering this question is the primary objective of the study we are conducting.

We are conducting a study of production methods that produce pre-recorded lecture materials while an instructor is conducting a live lecture. These production methods are low-cost in that they require minimal equipment and leverage the time an instructor has already spent to produce a segment of a live lecture. Initially we are experimenting with two low-cost production methods: narrated slides and instructor point-of-view (POV) video. Our focus is on short segments of live lectures that cover a single concept in undergraduate computer

science and engineering courses. We compare the learning outcomes of these low-cost pre-recorded lecture production methods to the learning outcomes of a live lecture covering the same material.

A. Related Work

In [2] the authors compared tablet-drawing style (i.e., Khan academy style) pre-recorded lecture materials to narrated PowerPoint slides. This comparison found a balanced set of strengths and weaknesses to both approaches: viewers found Khan-style handwriting more engaging because it was personal but found the narrated PowerPoint slides more effective because they were clear and legible. These findings prompted the authors to create a hybrid method called TypeRighting. With TypeRighting, text is written by hand but then fades into a particular typeface soon afterwards.

In [3] the authors compare live lecture recording (videos of an instructor using a blackboard), recording of Khan-style tablet drawing, and self-guided book reading. The study focused on mathematics instruction for high school students. The authors found that the live lecture recording of the instructor using a Blackboard resulted in the best learning outcomes followed by the Khan-style tablet drawing. The self-guided book reading resulted in the worst learning outcomes.

In [4] the authors present the results of a large scale Massive Open Online Course (MOOC) study of various pre-recorded lecture production methods. The focus of this study was on student engagement as measured by the time students spent watching pre-recorded lecture materials. The MOOC was administered by three top-tier universities in the United States: MIT, Harvard, and UC Berkeley. The authors' primary findings were that shorter videos, Khan-style tutorials, instructors that spoke fast and with enthusiasm, were the most engaging.

The study we are conducting complements the existing work by focusing on undergraduate university level material on computing at universities with significant populations of first-generation college students. A significant number of first-generation college students may result in large inherent variances of student performance. With a broad group of students that includes significant numbers of first-generation students

we may better understand the differences in the pre-recorded lecture production methods on student performance.

B. Outline

The remainder of this paper is structured as follows. In Section II we describe the setup of our initial experiments. Specifically, we discuss the two low-cost pre-recorded lecture production methods in detail, how we deliver those pre-recorded lecture materials, and how we evaluated the learning outcomes of the students. We continue in Section III with a presentation and evaluation of the results before we conclude this paper in Section IV.

II. EXPERIMENTAL SETUP

Our initial experiments were conducted for a lecture on a brief introduction to computer processes. As part of the experiment, students were presented with a pre-test, instruction, and post-test sequence as part of their course activities in two different settings. The live lecture evaluation was performed at a major public higher education institution in the Southwest with students that have a closely related major. The two pre-recorded lectures were delivered to students in a foundational class open for students across campus (i.e., a general education credit course) at a major public institution in the upper Midwest. In both experimental configurations, students had some degree of prior exposure to the overall computing concepts as part of their curricular and course progressions. An additional limitation of this pilot study is that we did not capture prior online learning exposures by students.

A. Lecture Presentation Formats

The underlying educational content for all three lecture presentation formats was identical and complete in a self-contained fashion. The differences inherent to our evaluation were introduced by the manner in which the content was presented to students: live, narrated slides, or instructor POV video.

1) *Live Lecture*: During a live lecture the instructor presented and discussed a set of slides that:

- introduced the concept of processes (units of computational work distinguished from a program)
- identified and discussed the sections of memory associated with each process
- identified and discussed the states that processes transition through during their lifetimes
- identified and discussed the data that an operating system maintains for each process (in the process control block)

2) *Narrated Slides*: Students were presented with pre-recorded narrated slides covering the same material presented during the live lecture. The narrated slides were produced using the “record slide show” feature of Microsoft’s PowerPoint.

3) *Instructor POV Video*: Students were presented with pre-recorded instructor perspective video of a lecture-style narration of the content, which places this approach in between viewing a live lecture and narrated slides. The video was recorded using Google Glass, which is a monocular head-mounted augmented reality display featuring a front-facing camera. Minimal post-processing was performed to concatenate segments of recorded instructor POV video.

B. Evaluation

To evaluate the impact that the different lecture presentation formats have on the academic achievement, in this contribution we focus on the near transfer of content immediately after learners experienced the different formats. The employed questions were selected to determine in a comprehensive fashion yet short duration if the student learners were able to grasp the main conceptual facets of processes and comprised of several different types, such as true-false (T/F), ordering of elements (Order), matching of elements (Match), and multiple possible selections (M/S). We provide an overview of the questions we employed in the pre- and post-test that surrounded the instructional content delivery in Table I.

To evaluate the subject matter understanding, different types of questions were utilized to evaluate several underlying concepts. The different questions were presented in-classroom as part of the traditional lecture as paper-based tests, with the same configuration on pre- and post-test. The narrated slide and instructor view configurations were delivered using an online learning management system and questions on pre- and post-tests were randomized for each student and attempt.

III. EXPERIMENTAL RESULTS

The gathered results were scored as achievement in each question (and in total) and were afterwards homogenized on a percentage scale to allow for overall comparisons. A total of $N = 48$ students participated in the study, with 19 students in the traditional lecture format, 21 students in the narrated slides format, and 9 students in the instructor view format groups. We compare the differences between the post- and pre-test as learning gain for each student learner’s pairwise attempt per question and overall by subtraction.

A. Overview

Initially, we evaluate the score attained for the pre- and post-tests separately. Interestingly, the evaluation of statistically significant interaction of presentation mode and difference between pre-test and post-test using a one-way ANalysis Of VAriance (ANOVA) did not result in any broadly observable trend. We provide the scores for each question as a relative a percentage in Table II. Comparing the individual questions, we note that on average, students exhibited an average passing level (considering a typical 60 % requirement for passing grades) in the pre-test. The only exception here is question 1 ($M = 0.35, SD = 0.48$), which a portion of students had apparent problems with, as indicated by the low average and high standard deviation. The remaining questions

TABLE I

PRE-TEST AND POST-TEST QUESTIONS PRESENTED TO PARTICIPATING STUDENTS IN ALL LOCATIONS AND FOR ALL EDUCATIONAL CONTENT DELIVERY MODES. QUESTIONS WERE PARTIALLY RANDOMIZED FOR ONLINE INTERACTIONS.

No.	Question	Type
1	A process control block contains compiled program code.	T/F
2	Multiple processes can be created from the same program.	T/F
3	Please correct the order of process states (if necessary): (i) Ready, (ii) Waiting, (iii) New, (iv) Running, (v) Terminated	Order
4	Write the letter of the most appropriate word for each description. (i) A set of instructions that describe a course of action the computer should take (Program). (ii) A sequence of instructions that are executed and memory utilized by the computer for a particular course of action (Process). (iii) A section of memory to store data associated with function calls (Stack). (iv) A section of memory containing data that is dynamically allocated (Heap).	Match
5	Please select all items that would be found in a process control block. (i) Process identifier, (ii) Process state, (iii) Program code, (iv) Process memory allocation information, (v) CPU register values	M/S
6	Please select all the reasons why a process might be in the waiting state. (i) Waiting for an I/O transaction to complete. (ii) Waiting for its time quantum to expire. (iii) Waiting for an event to occur. (iv) Simply waiting for its turn to execute.	M/S

TABLE II

PRE-TEST AND POST-TEST SCORES FOR ALL STUDENTS BY QUESTION AND OVERALL.

Quest.	Pre-test		Post-test	
	M	SD	M	SD
Q1	0.35	0.48	0.51	0.51
Q2	0.84	0.37	0.92	0.28
Q3	0.69	0.27	0.85	0.26
Q4	0.68	0.33	0.70	0.34
Q5	0.72	0.24	0.85	0.25
Q6	0.72	0.27	0.79	0.29
Total	4.00	0.87	4.61	1.16

TABLE III

DIFFERENCES BETWEEN PRE-TEST AND POST-TEST BY QUESTION AND INSTRUCTIONAL CONTENT PRESENTATION MODE.

Quest.	Instr. POV (N=9)		Narr. Slides (N=21)		Live Lecture (N=19)		Total (N=49)	
	M	SD	M	SD	M	SD	M	SD
Q1	0.11	0.31	0.19	0.39	0.16	0.37	0.16	0.37
Q2	0.00	0.00	0.10	0.30	0.11	0.30	0.08	0.27
Q3	0.11	0.18	0.10	0.27	0.24	0.26	0.16	0.26
Q4	0.00	0.56	-0.08	0.49	0.13	0.33	0.02	0.45
Q5	0.31	0.39	0.00	0.31	0.18	0.25	0.13	0.32
Q6	0.17	0.50	0.02	0.40	0.07	0.22	0.07	0.36
Tot.	0.70	1.30	0.33	1.55	0.89	0.82	0.61	1.26

scored about twice as high on average with lower differences amongst learners. This accumulates to a total average of $M = 4$ out of 6 attainable points, with a standard deviation of approximately 20 % ($SD = 0.87$). Shifting the view to the post-test, we observe that the overall trend remained, with question 1 receiving the lowest attained student performance with the highest variability ($M = 0.51$, $SD = 0.51$). Overall, the variability per individual question remained at the same level, but increased for the slightly higher average total score per student learner ($M = 4.61$, $SD = 1.16$).

Thus, students on average totaled better post-test scores, but the differences between their performance increased. Specifically, we note that the higher level of variability indicates that a large portion of students performed similar or slightly worse on the post-test when compared to the pre-test.

B. Impact on Learning

We now evaluate the impact that the different instructional presentation formats have on the learning gain. We present this gain in answering the different questions (as well as total test scores) as direct comparison between the post-test and the pre-test in Table III.

Initially, we focus on the entire student population, for which averaged learning gains between 2 and 16 percent are observed. Most misperceptions or not generally available prior knowledge can be determined for questions 1 ($M =$

0.16, $SD = 0.37$) and 3 ($M = 0.16$, $SD = 0.26$), whereby question 1 also exhibits a high variability across learners. Similarly, the total score increased by about 15 % on average, but with an increased level of variability ($M = 0.61$, $SD = 1.26$), as discussed earlier. As a portion of students did not showcase an increased performance on the post-test, with some students performing worse, we note that this observation could be indicative of ceiling effects that were encountered [5].

Next, we compare the results obtained by presentation mode. Here, we note that students performed best for question 1 when they viewed the narrated slides version of the content. Question 2 exhibits similar levels of increase for narrated slides and lecture presentation, but no average learning gain for students experiencing the instructor's view ($M = 0.0$, $SD = 0.0$).

Questions 3 and 4 required a more detailed retention of content from the participating subjects, as ordering and matching are more complex than true/false questions. We note that for these questions, the lecture was the most beneficial to students. Specifically, for question 3 students increased performance by 24 % in the lecture group and about 10 % in the other two groups. The matching question 4 posed a challenge, as students in the narrated slides group even experienced a question-specific reversal effect.

The last two questions interestingly scored highest for the

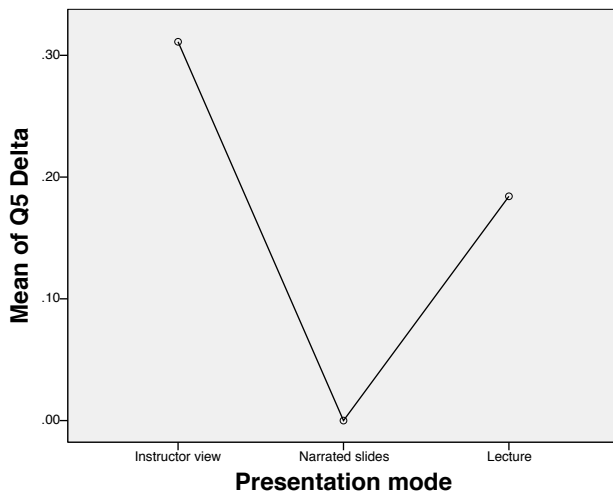


Fig. 1. Interaction by presentation mode for question 5 with significant interaction between the presentation employing narrated slides and recorded instructor views.

learners that went through the instructor's view presentation of content, with higher levels of gains ($M = 0.31, SD = 0.39$ and $M = 0.17, SD = 0.5$, respectively) than observed for the lecture presentation ($M = 0.18, SD = 0.25$ and $M = 0.07, SD = 0.22$, respectively). The main difference that was revealed by ANOVA was for the difference of question 5, with $F(2,46) = 3.781, p = .030$. A Tukey post-hoc test revealed that the difference between the instructor view and narrated slides for this question exhibited a significant interaction ($p = .014$), illustrated in Figure 1. Specifically, we note that the level of increase in correct answers for this question as highest for the students that were watching the instructor's view recording. However, only the difference to the narrated slides was high enough to be considered statistically significant.

Comparing the total score gain learners achieved between their pre- and post-tests, we note that the highest increase in performance is attained by students that attended a regular lecture ($M = 0.89, SD = 0.82$), followed by those that used distance education-friendly means of watching an instructor's first person view version of a lecture ($M = 0.70, SD = 1.30$), trailed by the narrated slides version ($M = 0.33, SD = 1.55$). The overall differences could stem from the cohorts of the sampled student populations across institutions or the individual students' prior exposure to online learning environments, both of which were not captured in the present study.

IV. DISCUSSION AND CONCLUSION

We are conducting a study of production methods that produce pre-recorded lecture materials while an instructor is conducting a live lecture. Our study, specifically, seeks to uncover whether low-cost (money and time) pre-recorded lecture production methods can provide similar learning outcomes to a traditional live lecture.

In this paper we presented our findings from initial experiments we have conducted comparing two low-cost production methods: narrated slides and instructor point-of-view (POV) video for presenting lecture material on computer processes. We found that overall, no statistically significant differences were exhibited for the different modes of instructional content presentation and student learning gains within the confounds of this pilot study. For practitioners, this yields the potential implication that the generation of content to support online instruction could be performed with very little additional efforts. When choosing to perform recording the instructor POV as part of regular lecture activities, the generation of content becomes almost transparent and might only require a very limited amount of effort, such as generally required for minor post-processing and content provisioning through online learning management systems.

We cautiously note, that this initial study only covers one specific subject matter in combination with near-transfer performance evaluations shortly after the described intervention with a limited set of questions. With an increase in learner numbers and the presentation mix across institutions paired with a more robust evaluation and recognition of prior online learning exposures and student progression through the provided materials, additional insights could arise.

The evaluation of student performances were tailored to a question format that can be readily administered using learning management systems, making them suitable for large hybrid/online settings as well, which will be part of our future works. This study, in turn, is ongoing and our plan is to expand our experiments along different dimensions while addressing the limitations of this pilot study:

- Expand the lecture subject materials to span a larger fraction of undergraduate material in both institutions
- Expand the number of low-cost pre-recorded lecture production methods studied with finer granularity of interaction and exposure
- Evaluate long-term impacts on learning gains within the presentation format mix for both institutions

These future endeavors will be inclusive of research covering examination approaches and far-transfer implications.

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Rapid Improvement of Students' Soft-skills Based on an Agile-process Approach

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Abstract—Manaus, the capital city of the state of Amazonas and the sixth Brazilian largest gross domestic product, demands highly qualified hardware and software developers for consumer electronics and telecommunication sectors of its free trading zone. However, what can be viewed as an opportunity for the youth alumni of local institutions of higher education contrasts with the low level of qualification provided by such institutions. As a consequence, most positions either remain opened or are occupied by professionals from other Brazilian regions. Moreover, the issue relies more on soft skills than on hard skills, as the local institutions are aligned with International standard academic curriculum and cover modern technologies. Soft skill is the enter barrier to the job market. English proficiency, communication skill, writing (in both Portuguese and English) skill, among others, are top listed failure reasons in the hiring processes. As one project manager highlighted: “it is much cheaper and quicker for the company to fill in some specific technological gaps, than to leverage a poor English proficiency”. This paper presents a proposal of an involving activity aiming to address several soft skills at the same time, with minimal disturbance in the student daily routine. The concept is based on the impact of immersing the student in a systematic project development experience. Clear communicated project goal, where the students have specific roles, with assigned accountable peers, everything under the umbrella of an Agile-like software development process (derived from SCRUM) are in the core of the activity. This paper details the incremental implementation methodology of the program among four research areas, and 23 projects or project activities, involving 34 students. The results of the two years running program will also be described, including the increase of progress visibility by advisors, the improvement of students communication and writing skills and the qualification on SCRUM software development process tools and documentation. The authors mapped important success factors in achieving relevant improvement on students' profile, and presented a list of recommendations for the next phase of the program, including some obvious one, as the importance of the active participation of advisors, and some less obvious one, like the resistance to the Internet online tool due to daily meeting coinciding with the peak of Internet usage in the University.

I. INTRODUCTION

Manaus, the capital city of the state of Amazonas in northern Brazil, hosts a free trading zone with up to 720 industries, concentrated in sectors such as consumer electronics, informatics, telecommunication, and two-wheels (motorcycles and bicycles). Given the technology driven aspects of such

industries, there is a high demand for qualified hardware and software developers to support R&D activities of product and manufacturing processes. However, what could be viewed as an opportunity for the youth alumni of the few local institutions of higher education contrasts with the low level of qualification provided by such institutions.

In short, specialized human resource in Manaus is an issue in quantity and quality. As a consequence, most positions either remain opened or are occupied by professionals from other Brazilian regions. Moreover, the issue relies more on soft skills than on hard skills, as the local institutions are aligned with International standard academic curriculum and cover modern technologies. English proficiency, communication skill, writing (in Portuguese and English) skill, among others, are top listed failure reasons in the hiring processes when the candidates show they are qualified in the required technology. As one project manager highlighted, “it is much cheaper and quicker for the company to fill in specific technological gaps, than to leverage a poor English proficiency”.

The present paper proposes an involving learning activity [1] aiming to address several soft skills at the same time, with minimal disturbance in the student daily routine. The concept is based on the impact of immersing the student in a systematic project development experience. Clear communicated project goal, where the students have specific roles, with assigned accountable peers, everything under the umbrella of an Agile-like software development process (derived from SCRUM) are in the core of the activity. This activity is in the context of a broader program denominated PROMOBILE (Large Scale Qualification **PRO**gram on **MOBILE** Technologies), and follows the learning vortices methodology [2], extending the involving activity principles to an interconnected approach. The principle behind a vortex is that any educational action is more effective when the enrolled student can see from the beginning the whole educational path, being constantly challenged to get the next step towards his career opportunity.

The implementation methodology of the program engaged four research areas, and 23 projects or project activities, involving 34 students. We also describe the results of the two years running program, including the increase of progress visibility by advisors, the improvement of students commu-

nication and writing skills, and the qualification on SCRUM software development process tools and documentation. The authors mapped important success factors in achieving relevant improvement on students' profile, and presented a list of recommendations for the next phase of the program, including some obvious one, as the importance of the active participation of advisors, and some less obvious one, like the resistance to the Internet online tool due to daily meeting coinciding with the peak of Internet usage in the University.

The most important contribution of this paper is a methodology to leverage soft-skills toward the needs of the global organizations. The methodology can be easily reproduced in any institution of higher education.

The remainder of this paper is organized as follows: Section II presents the context around the problem and the fundamental principles of this proposal; Section III details the solution applied to develop the needed soft skills; Section IV we present the results, and in Section V we conclude the paper with a few important remarks.

II. PROGRAM CONTEXT AND PRINCIPLES

The three (Federal, State and Municipal) spheres of Brazilian government defined a series of tax reduction policies in Manaus to promote the establishment of R&D activities by the companies with facilities in its free trading zone. The driven law, nicknamed as *Informatics Law* for Manaus free trading zone [3], has the explicit intention to deepening the product value chain in the region, with local added-value.

In an urge to fulfill the increasing demand for highly qualified professionals, government and private companies created new or improved existing local courses of higher education on a diversity of Science, Technology, Engineering, and Mathematics (STEM) related areas. Despite the improvement of the ranking of universities and colleges nearby, Manaus is located in the Northern region of Brazil, where the education facts and figures are worse countrywide. As a consequence, the efforts to increase the number of tech courses contrasts with the poor background of undergraduate candidates, leading to a dropout rate as high as 80%. Furthermore, the remaining 20% alumni struggle with lack of most basic skills such as Portuguese (native language) writing, or oral presentation. For the most qualified ones, the lack of English skills prevent them to access the best positions.

One may suggest the trivial solution to relocate qualified people from other places to Manaus. In the end we live in an global market, global companies have a long term experience with moving outsiders from here to there, and Amazon rain forest has its appeal, one may argue. However, life is not so easy for any HR department when the topic is to hire highly qualified personnel for positions in Manaus. The city is isolated from the rest of the country, surrounded by the jungle, with road connection to very few cities (see Figure 1), and flight ticket costs more expensive than average. As many Brazilian big cities, Manaus has profound infrastructure problems, including education and medical services. One may add to it: poor public transportation, high urban violence

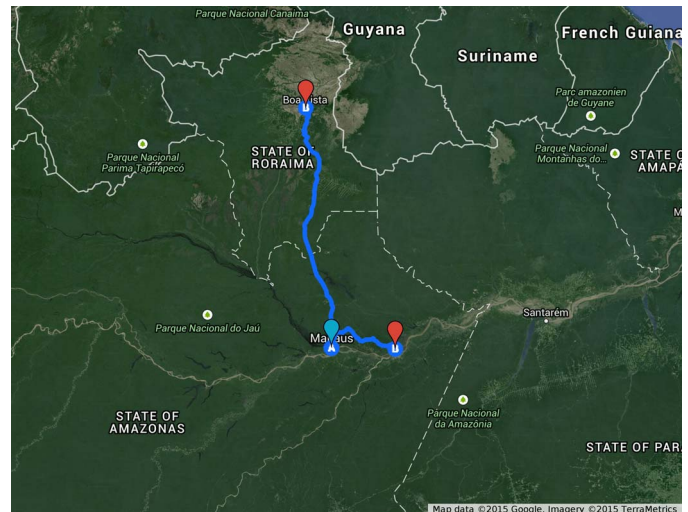


Fig. 1. Manaus (Green Mark), in the middle of the Amazon Rain Forest is located in the north margin of the Black River, the largest tributary of the Amazon River. Red Marks point to the two largest cities with road connection (in blue) to Manaus: Itacoatiara and Boa Vista.

records, high living cost, all-year hot and humid weather typical of the Amazon rain forest. Finally, one would then realize the big picture: relying on relocating professionals to Manaus is unrealistic.

A. Main Program: The Vortex Approach

In an attempt to deal with the situation, a group of researchers and company professionals met at the Institute of Computing (ICOMP) [4] of the Federal University of Amazonas to find a sound strategy to develop local human resources with adequate profile. The resulting program, named PROMOBILE, was conceived in the basis of the Student Involvement Theory[1]. However, we extend the concept of involving activities by grouping and interconnecting them under the same background. The activities have a common and well defined goal: building a professional profile out of students that are, with few exceptions, unmotivated, under-skilled, and immature [2].

The involving activity, a gear in the main Program, is called a *Learning Vortex*. The Learning Vortex is formally defined as “an activity occurring in one or more cycles, with a self-contained subject, and connected to another Vortex in such a way to contribute either in depth of knowledge or in number of persons to the whole Program” [2]. Table I lists the Learning Vortices defined by the Promobile program.

TABLE I
PROMOBILE LEARNING VORTICES.

#	Vortex	Quality	Quantity	cycle
1	Optional Subjects	medium	medium	semester
2	Talent Devel. Progr.	high	medium	year
3	Short-term events	low	high	semester
4	Advanced Training	high	low	year

The Vortex 2, the New talents development program, is defined as a participation in different projects where the students will receive scholarships, with clear granting and maintenance requirements. The candidates enroll in cycles of off-class project activities with different degree of challenges in different aspects. This is the chosen Vortex to host the strategy to develop soft skills, as the project environment naturally promotes communication and writing skills.

Targeting to better benefit from the potential of the activity, we tailored an well known Agile Software development process (SCRUM) to fit to our context, and to uniformly induce the learning actions. Native language writing and oral skills, leadership, English, besides the SCRUM itself, are just a few of the exercised soft skills. Highly productive students will receive leadership coaching. They also coordinate a small group of colleagues, and will receive a differentiated scholarship, promoting values, like meritocracy, punctuality, and self-starter attitude.

We describe the tailoring of SCRUM in the next sections. The details and how it is adopted by the several research groups inside Promobile are outlined as follows.

III. ADAPTATION AND ADOPTION OF SCRUM AT PROMOBILE

Over the past decades, several product development methodologies have been created. Among of them, there are the agile or light methods [5]. The agile methods propose to split the work in short cycles or iterations of a few weeks long aiming to achieve fast and adaptive product development process. The agile methods are adaptable and flexible and are indicated for rapid shifting demands in which results must be delivered in short periods of time. SCRUM is one of the agile methods [6].

While traditional product development strategies focus on processes and tools, the agile methods value individuals and interactions. In the same way, agile methods value customer collaboration over contract negotiation, responding to change over following a plan, and working software over comprehensive documentation [7].

A. SCRUM principles

SCRUM, as an agile method, is a framework in which people can deal and solve complex and adaptive problems, while delivering high value associated products in a productive and creative manner. SCRUM states the good practices to develop and manage products, so people can improve them [8].

The SCRUM framework associates roles, events, artifacts, and rules. Each component in the SCRUM framework has a specific purpose and is essential for the success of SCRUM. The roles associated with SCRUM compose the SCRUM team. The roles are: Product Owner, Development Team, and SCRUM Master. The events in SCRUM are: Sprint, Sprint Planning Meeting, Daily Meeting, Sprint Review Meeting, and Retrospective Meeting. The artifacts in SCRUM are: Product Backlog, Sprint Backlog, and Burndown chart.

A product owner has a complete view of the business and typically understands better the customer needs. The product owner represents an internal or external customer. The product owner determines demands and ranks each of them by importance and priority. Priorities are defined based on how valuable is the activity. Decisions are typically made based on customer priorities and on return on investment.

The Development Team is responsible for delivering usable products based on the inputs from the Product Owner. Development Teams are structured and empowered by the organization to conduct and manage their own work. Development teams are self-organizing and cross-functional.

The SCRUM Master has the role of keeping everyone aligned with the SCRUM principle. The SCRUM Master helps the Product Owner to produce a clear Product Backlog. The SCRUM master works together with the Development Team to keep focus on the chosen work items.

A Sprint is a time frame typically of two to four weeks. During the Sprint, the Development Team works to deliver parts of the product in a usable and shippable state. In the Sprint Planning meeting, together with the SCRUM Master and the Product Owner, the Development Team defines what will be developed in the coming Sprint. The work selected in the Sprint Planning Meeting to be done during the Sprint is known as the Sprint Backlog.

Daily, the Development Team meets for 15 minutes in the Daily meeting, or stand up meeting. The team checks the progress of each person by answering the following questions:

- What did I work from the last meeting until now?
- What am I going to work until the next meeting?
- What are the impediments blocking the progress of my work?

In the end of the Sprint, the Development Team demonstrates the work produced during the Sprint. The Product Owner judges if the produced items are acceptable or not, based on what has been defined in the Sprint Planning Meeting. Figure 2 illustrates a typical SCRUM workflow.

The work is organized as User Stories. All user stories are documented in a Product Backlog. The product backlog is maintained by the Product Owner, who is responsible to keep the priorities of each user stories based on their perceived added value. A subset of the product backlog is selected by the Development Team to be produced in every Sprint Planning Meeting. The set of user stories of each Sprint is the Sprint Backlog.

B. SCRUM in the academic context

SCRUM is being adopted as a structural framework by the industry to manage and develop complex products since the beginning of the 1990 decade. However, in the academic sphere, the reports of its usage are scarce.

There are experiments reported in specialized literature using students to compose the SCRUM teams [9], [10]. Also, there are literature reviews [11], [12] and systematic literature reviews [13], [14]. But most works focus on reporting case studies [15], [16], [17], [18], [19], [20].

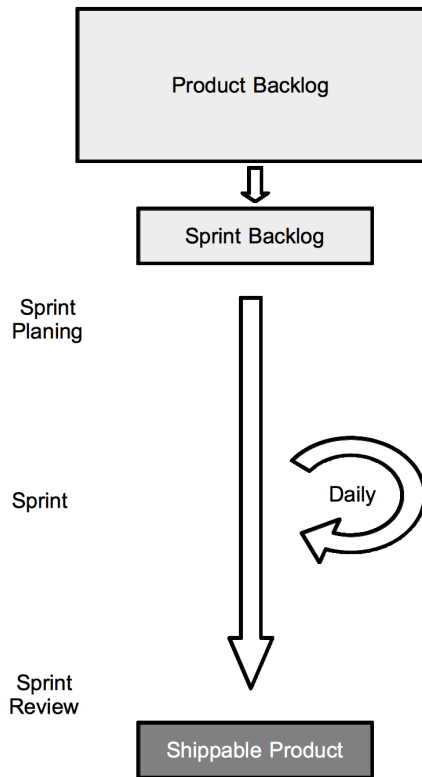


Fig. 2. SCRUM basic work flow. Part of the Product Backlog is selected to be developed during the sprint. During the Sprint, the Development Team meets daily in a 15 min stand up meeting. The Development Team delivers parts of the product in shippable state at the end of each Sprint.

To the best of the authors knowledge, this is the first work to report a case study with dozens of students as participants. This is also the first work to report the usage of SCRUM as the framework to conduct research projects within academic context.

C. The existing research group work flow

The existing advising process in the research groups involves periodic meetings in which a Senior researcher, the advisor, shares his/her vision about the research work ahead. A typical research group has a bi-weekly advising meeting. In some cases, the advising meeting happens once per week. The advising meeting is usually a one to one meeting, in which the advisor reserves one to two hours to discuss with one student his/her research project. Sometimes, the senior researcher aggregates students in groups of two or three, when their research topics are enough related to each other. A researcher group has from five to 20 students.

The challenges in this approach appear for both roles, students and senior researcher. On the researcher side, managing multiple projects is the key bottleneck. A common struggle heard from senior researcher is finding the right frequency for advising meetings so that the project would succeed. A

too frequent, such as every week, advising meetings may overwhelm the researcher and long periods without meeting the students may cause the students to work on unwanted items. In this context, students struggle to coordinate research project activities with their regular activities. Also, understanding correctly the activities to be developed combined with lack of specific technical knowledge are also recurring problems.

D. Similarities of SCRUM and the existing working flow

The adoption of SCRUM is made because its provision fits the needs of the current way of work flow of the involved research groups. We have noticed some similarities between the SCRUM framework and the existing working flow of the research groups. For example, at some extent, the existing working flow continuously and periodically reassess the project progress by means of advising meetings. Also, the Senior Researcher is the person who has best knowledge about the expect results of a research projects, sharing similar responsibilities and perspectives as a product owner with respect to a final product.

Table II illustrates the mapping between SCRUM roles, events, and artifacts with the way the research group activities were done before the SCRUM implementation. However, as the Table II shows, the mapping between some of the SCRUM entities are missing in the existing peculiar environment found in academic sphere. For example, the role of a SCRUM master is missing in the existing working flow of research groups. Also, the only official event present in the existing work flow prior to SCRUM is the advising meeting.

TABLE II
SIMILARITIES BETWEEN SCRUM COMPONENTS AND RESEARCH GROUPS EXISTING COMPONENTS. THE RESEARCH GROUP ENTITIES BEFORE THE SCRUM IMPLEMENTATION IS ON THE RIGHT COLUMN. THE SCRUM COMPONENTS ARE IN THE COLUMN SCRUM. N/E MEANS NON-EXISTING.

Type	SCRUM	Existing
Roles	Product Owner	Advisor (Senior Researcher)
	Development Team	undergrad and graduate students
	SCRUM Master	N/E
Events	Sprint	One/Two Weeks Time frame
	Sprint Planing Meeting	Advising Meeting
	Daily Meeting	
	Sprint Review Meeting	
	Retrospective Meeting	
Artifacts	Product Backlog	Research Objectives
	Sprint Backlog	N/E
	Burndown Chart	N/E

E. Implementing SCRUM

The process of implementing SCRUM for each research group was divided into three phases. Phase 01, training and coaching, is the most demanding and time consuming for all involved parts. Phase 02, monitoring, is the one in which

the involved parts understand the underlying process. Phase 03, self-improvement, the participants reach maturity with the process and start to improve it. Figure 3 shows each phase.

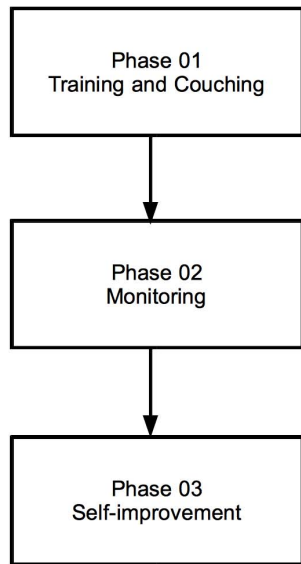


Fig. 3. The implementation of SCRUM in the academic environment took three phases. In the first phase, the team is trained and coached. The second phase the team becomes independent. The third phase the team starts to improve the process by themselves.

Phase 01 has two parts. In the first part, the students and the senior researcher participate in a series of training sessions. The training sessions are required to expose the SCRUM material to the involved people. In most cases, the undergrad students have already heard about SCRUM, but have never used it in practice. Graduate students tend to have real world experience with SCRUM. Sometimes, past experience may be problematic given that people may have used SCRUM differently or have bended its rules in several ways. Convincing all involved parts to follow the rules as strict as possible, at least for the first two sprints, is essential during the training sessions. The outcomes of the first part are: trained personnel in SCRUM practices, SCRUM roles definition within the research group, creation of the first version of product backlog for the research projects.

The second part of Phase 01 is composed by the first two sprints of the research group. The second part demanded strict coaching from a SCRUM experienced person, acting as a SCRUM master. During the first sprint, the newly defined development team and the product owner may have several

doubts and questions related to what to do and how to deal with the SCRUM practices. In the second sprint, the involved parts start to understand the process. During Phase 01, it is crucial to get full engagement from the senior researcher, who has the best knowledge about the research goals, the group deliverable, the project details, and the team best grouping combinations.

The team get independent enough to require minimal monitoring only after a couple of sprints. In Phase 02, the coaching required is reduced as the team has understanding of the implemented practices and each individual already knows what needs to be done. During Phase 02, the doubts about SCRUM are replaced by suggestions on how to improve the implemented practices.

Phase 03, the research group is fully independent and can be self managed. In Phase 03, the research group becomes self manageable and self improvable. Therefore, representatives from each research group, the nominated SCRUM masters, have periodic meetings to discuss improvements on the implemented practices and to share experience on how to solve problems in common related to the agile method.

IV. RESULTS

In this section we present the results obtained during the process of implementing SCRUM in a academic environment involving research groups.

A. Description of the SCRUM teams

The SCRUM implementation took place in four different research groups. The research groups are in Embedded Systems, Computer Vision and Robotics, Intelligent Systems, and Mobile Computing. The SCRUM teams are composed by a senior researcher, graduate students, and undergrad students. Graduate students participate in researches developed by the research groups. Undergrad students are part of Computer Science, Computer Engineering, and Information Technology courses.

The senior researcher takes the role of product owner. The scrum master is usually the most experienced student in the research group, typically a graduate student. The scrum master acts as such for the entire research group. The development teams have usually only one single participant. However, the SCRUM events are conducted with all members of the research group. Therefore, even though they are part of different SCRUM development teams, all members of the research group participate in the same sprint planing, sprint review, daily, and retrospective meetings.

Table III illustrates the new mapping between SCRUM components and the research group activities and roles after implementing SCRUM. As shown in Table III, we followed the SCRUM framework as much as possible. Some items of the SCRUM framework had to be adapted due to the peculiarities of the academic environment. The differences are detailed in Sections IV-C and IV-D.

In this process, four research groups participated. The first group has seven projects. The second and the third groups

TABLE III

SCRUM COMPONENTS IN THE NEW ENVIRONMENT. THE RESEARCH GROUP ENTITIES AFTER THE SCRUM IMPLEMENTATION IS ON THE RIGHT COLUMN. THE SCRUM COMPONENTS ARE IN THE COLUMN SCRUM.

Type	SCRUM	Research Group
Roles	Product Owner	Advisor (Senior Researcher)
	Development Team	undergrad and graduate students
	SCRUM Master	Experienced student
Events	Sprint	Four Weeks
	Sprint Planning Meeting	Sprint Planning Meeting
	Daily Meeting	Daily Meeting
	Sprint Review Meeting	Sprint Review Meeting
	Retrospective Meeting	Retrospective Meeting
Artifacts	Product Backlog	Research Objectives
	Sprint Backlog	Sprint Backlog
	Burndown Chart	Burndown Chart

have five projects. The fourth group has six projects. Most projects, sixteen out of twenty three, are composed by only one person in the development team. While four projects have two participants, only two projects have three participants in the development team. The largest development team, composed by four members, is part of the first research group. The second research group is composed by undergrad students only.

The initial scope of the product of each SCRUM team was software developed in the PROMOBILE training program. Some of the initial SCRUM projects became part of research projects. Therefore, research activities and results were incorporated into their backlog. Therefore, we realized that extending the scope to other research projects was possible. Thus, the scope currently covers also research results out of PhD or Master's theses of graduate students. Undergraduate students are involved in research initiation programs, which are also structured as a SCRUM team.

B. Characteristics of a Product Backlog of a research project

The Product Backlog of a research project in the PROMOBILE program is constructed following the recommendation of SCRUM. We followed the rules strictly. However, some characteristics of research projects make the user stories unique. Research projects include cyclic iterations and refinements that are typically not present in a software development project.

Research projects, in general, have investigation elements, experimentation phases, and reporting. Depending on the results of experimentation, new hypotheses may be created and may require to be retested. Therefore, recurring user stories and tasks may appear in the Product Backlog of a research project.

Another common user story is the reporting of results by means of papers. Writing papers is also a process that require constant refinements and recurring iterations and reviews with

senior researcher. Specially when the text is produced by students.

Recurring user stories and tasks are usually not well solved with SCRUM. The way they have been dealt in this context is to consider versions. Therefore, although one user story may be accepted, but after evaluating the experiment results new hypotheses appear, the cycle may be repeated, but now considering different conditions. Thus, new versions, or different results or parts of the research are developed in the new user stories.

C. Peculiarities of the academic world

We identified items specific to the academic environment that required us to change some of the SCRUM rules. The peculiarities of the academic world that conflict to SCRUM rules are:

- *Students do not engage a full working day.* The main objective of an undergrad or graduate student is his/her major course. The situation is even more peculiar for undergrad students, who engage in research project as secondary or complementary activity. They have to reserve a good part of their day to attend classes, for instance. Graduate students may engage in full day of research activities, however, they still have to attend classes.
- *Students have a busy schedule.* Because students participating in a SCRUM team are attending to different classes, sometimes in different phases of their courses, they usually have conflicting schedules.
- *Research projects developed by students tend to be done by an army of one man.* Undergrad and graduate courses require students to write dissertations or thesis on a research subject. This type of work is expected to be done by only one student. Therefore, most SCRUM projects will have a development team of one single person.

D. Changes in SCRUM

SCRUM had to be adapted to fit the peculiarities of the academic world. Here we list the changes we had to implement to adjust the framework to the applied environment:

- *Development team size.* SCRUM recommends having development teams of five to ten members. Because most projects are developed by one single person in this context, we had to overlook this rule to allow projects with one member.
- *SCRUM masters may be part of the development team.* In this SCRUM implementation, each research group had one SCRUM master. The SCRUM master, apart from acting as such for all projects in the research group, also had its own research project, in which he/she would participate as part of the development team.
- *Daily meeting frequencies.* Due to the tight schedule of students, daily meetings happened only three times per week. Some research groups also tried performing reports using virtual tools, such as instant messaging, or email.

E. Improvement of soft-skills by means of SCRUM practices

We have observed in SCRUM framework several opportunities for students exercise their soft-skills. During a regular Sprint, for instance, the implemented SCRUM offers three opportunities of 15 minutes per week of oral communication skill exercise to express objective and structured project progress by means of the daily meetings. Apart from oral communication skills, during daily meetings, students also exercise their leadership and decision making skills.

Sprint planning meetings, which occur once every four weeks, exercise oral communication skills. But during the sprint planning meetings, students also collaborate on project planning, in which they need to describe clearly their ideas in written form of user stories. During sprint planning meetings, students also exercise their ability to commit to the amount of activities they are capable to deliver in the coming four weeks.

The sprint review meetings are opportunities for oral presentation and demonstration of their results. The push to demonstrate something working motivates students to be well prepared to the meeting and show case their results. Presenting a working piece of their research project brings extra motivation for students. Even when they fail to deliver what they have promised, we have noticed that after a couple of sprints, students learned to confidently report their failure and use it to improve next sprints. Because a failure is the result of only four weeks, students feel confident to share the results and use them to help their decisions in the next sprint planning meeting.

In summary, we observed clear improvements in the following skills:

- **Writing:** Writing skills are exercised during the elaboration of reports, sprints reviews, and planning meetings. We observed that besides grammar, the ability to condense ideas and information is also exercised. The results of a questionnaire show that 70.4 % of the students report an improvement in their writing skills.
- **Oral presentation:** These skills are mostly exercised during the daily meetings. However, the sprint review and planning are the most intense moments, where not only the capacity to speak clearly is exercised, but also to communicate ideas under pressure. The results of a questionnaire show that 70.4 % of the students report an improvement in their oral skills.
- **Punctuality:** As most agile process, SCRUM is driven by a well defined and marked pace. All participants have to keep the schedule, daily meetings, follow that realization of features, and to be part of sprint reviews and planning meetings. Contrary to a regular classroom attendance, if one student delays 10 minutes he will be noticed by his peers. Stealing-time-of-others is a characteristic easily communicated to everyone. The results of a questionnaire show that 100.0 % of the students report an improvement in their capability of organizing their project activities and 100.0 % of the students also reported improvement in participating in group activities.
- **Leadership:** Leadership is specially developed by those

students assigned as SCRUM master. They have to organize meeting, call the participants and to drive them towards the completion of their sprints, even though they are peers with no clear hierarchy assigned. In this sense, leadership is also exercised among the other students, as they know that they have to support the SCRUM master. The questionnaire showed that 66.7 % of the students believe that they improved their leadership skills.

- **Transparency:** This is something that we observed during the sprint review and planning meetings. Students are encouraged to be open and to be very honest about the realization of their sprint, and to be realistic when deciding what new feature will be included in the next one. In the first sprint, some students tried to argue that their feature was satisfactorily deployed. However, after some interactions they also had the initiative to reevaluate an incomplete feature. The questionnaire showed that 88.9 % of the students have improved their decision making skills.
- **SCRUM:** Although the knowledge of SCRUM can not be seen as a soft skill, it is worth to mention the students also learn how to work under a development process. Moreover, most of R&D based in Manaus adopt SCRUM in their software development activities.

F. Report of improvements

We collected the most recurring improvement reports from the retrospective meetings of all research groups. The details of each improved item are as follows.

- **Organization.** Organization is the improvement most reported during the Retrospective meetings on all research groups. Students report that having guidelines and structured roles and events help to keep the motivation in the research project.
- **Communication.** The communication between the researcher and the students improved due to the structured and transparent way of writing user stories. The standard way of defining parts of the research project as user stories works as a protocol between the researcher and the students.
- **Pace.** The events implemented and suggested by the SCRUM framework serve as self motivation for the participants of the research project. Students report that they force themselves to be well prepared for daily meetings and sprint review meetings. Senior researchers report that the established pace help them to better organize their schedule.

G. Lessons learned during the Process

Here are the major difficulties found during the process of implementing SCRUM for the PROMOBILE program:

- **Daily meetings.** Daily meetings were the piece of SCRUM that most students reported difficulties to follow. The main reason for this problem is the conflicting schedules between the participants. We reduced the frequency

of this meeting to three times per week to mitigate this problem.

- Advisors engagement. We noticed that the engagement employed by the Senior Researcher is crucial for the success of SCRUM in this context. Specially during the training of Phase 01, students feel more confident and tend to reflect the engagement of their Advisor.
- Recurring impediment reports due to Internet connection. In order to enable virtual daily meetings, we adopted an online tool to track the SCRUM activities. However, this decision in some cases generated resistance to the Internet online tool due to daily meeting coinciding with the peak of Internet usage. At least one group reported they moved from the online tool to a spreadsheet based tool.

H. Recommendations for improvements

Targeting a better implementation and to reduce the reported difficulties, we recommend:

- Forming SCRUM teams with students that share similar schedule. In this way, the development team may be able to properly meet for daily meetings.
- Using physical boards to track the Sprint progress. Using online tools has advantages and disadvantages. In this context, for tracking the sprint progress, using a physical board may avoid problems accessing the online tool during daily meetings.

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V. CONCLUSION

We presented in this paper a novel methodology to develop students' soft-skills applied in the peculiar environment of the capital city of the state of Amazonas of Brazil. The methodology was tailored to fill in the identified gaps in the job market of Manaus based on reports of hiring managers, human resources professionals, and the youth alumni. The common understanding is that professionals graduated in local institutions of higher education lack soft skills, such as English proficiency, oral, and writing communication. In this text, we described a SCRUM based methodology, the process of implementing it in the *PROMOBILE* program, and the its impact on students' soft-skills.

The key differential of our approach is its applicability to any institution of higher education. The present work uses SCRUM as the framework to conduct research projects within academic context. Also, to the best of the authors knowledge, this is the first report of a case study with dozens of students as participants of four different research groups and 23 SCRUM teams.

After implementing the SCRUM based methodology, we observed noticeable improvements of the participants soft-skills. The SCRUM framework offers several opportunities for students exercise different skills by means of well structured events, roles, and artifacts. Writing, Oral presentation, Leadership, Transparency, Organization, and Pace are the improvements most reported by the involved people. Besides, SCRUM itself is a desired know-how, given that most R&D based in Manaus adopt SCRUM as their primary software development process. Even when they do not adopt SCRUM, the principles behind a systematic development process are still a good skill set to be carried by students as professionals.

As future work, we will follow up the research groups and their evolution as entities using SCRUM. We are going to replicate the methodology in other research groups and implement the suggested lesson learned. We are also interested in validating the outcome and the impact of this intervention in the hiring process of the students who participated in this study.

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Nanotechnology: Simulation and Design

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Abstract— A faculty team from Electrical and Computer Engineering, Biology and Physics have developed three 300-level general education lecture courses in nanotechnology and a 400/500-level supporting laboratory with NSF support. This paper focuses on one of these courses:

ECE/SCI 383U Nanotechnology: Simulation and Design.

The course is open to science/engineering majors and students from non-technical fields alike, with minimal pre-requisites, and qualifies as a general education course for most of these. It includes four components:

- A qualitative lecture course in nanoelectronics
- A lab course in nanoelectronics simulation with LTspice
- A reading and discussion course in nanotechnology generally, but focused on nanoelectronics, and
- A technical writing course using laboratory reports as exercises.

The paper reports on the background and structure, and experiences to date.

Keywords—nanotechnology; nanoelectronics; simulation; LTspice.

I. INTRODUCTION

The prediction is that a nanotechnology workforce of 6 million will be needed by 2020 to feed a \$3 trillion/year industry [1], and the challenge to educators is to meet this demand with inherently multidisciplinary programs [2]. Not all of these workers will be scientists or engineers and for students of other disciplines the need is for exposure to the technical aspects of nanotechnology at a level which can be integrated into their own disciplinary framework as general education.

A “sequence” of three 4-credit 300-level General Education (GE) lecture courses in nanotechnology, has been developed in the Departments of Physics, Biology, and Electrical & Computer Engineering (ECE). These are available as for elective credit in students’ majors, but are primarily designed for non-majors for GE credit [3, 4]. These courses are scheduled through the academic year as a sequence beginning with PH 382U *Introduction to Nanoscience and Nanotechnology* in fall, followed by BI 372U *Nanotechnology, Society and Sustainability* in winter, and ECE 383U *Nanotechnology: Simulation & Design* in spring, but in fact each course is actually stand-alone. The “U” suffixes stand for University Studies (UNST) which indicates GE eligibility.

GE at Portland State University (PSU) includes thematic “clusters” of junior courses. Students must choose three courses from one of these clusters which must be outside the student’s major. The three new courses are all taught by active learning principles and are included in the junior *Science & Liberal Arts* cluster as SCI 382U, SCI 372U and SCI 383U, and in the *Design Thinking/Innovation/Entrepreneurship* cluster in the School of Business Administration under their PH/BI/ECE identifiers. Every graduate must complete the entire GE sequence [5], which consists of:

- A freshman sequence of three quarters in a single elective cross-disciplinary topic
- Three elective sophomore courses which then serve as prerequisites to three of the many junior GE clusters
- Three elective junior courses from a single cluster which includes courses from multiple departments, grouped around a single theme.
- An integrating two-quarter senior capstone experience, including some form of community service.

A future goal is the introduction of nanotechnology capstone projects which will integrate STE and non-STE “graduates” of the nanotechnology courses alike into industrial nanotechnology projects as practiced in ECE Senior Design.

Every course at PSU which is approved for the GE (UNST) program has goals defined in terms of

- Inquiry and Critical Thinking
- Communication
- The Diversity of Human Experience, and
- Ethics and Social Responsibility

These goals are regularly assessed for all GE courses and actually provide a good match to the non-technical sections of the Accreditation Board for Engineering & Technology (ABET) accreditation criterion 3 f, 3g, 3h and 3j [6, 7]. For many engineering students, the linkage of the GE/UNST component of the degree structure to their technical studies will provide relevance and a more meaningful context [8].

The nanotechnology cluster courses are tailored to support interaction between STE (science, technology and engineering) and non-STE students, who take them together. There are no course-specific college-level prerequisites for any of them, which means more specifically that there can be no calculus expectations.

These courses have previously been reported on elsewhere [9-11]. A follow-on 2-credit ECE 410/510 *Nanotechnology Laboratory* course has also been developed and will be described separately elsewhere [12].

II. NANOTECHNOLOGY PROGRAM

Technically advanced nanotechnology courses are now relatively common, especially in active research departments, and many with an interdisciplinary flavor [13]. This program, however, addresses the recognized difficulties in developing technical awareness in the general population [14-17] by bringing STE and non-STE students together in the same classroom in courses with both technical and social contents. The overall program goals are to:

- Address the need for greater technical awareness in the general student population
- Extend the breadth of nanotechnology education for science and engineering majors, and
- Expose both student groups to the social, economic, and ethical issues of nanotechnologies.

and the program objectives are stated as:

- To expand the educational opportunities in Nanoscale Science and Engineering (NSE) for STE majors, and especially to open up a greater level of awareness of the roles of the other disciplines.
- To increase awareness of the potential applications of NSE technologies, based on a qualitative understanding of their underlying scientific and engineering principles, amongst the general non-STE student body.
- To develop an understanding in both student groups of the social, economic, and ethical issues which are posed by the development and adoption of NSE technologies.
- To provide hands-on NSE laboratory experiences for both STE and non-STE students, and
- To promote both broad and specialized NSE skills to enhance nanotechnology-related employment opportunities for STE and non-STE students alike.

These objectives have been achieved within the constraints of existing degree regulations and crowded curricula by using the existing campus junior GE elective structure. Each course is tailored to support interaction between the STE and non-STE. There are no college-level prerequisites for any of the courses which means no calculus!

The STE majors in the cluster courses outside the major (i.e. for GE credit) benefit in several ways:

- By seeing nanotechnologies from a different disciplinary perspective, supplementing their advanced nanotechnology studies within the major,
- By gaining an understanding of the social, economic, and ethical issues which surround their chosen area of specialization, and
- By satisfying their GE requirements with courses directly relevant to their major, providing context and greater interest.

For STE majors, the remaining GE requirements provide sufficient flexibility to complete the PSU institutional humanities and social science distribution requirements for STE degrees.

Examples from nanotechnology provide non-STE majors with an understanding of the role of technology in society and how scientists and engineers function, as they explore the same social, economic, and ethical issues. This awareness has a ripple effect, propagating into the general community through discussions and social interactions with their non-STE peers.

The university itself will also benefit from the program as a model for increased relevance of the GE sequence to students' majors in all specializations. The program enables STE students to improve communication on technical issues with non-STE students and simultaneously provides non-STE students with an appreciation for both the benefits and the potential pitfalls inherent in developing these (or any other) new technologies.

As the importance of nanotechnologies grows for local industry, it will benefit by the increased availability of both more broadly educated specialists and more technically aware non-specialists, and from the R & D efforts (including social impact studies) of the capstone teams.

The courses are of special interest for high school science teachers and the faculty team is currently planning a one-day workshop at the Oregon Science Teachers' Association's annual conference to discuss how the materials that have been developed might be used in high school (and middle school) classrooms. The course materials will also be made available to the academic community at large, e.g. on NanoHUB.

For STE majors who take the courses for technical elective credit, the engineering or scientific content must be sufficiently different from the core curriculum and other electives to augment that curriculum and maintain their interest in the technical side. At the same time, the equally important objective is to engage them in the broader social issues to be raised and discussed. For non-STE majors, the complementary challenge is to present technical material in an understandable way to students without the traditional technical background, so that the social issues can still be interpreted within a technical context. For some, those social issues provide the base from which they can interpret the technical aspects of the classes. Both groups need to appreciate the difficulty of predicting social consequences of nanotechnology. As

examples, while self-assembly manufacturing techniques may lead to reduced costs and promote wider use of new products, the escalating use of silver nanoparticles in health, electronics, and the home may be affecting the aqueous environment and food chain [18]. Nano-composite materials can provide increased strength and stain resistant coatings, but the toxicity of nanoparticles is poorly understood and differs from that of the corresponding bulk materials. Such examples further the goal of creating a better informed and more engaged citizenry.

III. ECE/SCI 383U NANOTECHNOLOGY: SIMULATION AND DESIGN

A. Course Objectives

Engineers rely heavily on commercial modeling and simulation software for both design and analysis. This course provides insight into the engineering design process for non-STE students and an expanded experience for ECE majors to modelling techniques beyond those used in the core curriculum. These are used to model nanotechnology phenomena, materials, structures, and devices, and to design applications in LT-SPICE. The software is free and is the ECE Department staple, being installed on all laboratory PCs and available for students to download should they choose to run their simulations on their own laptops or at home. Eventually, students develop and run their own models. The lab runs in an active learning mode with STE and non-STE majors working in pairs. Most of the non-STE students have never taken calculus, which is therefore not used. The course also draws upon the resources of the NSF- supported Purdue website repository "NanoHUB,"

The Course Outcomes are stated to be:

- Understanding of the basic concepts of nanotechnology
- Understanding of the role of computer simulation in engineering design
- Competence in the application of one simulation software
- Understanding of the physical operation of selected nanodevices
- Understanding of environmental, health and social issues of nanotechnology
- Ability to write competently and appropriately to the context

The challenge is to provide material accessible to students with no calculus or physics background, while offering appropriate challenges to ECE and physics majors. The technical content is focused on LT-SPICE modelling of nanoelectronic devices and circuits, presented as an example of how engineers employ modelling and simulation. A very brief introduction of the electrical concepts that will be needed, (but no others,) is followed by a familiarization exercise in graphical LT-SPICE modelling of simple resistive and RC circuits and a diode characteristic. From there on, the LT-SPICE simulations are selected to demonstrate selected

nanoelectronic examples in a studio/lab environment. Ideally the student groups are balanced, so each pair consists of one STE and one non-STE student, and effective bilateral learning here should be based on the STE/non-STE student interaction. The STE students are challenged to be able to explain technical concepts without benefit of mathematics, which colleagues who have previously taught similar crossover courses advocate as a truly educational experience. The course also presents challenges for ECE students, nanoelectronic examples requiring LT-SPICE capabilities that are not used elsewhere in the curriculum and a need to develop their own models.

Electron tunneling is the continuing theme of the lab simulations, with all but one based on this effect, albeit indirectly. The course also provides non-technical majors with some more general appreciation of how device principles can be employed in circuit and sensor applications. The most successful GE courses are usually those that incorporate the instructor's research interests or viewpoints which would not normally be included in core curricula. Hence, the course uses nano-devices such as TDs, RTDs, SETs, etc., and an emphasis on graphical techniques and graphics-based simulations. *Ad hoc* guest lecturers have also presented research related material, e.g. nano-laboratory safety issues, etc.

B. Course Structure

Catalog description: Introduction to basic electrical concepts, nanotechnology, and the principles of modelling and simulation. Modelling and simulation are used to examine environmental and health hazards and the applications of nanotechnology in environmental and biomedical sensing and in current and future nanoelectronic technologies. Course is designed for both STE and non-STE majors.

"This course will provide insight into the engineering design process for non-engineers and an introduction to the applications of nanotechnology in micro/nanoelectronics, environmental nanosensors, biomedical devices, etc. Understanding of these applications will be achieved by the combination of qualitative explanations of device operation with quantitative simulations of performance."

The course plan for spring 2015 is shown in Table 1. There is also a weekly discussion session based on the textbook [19] and to a lesser degree on a variety of specified references [20-25]. The simulation labs are based on publications in the research literature [26-38].

The course runs as:

- One 75-minute lecture (streamed on-line)
- One 75-minute discussion period
- One 170-minute lab period

These times meet the normal campus distributions for a 3+1 credit course. In addition, a block of time is scheduled for individual meetings with the WIC tutor.

Evaluation is based entirely on eight weekly lab project reports on the computer simulation exercises, a final individual discussion paper on a topic TBD, and on participation in the class discussions.

The complete grading scheme is shown below. There are no formal exams.

- Eight simulation assignment reports: 80%
 - Technical accomplishment (8x5.0%)
 - Technical report content (8x2.5%)
 - Writing (8x2.5%)
- Final topic paper: 20%
 - Content 15%
 - Writing 5%
- [Class participation bonus 10%]

Lectures	Simulation Labs
Syllabus & Introduction to EE concepts	Introduction to EE concepts (cont'd)
Introduction to EE concepts (cont'd); LT-SPICE	1. Introduction to LT-SPICE
Nanoparticles	2. Single electron box
Electron tunneling	2. Quantum Cellular Automata (QCA)
Carbon Nanotubes (CNTs)	4. CNT composites
Resonant Tunnel Diode (RTD)	5. RTD & circuits
Single Electron Transistor (SET)	6. SET & circuits
Memristors & Nanosensors	7. Nanosensors;
No lecture	8. Memristor & circuits
Guest lecture: Environment & Nanotoxicology	Lab visits: Nanotechnology & TEM/SEM labs

Table 1. Fall 2015 ECE/SCI 383U course outline

The course is a designated Writing Intensive Course (WIC), so 25% of the grade is specifically allocated to the writing, (format, spelling, grammar, style, etc.) with the emphasis always on writing to the target audience (e.g. peers, supervisors, lay readers, etc.) For ECE majors (only) the course may be substituted for the BSEE/BSCpE WR327 Technical Writing requirement, which is reflected in the writing assignment formats (e.g. technical report, executive summary, journal/conference paper, newspaper article, position paper, e-mail, Powerpoint™, poster paper, etc.) as specified in the lab notes. First drafts of the lab reports are due by e-mail on Friday after the lab on Wednesday. The WIC tutor provides feedback on the drafts (in person if the student attends the voluntary Friday WIC workshop) which are e-mailed back by 5pm on the following Monday, with the final version submitted the following Wednesday. This schedule provides a one-week two-step lab reporting cycle. Final WIC grading is completed by the end of the week and the instructor completes the technical grading for return at the Monday lecture. The WIC tutors are English graduate students who have completed a course in teaching writing.

The BSEE and BSCpE curricula are very full and students have a very limited choice of ECE electives which must be selected from a limited list for each specialization. The program's concept is based on a balance of STE and non-STE

students and the challenge is to attract enough ECE students to provide a STE core. The WIC designation and departmental acceptance as a replacement for the traditional Technical Writing class is intended to accomplish that, but given that half of the ECE juniors are community college transfers who satisfy their writing requirements prior to transfer, and assuming that the remainder take their writing course uniformly distributed across three quarters, it needs almost all of the eligible ECE majors to take the nanotechnology course to fill the STE slots and balance the non-STE students.

Instead of a graduate teaching assistant, the course employs an undergraduate "alum" as a mentor. Although undoubtedly dependent on the individual chosen, this has proved to be a key component to the success of the course.

IV. CONCLUSIONS

The course is running for the second time at the time of writing (spring 2015.) The external evaluation team runs on-line pre- and post-course surveys, student interviews, and classroom observations, but none of these were performed for the first offering. Consequently, the changes that were made for the second run had to be based on the internal campus student course evaluations and conversations with students during the course itself. As a result of these, the course was totally restructured.

The main point was that while students in BI/SCI 372U expressed a desire for more technical content, the reverse was true for ECE/SCI 383U, where the delivery of technical content was much too fast for the non-STE students, even with no calculus employed. In addition, while students expressed appreciation for the required textbook [19] and the prescribed reading schedule, the subsequent discussion promised in the syllabus generally gave way to the "need" to get through more theory to support the labs. Furthermore, the "lab" session was originally only expected to provide a start on the lab exercises which were to be completed at home. That worked for some, but in general it was clear that more lab time is needed to move others further along.

But the biggest changes required were modifications to the LT-SPICE labs themselves. The design of the experiments leant heavily on the research literature, and frankly some of the models could not possibly have worked as published. These are being reworked during the second offering of the course, and are working better. Nevertheless, more work is needed on the labs before the course runs again, and the undergraduate mentor is working with one of the students to identify ambiguities in the lab instructions and where more clarification is needed. In addition, new experiments are proposed, e.g. nanoCMOS, CNFETs, a more physically based tunneling model, etc.

Although the course title includes the word "design," there has been negligible design component to the course. It is intended that this be rectified by the addition of a small simple design component to each lab exercise.

One aspect of the course which did work extremely well was the interaction between the STE and non-STE students, primarily in the generous commitment of STE time to assist the non-STE students with the lab exercises. The limited discussion of social issues provided less need than expected for non-STE viewpoints. Also, there was no evidence of any disparity in the writing abilities of the STE and non-STE students.

The current class includes physics, chemistry, biology, pre-med, mechanical engineering and general science majors, but only a few qualifying as genuine non-STE. The STE/non-STE balance is a target that has clearly been missed, despite targeted recruiting.

Another missed target, although perhaps the same one, is the ECE student enrollment which was to have been encouraged by the technical writing provision. It turns out that the standard technical writing course is run totally on-line every term, including summer, and that almost all ECE students take it that way over summer. None of the other students (whether STE or non-STE) need the WIC qualification, there apparently being more than enough to meet campus requirements, so it is proposed to abandon the WIC component in future.

Interestingly, just on half the students currently enrolled have previously taken both the physics and biology courses and are very positive about the sequence, with one (non-STE) contemplating a change of major. These students qualify for an informal certificate of completion which seems to have been a motivating force, much to the faculty's surprise.

At the end of the spring 2015 course, (the second offering,) student comments on the course evaluations included: "A lot of work for a GE course," and "A difficult course but I learned a lot."

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Incorporating Parallelism and High Performance Computing into Computer Science Courses

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Abstract— This work describes research, efforts, and outcomes for several Computer Science courses after incorporating XSEDE High Performance Computing (HPC) Resources and recommended and required curriculum additions from the ACM 2013 Computer Science Curricula and IEEE Technical Committee on Parallel Processing Curriculum Guidelines. The work herein describes the courses affected by this work, including Computer Organization (44-345), Operating Systems (44-550), Software Engineering I and II (44-561/2), and Parallel Programming (44-599) - undergraduate and cross-listed courses at Northwest Missouri State University. Guidance for novel content in these courses was drawn from the ACM/IEEE CS 2013 Curricula and from recent research on HPC education. As recommended by the curricula guidelines, topics in parallelism were incorporated into many required Computer Science courses. Therefore, an analysis of contact hours devoted to parallelism in required CS courses at Northwest is also included. Results, based upon student surveys from the Operating Systems (OS) course and course reviews, indicate student interest and success in students having learned key topics in parallelism. Particular emphasis was placed on incorporating parallel computing topics into the OS course.

Keywords— *High Performance Computing; Novel Course Curricula; Parallel Programming.*

I. INTRODUCTION

Innovative course modules play an important part in students' university education. They allow educators to introduce material from research and stimulate students' interest. For example, advances in operating systems (OS) courses have come in many forms. These include the development of simulated operating systems for instruction (e.g. Nachos and Pintos) [1,2], kernel development modules [3], use of mobile operating systems [4], and many others. Course focus may vary widely, as well. Course assignments, particularly those related to parallelism may provide an application, simulation, or engineering-oriented focus or may emphasize other aspects depending upon students' interests.

Regardless of the focus of assignments and the audience, fundamental computer science courses such as Computer Organization and Operating Systems must provide coverage of basic principles. For example, introductory OS courses should include topics such as history, concurrency, synchronization, deadlock, scheduling and dispatch, memory management, security, and file systems. Elective OS topics might expand

upon core topics, consisting of modules on networking, kernel development, virtual machines, device management, file systems, real-time and embedded systems, fault tolerance, or system performance evaluation [1-15]. Similarly, Organization courses should include coverage of assembly, basic CPU architecture, fetch-decode-execute, etc [16,17]. Many existing OS and Organization courses provide coverage of multi-core and superscalar architectures, GPUs, and related operating system utilities. For example, the Calvin College OS course included coverage of multi-core scheduling in 2009 [18]. At Lewis and Clark College, the Organization course covers cache architecture and coherence through GPGPU programming [19]. Special topics in such courses are often related to parallel programming, multi-core architectures, and distributed computing [1-19]. To describe coverage of parallelism, a significant portion of this paper provides an experience report of the use of high performance computing (HPC) and parallel programming throughout the CS curriculum.

There are several compelling reasons to use HPC and parallel programming in instruction. First, adding HPC and parallel programming provides multiple learning opportunities and outlets to make the learning process more exciting. Students are able to access hardware that is generally only available to graduate students and faculty researchers such as NSF XSEDE supercomputing resources – TACC Stampede, TACC Ranger, and Purdue Steele [20]. Similar tools such as LittleFe Cluster computers provide an easy on-ramp to HPC tools [21,22]. This may provide a sense of ownership and pride over the class. It may also increase students' level of interest by making the course exciting and fun. Next, HPC utilities provide a platform for students to learn about UNIX/Linux, batch scripts, batch operating systems, C programming, and the message passing interface (MPI). Teaching about all of these tools gives students an opportunity to learn many details of multi-threaded and multi-process programming.

Coverage of topics in lecture and through assignments play a strong role in teaching and reinforcing concepts. These are covered in detail for courses applicable to this work. For example, Computer Organization students experienced lectures introducing multi-core processors, SIMD Instructions, Flynn's Taxonomy, superscalar and pipelined architectures. Assignments included questions on topics including GPGPU processing and supercomputing to increase awareness of parallelism. In Software Engineering I, coverage of testing topics such as parallel design, deadlock, and live-lock

increased student awareness of parallel processing issues. In Software Engineering II, students engaged in a semester-long project, requiring a database or another complex tool, which presented opportunities for experience with topics related to parallelism. Furthermore, OS class assignments using C, MPI, and POSIX threads (PThreads) included hands-on applications of threaded and process-based techniques such as semaphores, barriers, blocking and non-blocking message passing, thread scheduling, etc. Weekly lab assignments were included to ensure students were engaged with hands-on experience. Lectures covered POSIX and MPI Programming assignments, and homework emphasized use of parallelism. These started with threaded and MPI-based matrix multiplication to teach load balancing and scaling. Further assignments covered the producer-consumer problem using a gather pattern, deadlock through a cell phone tower simulation, and multi-core round robin scheduling. Final assignments included file I/O benchmarking using the Lustre parallel file system and a tutorial on the Xeon Phi coprocessor.

This work provides a description of the use of both HPC and Parallelism in several courses. These include in an application-oriented undergraduate OS course, Computer Organization, Software Engineering I/II, and Parallel Programming. First, background on curriculum standards, existing courses, HPC and parallel programming utilities, and hardware resources are provided. Course goals are described, including basic course components, topic coverage, and HW/SW coverage. Discussion of lectures and projects is also provided. Additional content covered includes research and information related to development of parallel curricula with emphasis on HPC technologies for the Computer Organization, Operating Systems, and Software Engineering courses. Thereafter, an analysis of the CS contact hours related to parallelism is presented as they relate to the ACM/IEEE CS 2013 Curricula [23]. Finally, survey results from the OS course are presented, and conclusions are drawn about the efficacy of the content presented.

II. BACKGROUND

Background coverage necessary for this document spans several areas. There are many existing courses from which Parallel Programming content and examples may be drawn. For example, an OS course could include coverage of the Linux and Android kernels [3,4], simulated or pedagogical operating systems [1,2], or even theoretical topics to introduce parallel, multi-threaded, or multi-core concepts. Guidelines for course content related to parallelism and HPC were drawn from textbooks and ACM/IEEE curriculum standards [23]. Software and hardware resources are discussed. Student background and interests were also considered. Background is provided on each of these issues in this section.

A. Survey of Existing Courses

A survey of several courses provides some insight into what is currently taught in Computer Organization, OS, and Parallel Programming. Many, introductory OS courses provide an overview of processes, threads, scheduling, synchronization, deadlock, memory management, security, and various advanced topics [1-15]. Computer Organization courses cover

topics including performance, assembly, digital logic, etc., as shown in [16], [24], and [25]. Finally, parallel programming courses cover libraries such as OpenMP and MPI and provide coverage of topics such as load balancing, message passing, parallel algorithms, parallel complexity, and more [26,27]. Discussion of Data Structures and Software Engineering courses is omitted in this section as ideas were drawn predominantly from curriculum standards. In this section, a brief survey of existing Computer Organization, Operating Systems, and Parallel Programming courses with emphasis on topics in parallelism is provided.

In Computer Organization and similar Systems courses, attempts to incorporate parallelism may be found at several colleges. For example, [24] and [25] include coverage of instruction level parallelism, superscalar pipelines, and even OpenMP. Reference [19] even includes coverage of CUDA to provide students a better understanding of the importance of cache. This is accomplished through control and comparison of CUDA local variables, shared memory, and global memory. These CUDA memory structures represent GPU registers, cache, and RAM [19]. Ideas from these courses and from the ACM 2013 Curriculum Standards were incorporated into 44-345 at Northwest and are discussed in the next section.

Numerous Parallel Programming course sites are available; however, ideas for 44-599 were drawn from a few major sources. These include [26], [28], and [29]. Content in such courses includes basic parallel programming concepts such as processes and threads, and often includes parallel primitives and communication tools such as map, reduce, scan, histogram, scatter, gather, and various all-to-all communications. Topics covered often include sorting, searching, linear algebra, FFT, image processing, and related topics.

Significant variety exists in topics covered in OS courses. At Berkeley, students study databases, networking, security, and privacy [15]. Calvin College faculty added multi-core scheduling and a comparison of POSIX and OpenMP threads to their OS and Networking course [18]. Some graduate level OS courses emphasize HPC. TAMUCC has a course in advanced operating systems using MPI for projects. It covers distributed variants of mutual exclusion, scheduling and process management, shared memory and file systems, recovery and fault tolerance [12]. Ideas for the 44-550 OS course at Northwest were drawn from the TAMUCC course as well as several distributed systems courses. These included use of MPI, threads, multi-core scheduling, and networked file systems. Additional content was drawn from a distributed systems course at the Australian National University [30], from the past OS instructors at Northwest [13], course materials from Tulane [5], the SC12 Advanced MPI tutorial (for MPI-IO) [31], and numerous discussions with HPC educators at various HPC conferences.

Some OS courses place emphasis on kernel engineering in assignments [3,4,9,11]. Reference [3] uses a standard Linux kernel, and [4] uses the Android kernel (likely the first OS course to use it). Such courses are quite interesting and allow students to learn about device drivers, disk IO, etc., directly. Another approach that many schools use is a pedagogical operating system such as Pintos or Nachos. In these courses,

students complete portions of a model OS without needing to understand system utilities [1,2]. Other courses use an application-oriented approach; wherein, assignments involve simulation of OS utilities and programming with existing OS tools [8,10,13]. Variations in approaches are often based on instructor preference and student skills. The approach used in 44-550 was both application and simulation oriented. Provided core competencies are met, such variation in course content provides different strengths to new computer scientists entering the workforce. Students at Northwest have strong experience in Java, and little experience with the command line and C programming. So, an application-oriented approach was chosen by the author.

B. Hardware and Software Resources

In this section, both hardware and software resources essential to the inclusion of parallelism and HPC in coursework are discussed. First, hardware resources such as desktops, laptops, and compute clusters are examined. Thereafter, various operating systems and software resources for parallel computing are investigated.

HPC resources or their equivalent are often readily available for educators. Many computer science and engineering departments have multiple rack unit servers available where a batch scheduler may be installed. Schools without access to such resources, can make use of a LittleFe cluster – a low-cost (>\$2000), 6-node, open-air cluster [21,22], the Extreme Science and Engineering Discovery Environment (XSEDE) [20], and Amazon's EC2. These and other free or low cost options can provide computing resources for educators. Access to XSEDE and EC2 resources do require the educator provide a CV and summarize planned work [20].

Since HPC resources (e.g. XSEDE) are often highly utilized, a batch queue is used to allow for sharing of resources. Resources must be requested using a batch script, and such systems are often built as a cluster with a linux variant for an operating system [20]. Such systems are often built from multiple nodes (e.g. multiple rack servers), and users often require free OS and software options. Therefore, distributed computing resources are often Linux-based. OS options studied by the author for parallel programming and/or distributed system use include Linux variants such as CentOS, BCCD (the Bootable Cluster CD), Ubuntu, and Cygwin (a Linux shell for MS Windows). These options are freely available and either include or have tools to easily install parallel computing tools. Many such tools provide for desktop/laptop users to easily and freely install parallel programming tools [10,20-22].

A wide variety of tools exist for parallel programming. These include C libraries such as Pthreads, OpenMP, and MPI [26,27]. Additional tools such as Java Threads, Python, and novel parallel programming languages like Chapel also exist. The message passing interface (MPI) library is used for HPC interprocess communication in C and Fortran and is available with limited support for Python and Java. Other such libraries are available, but MPI is perhaps the most commonly used HPC library for message passing. MPI is a library of functions that provides process creation, parallel file IO, point-to-point, process-to-process communication, and many other features. It

provides functionality for parallel and distributed computing across both homogeneous and heterogeneous compute nodes [31-33]. MPI can also be installed on a laptop and can provide added functionality, including the ability to oversubscribe or schedule more processes than processors available on a compute node. Additionally, MPI, when combined with a batch scheduling system and appropriate OS utilities, provides the ability to send messages back and forth between processes without concern for particular architecture or topology [31-33].

When teaching MPI, it is not necessary to present all the functions included within the standard. Basic functionality is more important [34]. For OS and Parallel Programming, functions to start and end MPI, to obtain basic environment data, and to send and receive messages are of particular importance. These allow students to learn Parallelism and OS fundamentals like concurrency, interprocess communication, race conditions, and deadlock [10,12]. A set of basic functions recommended to introduce students to MPI is provided below.

- `MPI_Init` – Initialize the Message Passing Interface
- `MPI_Finalize` – Close the Message Passing Interface
- `MPI_Comm_rank` – determine a process's identifier
- `MPI_Comm_size` – determine the number of processes
- `MPI_Send` – Send a message (blocking)
- `MPI_Recv` – Receive a message (blocking)
- `MPI_Irecv` – Receive a message (non-blocking)
- `MPI_Isend` – Send a message (non-blocking)
- `MPI_Test` – Determine message receipt (non-blocking)
- `MPI_Wait` – Wait for a non-blocking message
- `MPI_Barrier` – Wait for all processes to call barrier
- `MPI_File...` – Provides parallel file IO.

Teaching these functions and explaining their purpose gives students an introduction to many Parallel Programming and OS topics. Since the MPI environment creates multiple processes that execute all the code contained between the initialization and finalization steps, these provide a starting point for discussion of multiprogramming. `MPI_Comm_rank` and `MPI_Comm_size` functions provide environment information including the number of processes running and each process's identifier (i.e. its rank). Again, these are core issues in an OS course and reinforce process control block (PCB) content and understanding of the process table. The send and receive functions allow for discussion of interprocess communication with and without shared data. These functions also allow for early introduction of concepts such as waiting and deadlock without the need to review synchronization tools. Additional MPI functions that provide functionality for scatter, gather, broadcast, and all-to-all message passing can be covered in detail for Parallel Programming courses but are not necessary for OS. Finally, MPI file I/O tools allow for introduction to networked file systems [10,12].

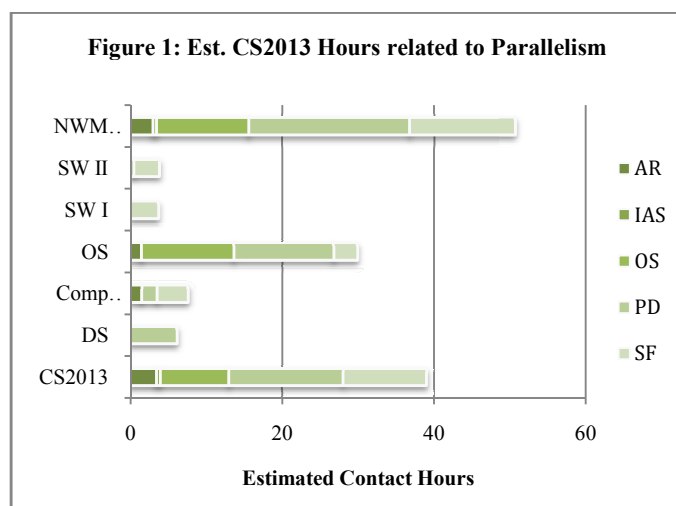
C. ACM 2013 Curriculum Guidelines

ACM 2013 Curriculum Guidelines (CS2013) call for increased inclusion of topics related to parallel computing in numerous "Knowledge Units" (KU). Areas related to parallelism include Architecture and Organization, Information Assurance and Security, Operating Systems,

Parallel and Distributed Computing, and Systems Fundamentals. Each KU has a minimum number of contact hours that institutions with Computer Science degrees *should* cover [23]. The author has estimated the minimum number of CS2013 contact hours related to parallelism by KU that an instructor should cover in the list below.

- 3.5 of 16 Architecture and Organization (AR) Hours
- 0.5 of 9 Information Assurance and Security (IAS) Hours
- 9 of 15 Operating Systems (OS) Hours
- 15 of 15 Parallel and Distributed (PD) Hours
- 11 of 27 Systems Fundamentals (SF) Hours

This minimal estimate was computed as the number of topics within a Knowledge Unit (KU) including parallelism, divided by the total KU topics, and then multiplied by KU contact hours. Thus, computer science students should experience at least 39 contact hours (e.g. one full course) related to parallelism during their undergraduate careers. An estimate of these items is provided in Figure 1.



III. COURSE GOALS AND METHODOLOGY

Within this section course goals and methods are presented for the Data Structures, Computer Organization, OS, and SW Engineering courses. Several generalized goals were set by the author for this work. These included meeting and exceeding CS2013 [23] requirements, improving student job prospects, making coursework more interesting and relevant to “real world” standards. Furthermore, the author desired to help students to become competent to assisting with research and/or jobs requiring HPC resources. This provided students with a thorough understanding of both parallel programming and parallel hardware.

A. Software and Hardware Resources

All students at the author’s university are provided with university issued laptops. Since 2013, installation of parallel programming tools such as OpenMP, Pthreads, and MPI have been straightforward. Such tools are supported through Cygwin and are also available on multi-node Linux clusters. Prior to 2013, the author provided all students with a bootable live

DVD of Knoppix that was remastered with OpenMPI [33,35]. Currently, students are able to install software such as OpenMPI in Cygwin, install a Linux virtual machine with BCCD, or to use a Linux cluster such as LittleFe or Stampede [20-22]. Thus, all students are provided with access to the necessary software. These tools provide students with the capability to compile, debug, and run programs locally and allowed them to experience a Linux operating system. Furthermore, at Northwest, OS and Parallel Programming students have access to HPC resources via XSEDE through educational allocations of 10,000 or more Service Units (SUs) where 1 SU = 1 CPU-core hour [20]. Students are instructed in the use of ssh/sftp and on using batch scripts to submit and run jobs on various clusters within two weeks of entering the OS or Parallel Programming courses.

B. Data Structures (44-242)

The Spring 2014 Data Structures course, taught by Dr. Phillip Heeler, included lectures consisting of approximately 6 contact hours on parallelism through a two week module. This module included an introduction to Java Threads including the start, run, and join methods. Examples including race conditions and semaphores were provided to students. Several lab assignments were completed or started by students in class and covered Linux and parallel programming on a LittleFe cluster. Additionally students completed an assignment involving computing binomial coefficients with multiple threads that required students to use the join method to synchronize their results [36].

C. Computer Organization (44-345)

Within the Computer Organization course, approximately 7.5 contact hours were devoted to topics related to parallelism [23]. Topics related to parallelism in this course have been refined over three iterations of the course (Spring 13, 14, and 15). In particular, contact time involved several lectures related to parallel hardware/software, and hands-on activities.

Lectures included discussion and interaction with cluster components from a LittleFe system including compute nodes, networking hardware (switches and cabling), and networked storage [16,21,22]. Such interaction involved logging onto the system in class, writing, compiling, and running a program [16,37]. Furthermore, in class activities included description and execution of the N-Body problem through the GalaxSee LittleFe learning module [21,22]. Several lectures were also devoted to benchmarking—multi- vs. single core, Amdahl’s Law and Speedup. Further lectures included coverage of multi-core CPU components including cache and vector registers. Finally, lectures were provided on Flynn’s Taxonomy; SIMD vs. MIMD instructions; shared, associative, and direct caching methods; and cache layouts with respect to UMA, NUMA, and ccNUMA architectures [16-19].

Students were provided with ten homework assignments and several projects. Several homework assignments were started in class and were partially or completely devoted to parallel topics. These included problems related to benchmarking, Amdahl’s law, and speedup. Additional problems included a research question asking students to compare of Xeon Phi and CUDA cores. Furthermore, students were asked to complete a Linux lab on a LittleFe

cluster; to compile, run, time, and compare several OpenMP threaded loops; and to run several snippets of Intel assembly code to gain a better understanding of Flynn's Taxonomy. The assignment related to Flynn's taxonomy included explaining assembly instructions and C code for SISD, SIMD, and MIMD such as AVX and SSE instructions and their differences with serial and threaded code [16].

D. Software Engineering I/II (44-561/2)

Software Engineering I was taught by the author in Fall 12 and 13, and it included approximately 3.6 Contact Hours on parallelism. This coverage included discussion of Java Threads and Sockets using instant messenger code from [38]. Additionally, students engaged in research papers over self-selected topics. Students were provided with potential topics and references and were asked to clear their choice of topic with the instructor. Such students wrote a 6-8 page paper and performed a 5-7 minute presentation in class. Excellent papers were submitted to a local contest sponsored by KCP&L, and 3 of 4 finalists were from 44-561. Students' topic choices were influenced by placing paper references related to parallelism on the assignment specification. Suggested topics included distributed databases (3 papers were written on HBase, Riak, Cassandra, and other NoSQL databases), accelerators – comparing CUDA programming, OpenACC and OpenCL; Concurrency, Parallelism, and Performance; OpenMP, MPI, and POSIX Threads; Cluster Computing; Evolutionary Algorithms; Reinforcement Learning; Supervised vs. Unsupervised Learning; Pattern Recognition; and Classification and Segmentation. Students were given the option to select their own topics and several chose Professional Certification, Introductory Programming Languages, and Mobile Programming Platforms.

In Software Engineering II approximately 3.75 contact hours were devoted to parallelism in the Spring 13 and 14 semesters. Lectures related to parallelism included discussion of defensive programming (e.g. live-lock) and peak loads [23]. A significant portion of class time was devoted to semester-long projects wherein students completed a complex application involving web services, a database, and another complex tool. These student projects were completed in teams of 4 to 5 students and included a massive online multiplayer game built from scratch that used sockets, threads, and UDP game connections [39]; Kritik – a speech presentation grading tool that involved a client (an oral communications professor), iOS, CoreData, CSV conversion, and the Dropbox API [40]; and an online Audio Manager that made use of Python, Jinja2, SQLAlchemy, MusicBrainz API, AudioDB API, FanArt API, and the LastFM API [41]. Project evaluation was accomplished with weekly in-class meetings, four in-class presentations/milestones, and weekly mini-milestones. This allowed for students to experience much of the software lifecycle and many aspects of the Agile Development process.

E. Operating Systems (44-550)

In the OS course approximately 29.8 contact hours were devoted to topics related to parallelism [10,23]. This included lectures, lab assignments, homework assignments, and projects of significant size. Lecture topics included coverage of PThreads and MPI related to CS2013 KUs and were

focused on hands-on, application-oriented coverage of KUs, and a significant portion of class time was devoted to labs. Lectures also included an emphasis on Scheduling, Memory Management, Load Balancing, Communication Primitives, Threads, Processes, File Systems, and Security [14].

Lectures were divided into modules spanning two to three week segments. As many students had little experience with UNIX/Linux command line utilities and C programming, a module providing a brief introduction covering command line compilation, syntax, control structures, and functions was provided. During these first two to three weeks, OS history and functionality was also introduced. Students were also provided with accounts on an XSEDE allocation (11,000 Service Units in Fall 2014) and LittleFe. Topics covered also included processes, threads, PCBs, thread descriptors, POSIX threads, MPI_Send, MPI_Recv, C memory allocation, and commands such as `fork` and `exec` [7,10,14,26,42].

The next three weeks of lecture included an introduction to Pthreads and MPI processes with heavy discussion of the ready, run, and blocked states; race conditions; an introduction to deadlock; interprocess communication; and discussion of tags (message identifiers) in MPI. Lecture also covered semaphores, the producer-consumer problem, race conditions, and the reader-writer problem. Finally, in preparation for the projects, it was necessary to cover non-blocking I/O including `MPI_Wait_some`, `MPI_Irecv`, `MPI_Get_count`, `MPI_Wait`, and `MPI_Irecv`. Lectures also included coverage of monitors, discussion of MPI types, and further review of XSEDE systems [7,10,14,20,26].

Weeks 6 through 9 included full discussion of deadlock including mutual exclusion, deadlock principles, prevention, detection and recovery, avoidance, the Banker's Algorithm, and resource allocation graphs. Further lectures included atomic transactions, dining philosophers program, an introduction to scheduling, and further discussion of deadlock in MPI and non-blocking I/O for a project that involved simulating cell phone tower switching [7,10,12,14].

In weeks 10 through 12, the author covered standard scheduling techniques including First-Come-First-Served (FCFS), Shortest Job First (SJF), Shortest Remaining Time Next (SRTN), and Round Robin (RR). Additionally, lectures included coverage of performance, Gantt Charts, and turnaround time. Continued coverage of parallel and HPC topics included multi-processor scheduling and review for a scheduling exercise that required semaphores to implement FCFS and RR schedulers. Additional lecture was devoted to real-time and dynamic scheduling algorithms [7,10,12].

Weeks 13 through 15 included coverage of file I/O, file and IO systems, and memory management. This included coverage of files, pipes, and redirection, and preparation for the fifth project on File I/O in C and MPI. Next, topics related to file management were covered including fragmentation (external/internal), bitmapping, file structures, MPI file data types, and partitions. File systems were also discussed and included FAT, FAT32, NTFS, Ext4, Lustre, and Virtual File Systems. Students were also provided with a discussion of disk mounting/unmounting, shared/unshared file pointers,

parallel file I/O, DMA, and disk drive variants. In the last week of class, lectures covered memory management and included process address space, binding, paging, segments, and discussion of the TLB. Finally, a project was introduced that required students to implement a threaded, paged memory manager [7,10,12,31,32,43].

F. OS (44-550) Assignments

Students were asked to complete several assignments on both LittleFe and TACC Stampede systems in Fall 13 and 14 and used TACC Ranger/Purdue Steele in Fall 12. Such assignments were graded for both compilation and correctness. Students in the most recent iteration of the course were subject to a 25% penalty for failure to complete assignments on Stampede. The most recent group of OS students completed 12 lab assignments, 5 homework assignments, and 5 projects. Brief descriptions of these assignments are provided herein [10,20-22].

Lab assignments were short assignments, often started in class, and were completed by most students with little help. Labs were similar to worksheets and provided significant instruction to complete specific tasks. The first three labs were straightforward introductions to Linux, C, command line compilation, PThreads, MPI, LittleFe, and XSEDE [10,20-22,32]. All students that attempted these labs completed them successfully, and students often referred back to such labs as reference material. Thereafter several labs on threads and MPI were provided with a significant amount of boilerplate code. These included a simple load-balancing example using square matrix addition, an MPI Pi Calculator using the Mersenne Twister pseudorandom number generator, and a threaded producer-consumer lab [10,26]. Further labs covered the dining philosophers problem using MPI, condition variables and scheduling with PThreads, and file I/O with MPI [7,14]. The final three labs included coverage cache using MPI matrix multiplication by row and column, study of Xeon Phi accelerators, and implementation of bash shell scripts [10,20,26,37]. Homework assignments covered straightforward mathematical, graphing, and practice programming problems typical of an OS course. Both homework and lab assignments were graded for correctness with a significant amount of leeway given for compilation.

Programming assignments in the OS course were two to three week assignments covering many of the lecture and lab topics. For most assignments, students were required to provide both a threaded and process-based solution. The first of these was a standard C assignment that involved control structures, functions, and multiple C files – e.g. storing books in a library [10,42]. The second of these was a simple load-balancing problem that required students to apply a blurring operator to a 2D matrix, using convolution. Since this operation is embarrassingly parallel, students were asked to implement the problem using both PThreads and MPI. Further assignments are discussed in detail, as they required significantly more effort on the part of students [10,26].

The third assignment for the Fall 2014 group was a Monte Carlo numerical optimization program that was to be implemented in both a threaded and MPI fashion. This required students to find the minimum of a mathematical

function using a pseudorandom number generator. Each of many worker threads or processes was to search for a minimum and report that result back to a master thread/process to allow for determination of a global minimum. Students were to ensure both programs were effectively load-balanced and compare runtimes [10,26,30].

For the fourth program students simulated a number of vehicles traveling in a circle. Within this simulation students assumed that one person per vehicle was talking on a cell phone. The goal was to create an effective system for switching calls between cell phone towers. To make this simulation easier, students were allowed to assume that cars would always move in one direction (that is, either a clockwise or counterclockwise direction). It was also assumed that towers had a circular transmit radius, towers were located almost directly on the road, and tower transmit radii overlapped. The transmit radius of every tower was also assumed to be the same. Each tower was represented as a process and distance covered by a vehicle per unit time was assumed to be constant. Students were to provide as input to the simulation: the cell tower spacing in degrees, the cell tower transmit factor, the radius of the driving track in miles, the number of time steps in the simulation in minutes, and the speed of the car in miles per hour. This simulation provided students a similar experience to the dining philosophers problem in a different format.

For the final project, students wrote a threaded, paged memory manager that provided paged management to worker threads that each performed either decryption, a dot product, or matrix multiplication. Input data for each thread was provided through the memory manager thread via file input. Additionally, as input, students provided memory size, number of frames per page, frame size, number of worker threads, and matrix filenames for each worker thread. Students were to assume each thread could cache one row and one column of the matrix and the sizes of the matrices belonging to it. Prior to performing computations threads were required to acquire data from the memory manager. To obtain data, threads were required to call to the memory manager and request data one element at a time by passing the appropriate row and column and matrix identifier to the memory manager. Next, the memory manager simulated the page table by finding the appropriate frame number in the page table, and using the frame number to access a simulated physical memory (an array). When encountering page faults, students were to swap matrix data out of memory and replace it with the data needed to continue processing. Students assumed all threads were processed at the same time in a first-come first-served manner. If there was not enough memory for a thread to perform its processing, that thread waited until memory was available. Provided available memory, the memory manager allocated space for an entire row and column for each active worker thread. Students provided as output, the average worker thread runtime in milliseconds, the average number of frames used per worker thread, the average number of page faults per worker thread, the total runtime, the total number of frames used, and the total number of pages used [7,10,14,21,22].

These assignments provided students with a thorough and extensive OS and HPC experience. They covered the required

CS 2013 OS topics and provided for extensive hands-on experience with parallel programming techniques. Such experience also covered many required topics from the IEEE TCPP recommendations [23].

G. Assessment

To assess student learning outcomes, the author conducted surveys of the Fall 2014 Operating Systems cohort. This group of students was surveyed at both the beginning and end of the semester and was asked the following set of questions. The results of these questions are presented in the next section.

1. Have you used a Linux operating system?
2. Have you used a Windows operating system?
3. Have you used a Mac operating system?
4. Have you used the command line?
5. If yes, check situations in which you have used the command line.
6. What is your opinion of the utility of the command line interface?
7. When do you think more than one computer is required for parallel programming?
8. Prior to this class have you ever used threads?
9. If yes, please mark the type of threading that you have used.
10. Have you ever used multi-process programming?
11. If yes, check the operating systems and/or frameworks in which you have used multi-process programming.
12. Prior to this class have you ever used any synchronization tools? Please indicate the tools that you have used and indicate your experience level.
13. In what manner have used synchronization tools prior to this class, please indicate your experience level with such tools?
14. If you have used scheduling tools prior to this class, please indicate your experience level with such tools.
15. Have you had experience with OS level memory management? Please indicate your experience level.
16. Have you had experience with cache or cache management?
17. Please indicate your experience with the following memory access models, especially as they relate to cache.
18. Have you had experience with CPU Pinning? Please indicate your experience level.
19. Have you had experience with any parallel programming primitives?
20. XSEDE Resources were _____ in this course.
21. I find the use of XSEDE resources _____ in this course.

IV. OPERATING SYSTEMS RESULTS

Teaching OS with MPI is not an easy task. It requires prior knowledge of students' skill sets and course content may require several rounds of refinement. Course reviews for the first and second iterations of the author's OS course were mixed. This was expected because the course content was new, and many students at Northwest had little experience with C programming. Moreover, many OS students had little experience with Linux programming or shell environments. Supplemental materials and lectures on C programming were provided to assist OS students in learning the CLI and C [10]. Starting with the second cohort (Fall 2013) of OS students, all students were required to use C for the entirety of the course. This improved course reviews from 3.0/4.0 in 2012 to 3.85/4.0 in 2014 and allowed for additional time to be spent on parallel programming concepts while maintaining adequate coverage of OS concepts. This is further evidenced by results from selected questions from the pre- and post-surveys, which are

provided in following tables. Pre-survey results are shown within parentheses, and post-survey results are shown without parentheses. Results were self-reported by students through two voluntary surveys. Students received a small number of bonus points for completing the surveys.

	Yes	No	Response Count
1. Have you used a Linux operating system?	86.4% (75.0%)	13.6% (25.0%)	22 (20)
2. Have you used a Windows operating system?	100% (100%)	0% (0%)	22 (20)
4. Have you used the command line?	100% (75.0%)	0% (25.0%)	22 (20)
8. Have you used threads?	100% (55.0%)	0% (45.0%)	22 (20)
10. Have you ever used multi-process programming?	86.4% (15.0%)	13.6% (85.0%)	22 (20)
16. Have you had experience with cache or cache management?	54.5% (25.0%)	45.5% (75.0%)	22 (20)

Table 1: Pre and Post Course Results (pre-course results shown in parentheses)

Table 1 indicates a significant increase in the number of students that gained exposure to the command line, threaded programming, and multi-threaded programming after completing the OS course. Students were also asked several questions to gauge student opinion, interest, and expertise.

6. What is your opinion of the utility of the command line interface?					
Not at all useful	Slightly Useful	Useful	Very Useful	Rating Average	Response Count
0 (0)	0 (7)	11 (8)	10 (5)	3.48 (2.90)	21 (20)

Table 2: CLI Opinion Question

12. Have you ever used any synchronization tools? Please indicate the tools that you have used and indicate your experience level:					
Answer Options	No Exp.	Little Exp.	Moderate Exp.	Expert	Response Count
MPI Send/Recv	1 (17)	10 (1)	10 (0)	1 (0)	22 (18)
Android Messages/Intents	9 (10)	2 (4)	8 (4)	2 (1)	21 (19)
Semaphores	1 (17)	10 (0)	10 (1)	1 (0)	22 (18)
Broadcast	11 (14)	9 (2)	2 (2)	0 (0)	22 (18)
Wait	3 (13)	13 (3)	4 (2)	1 (0)	21 (18)
Mutex Locks	2 (17)	11 (0)	8 (1)	1 (0)	22 (18)
Condition Variables	1 (15)	13 (1)	6 (1)	2 (1)	22 (18)
Atomic operations/variables	5 (16)	13 (1)	2 (1)	1 (0)	21 (18)

Table 3: Synchronization Tools Experience Question

In tables 2, 3, and 4, students were asked about their opinion of the command line and about their experience with synchronization tools. Notice the drastic change in students' opinions of the CLI after they completed the OS course, which had heavy focus on Linux, Processes, Threads, and the CLI. Post-course, all students believed this tool to be either useful or very useful. With respect to synchronization tools and usage, students' experience level with tools such as semaphores and MPI send/recv primitives showed a significant shift from "no

experience” to either “little” or “moderate” experience, indicating that students did indeed gain familiarity with such tools in both multi-threaded and multi-process applications.

13. In what manner have used synchronization tools, please indicate your experience level with such tools?					
Answer Options	No Exp.	Little Exp.	Moderate Exp.	Expert	Response Count
MPI	1 (17)	11 (1)	9 (0)	1 (0)	22 (18)
Android	9 (10)	5 (5)	7 (3)	0 (1)	21 (19)
Multi-threaded	0 (12)	10 (5)	11 (1)	1 (0)	22 (18)
Multi-process	1 (15)	14 (2)	6 (1)	1 (0)	22 (18)
Distributed across multiple systems	7 (17)	13 (1)	1 (0)	0 (0)	21 (18)
To prevent Deadlock	2 (14)	11 (2)	7 (1)	1 (1)	21 (18)
To prevent Livelock	16 (18)	4 (0)	1 (0)	0 (0)	21 (18)

Table 4: Synchronization Usage Experience Question

14. If you have used scheduling tools, please indicate your experience level with such tools.					
Answer Options	No Exp.	Little Exp.	Moderate Exp.	Expert	Response Count
First-come, first-served	2 (12)	12 (5)	7 (1)	1 (1)	22 (19)
Round Robin	2 (15)	11 (2)	8 (0)	1 (1)	22 (18)
Shortest Job First	2 (16)	15 (1)	4 (0)	1 (1)	22 (18)
Shortest Remaining Time First	2 (17)	15 (1)	4 (0)	1 (0)	22 (18)

Table 5: Scheduling Experience Question

15. Have you had experience with OS level memory management? Please indicate your experience level:					
No Exp.	Little Exp.	Moderate Exp.	Expert	Rating Average	Response Count
5 (18)	14 (2)	3 (0)	0 (0)	1.91 (1.10)	22 (20)

Table 6: Memory Management Experience Question

In tables 5 and 6, results are presented from questions asked to gauge students’ perceived experience levels with scheduling and memory management. Similar to the results in tables 3 and 4, these results also indicate that students did indeed gain familiarity with standard OS topics.

20. XSEDE Resources were in this course.					
Not at all useful	Slightly Useful	Useful	Very Useful	Rating Average	Response Count
3 (1)	2 (6)	13 (10)	4 (1)	2.82 (2.61)	22 (18)

Table 7: XSEDE Experience Question

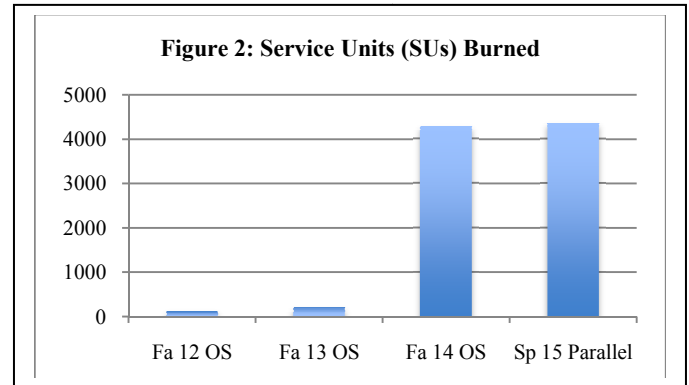
21. I find the use of XSEDE resources in this course.					
Not Interesting	Somewhat Interesting	Inter-esting	Very Inter-esting	Rating Avg.	Response Count
1 (4)	7 (6)	9 (6)	5 (2)	2.82 (2.33)	22 (18)

Table 8: XSEDE Interest Question

Tables 7 and 8 provide results from questions that gauged student interest in HPC resources, particularly those from XSEDE. These results do show increased student interest in HPC resources, but the results may include slight bias.

Students in Fall 14 OS and Spring 15 Parallel Programming courses were required to use XSEDE resources in all programming assignments and were informed that a 25% penalty would be invoked on each assignment where they did not use such resources. As a result, student XSEDE usage dramatically increased from 2012 and 2013 usages (approximately 20x CPU-hour use increase), but interest was not high enough to encourage most undergraduate students to take the Spring 15 Parallel Programming course. In fact, only one undergraduate student chose to take Parallel Programming as an elective.

Thus, OS students gained familiarity and experience with HPC resources, multiprocess programming, multithreading, and standard OS topics including concurrency, synchronization, deadlock, scheduling, etc. Results indicate that the OS course was successful in educating students about both OS topics and HPC. Based on the author’s experiences and student comments from the Fall 12 OS course, it is reasonable to conclude that using a single language such as C to teach all assignments is more effective than using both C and Java. Moreover, hands-on activities to ensure students are able to log into XSEDE resources were key to the success of the course. Experiences in the Fall 12, 13, and 14 OS courses when attempting to login to Ranger, Steele, and Stampede showed that a full class period devoted to logging in and system experience is necessary to ensure students do not experience difficulty in completing assignments with XSEDE.



V. CONCLUSION

Several undergraduate and graduate courses involving high performance computing were discussed. Implementation of such courses is possible at a regional university using free and low cost resources, but such courses require effort to maintain. Doing so makes HPC accessible to undergraduates. Inclusion of frequent lab components is especially beneficial to ensure adequate coverage of HPC topics and to stimulate student interest. Students did experience some difficulty in adapting to the command line, in using CLI text editors, in working with pointers, and in conversions between matrix dimensionality (e.g. 1D to 2D). They were, however, successful in learning both required content, parallelism and HPC topics.

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Representation of abstract concepts: differences across computing disciplines

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Abstract— Computer Science has evolved towards a discipline with different branches. Software is designed, produced and linked taking into account different viewpoints. This process typically involves multidisciplinary teams: Front End Developers, (OO)Programmers, Database Engineers. Software developers, who were educated in different computing disciplines, meet on the shop floor, where they link together software that was designed from different viewpoints. In this paper, the emphasis is on human characteristics, rather than on the formal properties of programming and modeling languages. Do the involved computing practitioners refer to the same concepts when they use the same words? A preliminary version of this study [1] addressed the assessment of differences in mental representations of abstract entities involved in programming and modeling. In this extended version we report the results of an experiment, designed to compare mental representations of abstract concepts with mental models described in the literature. We point at differences between groups of students, enrolled in different computing curricula, and explore possible explanations.

Keywords: computer science education, engineering education research, human factors

I. INTRODUCTION

In the past couple of decades, Computer Science has developed different branches, each with its own body of knowledge and its own problem area. Different computing curricula have their *raison d'être* in different approaches to the digitalization of information. What happens when the paradigms meet, when engineers link together software that was designed from different points of view? This area is characterized by persistent problems, such as the Object/Relational impedance mismatch.

Many attempts have been made to solve these problems by developing new software, such as Object Relational Mappings. This is problematic, though. The problem with these solutions is their validation. Multidisciplinary teams that work on tangible artifacts can discuss advantages and disadvantages of machine control software, plant engineering software or computer graphics software, knowing that they refer to the same tangible or visible artifacts. But many computing professionals work exclusively on abstract entities. Technical

solutions of the Object Relational Impedance Mismatch can only be evaluated if practitioners perceive a common field of application, if they work with the same abstract entities.

The new ACM/IEEE guidelines for the undergraduate program in Software Engineering (SE) [2] acknowledge the problem of working with abstract entities and the challenges it involves for “knowledge exchange during the process of [software] design” (pg. 11). Although we acclaim the attention for this phenomenon, we regret the location of the problem inside the SE discipline. We suspect practitioners from other branches than SE to conceptualize abstract entities differently than SE. More generally, we suspect different computing disciplines to operate from different conceptualizations.

We will focus on the cognitive backgrounds of the issue, rather than its pedagogical perspective, although we will touch on educational implications. This paper describes an experiment to assess differences in mental representations of abstract entities, involved in programming and modeling. We recruited students of comparable age and level of education, enrolled in different computing curricula, and asked them to help us understand the way they conceptualize abstract concepts. In a preliminary (work-in-progress) version of this study [1], we reported incompatible ways to characterize the abstract notion of “object”. We also found indications for group preferences: significant discrepancies between participants, enrolled in different curricula.

This extended paper focuses on the explanation of the differences we have identified. We compare the participants’ mental representations with mental models described in the literature. We provide an overview of the research on cognitive aspects of programming and database interaction and explore the notion of individual preferences in mathematical problem solving [3].

In section II we explore the notion of a mental model. In section III we give an overview of research on cognitive aspects of programming and database interaction, followed by discussion in section IV. In section V we design an experiment to assess possible differences in mental models between senior students, enrolled in different computing curricula. Results are

given in section VI, followed by a reflection in section VII, conclusions in section VIII and relevance in section IX.

II. BACKGROUNDS

A. Mental models

According to Craik, the mind constructs “small-scale models” of reality and uses them to anticipate events [4] [5]. Johnson-Laird [4] formulated a theory of mental models, meant to explain human thinking and reasoning. People, states Johnson-Laird, do not only apply inference rules while reasoning; they also consider the semantic content of the problems they are solving. Norman [6] is more specifically concerned with mental models in Human-Computer Interaction. Users, states Norman, construct mental models of computer systems incrementally, while interacting with systems. The resulting models are constrained by the users’ prior knowledge, needs and context. These models are often incomplete. They are limited by the human information processing system, by experience and by needs that can be contrasting: the need to focus and the need to retain important details. They are parsimonious in order to reduce mental complexity. User mental models are unscientific and unstable. They evolve over time: people learn, people forget. People use metaphors to simplify their models. Nevertheless, mental models are functional to support tasks such as planning, execution, assessment of results and understanding of unexpected events.

There is little agreement on the exact definition of the term “mental model”. Does the term refer to temporary structures in Working Memory (WM) or knowledge structures in Long Term Memory (LTM)? Cañas and Antolí [7] introduce this definition: a mental model is “*the dynamic representation that is formed in WM combining the information stored in LTM and the extracted information from the environment*”.

Knowledge, in particular knowledge concerning computing paradigms, is acquired by education and experience and stored in LTM as knowledge chunks that evolve in time. According to Norman, evolution is not necessarily positive: improvement is possible, deterioration also. These knowledge chunks can only be used if they are retrieved and instantiated in WM, in what we will call a mental model from now on, following Cañas’ and Antolí’s definition.

Human WM is limited. People take these limitations into account and adopt strategies to keep mental models manageable in WM. The question here is: can we assume mental models of practitioners with different backgrounds to be compatible with each other?

B. Individual preferences

Schwank [3] studies the way people select mental models to represent mathematical knowledge. Schwank distinguishes a *predicative* and a *functional* approach to mathematic thinking. Predicative thinking is “static grasping”, thinking in terms of judgments and relations; functional thinking is “dynamic grasping”, thinking in terms of actions, processes and their effects. Schwank adopts this metaphor: predicative thinking is like solving puzzles, where one looks for (static) patterns. Functional thinking is mechanical thinking, like using gear: the

focus is on what happens next. Most mathematical problems can be solved either way; this also applies to many problems in computer science.

Schwank used Raven’s progressive matrices to assess problem solving preferences (Raven, cited by Schwank [9]). 3x3 matrices lacking the lower right symbol were presented to the participants, which were asked to *construct* the last symbol to complete the sequence (instead of *choosing* the last symbol as is requested in Raven’s intelligence test). The participants were asked to argue why they draw that particular symbol. Schwank found support for the thesis that the preference for a predicative or functional mode in problem solving is a stable individual characteristic.

C. Assessing mental models: the teach-back protocol

Mental models can not be observed directly. Many authors draw conclusions about respondent’s mental models based on their behavior [11]. Van der Veer adopts a different strategy: he asks the participants. Van der Veer [12] extends an hermeneutic method designed by G. Pask, intended to elicit information about mental models (the Teach-Back method), and adopts it to detect differences in mental representations of users interacting with computers.

A situation is simulated where the respondent has to interact with a computer. He/she is asked to explain the computer’s functioning to an imaginary counterpart, a colleague or a student, who has similar experience with the situation. The questions are designed to activate both declarative and procedural knowledge structures, to obtain an overall picture of the participants’ mental models. Questions are presented on white sheets of paper, and the participants are instructed to express themselves in whatever way they consider most adequate: text, drawings, keywords, diagrams etc. In this manner, the participants are encouraged to externalize the mental model they made of the situation. Next, the protocols are scored “blind”, along pre-defined scoring categories in order to map the respondent’s mental representations. Rating implies (1) reading the protocol in its entirety and trying to understand fully what it says; (2) trying to formulate how the participant understands the space of the teach-back question and (3) classify the responses into relevant categories for the purpose of the study. Rating the answers is a complex task: the rater has to interpret the participant’s intention and classify it by means of scoring rules. This task requires considerable training. In order to safeguard reliability, two or more persons score the answers independently.

III. LITERATURE REVIEW

A. Objects

One of the basic notions of software development is the “object”. According to Booch, Rumbaugh and Jacobson [13] an object is “A concrete manifestation of an abstraction; an entity with a well-defined boundary and identity that encapsulates state and behavior; an instance of a class”. Objects are software constructs that can refer to real-world entities, entities that are also called objects (although some authors use the term domain objects [14]). A class describes a set of objects [13]. Equivalent objects can coexist during program running: instantiation generates bags of objects.

Nevertheless, the term instance is seen as synonym with object [13].

Handling these different natures of objects requires switching between mental models. In the next sections, we will review the literature on understanding of programming constructs.

B. Cognitive aspects of (OO) programming

Robins, Rountree and Rountree [15] provide us with an extensive literature review of research concerning learning and teaching programming between 1970-2003. In a survey study, D tienne [16] reviews empirical research on OO design and assesses claims about the cognitive benefits of the OO paradigm.

Robins, Rountree and Rountree mention different kinds of mental models involved in learning programming: mental models of the “task, problem or specification” that has to be solved by the program, mental model of the programming language, and mental models of the behavior of the running program. Many studies have noted a central role played by a model (or abstraction) of the computer. Du Boulay et al. [17] call this the “notional machine”, an idealized, conceptual computer that is defined with respect to the language. Novices should develop an appropriate notional machine to master a programming language: the notional machine underlying Pascal is very different from the machine underlying PROLOG. A study by Mayer [18] confirms that students supplied with a notional machine model perform better while solving some problems than students who are not given the model.

A model of program comprehension was provided by Pennington [19]. Comprehension occurs in the context of a problem domain. The program’s text is re-organized in mental representations with help of available knowledge structures. Pennington studies expert FORTRAN and COBOL programmers, and finds significant differences in their performances of comprehension tasks.

The OO approach has claimed to make modeling the problem domain easier for programmers. D tienne investigated this claim. She found that novice programmers have difficulties in class creation. According to D tienne, novices need to start with a procedural representation of the situation. This seems to indicate that knowledge is organized in terms of procedures, not in terms of objects and relations. But for expert OO designers, the claims find support. Experts do analyze problems in terms of objects and their relationships. Also the claim that OO designers design solutions that are closer to the problem domain is supported. Expert OO designers seem to shift between object view and procedure view.

D tienne comments on the oddity of the situation: if OO design is driven by domain knowledge, then the biggest benefit should be observed in novices; but this is not the case.

C. Cognitive aspects of user-database interaction

Today, the Relational Model is the leading model in database theory. There is no need to know how data are stored in a Relational Database in order to write a query: knowledge of the (abstract) data model of the database is sufficient.

Cognitive aspects of query languages were studied at the same time as cognitive aspects of programming (Reisner,[20]). One of the issues was the procedurality of the query language. Some query languages specify more step-by-step methods to obtain results than others. SQL, today’s standard, is a set-oriented language, and was been labeled “less procedural” or even non-procedural in the debate.

Chan, Wei and Siau [21] focused on cognitive processes of abstraction in the user-database interface. They distinguished three levels of abstraction: a conceptual level (a description of the user’s world), a logical level (describing the database world in in set-theoretical terms) and a physical level (describing states in computer memory). The authors concluded that naive users’ understanding of how to write queries was best supported by a model of the conceptual level.

De Haan and Koppelaars [22] explicitly address database professionals. Professionals need to control the RDBMS, which is why professional database engineers should master the logical level, and the database world’s description in terms of set theory. Database professionals work with “objects” in the database world, a mathematical construct, based on set theory. No studies on the cognitive aspects of this kind of user-database interaction are known to us.

IV. A NEED FOR EMPIRICAL STUDY

The question here is how programmers, designers and professionals characterize the abstract software structures they work with. We observe that this characterization can change over time. Novice OO programmers mainly adopt a procedural strategy and start with a procedural representation of the topic they are considering (Detienne,[16]) Expert OO designers are able to switch between object view, emphasizing relations in the problem domain, and procedure view, emphasizing the execution of the program.

We are interested in mental models, instantiated in WM by computing professionals while communicating with each other. WM has limited capacity. Experts seem to be able to switch between object view and procedure view. This does however not mean that they can use the two views simultaneously, or that they are able to switch while communicating with colleagues.

We found multiple references to mental models in the literature concerning cognitive aspects of (OO) programming and user-database interaction. These are: (1) the notional machine, simulating an idealized computer, (2) the object view, where the individuation of (problem domain) objects guides the design activity, emphasizing static aspects of the solution, (3) the procedure-centered view, emphasizing the dynamics of a program and (4) a set-theoretical model, describing the problem domain in abstract terms and thus defining the database world. The notional machine and a procedure-centred view correspond to Schwank’s functional thinking; set theory and the object-view correspond to predicative thinking.

We found references to discrepancies between professional groups. Pennington reports of expert COBOL and FORTRAN programmers performing differently on program comprehension tasks.

We also found unsolved issues, in particular the oddity reported by D tienne. If OO design is driven by domain knowledge, why do novice designers experience difficulties in class creation? This could match Schwank’s observation of functional thinkers: they are able to learn to accomplish “predicative” task successfully, but might need more time or perform worse than predicative thinkers.

We hypothesize differences between professional groups in the instantiated mental models used to handle a concept that is fundamental to most computing disciplines: the “object”.

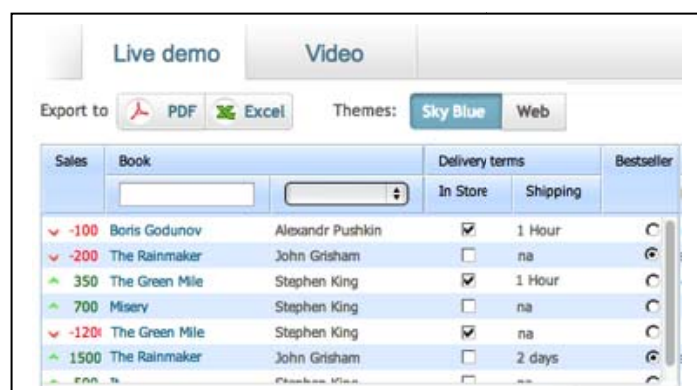
V. EXPERIMENT DESIGN

Do future computer professionals perceive sets of objects or bags of objects (instances)? Do they locate “objects” in the problem domain or in the programming domain? Do they think of software in terms of processes in the notional machine (sequences of events, communication between objects) or in terms of structures (attribute values, relationships, queries)?

We designed a Teach-Back protocol to elicit this information, and enquired students enrolled in different computing curricula. The participants’ answers were scored along categories, derived from the four types of mental models mentioned in section IV. Four raters were involved in this experiment. Three have been lecturing Computer Science in Dutch higher education for over 20 years; one is senior designer of documentation for scientific software. All the raters have a background in Computer Science and hold a Master’s degree or equivalent.

A. Context

The protocol is introduced by a brief case description, an online Bookstore (see Figure 1). It states that only information about books is relevant for our purposes, and that, therefore, the rest of the data is skipped. This results in a dataset with repeating rows having the same state. Participants are asked to describe the “Book-objects” they distinguish. No indications are provided for the choice of a theoretical context.



Sales	Book	Delivery terms	Bestseller
-100	Boris Godunov	Alexandr Pushkin	<input checked="" type="checkbox"/> 1 Hour
-200	The Rainmaker	John Grisham	<input type="checkbox"/> na
350	The Green Mile	Stephen King	<input checked="" type="checkbox"/> 1 Hour
700	Misery	Stephen King	<input type="checkbox"/> na
-120	The Green Mile	Stephen King	<input checked="" type="checkbox"/> na
1500	The Rainmaker	John Grisham	<input type="checkbox"/> 2 days

Fig. 1. Online Bookstore.

The situation is, in fact, ambiguous: the question can be answered by describing: (1) Book-objects in the problem domain (books in the bookstore’s assortment), (2) Book-objects in the programming domain (Book-objects in permanent storage), (3) Book-objects in the programming domain (instances of Book-objects), (4) objects in the programming domain (elements of the HTML-document).

B. Questionnaire

We asked the participants, how many different Book-objects they saw in the table in Figure 1. To answer the question, a mental model had to be instantiated.

Participants were presented with white sheets of paper and were instructed to explain in writing to an imaginary fellow student:

1. How many different Book-objects they saw and what these objects were,
2. What would happen if the system was asked to produce additional information about one of the books.

These questions activate declarative and procedural knowledge structures (section II-C). A last question aims to obtain an indication of the respondent’s preference for predicative or functional thinking. Following Schwank’s method, we used a matrix from Raven’s test (Figure 2) as explained in section II-B. We asked participants:

3. to add the missing symbol and to explain how they had constructed the solution.

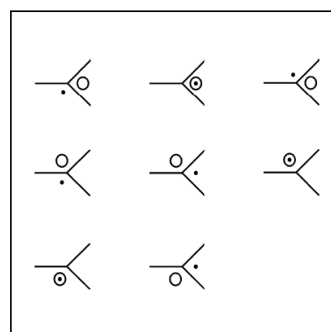


Fig. 2. The matrix used to match individual problem solving preferences.

C. Research questions and scoring categories

This experiment was designed to answer the following research questions.

- a) Are there differences across the disciplines in the amounts of objects counted by participants?

The aim of research question a) is to identify possible communication problems between computing professionals. Scoring was based on the participants’ answers to the first part of question 1 of the questionnaire (how many different objects do you see?).

Although differences in amounts of objects can indicate differences in mental models, their occurrence is not sufficient to draw conclusions. Research question b) focuses on the participants’ mental model.

- b) Are there differences across the disciplines in the mental models, instantiated by participants?

Scores concerning questions b were based on the interpretation of the participant’s answers to both questions 1 and 2 of the questionnaire. To determine the mathematical structure envisioned by participants (Set or Bag, see sections III-A and III-C) and the participants’ approach to software

(object view or procedure view, see section III-B), we defined the following sub-questions:

- b1. *Does the participant envision a set of Book-objects or a bag of Book-objects (instances)?*
- b2. *Does the participant make assumptions about the software implementation?*
- b3. *If the participant describes the programming domain, on which aspects does s/he focus?*

Different problem solving preferences might reflect on the approach to software, resulting in different mental models. We investigated the participants' problem solving preference, as defined by Schwank (see section II-B).

- c) *Which problem solving strategy adopts the participant to construct the solution of question 3?*

For each research question and sub-question, scoring categories were defined.

- a) To analyze discrepancies between the numbers of Book-objects counted by the participants, we scored:
 - 4 objects (or 5, if the participant counts the last row, which is only partially visible),
 - 6 objects (or 7, if the participant counts the last row),
 - A: a number that is not traceable to Book-objects,
 - N: no number mentioned,
 - Both: both answers "4 objects" and "6 objects" are mentioned and explained
- b) To determine the participants' mental models, we analyzed the answers to research questions b1..b3.
 - b1. Does the participant envision a Set of Book-objects or a Bag of Book-objects?:
 - S: a set of objects
 - B: a bag of objects (instances)
 - N: none of the above answers are supported by the participant's description
 - BS: participant sees both possibilities, a Bag of objects and a Set of objects

Rating the dominant aspect of software description (b3) is only possible if the participant describes the software. Many participants did not. We rated the granularity of software description (b2), and – if the software was described in some detail – the dominant aspect.

- b2. To determine the granularity of software description, we scored:
 - Macro: the participant describes the system in terms of its macro-structure, or as a black box. No details about the software's implementation are added.
 - Detail: the participant adds detailed hypotheses about (part of) the software's implementation.

- b3. To determine the dominant aspect in the description of software, we adopted the following categories:

- S: Participant focuses on static aspects of software (Détienne's object view)
- P: Processes are also described (Détienne's procedure view)
- M: Unclear. Participant provides mixed information

- c) To determine the participant's problem solving strategy, we used Schwank's categories,:

- P: Predicative thinking. Participants refers to the location of symbols to justify the solution he proposes
- F: Functional thinking. Participant perceives symbols as entities that can move, and performs motion analysis to justify the solution he proposes
- N: No choice could be made

D. Reliability

Scoring was done by two raters at the time. The raters interpreted the participant's answers and scored them along the categories we discussed in section V-C. The raters had been trained by scoring 6-10 questionnaires, followed by more sessions where interpretations issues were discussed. Still, discrepancies between raters do occur where interpretation is involved. The degree of agreement (inter-rater reliability) is expressed by Cohen's Kappa coefficient [23]. Generally, a coefficient above 0.75 is considered very good; between 0.6 and 0.75 as good and between 0.4 and 0.6 as fair ([23], page 280). Reliability was calculated on the questionnaires that had not been used for training purposes.

After scoring the categories and measuring the reliability, the discrepancies were discussed between the raters. If agreement was possible, the discrepancies were solved. In the other case, the answer was scored as "N" (research questions a, b1 and c) or "M" (research question b3). All issues concerning research question b2 could be solved.

E. Participants

The teach-back questions were answered by five groups of male Bachelor students, enrolled in professional curricula:

- 35 attending 1st year classes of Business IT and Management. Most of them enrolled in a professional curriculum in a computing discipline in 2013, 2 in 2010. They were not included in our samples.
- 19 attending 3rd year Business IT and Management, enrolled in a professional curriculum in a computing discipline in 2011. The exceptions: 1 enrolled in 2010, 1 in 2008.
- 18 attending 3rd year of Computer Science, field of study Information Engineering. Most enrolled in 2011. The exception: 6 enrolled in 2010, 1 in 2009, 1 in 2002.
- 29 attending 3rd year of Computer Science, field of study Software Engineering. Most enrolled in 2011. 4 enrolled in 2010.

- 4 enrolled in other computing curricula. They were not included in our sample.

All groups had attended at least one course “Relational Databases” and one course “Introduction to Programming in Java”. The Business IT and Management curriculum emphasizes modelling. The Computer Science curriculum concerns software development. Computer Science has two fields of study: Software Engineering puts the emphasis is on programming, Information Engineering on the construction of business solutions [24][25].

F. Hypotheses

Different computing disciplines seem to allow, or even to promote, fundamentally different conceptualizations of the “object”. These differences between disciplines can be systematic. Systematic differences would lead both to different conceptualizations and to different amount of objects detected, therefore to systematically divergent frequencies of the answers to the questions in section V-B. We cannot formulate expectancies about the magnitude of this effect.

To test the effect, we will investigate if we can reject the following null hypotheses in favour of plausible alternative hypotheses. We will reject the null-hypotheses if the probability p of finding our results less is than 0,05. In that case, we will conclude that the deviation from the null hypothesis is significant. We will state that we have found significant differences if the deviation is conform our expectation.

We will test the following null hypotheses:

Ha: “there is no difference between the amount of different “objects” reported by members of the following groups: 3rd year students Business & IT Management, 3rd year students Information Engineering and 3rd year students Software Engineering”.

Hb: “there is no difference between the conceptualization of the notion of “object” reported by the members of the following groups: 3rd year students Business & IT Management, 3rd year students Information Engineering and 3rd year students Software Engineering”

Hypothesis Hb can be divided in

Hb1: “there is no difference between the structures (set or bag) envisioned by the members of the groups mentioned above.”

Hb2: “there is no difference in granularity of description of the software between the members of the groups mentioned above.”

Hb3: “there is no difference in the aspects, emerging from the software descriptions of members of the groups mentioned above.”

Hc: “there is no difference between the problem solving preferences of the members of the following groups: 3rd year students Business & IT Management, 3rd year students Information Engineering and 3rd year students Software Engineering”.

VI. RESULTS

A. Ha: amounts of different objects reported

From the answers to question 1 of the questionnaire: “How many different Book-objects does the participant count?”, the following categories were scored:

- 4: 27 participants. Many of them explain their choice (“There are 6 Book-objects, but two of them occur twice, hence 4 different Book objects”, “there are 4 Book objects, since some are double”).
- 6: 19 participants.. Explanations vary from “n rows, n Book-objects” to “6 Book-objects. Some occur twice, but they are still different objects” and technological explanations (“I am thinking OO-Java”).
- A: 8 participants mention an amount of objects that is not traceable to Book-objects: they count 1,2,3,4,12,14 or 16 objects. They describe: classes, attributes, User Interface objects (e.g. search-fields) or attribute values.
- N: 12 participants do not answer the question. 4 out of these 12 give elaborate answers, incidentally illustrated with diagrams, without counting the objects (e.g. “7 books, described with title and author. 2 of them occur twice”).
- B: 0 participants. The answer: “We see 6 instances of 4 Book-objects” is never given. One student counts “6 instances of 4 Books”. He is one of the participants that were not included in our sample (see section V-E).

TABLE I. NUMBER OF BOOK-OBJECTS , SAMPLED BY CURRICULUM

	Number of objects			
	4	6	O	n
3 rd BIM	7	2	10	19
3 rd IE	5	10	3	18
3 rd SE	15	7	7	29

Discrepancies between raters were very limited (Cohen’s Kappa = 0,795). Agreement on 1 answer was not possible; it was scored “N”, as indicated in section V-D.

The scores of question a) are shown in Table I. Column “O” (“Other”) summarizes the categories “A” (a number, not referring to Book-objects) and N (not a number). Category “B” was not scored in our samples.

We found significant differences between the samples in Table I (chi sqr = 13,1 ; $p < 0,05$) and reject Ha. Students Software Engineering seem to count more often 4 objects. Students Information Engineering seem to prefer counting 6 objects. Student Business IT and Managements seem to elude the question.

B. Hb: mental models across the disciplines

To determine differences in mental model, the participants’ answers to the questions about the system (questions 1 and 2 of the questionnaire) were read in totality and interpreted. This could only be done if the participant had answered at least one

of these. This was not the case for two participants; one of them was included in our sample. Questions b1..b3 were scored for 17 students, enrolled in the Information Engineering curriculum, instead of 18.

The following categories were scored for research question b1 (“Does the participant envision a set of objects or a bag of objects?”):

- Set: 26 participants. (“There are 4 Book objects, because some of them are double”, “6 records representing 4 Book objects”).
- Bag: 25 participants (“6 instances”, “12 different objects, Books and Authors”)
- N: 14 participants. this category was scored if question 1 was not answered, if no useful answer was provided (e.g. “2 Book-objects”) or if the answer was contradictory (“Book objects are identified by their attributes: ID, title, author. I see 4 Book-objects with different ID’s”)
- BS: this category was not scored.

Some discrepancies between raters occurred (Cohen’s Kappa = 0.597). Agreement was not possible on 2 answers in this sample. They were scored ‘N’.

The meaning of the term “different” is ambiguous in OO-programming. Equivalent instances can refer to the same object. We found 3 answers reflecting this dilemma: “6 Book-objects, but two of them occur twice, hence 4 different Book objects”. They were scored as “Bag”.

TABLE II. SET OR BAG, SAMPLED BY CURRICULUM

	Set or Bag			n
	Set	Bag	N	
3 rd BIM	5	7	7	19
3 rd IE	6	11	0	17
3 rd SE	15	7	7	29

The answers to research question b1 are shown in Table II. We found significant differences between the samples in Table II (Fisher’s exact test, $p=0,0101279$) [27] and reject Hb1. Students Software Engineering seem to show a preference for the structure “Set”, where students Information Engineering appear to work with “Bag”s of objects. Students Business IT and Management are random divided between the options.

The case provides minor structural information about Book objects, in Figure 1. While scoring b2 and b3, the raters focused on information that was added by the participants, information that could not be traced back to the case or the questions.

Discrepancies between raters occurred (Cohen’s Kappa = 0.576). Agreement was not possible on the scores on question b3 for the answers of 5 participants. They were scored “M”.

The following categories were scored for research question b2 (assumptions about the software implementation):

- Macro: 18 participants roughly described the software they had envisioned without adding structural or process information. (“the name of the book is looked up in the database”, “If the user points at the row, the system displays information”).
- Detail: 48 participants provided more detailed information (list of attributes, class diagram, code, activity diagram, query)

TABLE III. GRANULARITY OF DESCRIPTION OF SOFTWARE, SAMPLED BY CURRICULUM

	Granularity of software description		
	Macro	Detail	n
3 rd BIM	9	10	19
3 rd IE	5	12	17
3 rd SE	3	26	29

The scores of question b2 are summarized in table III. Approximately 90% of the Software Engineering students provided implementation information, against ca. 70% of the Information Engineering group and 50% of the Business IT and Management group. The differences are significant ($\chi^2 = 8,21$, $df=2$, $p < 0,05$). We reject Hb2.

The following categories were scored for research question b3 (“dominant aspects in the description of software”):

- S: 28 participants mainly added structural information (attributes or relationships, class diagram, query)
- P: 14 participants mainly added information about procedures (activity diagram, sequences of events, communication between software components)
- M: 6 participants added both kinds of information

The scores of question b3 are summarized in Table IV. We found no significant differences between the samples in table IV. (Fisher’s exact test, $p=0,12682945$) [27]

TABLE IV. DOMINANT ASPECTS IN SOFTWARE DESCRIPTION, SAMPLED BY CURRICULUM

	Dominant aspects in software description			n
	S	P	M	
3 rd BIM	9	1	0	10
3 rd IE	5	6	1	12
3 rd SE	14	7	5	26

We found significant differences in mental models of students enrolled in different curricula, and reject HB. Apparently, there are differences in the way future professionals conceptualize software.

Some of the participants appear to be in doubt (it depends on the interpretation of the figure, on the relationship between title and author, etc.), but seem not to be able to give expression to their doubts.

C. Hc: problem solving preferences

For research question c, the following categories were scored:

- P: Predicative. (“the circle’s position is the same in every row, the dot’s position is the same in every column”, or: “I choose the missing symbol”)
- F: Functional (“In each row, the dot moves counterclockwise while the circle stays at the same place”)
- N: No choice could be made

Discrepancies between raters were limited (Cohen’s Kappa = 0.742). Agreement could not be reached on 2 answers; they were scored “N”.

The scores of question c are summarized in table V. We found no significant differences between the samples in table V. (Fisher’s exact test, $p=0,25695717$) [27]

TABLE V. PROBLEM SOLVING PREFERENCES, SAMPLED BY CURRICULUM

	Problem solving preference			n
	P	F	N	
3 rd BIM	6	7	6	19
3 rd IE	5	11	2	18
3 rd SE	14	11	4	29

VII. LESSONS LEARNED

Our initial ambition was to classify mental representations of “objects”, in problem domain objects, stored objects or instances. We partially succeeded. We were able to underpin some observations about the participants’ mental models. We determined the mathematical settings participants refer to while working with objects (set or bag), and assessed in which terms they envision software while communicating with colleagues (macro or detail). No conclusions could be drawn about the location of the objects in problem domain or programming domain. This might be due to different causes. One applies to the casus. Students know bookstore-cases from their courses on Databases. The choice for a bookstore might have appealed to previous knowledge, pointing towards a possible interpretation for the term “object”. Also, the formulation of question 2 of the questionnaire (“What happens if the system is asked to produce additional information about one of the books?”) might have suggested a macro approach to the system, reinforcing that interpretation. We will take this experience into account for the new version of the questionnaire.

Interpreting student mental models has proven to be challenging, even for experienced assessors of students’ work. The raters are puzzled by the measure in which their interpretations can differ. One example is: although “set” and “bag” are well-defined mathematical concepts, some of the participants’ answers gave cause for discussion. One student explained how he counted: “Objects are different versions. E.g. [if we have]: 1,2,1. 1 and 1 are the same: 2 different objects”. The raters (one has an engineering background, one is a former

database professional) scored respectively “Bag” (different objects: 1 and 1), and “Set” (different objects: 1 and 2). Both understood the other’s point of view, but agreement could not be reached. Rating in teams of mixed expertise appears to be crucial in this experiment. Structured interviews with participants may be necessary in the future to fully understand some of the answers.

VIII. CONCLUSIONS

Our investigation showed at least two ways to characterize the abstract notion of “object” that are currently used by professionals. Both characterizations are correct, but they are not compatible: they lead to different judgments on the number of “objects”. Some participants identified 4 Book-objects, others identified 6 Book-objects. The preference for 4 or 6 objects was not distributed at random. Apparently, Software Engineers are more likely to see 4 objects, in contrast with most Information Engineers, who show a preference for detecting 6 objects.

One third of the participants could not provide information about the amount of objects. Although some of them expressed doubts about the question, only one of them was able to point in the direction of possible ambiguity of the notion of “object”.

We found indications for the instantiation of different mental models across the disciplines. SE, IE and BIM students in our study seem to differ in their perception of the appropriate structure for objects (set or bag). More in general, they appear to differ in the measure in which they envision a possible implementation while discussing software. Further research is needed to better describe computing professionals’ mental models, and investigate differences across the disciplines.

We did not find significant differences in the way different groups approach software (object view or procedure view). No significant differences between individual problem solving preferences were found across the groups either. This might indicate that the differences we describe are acquired, hence a responsibility of designers of computing curricula.

IX. OUR MESSAGE FOR EDUCATION

The immediate relevance of our work is in curriculum design. We recommend all computing curricula to explicitly cultivate awareness for different approaches to computing concepts. Based on this study, we also recommend educators and practitioners to establish and use a refined terminology for the notion of “object”. A refined terminology will improve recognition of different mental models. Whether it will support computing professionals sufficiently in handling different mental models, is an issue that needs to be researched.

The lack of agreement about the definition of one of the basic notions of the computing discipline, we have found between students enrolled in different curricula, is worrisome, just as the apparent difficulties to recognize this issue and to discuss it properly.

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Teaching and Learning Software Project Management: a hands-on approach

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Abstract—Project management is an essential activity across several areas, including Software Engineering. Through good management it is possible to achieve deadlines, budgets goals and mainly delivering a product that meets customer expectations. Project management activity encompasses: measurement and metrics; estimation; risk analysis; schedules; tracking and control. Considering the importance of managing projects, it is necessary that courses related to Information Technology and Computer Science present to students concepts, techniques and methodology necessary to cover all project management activities. Software project management courses aim at preparing students to apply management techniques required to plan, organize, monitor and control software projects. In a nutshell, software project management focuses on process, problem and people. In this paper we proposed an approach to teaching and learning of software project management using practical activities. The intention of this work is to provide the experience of applying theoretical concepts in practical activities. The teaching and learning approach, applied since 2006 in a Computer Science course, is based on teamwork. Each team is divided into groups assuming different roles of software process development. We have set four groups, each one assuming a different role (manager; software quality assurance; analyst and designer; programmer). The team must be conducted across the software process by its manager. We use four projects, each group is in charge of managing a different project. In this paper we present the proposed approach (based on hands on activities for project management); we summarize the lessons learned by applying the approach since 2006; we present a qualitative analysis from data collect along the application.

Keywords—*Learning Project Management; Practical Activities; Teaching Methodology; Teamwork.*

I. INTRODUCTION

Software Engineering is a discipline to software production. Besides the technical issues, like process, methods and programming languages, there are people involved in. Concerning technical aspects, it is usual for teachers to use systems as cases your studies perform analysis, design, coding and testing, for example. However, teaching software engineering has challenged professors especially concerning software project management. Teaching software project management is usually a theoretical course, practical tasks are usually focusing on theory application using tools to simulate scenarios. Those tools are used to simulate what-if hypothetical scenarios, like [refs to simulations].

Most of the focus in the teaching project management

is based on theoretical approach. The practical part comes second, and in many cases not even addressed. Thus, students do not experience practicing. To tackle this problem, it is found in literature the use of system software simulating software development teams. However, such approach based on simulation do not allow students to deal with people: as manager, s/he must be trained to organize technical people into effective teams and coordinate them to achieve effective communication and results. Such issues are no addressed by simulators.

We consider important to students not only the opportunity to apply theoretical information into scenarios, but also the opportunity to handle situations with people as similar as possible to real projects. In this paper we present our experience on a practical approach to software project management teaching and learning. In this paper we also present the requirements for the application of practical approach proposed, as well as the lessons learned. We have used this approach since 2006 in a Computer Science undergraduate course. We considered the first year as a pilot study. After 2007, we have applied SPARTA using the organization presented in this paper, adapted year by year according to the lessons learned.

The remainder of this paper reports the teaching project and its results. In Section II is presented the context required and the processes to software development. Section III provides details about SPARTA approach and constraints to hands on software project management. Section IV presents the results and the discussion. Related works are briefly presented in Section VI. Finally, Section VII presents conclusions and further work.

II. THE CONTEXT: SOFTWARE PROJECT MANAGEMENT

Software development process is concerned primarily with software development. Methods, languages and tools [1]–[5] to support development tasks are usually focused on Software Engineering courses aimed to technical issues. The Technical Processes are used to define the requirements for a system, to transform the requirements into an effective product, to permit consistent reproduction of the product where necessary, to use the product, to provide the required services, to sustain the provision of those services and to dispose of the product when it is retired from service [6].

The *Technical Processes* define the activities that enable organizational and project functions to optimize the benefits and reduce the risks that arise from technical decisions and actions [6]. Therefore, such content must be presented to student before the management content, during previous course. For that, the curriculum of a Computer Science course must be organized in order to provide technical skills, before expose students to management content. Technical Processes are, for example, *System Requirements Analysis*, *System Architectural Design*, *Implementation Process*, *System Integration Process* and *System Qualification Testing Process*. They are out of scope of this paper, but considered as background to management and, consequently, essential to manager.

In addition, *Software Support Processes* provide a specific focused set of activities. A supporting process assists the *Software Implementation Process* as an integral part with a distinct purpose, contributing to the success and quality of the software project. *Software Documentation Management Process*, *Software Configuration Management Process* and *Software Quality Assurance Process* are examples of support process. They are also considered as background to management and, consequently, essential to manager since a manager has to decide about them [7], [8].

Concerning software management, there are several processes [6] involved, such as *Organizational Project-Enabling Processes* – they are: Life Cycle Model Management Process; Infrastructure Management Process; Project Portfolio Management Process; Human Resource Management Process; and Quality Management Process. Finally, the **Project Management Processes** are used to establish and evolve project plans, to assess actual achievement and progress against the plans and to control execution of the project through to fulfillment. The Project Management Processes – *Project Planning Process* and *Project Assessment and Control Process* – are applied with a level of rigor that depends on the risk and complexity of the project.

Individual *Project Management Processes* may be invoked at any time in the life cycle, as required by project plans or unforeseen events. Such dynamical characteristic requires from manager to attend different situations along software development. Frequent casual communications between developers and end-users, and between project managers and clients, are necessary to keep the project relevant, useful and effective for the end-users, and within the bounds of what can be completed. It is important to note that we do not have a real client, but we have *roles* presented in next section, one of them is the *client role*. Effective interpersonal communication and conflict management and resolution are important to software project management. While end-user participation, effective communication and teamwork are not sufficient, they are necessary to ensure a good outcome, and their absence will almost surely lead to a bad outcome. In SPARTA approach we encourage the students to establish and use their communication canal using tools to keep record (logs) used to student assessment (discussed in Section V).

Risk management is an important issue on *Software Project Management*. It consists in measuring or assessing risk and, then, establishing strategies to manage the risk. In general, the strategies employed include transferring the risk to another phase, avoiding the risk, reducing the negative effect of the

risk, and accepting some or all of the consequences of a particular risk. However, considering the context of SPARTA approach – a practical activity in a course – it is not fair to expose the student to real projects with real risks, what would result in students fail the course. Therefore, we create a controlled environment that avoid some risks, such as risks related to technological aspects, equipments and market, which includes a cost-benefit analysis as well as a list of fallback options for project failure, called a contingency plan. The avoided risks are presented in theoretical ways, but not considered in practices. During the practical project, the students have to deal with risks like human resource availability.

Requirements management is the process of identifying, eliciting, documenting, analyzing, tracing, prioritizing and agreeing on requirements and then controlling change and communicating to relevant stakeholders. Also, considering the context of SPARTA approach we must establish a controlled environment regarding requirements, using a set of requirement suitable to time (course length) and avoiding modifications along the development. Change impact analysis of altered scope, which includes requirements analysis at the change level, is an important part of the software engineering process – whereby business analysts or software developers identify the altered needs and, then, they are then in a position to re-design or modify a solution. Theoretically, each change can impact the schedule and the budget of a software project. Regarding project management, changes must consider risk-benefit analysis before approval. However, change impact is not handled during the course, and it is out of scape of SPARTA.

III. PRACTICING PROJECT MANAGEMENT: THE SPARTA APPROACH

The main idea is to allow students the experience on software project management, but who manage, manage other people activities and tasks. For that, we proposed an approach based on *roles*. In general, the *roles* are chosen to address management and non-management tasks. Non management tasks are chosen among *Software Support Processes* and *Technical Processes*.

For that, the class is divided into *groups*, and their members will play different *roles* for a given *project*. For a given project, one is the *manager* and others play different roles in charge of different tasks from *Technical Processes* and *Software Support Processes*. Other projects must be assigned to the group, choosing another one as *manager*, in a rotating assignment – consequently, the manager of the first project will assume a different role on the second project. The number of projects assigned to a group depends on the number of roles defined. SPARTA organization is shown in Table I. Considering the project *P1*, the team *11* is the *manager*, and the teams 12, 13 and 14 assume different roles. And teams 12, 13 and 14 are managers of other projects. As mentioned in Section II, the projects must be chosen in order to avoid risks, especially time constraints.

To chose the roles it is necessary to balance the number of students and time to development. Also, it is necessary to take into account subjects from students background, deciding which subject should be prioritized. In order to emphasize

development and quality assurance skills, we have used four roles: **Manager, Analyst & Designer, Programmer** and **Software Quality Assurance (SQA)**. Thus, we used four projects, as shown in Table I: for instance, the Group 1 is composed by teams 11, 12, 13 and 14, and a Project P1, *Team 11* is responsible to manage the software development activities, planning tasks and controlling their results; *Team 12* is responsible by Software Quality Assurance (SQA) activities; *Team 13* is responsible for project analysis and design; finally, *Team 14* must implementing the project. Each roles is discussed in the following subsections.

A. Manager Role

The main focus is the **manager** role. The manager must define the plan to software development and control the evolution. The purpose of project planning is to identify the scope of the project, estimate the work involved, and create a project schedule. Project planning begins with requirements that define the software to be developed. The project plan is then developed to describe the tasks that will lead to completion. The purpose of project monitoring and control is to keep the team and management up to date on the project's progress. If the project deviates from the plan, then the project manager can take action to correct the problem. Project monitoring and control involves status meetings to gather status from the team.

The first task for managers is "hire" their teams, what is done during the first class. For the students, the *hiring* consists in choosing their partners. Considering the rotating assignment, note that a manager hires and is hired at same time.

Secondly, a project is assigned to a manager by the teacher (a software requirement document is provided). To emphasize manager responsibilities and leadership, the teacher communicate only with the manager about the project. The manager, has, then, sets objectives (the manager must set goals for his/her team, and decides what work needs to be done to meet those goals), organizes their teams (the manager divides the work into manageable activities, and selects people to accomplish the tasks that need to be done) and define measures for planing and controlling tasks (the manager establishes appropriate targets and yardsticks, and analyzes, appraises and interprets performance).

For that, the manager must use the requirement document to obtain estimation about size, effort and time to develop. We have used empirical models, such as Constructive Cost Model (COCOMO) and Walston and Felix model [9]. After estimations, the manager must choose a methodology for software development and breakdown into tasks – see discussion on next subsection. In addition, the manager must define the schedule assigning tasks and deadlines to each team. We have used PERT/CPM charts to analyze critical paths, and Gantt charts. The manager have used MicroSoft Project [10] as tool to create schedules (Gantt charts).

The processes (and methods) used to complete the work defined in the project plan to accomplish the project's requirements are executed – other teams must follow the planning executing what was assigned to them. Manager are also in charge of monitoring and controlling the execution, to observe project execution so that potential problems can be identified

in a timely manner and corrective action can be taken, when necessary, to control the execution of the project. Manager must chose an approach (task or time based control) to observe and measure regularly the evolution to identify variances from the project management plan.

Regarding Monitoring and controlling tasks, they consist in: Measuring the ongoing project activities; Monitoring the project variables (cost, effort and scope) against the project management plan and the project performance baseline; Identify corrective actions to address issues and risks properly. As mentioned, SPARTA approach assume a controlled environment to constraint risks, so that manager are required to monitor effort and time.

B. Analyst-Designer Role

The Analyst-Designer role is in charge of developing the software, following the plan defined by the *manager*. We have encouraged our students to use the method described in [11] because it is iterative and evolutionary. Therefore, the *manager* must create the plan using the phases Plan and Elaborate, Build and Deploy, as depicted in Figure 1.

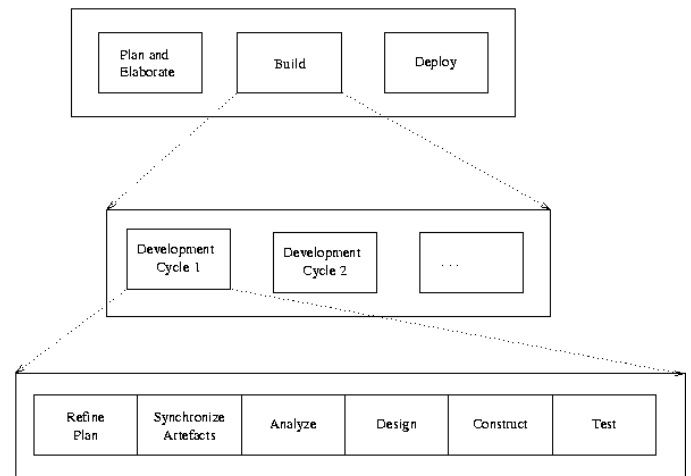


Figure 1. Iterative Development Cycles [11].

An iterative life-cycle is based on successive enlargement and refinement of a system through multiple development cycles of analysis, design, implementation and testing, which demand the continuous monitoring by managers. In addition, it helps the *manager* to distribute the tasks along the project timeline avoiding concentrating long tasks to human resources.

We do not specify any tool to support Analysis and Design tasks, but most of students have used *Astah UML*, is a modeling tool that supports Unified Modeling Language¹.

C. Software Quality Assurance Role

The Software Quality Assurance role is in charge of review software artifacts in order to create a software in good standard of quality design. The main goal is to apply techniques to validate software artifacts, especially to create and execute test cases. The Software Quality Assurance role must follow

¹The tools is available from <http://astah.net/>

TABLE I. SPARTA ORGANIZATION USING FOUR ROLES

Groups	Teams	ID	Projects			
			P1	P2	P3	P4
1	1	11	Manager	SQA	Analyst/Designer	Programmer
	2	12	Programmer	Manager	SQA	Analyst/Designer
	3	13	Analyst/Designer	Programmer	Manager	SQA
	4	14	SQA	Analyst/Designer	Programmer	Manager

the plan defined by the *manager*, using the artifacts created by *Analyst-Designer* and *Programmer* roles as input. One might observe in Figure 1 that software quality assurance tasks crosscut the method suggested, facilitating the *manager* task to reduce risks.

We have used different SQA method depending on the artifact to be verified/validated. To document requirement, we have used Perspective Based Reading [12], [13]. To program validation, we have used JUNIT test cases.

D. Programmer Role

The Programmer role is in charge of implementing the software design, following the plan defined by the *manager* and the design specification created by *Analyst-Designer*. We have encouraged our students to use JAVA language.

E. The Teacher

During SPARTA execution, the teacher has two different roles basically. Initially, the teacher plays the client role, defining the requirements to the *manager*. As an instructor, during the development, the teacher might provide support to managers as an external consultant, in order to inquire manager into decision leading them to think about alternative ways to software development under construction.

F. The Projects

We have used four projects, briefly described here. The first system, identified as *P1*, aims to provide support to the activities involved in management courses, as record curricula, distribution of lessons, didactic and pedagogical planning, monitoring of teaching activities, among others. Since it is a support system (sub-system), it must be able to exchange data with other systems available through text files. There are 25 requirements, 3 of them considered medium and 22 considered low level of difficulty.

The second system proposed, identified as *P2*, aims to provide support to the activities involved in the management of bank accounts, whether they are current accounts, savings or credit card accounts. The system must be able to exchange data with other systems available through text files, especially files containing your banking, obtained over the Internet. There are 20 requirements, 6 of them considered medium and 14 considered low level of difficulty.

The third system, identified as *P3*, aims to provide support to the activities involved in the management of resources that can be shared by multiple users, should be established time-lines or reservations for effective use. The resources managed by the system can be, for instance, classroom, laboratories, and computers. Therefore, the system must be able to deal

with different types of resources and suggest similar resources available during reservation. There are 21 requirements, 6 of them considered medium and 15 considered low level of difficulty.

The forth system, identified as *P4*, aims to keep a music library, with musical productions, authors, performers, etc. The system should also play a particular song, or playlist, chosen by the user. There are 26 requirements, 3 of them considered medium and 23 considered low level of difficulty.

An important issue about the system chosen is: all of them were defined considering their length, not only in requirements and technical similarities, but also the Function Points estimation [14] – both systems result in similar points. Also, some requirement were intentionally chosen to have a vague specification, in order to introduce variations across multiple implementation, allowing different technical decisions along the project development.

IV. RESULTS AND DISCUSSION

The results were collected after students had answered a survey about the project. This survey was applied at the end of the Software Engineering Course. The first question is about the organization of teams, it was asked if the organization with defined roles was useful for practice and activities learning. Answer are shown in Figure 2, the great majority of students rated as beneficial the division of the team as pairs with defined rules. According to students the division helped the development process of the project that they managed.

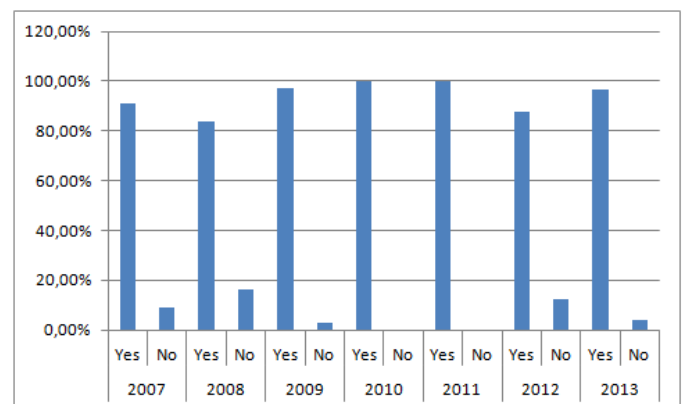


Figure 2. Question 1: team organization.

The second question is about the proposed practical activities, students answered if these activities helped to sedimentary acquired technical knowledge, as shown in Figure 3. Students justified their answers saying that with the Software Engineering subjects were easier to be consolidated, highlighting

the importance of defined roles. Besides, it was a excellent opportunity to learn from mistakes which emerged with the implementation of activities.

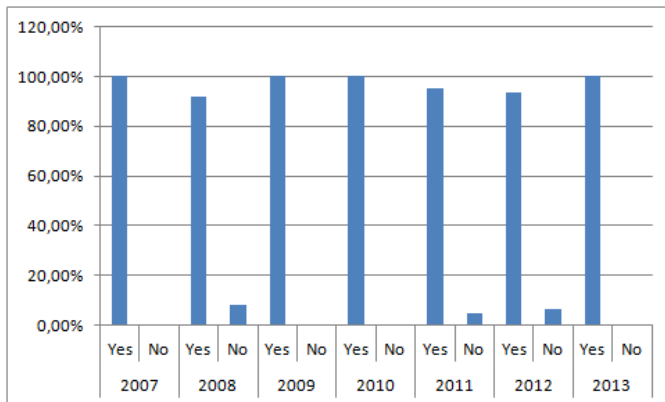


Figure 3. Question 2: practical activities.

In third question students discussed the importance of managing a software project. The answers were categorized into three assessment standards: great, good and regular, as shown in Figure 4. Evaluating the results in these it was concluded that most students agreed that the experience of managing a project was valid.

The students said that it was essential for learning and gaining experience in the application of Software Engineering knowledge in real projects of companies or organizations. Also it was a great way to understand and be able to apply knowledge in activities involving teamwork, deadlines and organized work. Students that had their answers as regular said that they already had some knowledge, so it was a opportunity to review some concepts.

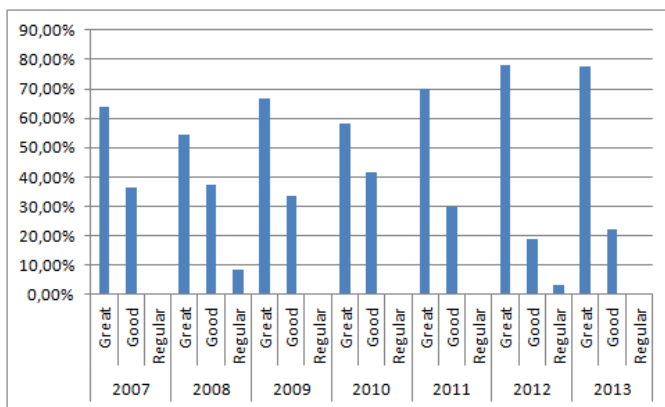


Figure 4. Question 3: importance of managing a software project.

In Question 4 it was asked about if it was possible to apply theoretical concepts learned in classroom in a project management. Almost the totality of students agreed that they were able to apply the concepts in practical activities, as shown in Figure 5. During the management they applied the most important and essential concepts learned in the classroom, as the use of some design patterns, the conduction of Technical Reviews [12], [13], metrics and estimation software tasks, the methodology to development [11]. The activities of manage

demed a caution. Also, it was important to ensure that the schedule was running as planned, i.e., if the control points verification.

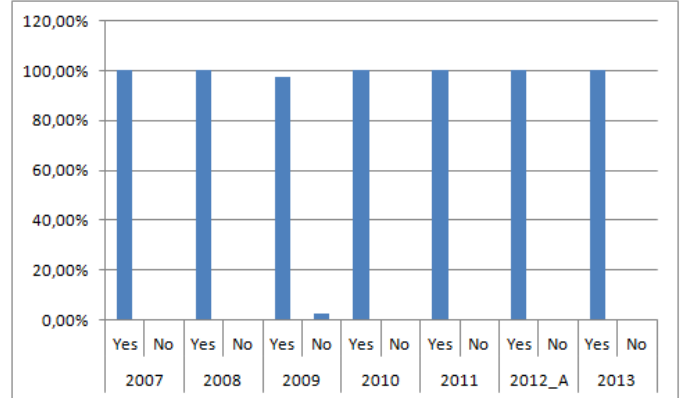


Figure 5. Question 4: applying theoretical concepts

In Question 5 students answered about their difficulties on managing a project. The difficulties can be categorized into human resource management and planning and control of the project, as indicated in Figure 6. In all years, except for 2012, the biggest difficulty has been dealing with the human factor, since the vast majority had no experience in managing people before. Project managers were unable to deal with delays and non-compliance with some tasks. On the other hand, the lack of experience was appointed as the reason for the difficulty in planning a schedule and most important, follow it.

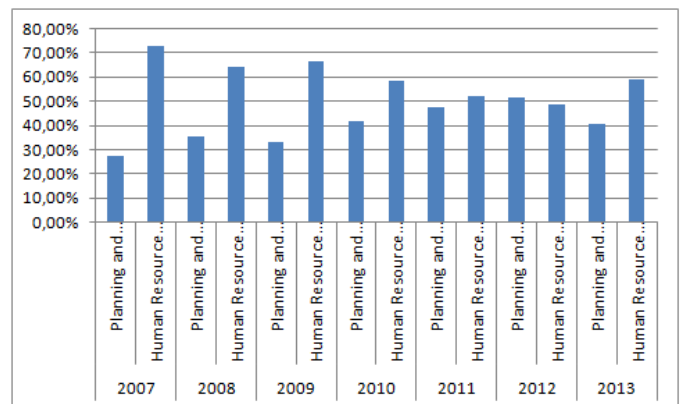


Figure 6. Question 5: difficulties on managing a project

The last question was about the team performance, students were asked if they as manager/owner condition, would hire their employees based on their performances. The hiring rate is shown in Figure 7, which was an opportunity for students to individually evaluate each team element of the project development.

Although human resource management be pointed as the major difficulty in the project management, in most cases managers would hire their staff. Factors such as theoretical knowledge, practical skills and mostly, a good capacity of teamwork were crucial for the evaluation. On the other hand, delays and lack of commitment to the project were identified as the main reason for not hiring.

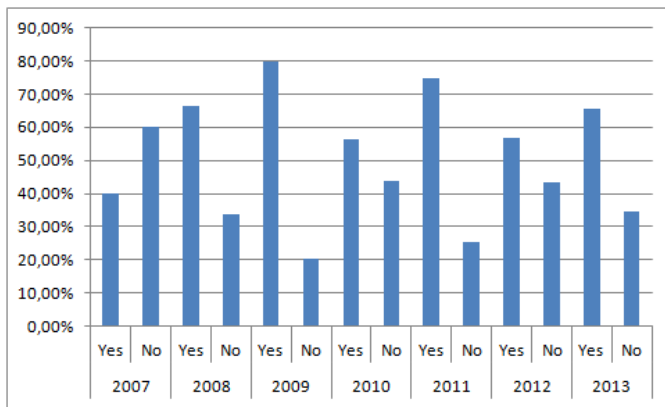


Figure 7. Question 6: hiring rates

Finally, it was asked to each student whether s/he approved SPARTA approach and we summarize the results in Table II – more than 90% approved SPARTA approach as a way to practice software project management.

TABLE II. POSITIVE FEEDBACK FROM STUDENTS PER YEAR AND ITS PERCENTAGE

Year	Enrolled Students	Positive Evaluation	
		Students	Percentage
2007	24	22	91,67%
2008	43	36	83,72%
2009	42	39	92,86%
2010	34	30	88,24%
2011	39	39	100,00%
2012	34	31	91,38%
2013	51	44	86,27%
Total	267	241	90,26%

V. LESSONS LEARNED AND OBSERVATIONS

We have applied SPARTA since 2006. We considered the first year as a pilot study. After 2007, we have applied SPARTA using the organization presented in this paper. Year by year we have improved details considering the feedback provided by students.

Initially (2006 and 2007), the teacher had no role specific: the teacher only provided the requirement documents to students and monitors them as *managers*. After 2007, some requisites were modified and defects (such as, ambiguity and inconsistency) were introduced demanding SQA activities and corrections. Also, the teacher assumed the *client* role, supporting the managers to clarify requirements and receiving the final product at deploying phase. We introduced client role after have observed problems in communication – both on interpreting requirements and interpersonal communication. Also, some groups reported excessive delay in project plan and conflicts among members.

By introducing *client* role we reduced the conflict and, consequently, we facilitate its management and resolution. Software developers, users, project managers, customers and project sponsors need to communicate regularly and frequently. The information gained from discussions allows the project team to analyze threats and to act in order to minimize

threats. For example, casual conversation with users, team members, and other stakeholders may often surface potential problems sooner than formal meetings. However, the *client* must be contacted by students independently of role – in other words, the *client* has no proactive attitude, but students are encouraged to be proactive. The communication must focus on whether the team has understood the project and whether the team is making progress towards that goal.

Another lesson learned is regarding the evaluation criteria and schema. Each manager should evaluate their team members, individually. Considering the crossing assignment, one might assign unearned grades to colleagues aiming at receive back unearned grades. For that, we considered the crossing evaluation but introducing the teacher in order to avoid collegiality in grade assignment. The rationale is: whether a manager gives high grades to their employees, but present poor results, it is possible to infer that s/he is a poor manager. Consequently, the teacher should apply penalty, decreasing the grade to the manager.

Risk management is a weakness in SPARTA approach. The controlled environment, especially regarding requirements, does not allow student practical activities on measuring or assessing risk and, consequently, developing strategies to manage the risk. In general, students are allowed only to deal with tight schedule, and the strategies employed include transferring the risk to another phase (see Figure 1), reducing the negative effect of the risk (i.e. rework), and accepting some or all of the consequences of a particular risk. Hypothetical situations are explored in theoretical discussion to mitigate such weakness. In addition, budget is out of scope of SPARTA – we have proposed scenarios (*what-is* situations) to managers in order to instigate them to think about budget and take decisions considering financial impact.

Regarding *requirements management*, the process of identifying, eliciting and documenting are underexploited. However, the process of analyzing, tracing, prioritizing and agreeing on requirements and then controlling change and communicating to relevant stakeholders consist in strength points in SPARTA. By allowing students to practice management, they must take decision especially about tracing, prioritizing and agreeing on requirements.

Initially (2006 and 2007), we do not defined any software configuration management – each manager should use as his/her own convenience. Next, for two year we provided an infrastructure to be used: we defined a server to be used to version control, and the teacher had access to all project area. However, the resources available nowadays motivated the use cloud services chosen by each manager.

One might argue about four groups – why four? why manager, software quality assurance, analyst and designer, and programmer roles? In fact, *analyst* and *designer* roles in different groups would be an option to instantiate SPARTA using five groups, but we considered the increased communication among groups as a threat to the work (and schedule) proposed.

VI. RELATED WORK

Usually, teaching software project management uses simulations tools. Simulations have been becoming increasingly

more prevalent in the education system over the past several decades [15]. Many critiques and reviews regarding management and business simulations have been produced [16]–[18]. However, Salas et al. [19] pointed out that the majority of the literature focusing on simulation in management education is descriptive rather than prescriptive – it describes the current state of simulation technology in management education and what types of simulations are used, but does not provide guidance as to how to most effectively utilize simulation based training (SBT) to develop the skills of management students. They also agree that SBT should be used more frequently in management education. However, tools are not enough, the different perspectives of teaching and developing require methodological approaches to organize the usage of mechanisms to support the teaching-learning process [20].

Also, system project dynamics [21] models have been used supporting risks in software project management [22]. However, we have found no hands on approach for teaching and learning software project management.

VII. FINAL REMARKS

Magni et al. [23] pointed out that: a) organizations and educational institutions are moving toward a training approach that emphasizes the active involvement of participants; b) there is growing interest in understanding how individual engagement in the training experience affects practicing managers' individual learning. Instead of work with models and simulations, we proposed a hands on approach to allow immersion in realistic situation.

Fred Brooks pointed out that there was “no silver bullet” that would ensure project success [24]. We are aware that SPARTA approach is not a “silver bullet” on teaching and learning software project management, but it is worthy. Working in group, using different roles, the student is exposed to different views, what might be helpful to emphasize absorption of concepts and good practices. We have observed that group-level behaviors can mitigate negative effects on individual learning. Most of students have pointed out be worthy to use a hands on approach, even after having faced difficulties during the development process, especially regarding communication.

Most students did not know anything about project management, others had no idea of existence of tools that help for good project managing. Therefore, it was very important the application of these project. Besides, some students were encouraged to research about practices of PMI (Project Management Institute) to apply to their projects.

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Computational Platform for the Educational Model based on the Cloud Paradigm

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Abstract - The Department of Computer Science at the University of Los Andes has proposed a new curriculum model based on the profile defined by ACM/IEEE, and a pedagogical model based on the "learning by doing" paradigm, in order to ensure a process of self-formation of the student. The knowledge management and the learning process are based on the concept of clouds. The new educational model is based on three clouds: a) the self-formation cloud which is composed of everything related to the student's education (curriculum, etc.); b) the learning paradigm cloud which is related to the paradigms, strategies, forms of assessment, and learning tools; and c) the knowledge sources cloud which is composed of all existing knowledge in the world, in all its forms, from all possible sources. To give support to the educational model, a web platform based on Service Oriented Architecture (SOA) is proposed in this work. The system consists of three management layers; each one manages each one of the clouds described above. The implementation of each layer is made as web services. Each layer has its own data structure defined like ontology. This is called Extended Database, which also has the ability to support processes of reasoning over it.

Keywords: *Learning Platforms, Ontology Driven Architecture, Tutoring Ssystems*

I. INTRODUCTION

The challenge of the Modern learning environments is exploited the strengths of the students, offering flexibility and openness to the access to resources. An open and flexible learning environment allows sharing knowledge and practices, in order to improve the learning process. In general, e-learning describes the utilization of Information and Communication Technologies (ICT), to support educational activities [4, 11]. But ICT can be used to catalyze innovations in teaching and learning processes. There are several domains where the ICT can be used to do new things, to enable transform teaching, learning and the curriculum [4, 11, 12, 17, 18]. One of these domains is to produce computing tools that are pedagogically and functionally relevant to the learning context. For this case have been studied the learning styles, based on the premise that different students learn in different ways. Some papers have proposed computing tool to provide recommendations about educational resources according to necessities of the

students [12]. Other domain more recent is based on Smart Classrooms, where the environment assists professors, with the integration of the ICT in the learning process [2]. Cloud computing is another domain which is been used in the domain of education. For example, Seattle is a free educational research platform that is community-driven, and supports a variety of pedagogical uses based on the cloud computing paradigm, among others [5].

Additionally, the "Age of Knowledge" is delineated by the continuous and dynamic advancement of technology and information [15], in which there is an immense knowledge available. Today, thanks to the Internet, the information and tools necessary for students to acquire knowledge are completely in its scope, in the most varied forms and perspectives. In the age of knowledge new skills are required, such as [1, 15]: Learn to Learn and Unlearn, Collaboration, Creative Thinking, Technological Culture, leadership development, career self-management, etc. Higher education faces the challenge to stop being a model of teacher-centered education to become a learner-centered model whose emphasis is on providing students with the tools and resources to take responsibility their own learning.

Moreover, there is a growing requirement of professionals trained in the areas of computing, telecommunications, information technology and related (statistics, etc.), with social sensibility. International organizations such as the IEEE and ACM define five profiles of professions covering such areas [7, 13]. As described in [1], in Venezuela different universities offer courses that cover some aspects of these areas, become hybrids of the profiles defined by such organizations.

From the above, the need arises to propose the creation of careers in Computer Science, inspired by the profiles defined by the IEEE/ACM and in the "knowledge era", focused on the needs in ICT of each country; based on the paradigm of learning "learning by doing", also with flexible mechanisms to constantly update the corpus of knowledge.

Thus, the Department of Computer Science, at the University of Los Andes has proposed a career in Computer and Informatics Engineering, based on an educational model, called "Mother Project", which considers the previous aspects. This career has defined a curriculum with

the 5 profiles defined by IEEE/ACM for careers in the computer field [7, 13]. The definition of the flexible curriculum consists in that the student can choose its modules to study, such that he autonomously defines his academic path. The curricular model allows several intermediate outputs (Technician, Engineer, etc.). The Mother Project is based on the concept of clouds. The Project has defined three clouds: the self-formation cloud which is composed of everything related to the student's education (curriculum, etc.); the learning paradigm cloud which is related to the paradigms, strategies, forms of assessment, and learning tools; and the knowledge sources cloud which is composed of all existing knowledge in the world, in all its forms, from all possible sources.

Currently, the project has not a technological platform to support it, so it is essential to build a system that, in addition to manage the students educational process (student registration, etc.), could consider services involved in the student training (adequate educational paradigm, learning objects and online courses that complement the educational process, etc.). In this paper is proposed a web platform to manage the different clouds, based on SOA. In particular, the platform is composed of web services, which offers the student the basic services such as registration, access and view curriculum; but also services tailored to the students. I.e., the system is able to examine the characteristics of the student during his training, and analyze his performance during the career, in order to provide educational services to each student, as tools, activities and evaluation forms suitable for him. This adaptive capacity is the main difference with respect to current educational platforms like Moodle.

II. THEORETICAL BASES

A. Learning environments

An educational platform is a tool, physical or virtual, or physical-virtual combination, which provides the ability to interact with one or more users for educational purposes. It is a tool that helps in the process of learning and teaching. This platform is classified according to distinct aspects:

Teaching Mode: it can be of two types [18]: in classroom, where the teaching-learning relationship is in the same place. The virtual does not require the physical presence of the people using the tool on the same place.

Adaptation: may be general tools that provide generic functionality for users; or customize, which are set according to individual needs of small groups [18].

Features of the Contents: these are subdivided in [18]:

- OpenCourseWare: It is a set of contents in education that can be used as a supplement in a particular course, or as a base of knowledge to communities.
- Learning Management Systems (LMS): set of software tools that provide an online space to facilitate learning and teaching.
- Content Management Systems: collection of procedures used to manage the activities and contents in a collaborative environment, in real time.

- Knowledge Management System: it is a system that is responsible for making operations for the management of knowledge database within an organization.

In an educational platform the students can communicate in 2 ways: asynchronously as blogs, wikis, email; and synchronously as chat, video conferencing, etc. Some educational platforms are [1, 3, 4, 5, 6, 11]: Moodle (Modular Object Oriented Learning Environment), Seattle, Aula CESGA (an e-Learning platform for training, teamwork and innovation experiences in education and research) and Chamilo (LMS for b-learning or e-learning).

B. Ontology Driven Architecture (ODA)

Models Driven Architecture (MDA) proposes the use of models to specify the business logic of an organization, regardless of the specific technology platforms where they are implemented. MDA adopts UML [5, 6] as the modeling language. The main idea using MDA is the separation of the system specification of the specific aspects of the implementation. MDA proposes three models, which are the results of the phases with the same name [10, 16, 19]:

- *Computing Independent Model (CIM):* This model is centered on the system domain as well as functional requirements, non-functional properties, business rules, goals, structure, and processing strategies that the system must satisfy.
- *Platform Independent Model (PIM):* This model defines the system specification. This model represents issues that will not change from one platform to another.
- *Platform Specific Model (PSM):* This model combines (PIM) with details and characteristics of the development platform. In this model are established all aspects for the implementation of the application.

Ontology-Driven Architecture (ODA) is a hybrid approach for the development and deployment of information systems, combining the Semantic Web technologies with development languages such as UML, where ontologies can be considered a special class of models with a formal semantics based on logic [16, 19]. This approach combines formal representation techniques designed for the Semantic Web, with commonly accepted software engineering practices. In general, ODA responds to the need to automate the processes of software engineering from a cognitive perspective, reasoning about required software components, inferring the processes of design and development, among other things. Specifically, we have proposed ontologies to describe the information of each phase [10, 11].

III. MOTHER PROJECT

The Department of Computer Science at the University of Los Andes has proposed an educational model, called "Mother Project", which aims to define a Career in Computer Engineering and Informatics, based on a curriculum with the 5 profiles defined by IEEE/ACM for careers in the computer

field, these being Computer Science, Software Engineering, Computer Engineering, Information Systems and Information Technology [1, 7, 14]. To do this, the curriculum is flexible, allows students the option to choose the modules to be studied, and allows intermediate outputs (Technician, Engineer, etc.).

The Mother Project proposes an educational model which exploits the new tools offered for Internet. The proposed educational model focuses on the paradigm of "learning by doing" [1]. This model is based on a metaphor of clouds, which has been explained in detail in [1, 9, 14]. In general, this metaphor introduces the idea of "clouds effect", which makes their internal dynamics to move with the wind (with the global and national events, industry, etc.), in order to allow the emergency of activities, to-do, etc., and also criss-cross, generating a powerful educational synergy.

Learning Paradigm Cloud

This cloud is related to the paradigms, strategies, forms of assessment and learning tools. Its aim is to provide the learning mechanisms necessary for the process of self-formation. It will guide the dynamics of self-training, establish ways of accrediting courses, collaborative work, among other things. The learning process provided to the students is adapted with this cloud permanently based on the characteristics of each student (learning profile of the student). Some qualities of this module are:

- It is inspired on the paradigm of "learning by doing", which seeking active participation of the students in a work, which can be artistic, technological, scientific, etc.
- All forms of learning which promote learning by doing (active learning, agile learning, blended learning, etc.) are possible to use.
- The collaborative work, sharing knowledge, multidisciplinary work, are issues that enrich the teaching process. Those aspects must be promoted by the different strategies, tools, etc.
- It requires many tools and applications from Internet to manage shared spaces and groups, to assign responsibilities, to monitor works/projects.

Knowledge Sources Cloud

This cloud is composed of all existing knowledge in the world, in all its forms, from all possible sources. Its purpose is to enable greater access to knowledge available worldwide. Learning objects, online courses, e-books, etc., become fundamental sources of knowledge, and are linked by the modules in the self-formation cloud. The methodologies, tools and techniques of this cloud must allow an access critical to that knowledge provide by the other clouds [1, 7, 14]. So, we are not talking about a passive, neutral, access to knowledge, but critical, seen from the process of self-formation according to the curriculum dynamics established in the Self-formation cloud and the learning process dictated by the *Learning Paradigm Cloud*.

Self-formation Cloud

This cloud is composed of everything related to the student's education. The student learning consists of building itself the curriculum, which is composed of modules which are self-contained. In the curriculum are given the option to various degrees, these depend on the number of credits reached and profile chosen by the student. The possible profiles for the students are inspired in the curriculum defined by the IEEE/ACM. Paths for these profiles are proposed initially, but as the student is autonomous, guide his own process of self-education so that he chooses his profile. In this way, the student builds his own net curricular.

IV. SYSTEM ARCHITECTURE

The design of the web platform is based on SOA and on the educational model called *Mother Project*. The system functionality is described in Figure 1, which is composed of three layers, each one manages one of the clouds of the Mother project. The *first layer* manages everything regarding the student, teacher and curriculum. This layer has the different services they need, both the student and the teacher, to manage the process of self-education, such as student registration services, queries to the curriculum, etc. The *second layer* manages the search of virtual objects, both learning objects and digital contents, and offering the student the proper learning resources to their needs, according to their educational profile and position in the curriculum. The *last layer* manages the learning paradigms, in order to specify the tools, types of evaluations and educational activities appropriate for the student's learning style. The implementation of each layer is made as web services. Each layer has its own ontologies, whose instances represent the stored information. That is called in Figure 1 Extended Data Base, which also has the ability to support processes of reasoning.

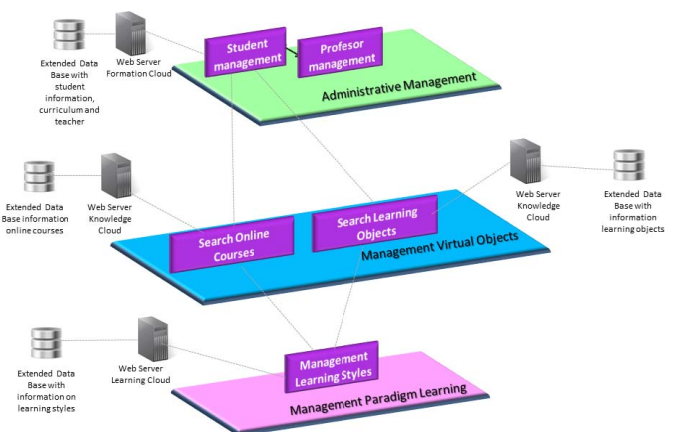


Fig. 1. General Architecture of the Web Platform

An example of utilization of our architecture is defined in the Figure 2, in the case of a student taking a course (module) of the curriculum. He begins with the request by the self-formation cloud (a student already registered) to the cloud of knowledge of a list of learning objects and digital contents for a particular topic for a given module and a student learning profile (step 1). That list should be consistent with the description of the student; for this, the cloud of knowledge makes a request to the learning cloud, to know the tools, activities and evaluation mechanisms to be used by the profile of the student (step 2). That information is sent by the Learning Cloud to the self-formation cloud (step 3). Once with this information, the knowledge cloud searches the appropriate virtual objects, and sends to the self-formation cloud a list ordered by priority, of different learning objects and digital contents associated with that particular student (step 4). Every cloud has a web server with the set of services to be provided. Each server connects to information that has been stored in the extended databases (or ontologies), to respond to requests from the system.

V. SYSTEM DESIGN (PIM AND CIM)

A. Self-formation Subsystem

We begin by defining the non-functional and functional requirements of the platform.

Specification of the CIM.

Functional requirements: The functional requirements required by the system are for two actors: the students and teachers. In the case of students:

- Register in the System: This includes storing the student data, the learning profile, etc. In addition, the student may also enroll modules to study at a given quarter.
- Perform Queries: Queries that can make the student (characteristics of its modules, learning objects and online courses associated with these modules and profile, etc.), characteristic of his learning profile (tools, activities and evaluation techniques appropriate), etc.

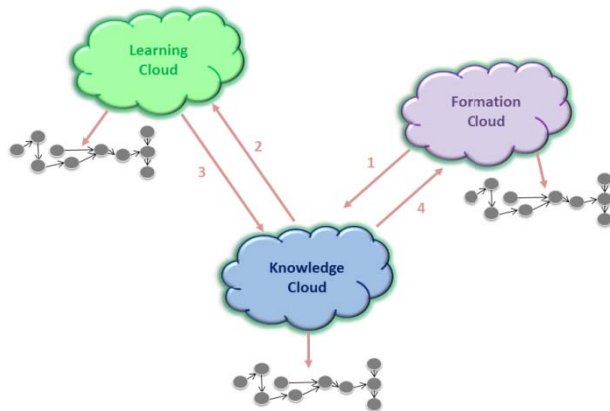


Fig. 2. Invocation process between the clouds.

For the Professors:

- Register in the System: This includes data of the teacher and modules that dictates.
- Store Notes: Allows the teacher, after completion of a course, assigning notes to the students.
- Management of Virtual Objects: Allows the teacher, once evaluated a group of virtual objects, certifying. This certification is stored in a database of certified virtual objects, for future use. This database is used by the cloud of knowledge for a faster search of virtual objects.

The diagram of the general activities of this layer is shown in Figure 3. Once a user, either teacher or student, joins the system, the web platform will allow a number of activities. For inquiries is necessary to use the knowledge base (ontology) to reason about the information, for example, module belongs to a subject, subjects belonging to a profile, modules seen by a student, etc.

Non-functional requirements: Among the non-functional requirements that the system must meet, is scalability (the educational platform should be able to allow further development of new functionalities), and quality attributes like security, interoperability, and friendly interface.

In Figure 4 is shown the ontology of the CIM layer. It summarizes the different concepts linked to the web platform and its requirements.

Specification of the PIM.

Each of the functions of the system is developed using web services. Some web services of this layer are:

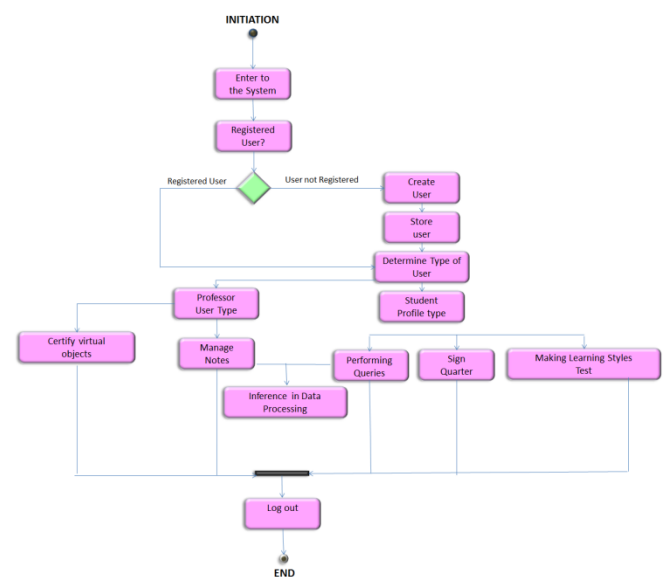


Fig. 3. Activities Diagram of the Self-formation Subsystem

- Query: it is responsible for receiving the name of a module and the ontology queries: code, themes, profile, learning objects, digital contents, among others.
- Store student information: it is responsible for extracting the information provided by the students through forms, and storing it in an ontology. Among the stored information of a student are his data, studied modules, and learning style.
- Store information of a teacher: Records in the ontology data of the teachers, the note to the students, and the virtual objects certified.

The PIM ontology is shown in Figure 5. It describes the web services, and with the class diagram of a web service (see [4, 8]) is obtained a complete description of the system.

B. Knowledge Sources Subsystem

This layer recommends general digital contents (guides, courses, images, videos and others) and learning objects for the self-formation cloud.

Specification of the CIM.

Functional Requirements: Some of them are:

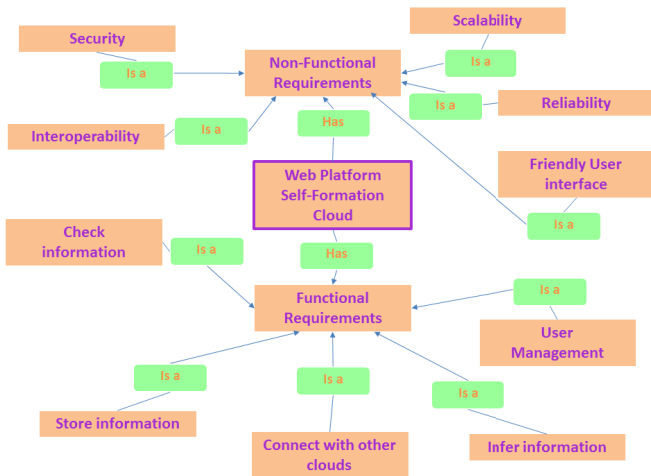


Fig. 4. Ontology of the CIM Layer of the Self-formation Subsystem

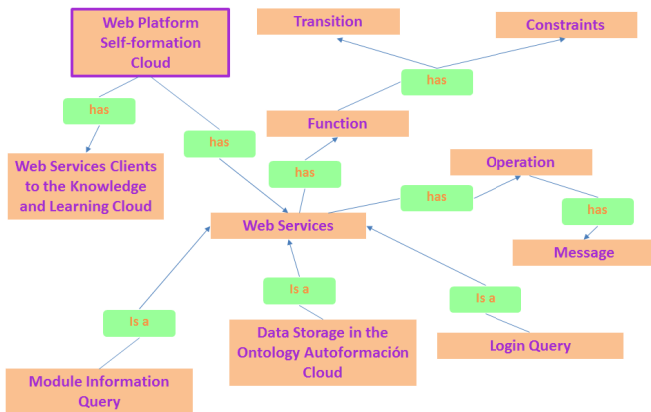


Fig. 5. Ontology of the PIM Layer of the Self-formation Subsystem

- Query: It allows at the student and the teacher to consult the information of the digitals contents, depending on the necessity that they have, for example, title, description, tools, activities, and others. Likewise, it too must permit to carry out inferences about the digitals contents that match with a learning style and a specific topic.
- Record: This functionality allows add digital contents.

Non-functional Requirements: the non-functional requirements that the subsystem must fulfill are the same of the previous subsystem. In the Figure 6 we can observe the conceptual ontology of this subsystem.

For other side, the digital contents are described using the standard of the W3C Ontology for media resources 1.0, which is shown in Figure 7.

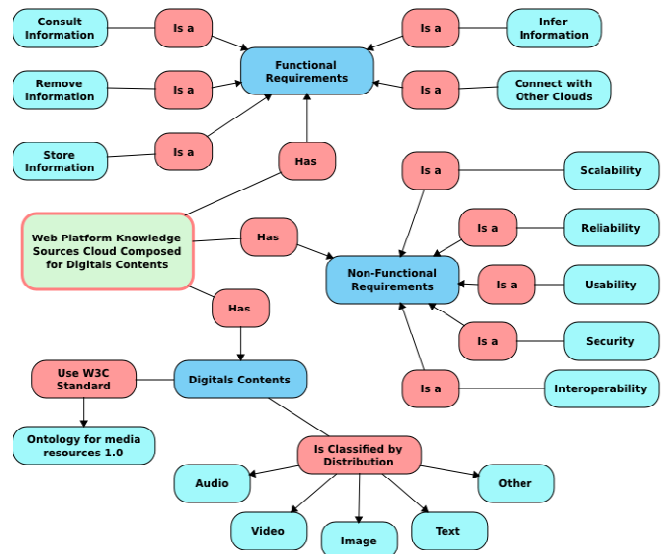


Fig. 6. Ontology of the CIM Layer of the Knowledge Sources Subsystem

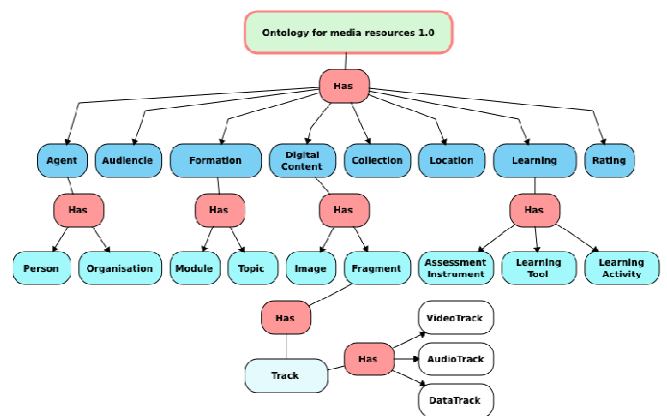


Fig. 7. Ontology for media resources 1.0

Specification of the PIM

The ontology of this layer is shown in Figure 8, where we can observe the functionalities of the subsystem, described how web services. With the general diagram of classes of this subsystem (see [9, 14]) is obtained a complete design of the system.

C. Learning Paradigms Subsystem

Specification of the CIM.

Functional Requirements: This subsystem defines the learning paradigms, learning activities, and learning tools, according to Felder-Silverman learning model (see [8, 9] for more details about that). In specific:

- Check Learning Paradigm, activities and tools. Allows know the paradigm for a student.
- Infer learning activities. It infers the learning activities to be performed for a student, according to his learning style.

In Figure 9 is shown the ontology of the CIM layer.

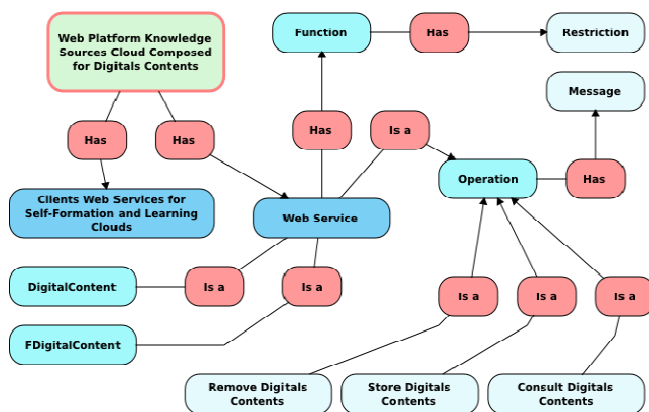


Fig. 8. Ontology of the PIM Layer of the Knowledge Sources Subsystem

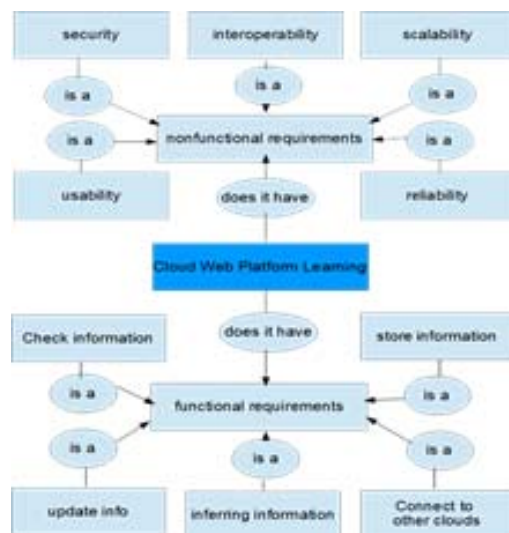


Fig. 9. Ontology of the CIM Layer of the Learning Paradigms Cloud.

Specification of the PIM

Remember, each of the functions of the system is developed based on the Web Services paradigm. With the diagram of classes of this subsystem is obtained a complete design of the system. This subsystem consists of 6 main classes. In the class FelderSilverman is used the FACT ++ reasoner to infer the activities, tools, instruments, paradigms and learning profiles. The BD class allows connecting to the database used by this layer, and performs SQL queries. The rest of classes are defined in [9, 14]. The domain ontology for this layer includes concepts as learning paradigms, learning tools, learning activities, etc.

The ontology of the PIM layer is shown in Figure 10, but now detailing some aspects of that domain ontology of the cloud must solve: determine the profile of student learning, establish parameters for digital/learning objects content search (tools, activities, etc.), among others.

VI. SYSTEM IMPLEMENTATION (PSM)

The system implementation is described in Figure 11, a layer called server contains all web services provide by each cloud, these web services have been developed with JAX-WS. Each service needs to connect to an extended database (ontology) that manages information of each cloud. This connection between web services in Java and ontologies in protégé is through the OWL API, it manages information using the Fact++ reasoner for OWL language.

The client tier hosts all references to Web services of educational platform, allowing use information and knowledge stored, plus it provides the user interface of the system. The communication between client and server layers is through a bus service.

In general, the components of the system are:

- Client browser, this client uses the HTTP protocol to connect to the application server, which contains the complete web application with communication to the knowledge base.



Fig. 10. Ontology of the PIM Layer of the Learning Paradigms Cloud.

VII. EXPERIMENTS

- Web Services (WS), which are classified in web services for the student and the teacher; web services for managing virtual objects or digital contents, and web services for determining the learning paradigm.
- Application server (SWS): contains web applications that define cloud services, communicating via the SOAP protocol.
- Server with the Knowledge Base: groups all the ontologies used by web services hosted on the application server.

The Figure 12 shows the ontology of this layer, where it denotes the different technologies utilized to build the platform: Apache Tomcat, Jax-WS, OWL-API, Protege, FACT ++ and PostgreSQL.

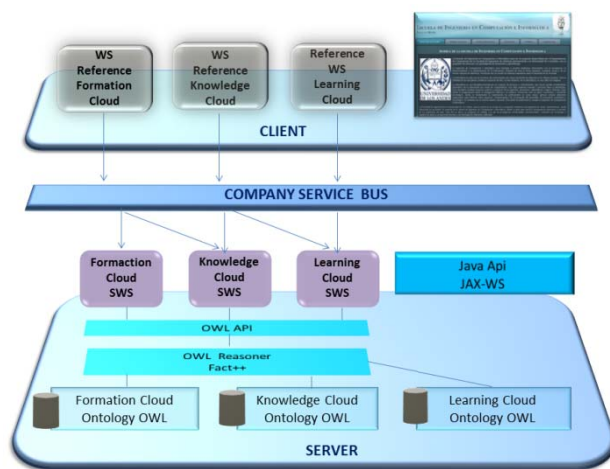


Fig. 11. Implemented Architecture of the Web Platform

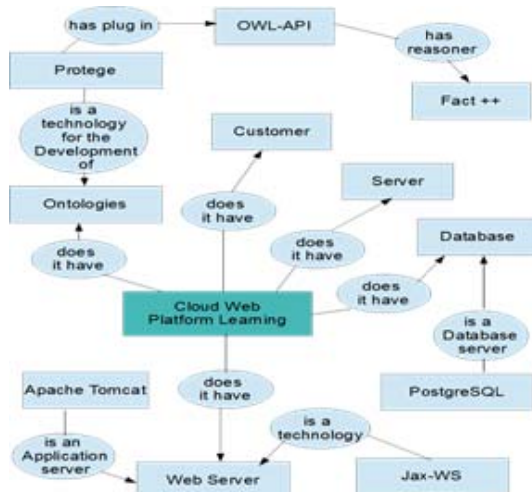


Fig. 12. Ontology of PSM layer of the Web Platform

It is defined for the web platform prototype an experimental protocol that helps verify system behavior. The overall objective is to verify proper operation of the web platform. Various tests are proposed, which are of two types: performance testing and integration.

A. Performance testing

In general, these tests seek to revise the correct for each of the features offered by the system. The first one is to know if the system provides the correct learning style of a student. For that we need to analyze the responses obtained by the student, and calculate a number that will be sent to the cloud of learning paradigms, which represents the style of the student. The form of learning styles is filled out with student data, who completes a test consisting of 44 questions, as shown in Figure 13.

We define an expected result, in this case [4534]. The Figure 14 shows that the test obtained on the platform after the student answers 44 questions, corresponds to that described above. Thus, the proper functioning of the test is checked for the learning styles.

Now we will verify the correct behavior to infer the learning paradigm. To perform the test, we assume the learning style 2121. The learning cloud gives like a learning paradigm for this style: ParadigmB_Learning (see Figure 15).

If we go to Felder Silverman model, theoretically the paradigm B_Learning is ideal for an active, sensory student that learns sequentially and uses visual aids [8, 9]. If we analyze the value 2121, it corresponds to a value that qualifies an active medium, a high sense, a visual medium and high sequential. Thus, the deduction of our ontology that corresponds to the paradigm B_Learning 2121 is correct.

Fig. 13. Interface of Learning Styles

Fig. 14. Test results on the web platform.

B. Integration testing

Now we test how the three clouds work together. The system architecture offers several features, which are distributed in different clouds, which technically represent different web services. We need to verify whether the connection between them work correctly. In particular, the self-formation cloud initially determines the value of the test according to Felder Silverman model. Once the student answer all questions, the result of the questions is shown (the four digits describing the student's learning style, see Figure 15).

After calculating the value of the test, we proceed to determine the appropriate learning resource for that student's learning style (in this case 4534, which corresponds to the paradigm ActiveParadigm). To do this, all four digits are used by the self-formation cloud when invokes the knowledge sources, and those same digits are used by the cloud of knowledge when invoked learning cloud. With that information, knowledge cloud searches learning objects or virtual contents that meets the specifications indicated in the activities (workshops, exhibitions, etc.), tools (video, diagrams, etc.), etc. of that paradigm (see Figure 16).

Figure 16 shows the digital contents proposed by the platform for a student whose educational profile corresponds to 4534, for the theme "Algorithms and Problem Solving" of the course "Fundamentals of Programming 1". According to ActiveParadigm paradigm, these digital contents or learning objects have the following characteristics: based on problems, reading, problem solving; tools can be tutorials, blog, email; and test tools can be based on issues, like questions and answers, individual test. The client Web application of the self-formation cloud references to the web service of the knowledge cloud that performs semantic search of learning objects hosted on a remote server. This service is invoked from the JSP page using scriptlets.

VIII. CONCLUSIONS

This paper proposes a Web platform for "Mother Project" based on the paradigm ODA. A preliminary comment is that there is not methodology for ODA paradigm, so a methodology that combines various methodologies such as MDA and Methontology, was used. CIM, PIM and PSM layers were specified, by merging various UML diagrams with specific ontologies to define each of the layers.

The system architecture is based on the paradigm of SOA. This model shows the features of the 3 cloud systems (self-formation, Knowledge, Learning Paradigms) and how they communicate with each other, achieving an integrated system. The different services were implemented using web services, which ensure great flexibility in system maintenance, enable massive reusability and reduce the level of coupling system, making it easier to update the system functionality in the future. All this facilitates scalability.



Fig. 15. Query of the 2121 style to the Learning cloud



Fig. 16. Answer given by the cloud of knowledge

In turn, the use of ontologies and knowledge bases allow analyzing the information stored by inference processes. This allows in development time the domain understanding, the standardization and the reuse of knowledge; and at runtime, the integration of data sources. That enables the interoperability system.

The learning process is based on "learning by doing", using a learner-centered model. The platform finds learning resources on its registers or Internet, based on the student style and current level of its training. The platform can consider these aspects, in order to provide an excellent learning environment adapted to each student.

As future work we propose to add more security to the web platform, which must consist of a set of preventive and reactive measures that allow safeguard and protect the information handled by the system, seeking to maintain the confidentiality of information, together with the availability and integrity of the same. Other further works need to add the feature of autonomy to the platform, i.e. make the platform has the ability to be reconfigured over time, with features such analyzes the curriculum and update it by learning obtained from the behavior of student (recalculate the learning style of the student based on the academic performance) or learning analytics, among others.

ACKNOWLEDGMENT

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Experience of Experimental Teaching and Management Based on Cloud Computing

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Abstract—Many laboratories were set up in Chinese higher education institutions in recent years. Some of them in the same university are equipped with similar rigs, which may lead to waste of money and human power in their setup and maintenance, and inconvenience and inefficiency for both faculties and students. An experimental teaching and management system, Open Laboratory Access (OLA), based on cloud computing technology is presented to enable full sharing and deep integration of experimental resources among laboratories and provide improved user experience. OLA provides a comprehensive and multi-angle virtual experimental teaching and management functions, including online experiment schedule and laboratory rig reservation, intelligent experiment guidance, teaching effectiveness evaluation, automatical experiment results statistics, etc. Thin-clients are adopted to reduce cost and ensure consistent user experience. After a one-year trial, the results of a user experience survey indicate that OLA provides good experience of experiment for both faculties and students.

Keywords—cloud computing; thin-client; virtual laboratory

I. INTRODUCTION

Laboratory hands-on experiment is a crucial practical component in many courses for college students to improve their practical ability. Since laboratory rig resource is often scarce, much attention have been paid and a lot of efforts made to have it available online for users (students, faculties, administrators, etc.) to book, collect data from or manage.

Yet we have another problem different from that. In recent years, the importance of experimental teaching is acknowledged by more and more universities and colleges in China. Many laboratories with similar rigs were set up simultaneously and usually managed in a separated way. They are often located in different rooms or buildings and managed without sufficient resource sharing and integration. Although computing power can indeed be shared to some extent among different laboratories by means of file sharing, remote login, etc., performance and user experience, especially those of multimedia, are still poor as a whole due to incomplete data, non-real-time delivery and inconsistent user interfaces. When confronted with virus infection, system or application software upgrading, administrators usually spend a lot of time and energy in recovering the experimental teaching environment.

Moreover, current laboratory management systems for those laboratories are usually intranet-based, thus cannot provide all-time service for users. Support staff of each laboratory have to print blank calendar at beginning of every semester for teaching faculties to fill in to determine experiment schedule, and then teaching faculties need to inform students. That leads to waste of time for both support staff and teaching faculties, and also non-real-time information for students.

A booming trend of making laboratories more open and easier to access has been arising since the beginning of the last decade. A. Gallardo, et al. present the conceptual model and technical design of an online rig booking system for scarce rig resources [1]. Mateos, et al. discuss several access solutions for online virtual laboratory and propose a system design based on SCORM [2] standard [3]. But both of them are not implemented, so the effectiveness is difficult to evaluate. There are some Learning Management System (LMS) frameworks for researchers to work with like [4][5][6], and plenty of systems has been done as modules or plug-ins based on them in the past over one decade. Those frameworks can serve as basic LMSs but difficult to be seamlessly connected to our existing laboratory environment. L. Xu, et al. propose the design and implementation of a virtual laboratory for network security education [7]. Y. Tateiwa, et al. present a virtual system for network administrator education [8]. Those special-purpose systems can be a good fit for particular courses or training objects, but still not suitable for our general-purpose situation.

An experimental teaching and management system, Open Laboratory Access (OLA), based on cloud computing is designed and implemented. Through OLA, faculties can plan experiments and issue the schedule; students are then allowed to book needed experimental rigs online and enter the laboratory afterwards on schedule, powering on the reserved rigs by authentication with their student ID cards to start experiment. After the experiment, faculties can manage the evaluation results and get the statistical data entirely online. Thin-clients are adopted as terminals for software based hands-on experiments instead of PC to reduce the cost of laboratory setup and maintenance, and provide consistent user experience.

II. SYSTEM ARCHITECTURE

The architecture of OLA is shown in Fig. 1. Master Server works as the control and information center of Server Cloud. A

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course management system resides in it to provide course related services, e.g., rig booking, courseware management, etc., and control Slave Servers to fulfill tasks. Video files are also stored in it and sent to Slave Servers for caching when requested. Supervised by Master Server, each Slave Server, providing virtual desk service for thin-clients, serves for one or two physical laboratories. Thin-client is used instead of full-function PC traditionally used in laboratories since it is cheap, virus immune and system update free [9].

For every thin-client or experimental rig, a Wi-Fi module is developed to work as Power Controller, as shown in Fig. 1. When a student swipes his in-university ID card through Card Reader attached to Control Workstation in physical laboratory, a specific signal is sent through Wi-Fi channel to it and a relay switch in it applies power to the reserved thin-client or experimental rig. The circuit board of Power Controller is shown in Fig. 2.

A. Course Management

The course management system in Master Server provides a comprehensive support for virtual experimental teaching functions including experimental teaching schedule, courseware management, portals for students' booking, typical experiment database maintenance, experiment intelligent guidance, teaching effectiveness evaluation, experimental result statistics and other laboratory management related auxiliary functions. Function modules of the course management system are shown in Fig. 3. Workflows of student rig booking and action in laboratory are shown respectively in Fig. 4 and Fig. 5.

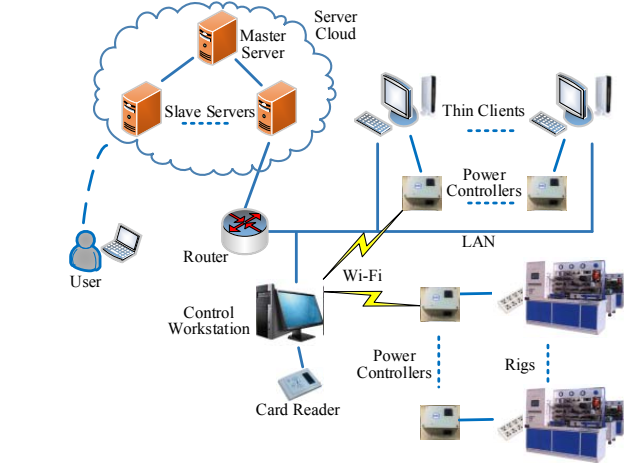


Fig. 1. System Architecture.



Fig. 2. Power Controller.

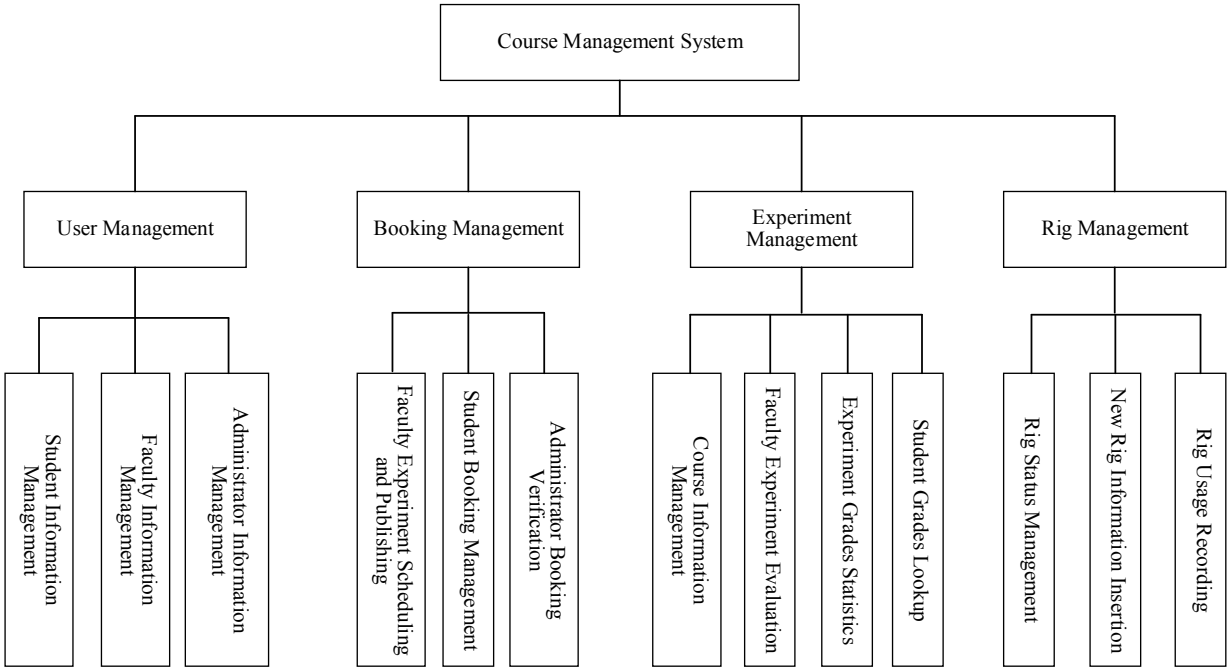


Fig. 3. Course Management System Modules.

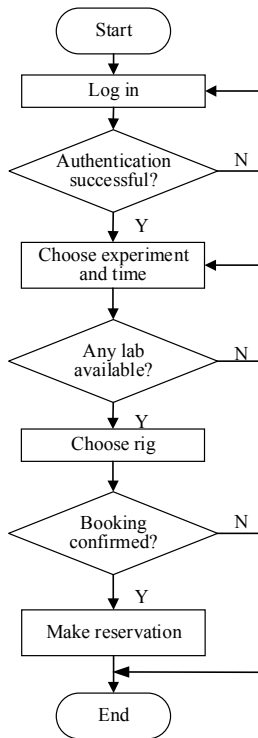


Fig. 4. Student Rig Booking Workflow.

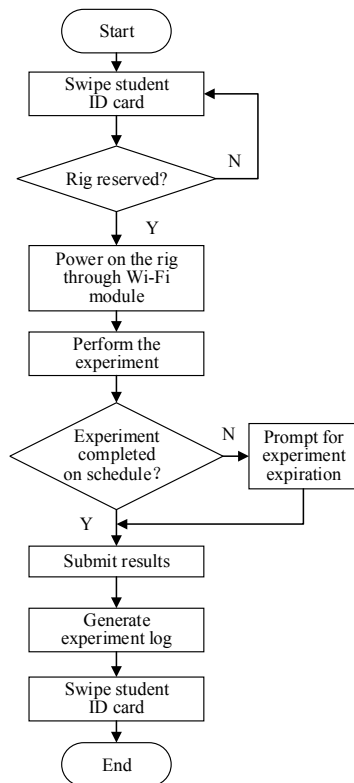


Fig. 5. Student in-lab action workflow.

B. Data Transfer between Slave Server and Thin-clients

The data communication model of *Server/Thin-clients* is adopted for students to perform software-based experiments. Each server (Slave Server in Server Cloud shown in Fig. 1) can generate different pools of virtual desks based on different templates consisting of different amount of computing resources, e.g., CPU, memory, disk, etc., and different kinds of course content [10], as shown in Fig. 6. Each virtual desk pool can be assigned to serve a course like Software Engineering, Java Programming, etc.

A thin-client is a computer that depends heavily on its server to fulfill its computational roles. Almost all data-processing work are done on its server, while thin-client itself is just responsible for displaying graphical user interface to user and pass user's input to its server. When a thin-client is powered on by its user, it directly connect to a Slave Server, and after logging in, a virtual desktop environment will be assigned depending on the user's role to facilitate the hands-on experiments. Using thin-client rather than PC can significantly save the cost of setup and maintenance of the laboratory, e.g., a thin-client of Chinese local brand may cost only 400 RMB (around 65 dollars) or less which is much cheaper than a PC. Traditional thin-client system has some defects, such as over-reliance on computing power of servers, high requirements of network bandwidth and poor performance for multimedia application [11]. To ensure multimedia performance, we chose four thin-client products including NComputing L300 [12] and three products of Chinese local brands, Share FL300 [13], LYBOX C200 [14] and Jieyun J60 [15], to conduct a comparative performance test on data transfer between server and thin-clients. The server is equipped with a CPU of Intel i7 (4770), 8G memory and the OS of Windows Server 2012. Each round of test was conducted in a Local Area Network (LAN) with a Gigabit switch connecting the server and 5 thin-clients of the same brand. After startup, all the 5 thin-clients request in parallel the same video clip with a resolution of 1920*1080. Thin-clients' startup time and the server's consumption increase of CPU and memory are recorded, and client-side video quality are evaluated, as shown in Table I.

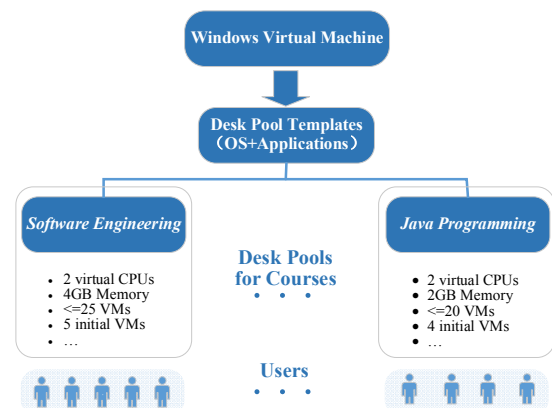


Fig. 6. Pools of Virtual Desks.

TABLE I. PERFORMANCE TEST RESULTS OF THIN-CLIENT PRODUCTS

Features / Performance	NComputing L300	Share FL300	LYBOX C200	Jieyun J60
Virtualization Manager	vSpace	None	LYVM	Jieyun Desktop
Thin-client Startup Time (Seconds)	37.11	28.35	27.52	28.64
Server CPU Consumption Increase	15%	<5%	30%	<5%
Server Memory Consumption Increase	30%	<5%	<5%	<5%
Client-side Video Quality ^a	4	4	5	5

^a Average scores of 10 users in Likert Scale [16]

Results in Table I indicate that Share FL300 and Jieyun J60 are better in multimedia performance. But the former does not have a server-side virtualization managing software, so the latter was adopted.

III. USER EXPERIENCE OF OLA

OLA has been deployed in three laboratories located in two buildings in Dalian Maritime University for more than one year, consisting of 1 master server, 2 slave servers, 50 thin-clients and 24 electronic experiment workbenches. More than 15 faculties and 300 students have taken advantage of it in 5 different courses. To validate the effectiveness and user experience of OLA, a questionnaire survey was conducted among them. There are two versions of questionnaire, one for faculties and the other for students. Both of them consist of three parts: general attitude to virtual laboratory, course management system user experience and in-lab user experience. Altogether, the faculty version contains 18 statements and the student version 17. We recruited 10 faculties and 30 students as participants with gender ratio of 1:1 for each. Average scores (1-5 points in Likert Scale [16]) on some of the overall evaluation statements from faculties and students are shown respectively in Table II and Table III.

TABLE II. AVERAGE SCORES OF FACULTY EXPERIENCE ON OLA

Statements for Faculties	Scores
Virtual laboratory does good to experimental teaching.	4.5
Experiment Scheduling and Publishing is useful for me.	4.4
Experiment Scheduling and Publishing has most features I need.	4.1
Experiment Scheduling and Publishing is easy to use.	4.2
Thin-clients are easy to use.	4.2
Quality of video played by thin-clients is high.	4.0

TABLE III. AVERAGE SCORES OF STUDENTS EXPERIENCE ON OLA

Statements for Students	Scores
Virtual laboratory does good to experimental learning.	4.4
Online booking is useful for me.	4.0
The booking website has most features I need.	4.2
The booking website is easy to use.	3.9
Power control by swiping student ID card is convenient for me.	4.5
Thin-clients are easy to use.	4.1
Quality of video played by thin-clients is high.	4.0

Results in Table II and Table III indicate that both faculties and students show positive attitude to virtual laboratory and have good experience on OLA usage.

IV. CONCLUSIONS AND FUTURE WORK

Focusing on the current status of experimental teaching management of Chinese universities, this paper presents the design and implementation of an experimental teaching and management system based on cloud computing technology. The problems, such as limited time and room for hands-on experiments, shortage of human power for managing and maintaining, application updating and information security threat, have been effectively solved. The course management system provides open, multi-dimensional and interactive teaching environment to improve the utilization of laboratory and experimental rigs, the efficiency of laboratory management and students' ability of practice, innovation and self-learning.

In the future, we plan to do the following work to improve OLA and serve for pedagogical goals.

- Recruit a higher number of students to answer the questionnaire in order to obtain more consistent results.
- Deploy OLA in a wider range and conduct corresponding performance test to technically prove its performance further.
- Introduce multicast and flow label technology for multimedia application to ensure performance of larger-scale deployment.
- Deploy high availability and redundancy to enable a more reliable platform.
- Evaluate the impact of the virtual laboratory in students' performance (grades, knowledge acquisition, etc.).
- Design pedagogical models suitable for different kinds of curricula on a basis of OLA adoption to achieve better teaching and learning results.

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Teaching Research and Practice of Blended Learning Model Based on Computational Thinking

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Abstract—with the wide use of computers, how to make students understand the special way of thinking of computer science and find the appropriate methods to solve problems in their own fields like computer scientists are the challenges for educators. This paper proposed a computational thinking model based on blended learning *MCTBBL* and a descending dimension method for problem-space transformation. The *MCTBBL* model analyzes and researches the application of computational thinking in computer science by the organic combination of computational thinking and blended learning in a life-cycle perspective. On one hand, the model can summarize the core concepts and important principles in computer science and extract the typical thoughts and general methods of solving problems; on the other hand, the model can implement the teaching and learning of computational thinking by means of blended learning. Based on the model, the teachers can teach the problem-solving process by using computer more intuitively and clearly and the students can understand the application of computer knowledge more easily and simply. The *MCTBBL* prolongs the study life cycle which takes preview as beginning, teacher-student discussion as body and practical application as core to ensure integrity, endurance and consistency of teaching.

Keywords—Computational Thinking; Blended learning; Descending dimension; Abstract; Automation

I. INTRODUCTION TO COMPUTATIONAL THINKING

With the promotion of information technology, computers are everywhere and can be used to solve any problem. Computers not only change the way we live, learn and work, but also affect the way we think and the education patterns we use. Computers have strong ability to process information which greatly expands the scope of science to understand the complex world and improves the ability to solve the real problems. Therefore, the traditional computer education - “teach knowledge, learn tools, master skills” cannot meet the demand for training compound talents in modern society. [1] The great challenges of education are explained as follows: how to make students understand the particular thinking pattern of computer and how to make them apply computer knowledge to solve the problems in their own fields like computer scientists; how to make teachers clearly express human being’s thinking process of solving problems with the aid of computers and how to make them convert the teaching principle from explaining knowledge to teaching thinking.

Computational Thinking (CT) was first put forward by Jeannette M. Wing, a professor of Carnegie Mellon. She thought CT is a series of thinking activities to solve problems, design systems and understand human behaviors by applying

the basic concepts of computer science, which means machine can be used to do some intellectual activities instead of human being. CT is a natural product of the development of computer science and its essences are abstraction and automation. [2] CT contains three core elements: thinking consciousness, computational methods and computing tools. Abstract is a process of transforming the characteristics, states and inherent laws of thing into a symbolic representation through the methods of simplification, transition, recursion, etc. Automation indicates it can take the advantages of computers to solve problems to make up human being’s weakness, e.g. slow calculation speed, low calculation accuracy. [3,4] Therefore, CT is a man-machine thinking mode which emphasizes the formalization, programming and mechanization of human’s thinking and it drives the development of mechanization of thinking. The essences of CT not only directly reflect its two stages to solve problems, but also imply the relationships between the core elements: first, people abstract a practical problem in the real world to a corresponding algorithmic model in the computer world with a special calculation method through conscious thinking; second, people convert the algorithmic model to a symbolic description by a kind of programming language. CT highly summarize the computer’s problem-solving process: using computer to simulate human’s thinking. But this kind of simulation is indirect, constrained and approximate. Because the simplification of the algorithmic model when abstracting the real system, the constraint of the application program when converting the algorithmic model and the error of the result when executing the application program will all affect the quality of solution. The significance of CT is to make people recognize the differences between the practical problem in the real world and the ideal model in the computer world and distinguish what can be solved by computer’s calculation and what must be analyzed through human’s thinking. [5-7] People can obtain a more accurate solution by using computer more efficiently and more easily and can deeply understand the methods and problem-solving process of computer after some specific thinking training. CT can reduce the barriers to human-computer collaboration and make them exert their respective advantages as much as possible. Therefore, the core of CT is to make thinking have the features of computation. But the thinking and computation are limited by computer science, which means the implementation of thinking consciousness is the process of solving problem guided by the laws of computer science and the application of computation methods is the process of writing programs supported by the knowledge of computer science.

But thinking is an innate ability of human and how to clearly express the way of thinking which is understood by students' apperceiving, we need to find an appropriate teaching method. This paper proposed a **computational thinking model based on blended learning** M_{CTBBL} and a **descending dimension method for problem-space transformation** and described the whole teaching and learning process in a modeling way and introduced the application of computational thinking methods in a formal way. This model can make teachers teach *CT* methods more clearly and make students learn *CT* applications more easily.

The rest of the paper is organized as follows. In Section II, we introduced related work of computational thinking and blended learning. Section III analyzed the relationship between computational thinking and blended learning. IV described the M_{CTBBL} model and the descending dimension method. We concluded in section V.

II. REALATED WORK

Computational thinking originated from America. In June 2005, PITAC (President's Information Technology Advisory Committee) submitted a report "*Computational Science: Ensuring America's Competitiveness*" to American President. In this report, they said "The most scientifically important and economically promising research frontiers in the 21st century will be conquered by those most skilled with advanced computing technologies and computational science applications" and "computational science advances all of science and engineering, because all disciplines benefit from high-resolution model predictions, theoretical validations, and experimental data analysis". [8] In March, 2006, Jeannette M. Wing, then the president's department of computer science, Carnegie Mellon University, published a paper in a leading computer journal and first put forward Computational Thinking. Professor Wing. described computer science from the view of thinking and explored the value of computer learning. [1] In the same year, NSF (National Science Foundation) put forward a national plan which contains four projects to develop the students' computational thinking at various age levels. The projects are BPC (Broadening Participation in Computing), CPATH (CISE Pathways to Revitalized undergraduate Computing Educating), CDI (Cyber-Enabled Discovery and Innovation), CE21 (Computing Education for 21st Century).[9]

Since 2007, computational thinking has been widely concerned and developed quickly. In 2007, the CPATH was actually implemented to integrate computational thinking with undergraduate education. [10] In 2008, the Computer Science Teachers Association (CSTA) published a report (Computational Thinking: A problem solving tool for every classroom) supported by Microsoft, which summarized what is computational thinking.[11] In Jan, 2008, professor Wing. made a study of computability and proposed five hierarchical problems: $P=NP$? What can be calculated? What is intelligence? What is information? How to establish a complex system easily? And she discussed them in details. [12] In the same year in July, professor Wing. proposed that computational thinking will affect each filed and each person. And this idea presents a number of new challenges to education. [13] In 2012, with the support of NSF, Carnegie Mellon University constructed an

advanced course which included basic knowledge of computer science and computational thinking. [14]

Computational thinking mainly solves the problems from theory aspect, e.g. the reform of teaching, the integration of computer science and other subjects. And with the rapid development of network multimedia technology, blended learning has emerged. The blended learning provides an effective method for the computational thinking's application in teaching and makes it possible to teach and learn thinking. In 2002, Delaney and Leonard, at the University of British Columbia, said, putting network learning into classroom teaching can not only make students acquire more knowledge, but also have more interaction between teachers and students, which was published in a report. [15] And many educators give different definitions for blended learning according to their own understanding. Curtis J. Bonk described blended learning in a simplest way. He thought it is a combination of face-to-face instruction with online learning. [16] Michael E.W. regarded blending as a combination of E-learning and classroom teaching. [17] Anthony elaborated blended learning in two aspects: in broad sense, blended learning means the combination of the traditional face-to-face teaching and various technologies or media; in narrow sense, it means the combination of traditional teaching method and network teaching mode. [18] Margaret Driscoll thought blended learning can be implemented through combing various elements: the combination of teaching methods and techniques, the combination of teaching tasks and techniques. [19] Kekang He, a Chinese educator, gave a comprehensive definition: blended learning is the combination of the advantages of E-learning and the advantages of traditional learning mode, which makes teachers play a leading role in guiding, inspiring and supervising teaching and makes learners play a principal role in learning. [20]

III. RELATIONSHIP BETWEEN COMPUTATIONAL THINKING AND BLENDED LEARNING

Thinking is a human specific mental activity which indicates human cognitive process of analyzation, synthesization, judgment and reasoning based on appearances and conceptions. *CT* is a series of thinking activities of human being who apply the methods and theories of computer science to simplify, insert, transform and simulate problems. It is a process of internalizing the computer knowledge into the cognitive ability. But thinking is invisible, subjective and independent. We need to find an appropriate carrier to represent it visually and systematically. Through a lot of investigation and analysis, blended learning is supposed to fit the characteristics of *CT* perfectly and it provides an effective method both for the teachers who teach the methods of *CT* and for the students who learn the applications of *CT*. Blended learning is the effective combination of learning styles, learning theories, leaning contents, leaning strategies, leaning medias, leaning resources, leaning activities and leaning environments. The main aspects are explained as follows: (1) the combination of teachers' dominant role in teaching and students' principal role in learning; (2) the combination of classroom teaching and online learning; (3) the combination of the traditional teaching resources (teaching material, courseware, audio-video file) and the digital media resources (virtual classroom, teaching

software, course platform); (4) the combination of studying objective knowledge and constructing subjective cognition; (5) the combination of the planned study based on the teaching schedule and the unplanned study according to the learning situation; (6) the combination of teaching model (situational teaching, online teaching) and the learning model (independent learning, collaborative learning); (7) the combination of learning theories (cognitivism, constructivism, humanism). The purpose of blended learning is to achieve the best result through reasonable combination, proper blending and optimized integration. In a word, it provides appropriate methods to appropriate persons in appropriate ways through appropriate mediums.

A. CT tasks students as the center of learning and teachers as the guiding of teaching:

The teaching objective of *CT* is to teach students how to solve the problems in their own fields by applying computer knowledge more efficiently and to form their good habits of thinking. The evaluation standard for *CT* is the students' cognitive levels and constructive abilities which refer to the degree of comprehension of the natures and laws of thing, but not the capacity of knowledge instilled into the students' mind by teachers or the degree of external stimulation. "Knowledge cannot be taught by the teachers' passive teaching, but obtained by the students' active learning". Students play an irreplaceable and principal role in *CT* and each aspect of teaching, e.g. teaching objective, teaching object, teaching process, teaching evaluation, involves in students. Students are the seeker of seeking knowledge, the performers to construct knowledge, the implementers to apply knowledge and the solvers to solve problem. But *CT* is an innate thing and cannot be acquired by self-study. In order to improve students' abilities of thinking, teachers should play a guiding role. The tasks of teachers are changed from imparting computer knowledge to designing learning materials, guiding learning process and training thinking ability. Teachers are instructors to guide students to learn theoretical knowledge, master the way of thinking, understand research methods and are assistants to help students to explore essences, develop principles, discover relationships and are facilitators to encourage students to find problems, pose problems and solve problems. The relationship between teaching and learning in *CT* is consistent with the purpose of blended learning: students can study effectively under the guidance of teachers and teachers can teach knowledge purposely under the demand of students. On one hand, teachers can play their leading role by guiding, inspiring and monitoring teaching; on the other hand, students can play their principal role by adaptive learning, developmental learning and creative learning.

B. CT takes classroom teaching as core and extracurricular activities as support:

The training of *CT* is a long and complex process, because it not only depends on the subjective endeavors of students and the external stimulation of educations, but also has much to do with the existing knowledge, cognitive structure, non-cognitive factors, etc. Classroom teaching cannot meet the demands students' thinking training in *CT* such as logic analysis, abstract thinking and formal description because of its disadvantages of discontinuity and decentralization and it must

be supplemented with a series of extracurricular activities, e.g. discussion online, coaching after-class, to form a centralized and continuous teaching process. *CT* greatly enriches the classroom contents and organically combines classroom teaching and extracurricular activities. It makes full use of extracurricular activities for the advantages of various forms, temporal flexibility and fewer limitations, which makes teaching not restricted by the time, space, resources or forms. Teachers just pay attention to how to teach methods, how to train thinking and how to analyze problems and the general, basic and conceptual knowledge is learned through students' self-study before class and the practical, comprehensive and innovative problems are explored through teamwork after class. Furthermore, the students' ability to solve the problems in their own fields by applying *CT* methods cannot be obtained through simple learning, like memorizing the knowledge mechanically or copying the methods directly but be trained by deep learning, like understanding, processing and applying knowledge continually, which can only be achieved through extracurricular activities. The combination of classroom teaching and extracurricular activities in *CT* is consistent with the various forms in blended learning which indicates the best teaching effect can be attained by appropriately combining different teaching methods to exert their respective advantages.

C. CT tasks classroom teaching as selected spots and online learning as entire areas:

CT well reflects the combination of classroom teaching and online learning. On one hand, the learning of *CT* cannot be implemented without classroom teaching whose characteristic is Face-to-Face teaching. *CT* needs teachers to play their leading role in teaching in the aspects of taking "paying enough attention to the most students' understanding" as principle, taking "organized, articulated and systematical teaching" as body, taking "centralized teaching, questions and answers, group discussion" as form, which makes students master the key concepts, thinking methods and application skills in a limited time as soon as possible. It can eliminate barriers to learning and improve teaching efficiency; on the other side, the developing of *CT* cannot be achieved without the support of online learning whose character is networked learning. Online learning greatly makes up the disadvantages of classroom teaching which is extremely restricted by time, space and form and results in the simplification, non-repeatability and restrictions of teaching activities. It constructs a new study environment which is composed of networked media resource, virtual learning community and online course platform to extend, expand and improve study in depth, extent and strength. Online learning makes fully use of the advanced information and virtualization technologies to make teaching forms much more flexible and various, e.g. repetitive learning, adaptive learning and personalized learning, to play the students' principal role as much as possible. It pays more attention to develop the students' initiative, positivity and creativity and plays an irreplaceable role in training thinking skills, mastering thinking methods and cultivating thinking habits. In *CT*, the classroom teaching and online learning are combined properly and they can promote each other. Online learning is developed based on the objective of classroom teaching and classroom teaching is modified according to the feedback of online learning. Online learning is a powerful complementarity and

infinite extension to classroom teaching and in turn, classroom teaching plays a guiding and supervising role in online learning. *CT* is the best embodiment and executor of blending learning.

D. CT takes thinking development as objective and knowledge learning as foundation:

The objective of education is to cultivate a creator who can think independently and solve problems effectively. The ability of *CT* cannot be developed directly by students' natural talents or self-awareness or by teachers' teaching, but is gained by knowledge internalization. The abilities of students' finding, proposing, analyzing and solving problems are on the premise that they can build a reasonable knowledge structure, accumulate a lot of knowledge and acquire the newest knowledge. Thinking and knowledge are in a proportionality relationship and the more complicated the problem is, the deeper we will think and the more knowledge may be required. *CT* focuses on the teaching process of how to internalize the computer knowledge into the abilities to understand, analyze and solve problems. Teaching computer knowledge plays a fundamental role in applying *CT*. Only with a certain amount of domain knowledge, students can continually acquire, apply and create new knowledge and then they can have a correct and reasonable *CT* ability, which makes knowledge and thinking develop in a spiral way. But the core of *CT* is not teaching knowledge, but developing the students' ability to understand concepts, internalize knowledge and gather experience in the thinking process of solving problems. The real objective of teaching should be identified as thinking development. The purpose of teaching the declarative knowledge of computer (e.g. theory, principle) is to make students understand the characteristics and rules of the procedural knowledge. Teachers should make students understand how to apply knowledge rather than only teach what the knowledge is. The combination of thinking development and knowledge learning in *CT* is consistent with the combination of learning objective knowledge and constructing subjective cognition in blended learning: the development of subjective cognition is based on leaning objective knowledge and in turn, the teaching of objective knowledge must accord with the students' level of subjective cognition, which fully reflects the viewpoint of the unification of subject and object of epistemology.

IV. COMPUTATIONAL THINKING MODLE BASED ON BLENDED LEARNING

CT is designed based on the theory and practice of blended learning, whose core idea is the integration of teaching resources, learning theories and teaching methods under the guidance of *CT*. Students can construct their own knowledge by consciously applying the methods of *CT* with the assistance of teachers and they can learn knowledge, discover laws, master methods and develop thinking in the process of problem solving like computer scientists. The *CT* model based on blended learning refers to each aspect of teaching which includes the action set of teacher, the action set of student, the learning resource set and the teaching evaluation system set. The *CT* model is a three-dimensional and conceptual teaching-learning model, which includes multiple layers, multiple elements and multiple stages. In the model, its elements are

interacted, restricted and influenced with each other. The mathematical expression of the model is shown as follows:

$$M_{CTBBL} = \sum_{i=1}^n F(AT_i, AS_i, RS_i, EV_i) \quad (1)$$

In formal (1), M_{CTBBL} represents the *CT* model based on blended learning. F represents a function. AT_i represents the teachers' action set of the i th class and it is an ordered set of teaching activities which indicates the process of teachers' teaching *CT* methods; AS_i represents the students' action set of the i th class and it is an ordered set of learning activities which indicates the process of students' learning *CT* methods; RE_i represents the set of learning resource of the i th class and it refers to the learning resources which are selected, utilized and optimized under the guidance of *CT*; EV_i represents the set of teaching evaluation system of the i th class and it refers to the teaching evaluation system which is updated, perfected and improved under the guidance of *CT*;

A. AT_i is a two-dimensional ordered array and plays a leading role in M_{CTBBL} :

According to time, AT_i can be subdivided into the three phases, $AT_i = [AT0_i, AT1_i, AT2_i]$, they are teachers' action set before the i th class, in the i th class and after the i th class, respectively.

$AT0_i$ represents the action set of teachers before the i th class, which contains three elements, $AT0_i = [preCon_i, desQue_i, preLes_i]$. $preCon_i$ indicates designing preview contents before the i th class. The preview aimed for *CT* is not to publish the teaching materials directly or to combine the learning resources simply, but to establish a reasonable preview objective and write some special preview materials according to the course schedule and the students' characteristics. The purpose of preview is to build a foundation for classroom teaching and it not only introduces the basic knowledge, fundamental principles and practical skills for students' self-study, but also represents the methods and process of problem solving, which eliminates the learners' barriers to learning and makes them get into learning in advance. The preview contents are designed based on microteaching and are presented in the form of micro segments with the demands of concise text, specific subject and appropriate difficulty and it must be suitable for students' psychology and make them get pleasure and fulfillment from self-study. Meanwhile, teachers invisibly guide students to do the preview by adding annotations and problems into the materials. When teaching Operating System, learners can master the basic concepts (e.g. thread, process) through self-study. Teachers will pose the practical questions related to the knowledge progressively, e.g. "how to arrange your several exams reasonably?", "what conditions must be satisfied?", "is there an optimal solution?". Based on these questions, teachers guide students to think about CPU scheduler algorithm. Students are not allowed to have all the accurate answers, but they can learn knowledge more purposely in class after careful thought and can be directly involved in the process of finding, analyzing and solving problems. $preCon_i$ plays an irreplaceable role in *CT*, which can extend time, expand contents and improve

efficiency for teaching and it is a necessary supplement and strong support to classroom teaching.

$desQue_i$ indicates designing a baseline questionnaire before the i th class: $desQue_i$ is implemented after $preCon_i$, which is used to know about students' leaning in the $(i-1)$ th class and their preview before the i th class, update the contents and adjust the plan. The contents of baseline questionnaire are designed based on the contents of $teaCon_{i-1}$ and $preCon_i$ with the characteristics of understandability, concision and practicality. The type of questions is mainly objective ones and the number is better set from 10 to 15. $desQue_i$ plays an important role in CT , which is used to connect the $(i-1)$ th class and the i th class seamlessly. It feeds both the learners' i th preview and their $(i-1)$ th learning back to the teachers' i th preparation, as shown in figure 1. With the action of $desQue_i$, $preCon_i$ can provide an important reference value to $preLes_i$.

$preCon_i$ indicates preparing a lesson before the i th class. Under the guidance of CT , teachers design teaching materials and write teaching scripts based on the results of $desQue_i$. $preCon_i$ includes two level: in the first level, teachers design teaching cases with the aim of introducing computer knowledge and understanding CT methods. Teachers should teach computer knowledge along based on CT and make students understand computer scientists' problem-solving process with the CT methods of recursion, separation of concerns, simplification, transition, simulation, heuristic reasoning, etc. When teaching networking protocol and OSI model, the abstraction and separation are introduced; when describing memory structure and the process of instruction, the methods involved with cache and automation are explained. In the second level, teachers design practical cases with the aim of solving real problems and applying CT methods. Teachers should design some practical cases related to the knowledge, e.g. designing a course selection process, implementing a document retrieval algorithm, to make students have the experience in the application of CT . Practical cases should be designed more realistically and more sensibly, which can make the abstract knowledge more understandable. $preCon_i$ is the essential phase of ATO_i , which plays a decisive role in CT , because it is the precondition and foundation for successfully implementing ATI_i and directly influences the effect and quality of teaching.

ATO_i is the beginning of the whole CT teaching and it directly determines the number and the value of all the other elements in M_{CTBBL} model. The more prepared by ATO_i , the better performed by ATI_i .

ATI_i represents the action set of teachers in the i th class, which contains two elements, $ATI_i = [teaCon_i, disCon_i]$. ATI_i is the concrete implementation of $ATO_i.preLes_i$, whose two elements correspond to the two levels of $preLes_i$. $teaCon_i$ indicates teaching knowledge in the i th class, which means teachers play a leading role in teaching computer knowledge. In this phase, teachers should emphatically explain the computer scientists' problem-solving process with CT methods while reducing the introduction of basic concepts. But thinking is the product of brain activities and how to clearly express the internalized thinking process is the key

problem needs to be solved in this paper. It needs to find an effective teaching method. Based on the intensive research and practice, this paper proposed **descending dimension method** based on CT which indicates the sensory perception of real problem existing in brain's multi-dimensional space can be transformed layer by layer and finally be mapped into the model existing in computer's one-dimensional space through CT methods. According to the three levels - sensibility, intellectuality, rationality - in human beings' cognitive theory proposed by Kant, the process of descending dimension is mapped into three stages of problem solving with CT methods: formal description, abstract modeling and automatic solution. Taking TSP as example, in the first stage, teachers describe the real problem. Students intuitively acquire the sensory knowledge which describes the problem's appearance by imaginal thinking and they can understand how to state problem. But this kind of sensory perception is usually in a multidimensional, complicated and confusional state. In the second stage, teachers apply CT methods, e.g. "separation of concerns, simplification, transition", to demonstrate the process of abstract thinking to students: how to convert the real problem into a mathematical description (composed of symbol, figures, steps) through simplification and quantification. The mathematical description has the characteristics of formalization and structuralization which is easy to be implemented by computer. Students further acquire the intellectual knowledge which describes the problem's critical characteristics and internal relations by abstract thinking. In the third stage, teachers convert the mathematical description into a data structure which can be stored in one dimensional space and an algorithm which can be implemented by computer based on mathematical model, algorithm theory and the CT methods of iteration, recursion, deduction, etc. Students continuously acquire the rational knowledge which describes the problem's essential attributes and the solutions by computational thinking. The process of teaching CT is the process of descending dimension which contains a series of conversions from the real world to the information world to the machine world. The conversion process is considered to have a programmed characteristic which indicates it can be summarized into a model.

The methods of CT are applied since the second stage. From the first stage to the second stage, it pays attention to human being's thinking and reflects the students' abilities to use the computer. From the second stage to the third stage, it focuses on the implementation of computer and indicates the students' level of computer use. In $teaCon_i$, teachers teach computer knowledge and CT methods with the teaching methods of transforming knowledge into questions and dividing questions into different levels, which are proposed based on CT . It makes students possibly understand the essential differences between human being's thinking and computer's thinking in a cyclic process of asking questions, learning methods and solving questions. (The characteristics of human being's thinking are multidimensional, qualitative and indeterminate; the characteristics of computer's thinking are one-dimensional, quantitative and determinate). Through CT learning, students

can distinguish what must be done by human being and what can be implemented by computer and then they can use computer to solve problems appropriately.

$disCon_i$ indicates implementing practical cases in the i th class, which means learners play a principal role in learning CT methods through class discussion. “ CT can be taught” implies students can gradually understand the thinking process with the programmed characteristic through internalization, self-study and self-experience, which means the ability of CT cannot be obtained directly by teachers’ teaching, but be grasped better through discussion. Teachers emphasize on developing and training students’ thinking methods, thinking consciousness and thinking abilities. In $disCon_i$, teachers change their role from initiators who teach knowledge to instructors who train thinking. They apply various teaching forms, e.g. group discussion, homework presentation, questions and answers, to stimulate students’ desire and interest to solve problems. On one hand, the practical cases are designed based on the requirements of $teaCon_i$; on the other hand, it should be expanded by some new contents for knowledge consolidation and thinking migration. Corresponding to the explaining of TSP in $teaCon_i$, teachers can design some life examples, e.g. courier route, aircraft route, which are easily understood. Students can find the solution to a deeper problem independently through simulating the teachers’ thinking process and then from their own thinking methods gradually. Under discussion, teachers should establish a loose and exciting environment in class, organize students’ discussion and control the schedule. Some training skills, e.g. “Time Limitation, Quick Responses, Group Competition”, are used to keep students’ brains in a good condition. $AT1_i$ reflects the characteristics of CT : teachers not mainly introduce computer knowledge, but regard computer knowledge as a medium to make students apply the CT methods to solve problems. On the basis of simulating and understanding the existing CT methods, students can solve problems creatively.

$AT2_i$ represents the action set of teachers after the i th class, which contains four elements, $AT2_i = [desHow_i, corHow_i, ansQue_i, febTea_i]$. $desHow_i$ indicates designing homework after the i th class. The homework is designed concerning both $teaCon_i$ and students’ actual abilities, while with relative difficulty for training the students’ thinking. The homework can be divided into different categories to meet the needs of students at different levels. Some difficult or comprehensive homework can be completed by collaboration. $corHow_i$ indicates correcting homework after the i th class. Teachers must correct homework timely and properly adjust the teaching plan. $AT2_i$ is an important method to appraise teaching effect. $ansQue_i$ indicates answering questions after the i th class. Teachers should answer the students’ questions as soon as possible through various means, e.g. online course platform, instant communication tools, face to face coaching, etc and perform a statistical analysis to summarize the common or typical questions to supplement classroom teaching. $febTea_i$ indicates feeding effects back to teaching. According to the students’ learning situation, teachers should

do reflection, amendment and evaluation of the completed teaching activities and do modification, updating and estimation of the teaching activities which are not yet implemented.

$AT2_i$ plays an auxiliary role in CT . It serves as a link between the past teaching activities and the future ones: it tests the teaching effects of AT_{i-1} and guides the activities of AT_i .

B. AS_i is a two-dimensional ordered array and plays a principal role in M_{CTBBL} :

Corresponding to AT_i , AS_i is also a two-dimensional ordered array. Based on time, AT_i can be subdivided into the three phases, $AS_i = [AS0_i, AS1_i, AS2_i]$, they are action sets before the i th class, the action set in the i th class and the action set after the i th class, respectively.

The purpose of M_{CTBBL} based on blending learning is developing students’ ability to solve problems. Therefore, the value of M_{MBLM} is decided by the learning effects of most of the learners, not by the teaching quality of a single teacher.

$AS0_i$ represents the action set of students before the i th class, which contains two elements, $AS0_i = [preCon_i, ansQue_i]$. $preCon_i$ indicates previewing contents assigned by teachers before the i th class. Under the invisible guidance of teachers, students analyze the materials by themselves to improve their abilities of retrieving information, exploring problems and constructing knowledge. Meanwhile, they should do take notes properly and write down the difficult problems in time, which can promote the class activities in the subsequent phase in a problem-driven way. $ansQue_i$ indicates completing the baseline questionnaires designed by teachers before the i th class. Students must carefully complete the questionnaires with the quality and quantity guaranteed in a matter-of-fact way.

$AS1_i$ represents the action set of students in the i th class, which contains two elements, $AS1_i = [lsnTea_i, disCon_i]$. $lsnTea_i$ indicates listening to the teachers as objects in the i th class. In class, students learn knowledge in a problem-driven way which can make thinking highly centralized and continuously active. $disCon_i$ indicates discussing the cases as main body in the i th class. Collision and stimulation can produce thinking. Therefore, students can gradually master CT methods, understand the programmed process of solving problems through a planned, aimed and designed discussion guided by teachers. Finally, students can solve the problems in their own disciplines by applying computer knowledge like computer scientist as much as possible.

$AS2_i$ represents the action set of students after the i th class, which contains four elements, $AS2_i = [rewCon_i, doWork_i, askQes_i, febLea_i]$. $rewCon_i$ indicates reviewing the contents after the i th class. Through further learning the computer knowledge and deeply researching the CT methods Students complete a spiral process of study. The spiral process involves two aspects: enhancing computer knowledge with CT methods and summarizing CT methods based on computer knowledge. $doWork_i$ indicates finishing homework after the i th class. Students should complete the tasks by means of applying CT methods, reading relevant materials, discussing with others. According to the difficulty, the homework can be finished by

individuals or groups. $askQes_i$ indicates asking questions after the i th class. Students consult teachers by online course platform, instant-communication tools, etc. $febLea_i$ indicating feeding effects back to learning. Students continuously regulate their learning process by means of reflection, modification and comparison for developing the right attitude and correcting bad study habits and $febLea_i$ can promote the students' learning abilities.

- C. RS_i is a two-dimensional unordered set, which is used to provide the hardware resource and software resource to AT_i and AS_i :

RS_i can be subdivided into the two parts, $RS_i = [hwRs_i, sfRs_i]$. $hwRs_i$ indicates the hardware conditions required in the i th class, which contains two elements, $hwRs_i = [fieldRs_i, equipRs_i]$. $fieldRs_i$ includes the classroom and laboratory provided for class and the meeting room used for coaching or discussions. $equipRs_i$ refers to the instrument, equipment and network environment needed for ensuring the activity of teaching. $sfRs_i$ indicates the software resource adopted in the i th class, which contains three elements, $sfRs_i = [platRs_i, virRs_i]$. $platRs_i$ is online course platform which is mainly used for online learning. It includes resource sharing, online discussion, homework management, online test, etc. $platRs_i$ can be built by some open source software. The commonly used software is called Learning Content Management System (LCMS) which can allow users to build a teaching web site without writing any code. Currently, the most popular LCMS are Moodle, Sakai, ATutor and Claroline. $virRs_i$ is virtual classroom which is provided for remote learning. It is composed of screen-sharing, audio-video transmission, white boards, remote desktop, etc. $virRs_i$ can be designed with the technologies of virtualization and information and it is better to do the secondary development based on the existing systems, because different courses have different teaching materials, teaching patents and teaching scales. Currently, the common software used for real time communication are WebRTC, Openmeetings, Bigbluebutton,

- D. EV_i is a two-dimensional unordered set, which is used to evaluate the teachers' teaching quality and the students' learning effects after teaching:

EV_i can be subdivided into two parts, $EV_i = [teaEv_i, stuEv_i]$. $teaEv_i$ indicates the teachers' teaching quality for the i th class, which contains student evaluation, peer evaluation, expert evaluation and self-evaluation, $teaEv_i = [lerEv_i, perEv_i, eprEv_i, selEv_i]$. All of the evaluation subjects evaluate the teachers' actions in AT_i , respectively. The evaluation contents can be categorized into several indexes: teaching attitude, teaching knowledge, teaching method, teaching ability and teaching effect and each index can be subdivided into many factors, e.g. the evaluation of teaching materials contains highlighted important points, appropriate difficulty, innovative contents, relating to the practice, etc. In view of the practicability, $teaEv_i$ is better to be implemented in the form of marked and each evaluation subject is not forced to complete each $teaEv_i$. $teaEv_i$ reflects the objectivity and fairness of evaluation based on the diversity of evaluation subjects and implements quantitative analysis and qualitative judgment through

modeling methods of analytic hierarchy process and fuzzy decision. $stuEv_i$ indicates the students' learning effect for the i th class, which contains teacher evaluation and self-evaluation, $stuEv_i = [eduEv_i, selEv_i]$. $stuEv_i$ mainly reflects teachers' evaluation of students' actions in AS_i and its evaluation contents can be categorized into several indexes: learning attitude, knowledge and skill, ability and quality. Each index can be subdivided into different factors, e.g. attendance rate, performance in class, online learning time, online community effect, etc. The student's evaluation which is implemented by teachers can be regarded as a management process of lifecycle. Teachers can capture the dynamic learning state of each learner as much as possible by tracing his daily activities in different stages (before class, in class and after class). $stuEv_i$ uses a series of evaluation methods: the combination of self-evaluation and others' evaluation, qualitative evaluation and quantitative statistics, process tracing and result analysis, static evaluation and dynamic evaluation. It not only can make students know their learning behaviors objectively, but also can provide the timely and adequate feedback information to teachers to ensure the normal development of teaching.

EV_i plays a feedback role in M_{MBLM} and it can regulate and control the teaching activities as a whole. Fundamentally, EV_i belongs to a kind of value judgment and in order to draw a scientific conclusion, it must have at least two conditions: first, having scientific evaluation criteria; second, having evidences and materials supported for the final conclusion

V. CONCLUSION

Learning knowledge is closely connected with developing thinking. The emergency and development of computational thinking has great effect on education. The computational thinking model based on blended learning deeply analyzes and researches the application of computational thinking in computer science by the organic combination of computational thinking and blended learning in a life-cycle perspective. On one hand, the model can summarize the core concepts and important principles in computer science and extract the typical thoughts and general methods of solving problems based on the theories of computational thinking; on the other hand, the model can design scientific teaching methods and practical cases. Based on the model, the teachers can teach the problem-solving process by using computer more intuitively and clearly and the students can understand the application of computer knowledge more easily and simply. The teaching philosophy proposed by the model is consistent with the ultimate aim of teaching, which makes students to be a real problem-solver, not the knowledge-copier.

In a word, the computational thinking model based on blended learning provides effective help and guidance for developing students' computational thinking ability and affords theoretical basis and resources for building three-dimensional and blended learning environment and enriches the researches of computational thinking and blended learning.

ACKNOWLEDGMENT

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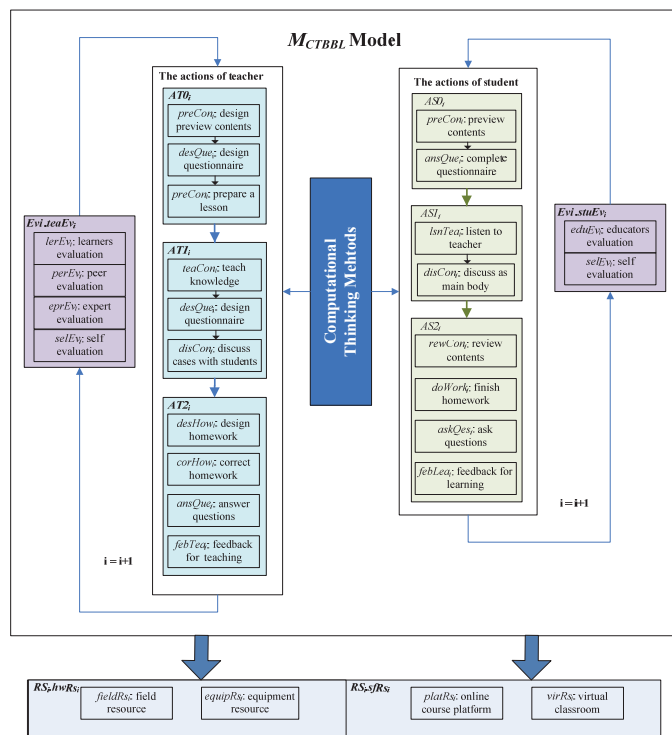


Fig. 1 The frame diagram of MCTBBL Model

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Be a Simulator Developer and Go Beyond in Computing Engineering

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Abstract—This work presents a methodology based on simulator developers to be applied in several courses as well as research activities. This proposal is also based on “The Cathedral and the Bazaar” lessons. First, good programmers know what to write, however great ones know what to rewrite. Students could learn by developing new components to be added to the current simulator. Second, any tool should be useful in the expected way, but a truly great tool lends itself to uses you never expected. The proposed simulator has been developed to teach digital circuits. However, it can be used in many other computing engineering fields. Third point is motivation, where the lessons are driven by the following principle: To solve an interesting problem, start by finding a problem that is interesting to you. Nowadays, we are surrounded by Internet of things, where the simulator engine could be connected to learn and to motivate the students. Image processing could be taught by connecting your web-cam and/or your mobile device camera to your simulator engine. Moreover, mobile phones and/or Arduino devices have a set of sensors that could be captured inside of the virtual simulator lab.

I. INTRODUCTION

Following web popularization, the use of web has been addressed in several approaches to teach in various fields of computer science and engineering in university courses. New innovative practices in education includes: massive open online courses (MOOCs), learning-by-doing or problem-based learning, hands-on homework assignments, virtual labs, Internet of Things (IoT), social networks, video-based learning, flipping, mobile devices (tablets and smart-phones), games, robots, augmented reality systems, etc. In 2014, a survey done by [1] shows that more than 90% of students uses smart-phones, however only 37% of them have used them to study: the most common use are social networks, while laptops are still very popularly used for studying. One approach is to provide interactive exercises/tools to get student immediate feedback based on their interactions in a non-passive way.

Nowadays, the world has a hardware/software heterogeneity which requires that the developer conducts careful planning and design prior to implementation of an application where simulation has an important role. Moreover, there is a great need for programmers to have the qualifications needed to develop software for embedded, mobile, and cloud computing. Skills as object-oriented languages, event-based and distributed programming are important basic fundamentals for these purposes.

Simulation for many reasons is broadly used for educational and research purposes, through training and decision support. More than working with a simulator, this work propose to teach the student how to contribute and collaborate as a simulator developer. Additionally, a simulated-developer approach could be applied in several courses related to engineering and computing education. Since students should learn the fundamental principles of programming prior to working with deep challenges, the proposed approach is incremental and multilevel. Our approach is based on a simple digital circuit simulator, where the students can familiarize themselves with the platform and quickly and easily solve common problems in many domains. Moreover, our proposal is simple, intuitive, and based on engaging technology to be easily integrated to the web, mobile and IoT world.

II. FREE SOFTWARE LESSONS

The proposed methodology is also based on the free software lessons pointed by Eric S. Raymond in his book “The Cathedral and The Bazaar” [2], where he describes good practices used by the open source software community. Although 19 software developer lessons are described in [2], our current proposal explores a subset of them (however, all lessons could be incorporated). This work aims to provide teaching and learning skills in addition to software developing.

The first lesson is code reuse, where the original lesson is “Good programmers know what to write. Great ones know what to rewrite (and reuse)” [2]. Learning-by-doing and learning-by-example approaches could be used from the beginner to the advanced level. When a student modifies and tests his code derived from previous examples to produce new features, these actions will produce a fast feedback to himself. The second lesson justifies our simulator tool choice since “Any tool should be useful in the expected way, but a truly great tool lends itself to uses you never expected” [2]. The Hades simulator was proposed to teach digital circuit design [3], however this work shows that Hades could be useful in many domains to teach and learn computer science subjects. The third lesson is related to motivation and mentions that a good work will be started by a personal itch. Others free software lessons are: release early and often since other students could evaluated your work, choose smart data structures, and at last not at least, perfection is achieved when there is nothing more to take away, as said by Antoine de Saint-Exupéry. Moreover,

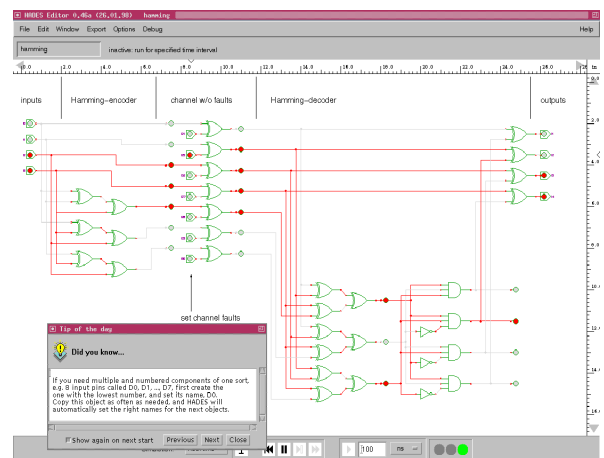
nowadays it is easy to solve a problem by connecting boxes, however the students should go beyond scratching the surface: they need to go deeper to model and to implement inside the black boxes.

III. HADES SIMULATOR

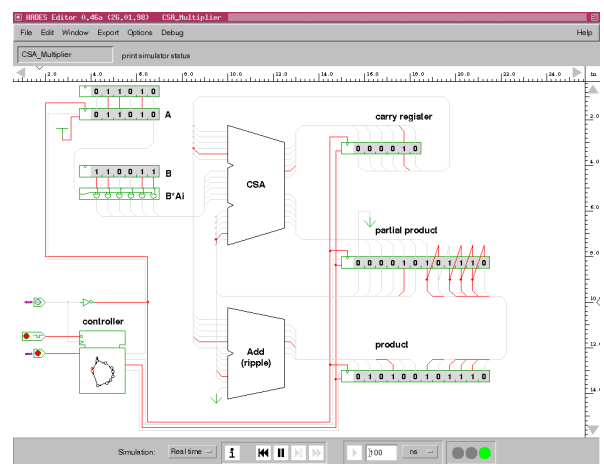
This work proposes to extend the Hades simulator tool [3]. This section describes the main Hades' features and the following sections will illustrate our proposal. Hades (Hamburg DESign) is a Java-based simulator from Hamburg University, Germany, which was presented in [4] to simulate digital circuits. The Hades is available on the web [5], and it could be executed locally or remotely by using a web browser. Therefore, it could easily be integrated in massive open on-line courses (MOOCs). Even when it executes locally as a Java program, the student could directly open an example design from any URL. Fig. 1 depicts three Hades screen-shots: a gate level circuit, a RTL design and a simple processor. Although, Hades was proposed in 1998 for a specific purpose (digital simulation), due to its simplicity and flexibility it is still useful as pointed out by recent e-learning survey papers [6], [7]. First, the implementation is object-oriented based in the Java language and, therefore, it provides all advantages of Java language as a large amount of code reuse and portability. The basic component class has a minimum set of methods that provides a fast learning curve inside a general purpose framework. A wire which connects two or more components is also an object, and it could be used to send/receive from a single bit, a string, a image up to a complex data structure. All designs are stored in a simple structural text format: a component list followed by a wire list. Additionally, all components could have parameters to save and restore the simulation configuration. A new component could be added to the current component library without any modification in the main tool. The simulator engine is an event-list which is simple and generic to model most problems as a distributed system. The graphical user interface (GUI) is simple and parameterizable. The simulator could also be executed in batch mode with or without graphical interface, and it could be controlled by a test/validation script.

A. Component Class

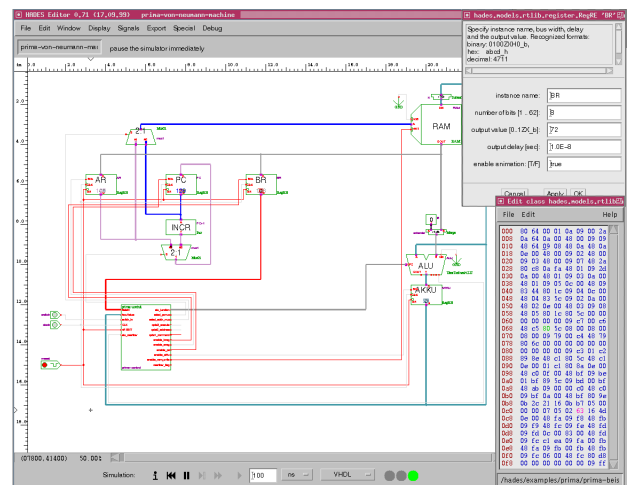
Following the free software lessons, we could say that the component class has a smart structure which simplifies the code and it could reach the perfection since there is nothing more to take away as said Antoine de Saint-Exupéry. The basic Hades class to create a new component has few methods. First, the class *constructor* initialize the port array, which defines the input/output interface. A port could carry any object to communicate to/from an external component wired in this port. When an event occurs in an input port, the *evaluate* method will be called to handle this event. This method implements the component behavior. A component could also generate itself a new event by using the wake-up method. Additionally, the *configure* method is used to open a graphical window to setup the component parameters. Finally, *write* and *initialize* methods are automatically called when a design file is loaded or saved. For more details, readers could refer to Hades tutorial available in [5]. In this work, our examples will complement the Hades documentation to provide new ideas to the future simulator



(a)



(b)



(c)

Fig. 1. Hades Screen-shots: (a) Gate level Hamming Decoder; (b) Multiplier and visualization; (c) Simple processor and memory debug.

developers. Moreover, the component class encapsulates the main features. Inheritance, polymorphism and a graphical user interface (GUI) can be easily integrated using this class. The component class ensures that students remain focused on the

problem modeling, solving approaches and algorithms, without getting distracted by the interface elements. Therefore, the student has a platform with low development cost, which provides a quick expansion, and continuous updating. The GUI is user friendly and it could be used to design from fundamental logic circuits to complex communication applications. Java is familiar to most students and currently one of the most widely used programming language. Finally, learning object oriented programming is included in all computer science curriculum, its use on different context provides opportunities to improve student knowledge.

B. Previous Work and Hades

Since 2004, the Hades tool has been used in teaching and research activities at University of Vicoso (UFV, Brazil). To teach, Hades was used in logic digital design, embedded systems and computer architecture at undergraduate and graduate level, which is the Hades main purpose. Following the free software lessons, "a truly great tool lends itself to uses you never expected" [2], we have taught image processing by using Hades, where the wires carry images instead of bits. Additionally, the students have created new components as well as modified the previous ones, and they also enhance the image component library by encapsulating ImageJ [8] which has a large library of Java source code freely available and in the public domain. ImageJ could manage all formats, and it can filter a 2048x2048 image in 0.1 seconds (40 million pixels per second). As a research tool, Hades has been used to simulate dataflow architectures [9], FPGA compilers [10], coarse-grained reconfigurable architectures (CGRA) [11], and wireless sensor networks [12]. Moreover, as a research and educational tool, Hades versions have been proposed to teach advanced computer architecture concepts in [13], [14], and visualization of the advanced encryption standard (AES) algorithms in [15].

IV. PROPOSAL METHODOLOGY

This work proposes to teach the student to be a simulator developer. The proposed approach is multilevel, and it addresses beginners as well as advanced students in one or more of the computing and/or engineering areas. This section presents examples to illustrate the proposed approach. The first example in Section IV-A shows from the scratch how to model a classical distributed programming problem: philosopher's dinner. As already mentioned, Hades was design as digital circuit simulator, however we will show how to use it to teach a different subject as a high level distributed programming problem, and also to teach graph algorithms in Section IV-B. Section IV-C presents an incremental approach to teach processor design. Section IV-D shows image processing examples. For instance, how to connect the web-cam and import its image inside the Hades simulator. This section also presents a machine learning example. Section IV-E presents two new Hades educational components: a configurable quiz form and a video-player. Finally, Section IV-E shows example how to connect to the real world by using sensors and low-cost Arduino devices.

A. Distributed Programming

We have chosen a distributed programming problem to illustrate our approach. Moreover, students should actually

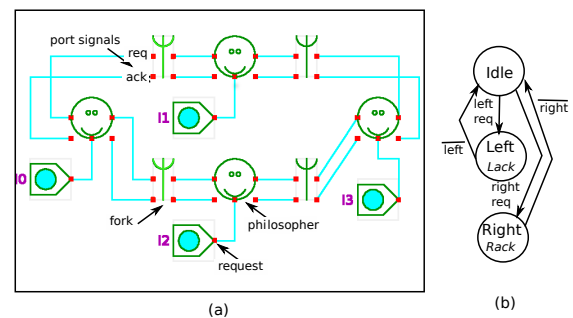


Fig. 2. (a) Hades philosopher dinner screen shot; (b) Fork Behavior as a Finite State Machine.

master the skills of programming of parallel events, and the proposed approach is a easy way to get started. Consider the philosopher' dinner problem, which is a classical problem in literature [16]. Assuming a set of 4 philosophers and 4 forks in a round table as depicted in Fig. 2(a). Each philosopher needs two forks (the ones at his left and right sides) to dinner and, of course, it is impossible that all philosophers have dinner simultaneously.

Assuming two components: the philosopher and the fork. We will show how to produce an initial implementation by thinking locally and by graphically connecting the objects. First, the fork source code is detailed. Assuming that a fork has the left and the right side, a simple interface is a pair of request/acknowledge ports on each side. In addition, we should model the fork behavior. Let us consider the model depicted in Fig. 2(b). For ease of implementation, let us assume that the left side has priority if two requests arrive simultaneously.

As already mentioned, Hades has a large library of components. Let us create our first component by extending a logic gate which is the first example detailed in Hades documentation. The fork Java code is depicted in Fig. 3. The fork class inherits from the *GenericGate* class, and only two methods are overwritten. One is the constructor (lines 6:18), where 2 pairs of request/acknowledge ports are defined, and the fork initial state is set to *idle*. The second method is the *evaluate* where the component behavior is implemented. When any event occurs at any input port, this method is automatically called. Lines 27:46 implements a state machine for the request/acknowledge protocol depicted in Fig. 2(b), where the left request has priority. The *ack* outputs are scheduled by using the *scheduleOutputValueAfter* method, that is inherited from *GenericGate*. Therefore, when an event occurs in any input port, the *evaluate* method handle it and the component reaction is sent back thought the output ports.

In addition to the component code, the student should create a symbol to graphically represent the component. The symbol could be static or dynamic. A static example of symbol definition is shown in Fig. 4, where the I/O port graphic positions are defined in lines 3:7, where the left ports are placed on the left side and the right ports are placed similarly. The fork drawer (a line plus an arc) is described by the lines 1:2.

Once compiled, the component could be evaluated inside the Hades tool. The philosopher component could be implemented by using the same approach. Next, a scenario

```

0 public class fork extends hades.models.gates.GenericGate {
1   static final int IDLE = 0; static final int LEFT = 1;
2   static final int RIGHT = 2; private int state;
3   portStdLogic1164 port_LeftReq, port_Left, port_RightReq, port_RightAck;
4   private StdLogic1164 leftack, rightack;
5
6   public fork() { // Constructor
7     super();
8     port_LeftReq = new PortStdLogic1164( this, "LReq", Port.IN, null );
9     port_LeftAck = new PortStdLogic1164( this, "Lack", Port.OUT, null );
10    port_RightReq = new PortStdLogic1164( this, "RReq", Port.IN, null );
11    port_RightAck = new PortStdLogic1164( this, "RAck", Port.OUT, null );
12    ports = new Port[4];
13    ports[0] = port_LeftReq; ports[1] = port_LeftAck;
14    ports[2] = port_RightReq; ports[3] = port_RightAck;
15    state = IDLE;
16    leftack = new StdLogic1164( StdLogic1164_U );
17    rightack = new StdLogic1164( StdLogic1164_U );
18  }
19  public void evaluate( Object arg ) {
20
21    SignalStdLogic1164 signal_left = (SignalStdLogic1164) port_LeftReq.getSignal();
22    SignalStdLogic1164 signal_right = (SignalStdLogic1164) port_RightReq.getSignal();
23    if (signal_left != null && signal_right != null) {
24      StdLogic1164 value_left = port_LeftReq.getValueOrU();
25      StdLogic1164 value_right = port_RightReq.getValueOrU();
26      System.out.println(state);
27      switch (state) {
28        case IDLE: if (value_left.is_1H()) { // Left request
29                    state = LEFT;
30                    leftack.setToCopy( value_left );
31                    rightack.setToInvert( value_left );
32                  } else if (value_right.is_1H()) { // Right Request
33                    state = RIGHT;
34                    leftack.setToInvert( value_right );
35                    rightack.setToCopy( value_right );
36                  }
37        break;
38        case LEFT: if (value_left.is_0L()) { // Left release
39                    state = IDLE;
40                    leftack.setToCopy( value_left );
41                  }
42        case RIGHT: if (value_right.is_0L()) { // Right release
43                    state = IDLE;
44                    rightack.setToCopy( value_right );
45                  }
46        break;
47      }
48      scheduleOutputValueAfter( port_LeftAck, leftack, t_delay );
49      scheduleOutputValueAfter( port_RightAck, rightack, t_delay );
50    }

```

Fig. 3. Fork Java code Component

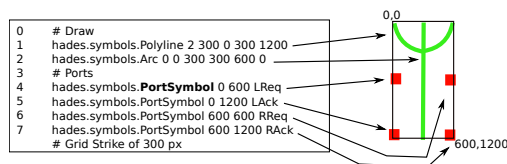


Fig. 4. Fork symbol definition

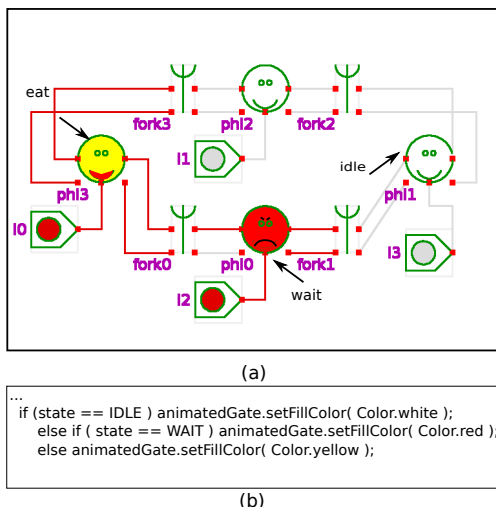
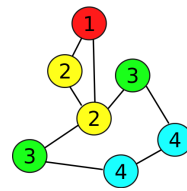


Fig. 5. (a) Color philosopher dinner screen shot; (b) Animation code.

composed of a set of philosophers and forks are created inside the graphical interface and the student can simulate and validate its first implementation. Since Hades has many



```

evaluate()
if ( receiveMsg() and
    not visited )
setcolor(Msg())
for x in Output
x.sendMsg(Msg()+1)

```

Fig. 6. A graph local node algorithm for a breadth-first search and a graph example

resources, for this example one could add an animation to easily debug the code. For instance, the philosopher has three states: idle, wait and eat. Each one could use a different color as shown in Fig. 5(a). Few lines of code should be added as shown in Fig. 5(b). In this example, the philosopher state depends on the request input which is connected to a boolean Hades switch (for testing purposes). However, one could add a clock generator to send request regularly or the student could modify the code by using the mouse click method.

Finally, as depicted in this section, a student could easily create an implementation based on components and events. The graphical interface helps the verification of the code and, also, the better understanding of how to solve a problem. In addition, the student will incrementally learn a simulation tool, Java language, object-oriented programming, graphical interface, etc. It is also important to highlight that the student does not need to understand the simulator engine code to create his first components, since it is encapsulated by an event-list and GUI, and provide a high level simulator framework.

B. Graph Algorithms

Every year, graph algorithms become even more a standard tool not only in computer science but also in several fields in science, humanities and biology. One common strategy on graph algorithm is thinking locally: a node receives a signal and propagates it to its successors. Another example of an unexpected and useful Hades application is to teaching graph algorithms. The student should only code a local node, and then by using the graphical interface build his example and visualize the results. A node could send/receive number or strings as well as change colors.

Fig. 6 displays an example of a graph breadth-first search starting in the red node. Colors and numbers are used to visualize the results. Once modeled the node, the student can instantiate nodes and connect them by using the GUI editor. Then, one node is selected as a starting point, the simulator will automatically propagate the numbers and colors to visualize the breadth-first traversal. One could change few edges (wires), and restarts the algorithm execution. In addition to small examples, the student could write a graph generator and/or import a graph to play with a large number of examples since the Hades design file has a simple form.

C. WYSIWYG Simulator

Most processor simulators have a static interface and the processor behavior is embedded on a specific processor simulator code. For instance, Ravi [13] is a graphical MIPS pipeline simulator with animation and colors. However, the processor

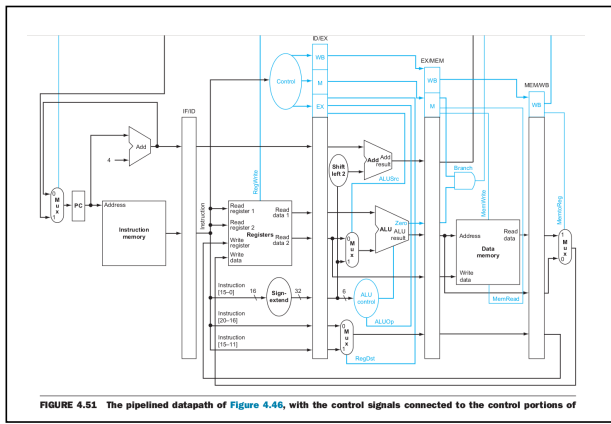
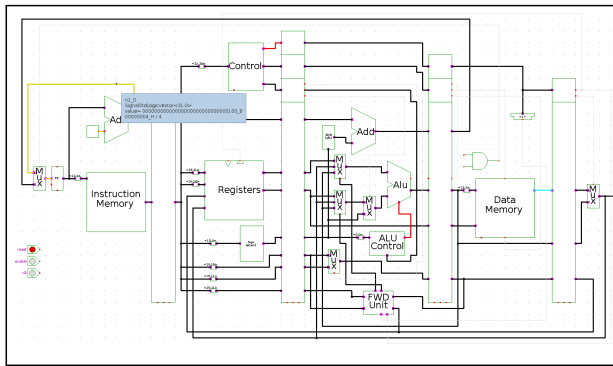


FIGURE 4.51 The pipelined datapath of Figure 4.46, with the control signals connected to the control portions of

(a)

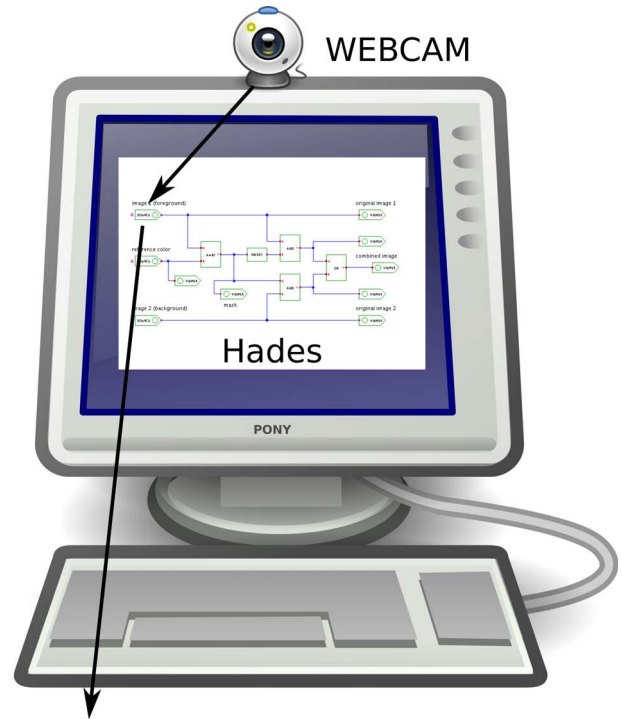


(b)

Fig. 7. (a) MIPS figure extract from the Patterson&Hennessy book [17];(b) Hades Mips screen shot.

design could not be modified without changes in the simulator core code. In [18], the authors propose the DEVJAVA MIPS32 processor simulator, which provides visualization and reusability, and it also based on Java. However, our approach is more general purpose to implement and to visualize. We propose a dynamic and WYSIWYG simulator ("What You See Is What You Get") for the popular MIPS processor, a classical example from the Patterson & Hennessy' computer architecture book [17], which is the first book in Amazon ranking on Microprocessor Design. Fig. 7 shows the book picture and the Hades screen shot. The book methodology presents the processor design by using an incremental approach. Since most of needed components already exist in the Hades library, a student could easily follow the book steps to create his design. In 2014, as a two week student assignment at graduate course of University of Vicosa (UFV), four students have extended few Hades components and redrawn component symbols to make the processor visually similar to the book picture as shown in Fig. 7. Therefore, the students could simulate the processor version and, moreover, they could modify the datapath (by adding multiplexers, wires, adders, control units, ...) to include new instructions or create a new processor implementation. Memory and register bank has a The graphical interface which simplifies the process of design debugging and teaching. Furthermore, since the students could create and model new components, they could deeply understanding inside "the book pictures".

In 2014, four students also implemented a tool that gen-



```
import com.github.sarxos.webcam.Webcam;

.....
public class webcamwindow extends SimObject
{
    public void evaluate( Object arg ) {
        SignalStdLogic1164 signal_s = (SignalStdLogic1164) port_S.getSignal();
        if (signal_s.hasRisingEdge()) {
            getImage();
            if (image != null) scheduleImage();
        } /* evaluate */
        public void getImage() {
            Webcam webcam = Webcam.getDefault();
            webcam.open();
            image = webcam.getImage();
        }
        public void scheduleImage() {
            if (simulator == null) return;
            if (image == null) return;
            Image newimage = image.getScaledInstance(300,300,
                Image.SCALE_SMOOTH);
            Signal signal_Y = port_Y.getSignal();
            if (signal_Y == null) return;
            simulator.scheduleEvent( new SimEvent(
                signal_Y, simulator.getSimTime()+0.5, newimage, port_Y ));
        }
    }
}
```

Fig. 8. A Hades web cam component based on Sarxos web cam Java package

erates Verilog code based on a Hades design as final graduate course assignment in computer architecture. Therefore, a MIPS processor could be simulated on the Hades tool, and the design could be exported to Verilog code, that could be mapped and implemented on a FPGA board. The generator was developed as an external tool, that extends a Hades script tool originally developed to export designs to a subset of the VHDL language.

D. Image Processing

Image processing features have been already implemented in Hades: a small library and a set of example are available in Hades page [5]. Instead of using a local image file or web image, why not to use the student's web cam to capture an image during the lecture to motivate them with real world examples ? A new component to connect Hades to an external web cam can be developed by using Java code available on

```

import com.heatonresearch.book.introneuralnet.neural.feedforward.FeedforwardLayer;
...
public class neural extends hades.models.gates.GenericGate {
...
public neural(){
    super();
}; ... // Neural I/O
port_A = new PortString( this, "A", Port.IN, null);
port_Y = new Port( this, "Y", Port.OUT, null, StringSignal.class );
...// Neural Training Vectors
M_INPUT = new double [MAXIMAL][7];
M_IDEAL = new double [MAXIMAL];
network = new FeedforwardNetwork();
}
public void evaluate( Object arg ) {
...// build training Vector
// set network input value
M_INPUT[train_sample][i] = Double.valueOf(port_phi[i].getValueOrUUU());
// set network output
M_IDEAL[train_sample] = Double.valueOf(port_A.getValueOrUUU());
if (train_sample < MAXIMAL) train_sample++;
...// Training
double INPUT[][] = new double[train_sample][7];
double IDEAL[][] = new double[train_sample][1];
for (int i =0; i< train_sample; i++) {
    for (int j=0; j < 7; j++)
        INPUT[i][j] = M_INPUT[i][j];
        IDEAL[i][0] = M_IDEAL[i];
    }
}
Train train = new Backpropagation(network,INPUT, IDEAL,
0.7, 0.9); int epoch = 1;
do {
    train.iteration();
    epoch++;
} while ((epoch < 5000) && (train.getError() > 0.001));
...// Using.....
double actual[] = network.computeOutputs(IN);

```

Fig. 9. A Neural network component

the web. Fig. 8 shows a web cam component implemented by using few lines of Java code and an open-source web cam package [19]. In addition to capture an image, the web cam package [19] provides motion detection and many others functionalities to elaborate creative and educational projects. The student could also get images by using his mobile device with a mobile application like Droicam [20].

Machine learning is a hot-topic due the Big Data phenomena. Neural networks are one of the widely used machine learning approaches. Fig. 9 depicts a Hades component which includes a neural network from [21]. The full code has around one hundred lines. First, the constructor defines the I/O ports and creates an instance of a neural network. The *evaluate* method performs three tasks. Our implementation is based on a finite state machine model. The first state builds the training vector. The second state creates the neural structure as a function of the training vector. Finally, the neural network computes the output values in the last state as shown in Fig. 9. The neural network component was used to implement a shape recognition application based on moment invariants (translation, scale and rotation) [22] during the image processing undergraduate course at University of Vicosa (UFV) in 2010.

E. Quizzes and Videos

We also includes two educational components: a quiz form and a video player. Since video-based learning is widely used approach for teaching [23], we propose to include a video player inside Hades. Our goal keep all in one window: the student project and the educational support (video, quiz, etc.) as depicted in Fig. 10. We propose two implementations for the video player component. The first one is quite simple, and it only includes a system call to the VLC player. The second one is based on VlcJ [24], which provides a Java framework to allow an instance of a native vlc media player to be embedded in a Java AWT Window or a Swing JFrame. Therefore, the

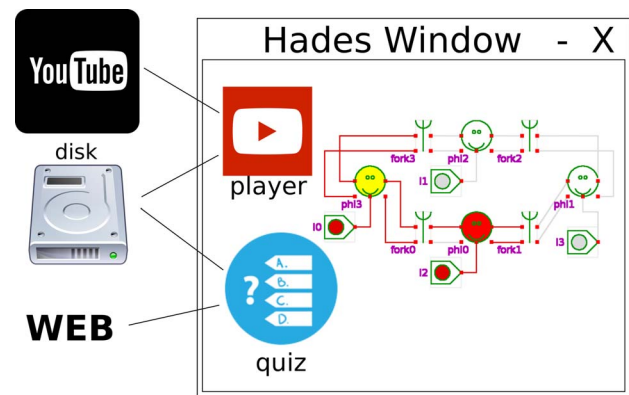


Fig. 10. All in One Window: Video, Quiz and Design

```

<q> What is a deadlock ? </q>
<a1>Sharing the same resource are effectively
preventing each other from accessing True</a1>
<a2>A severe deficiency in caloric energy
intake False</a2>
<a3>bli bli bli ... True</a3>

<q>Question 2 .....</q>
<a1>Answer1 False</a1>
<a2>Answer2 True...</a2>
....

```

(a)

(b)

Fig. 11. (a) Quiz form file example; (b) Quiz window.

student has a box component inside a Hades design. The video could explain the current task to be developed during the lecture or assignment. The video could be upload from the local disk, web or directly connect to the youtube. Although, videos usually receive a high rating from the students in comparison to other resources offered for learning, professor's lecture notes and exercises receives "very important" ratings according to recent survey presented in [25]. In addition to creating new components and modeling and solving problems, the students also could produce a video to explain their contributions. Unfortunately, textbooks only have been classified as "very important" by 30% of students in [25]. As well as during the problem-modeling and simulation process, significant learning could also be achieved during the video creation process, because in both activities the students should understand better the concepts that they have to learn how to create the video and the simulation.

In addition to video, quizzes are among the most widely used resources in traditional courses as well as in web-based education. We also includes a general purpose component to add quizzes to the design editor. Therefore, teachers and students can produce reusable quizzes and enhance existing materials. The proposed component read a quiz form from a

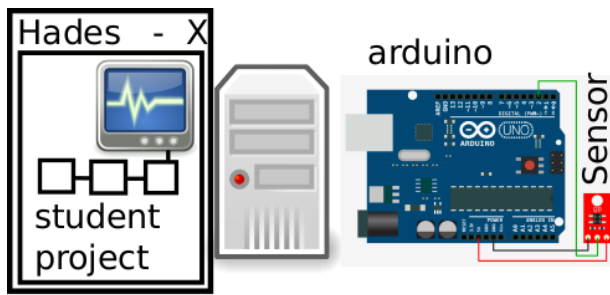


Fig. 12. Hades connected to an external Arduino board to capture real world sensors.

text file as shown in Fig. 11(a). The quiz form consists on a list of questions. Each question has the question text and a set of answers. Each answer has a text and *True/False* tag. A quiz form could randomly pick up one question from the question list. A quiz form could be also download from the web, or the students could propose questions about the current assignment. Therefore, as a collaborative task, new questions could be produced. The quiz form window is shown in Fig. 11(b).

F. Sensors and Mobile

Nowadays, mobile devices and Arduinos are widely used. Hades could also be easily connected to these kinds of devices to provide new opportunities for teaching and learning programming. In addition to the web cam shown in Section IV-D, a mobile device could export its sensors data through the wireless network by using a sensor application as [26]. Moreover, the Arduino platform and the sensors/actuators are widely used by the student community. In addition to provide a flexible and easy-to-use hardware and software platform, the Arduino IDE has been implemented in Java, and therefore an Arduino component is directly integrated in Hades as depicted in Fig. 12. LabView framework as well as Hades could be easily connected to an Arduino boards, and the student start to play. However to solve more complex problems, it is important to highlight that the software component will require the most attention [27], and once motivated, the student should write code to solve/learn the assignments. Furthermore, the student could perform lab experiments at home.

G. Suggestions

In addition to the examples shown in this work, this section points out some suggestions. First, computer networks is one domain which could be explored by using our approach. Some examples: routing algorithms with a packet viewer as shown in Fig. 13(a), protocol layers as depicted in Fig. 13(b), packing and unpacking, etc. Second, multiprogramming and concurrent programming is also an important skill that can be learned by writing local code and by exploring different connection topologies. Multi-agent systems is also another option to be taught by using our approach.

V. RELATED WORK

Nowadays, motivation strategies include IoT [28], mobile devices and their sensors [29], virtual labs, etc. All these approaches are complementary to our simulator developer

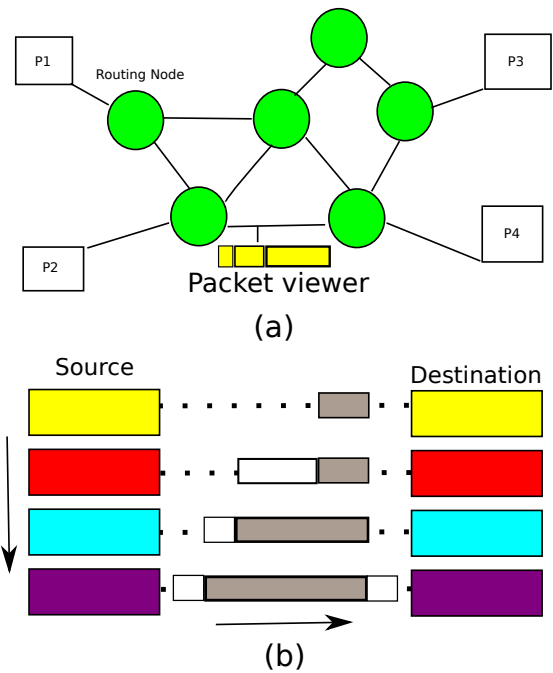


Fig. 13. (a) Routing algorithm and packet viewer; (b) Protocol vertical communication.

proposal and since Hades is Java-based, most of them could be easily integrated. Moreover, we agree with the authors of [30], who mention that there is no silver bullet that would allow to learn in fewer hours. Videos, quizzes, examples and practical assignments as well as lectures are the basic tools. The simulator developer approach is an additional tool to the learning process.

Some approaches includes real-world experiences as the one presented in [31], that was performed by students in six different courses related to software engineering subjects. Our proposal is also to be used in as many courses as possible since it is a general purpose simulator to construct a workplace that offers a self-studying environment to be used in classroom, home and laboratory activities.

Robotics is a complementary approach that, even though it is fun, most of efforts are spent in the hardware and mechanical parts, which could be also very costly, while our proposed software approach is free of cost.

Finally, new methodologies as Flipping, which introduces learning materials (videos and quizzes) prior to the beginning of the classes (first phase) and, then, use class time for more interactive activities (second phase) could also use the simulation approach. As the proposed tool is a simulator and at the same time is a methodology to teach simulator developers, the tool could be used in both flipping phases.

VI. CONCLUSION

MOOCs based on recordings of classes that already exist are not attractive. In addition to record videos, more material as quizzes, practical assignments and virtual labs should be added. Furthermore, we propose to include a simulator developer approach to improve student engagement in learning.

Better than only simulate, the student will enhance the simulation tool, we believe that simulation and visualization will add little educational value unless it engages learners in an active learning activity, as point in [32]. As shown in a long-term study of student performance [30], the students should go deeper to improve their performance. The proposed approach is based on Java and free software lessons: reuse code, find new functionalities, release early and often, and perfection is found when nothing should through away. Even though the Hades simulator was originally proposed for digital logic education, we have shown that this tool could be used in an expected way to teach and learn several computer science subjects and courses. One strategy is to establish closer relationships between programming activities and real-world to motivate the students, which could be done by connecting the virtual and the real worlds. Go beyond by enhancing a simulator tool with designs, models and components could be used by a variety of institutions and organizations worldwide. The Hades tool is simple and powerful enough to perform theses tasks. Our goal is not to replace commercial tools such as LabView, MatLab, and other standard tools, but to offer to the student a flexible tool with a fast learning curve, a large set of educational and research resources and connectivity, and furthermore provide a tool where the students could not only scratch the surface but also he could (and should) go deeper and beyond to improve their skills.

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The Approach to Design of STEM Courses' Learning Resources based on Students' Activity with the use of Scientific Resources' Databases

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Abstract—STEM education is a wide, advanced and fast-growing educational area. Thus, STEM (Science, Technology, Engineering, Math) courses may become obsolete very quickly (as soon as the next semester). To gather up-to-date information for the core of a course (learning resources) for case studies and seminars, we propose an approach based on the study of recent scientific developments reflected in articles from international research databases.

The process to prepare basic information to design a course in STEM follows the following steps:

1. Students must present one paper to classmates in a seminar (student prepopulates and sent to the teacher specially prepared for this purpose form).

2. Based on several papers, students must present different solutions for one problem in the area defined by the teacher, e.g. urban studies.

We applied our approach experimentally to develop initial learning materials with the first intake of students to a new master program in Urban Supercomputing. During "Urban Systems Analysis" course, students prepared the materials for the next course "Urban Computer's Simulation". The experiment shows, that the proposed approach reduces teacher load in terms of designing learning resources and allows students to adopt and develop additional skills from individual work, project-based training and context-based learning.

Keywords—initial learning materials; learning resources; scientific papers and database; additional skills

I. INTRODUCTION AND RELATED WORKS

Contemporary society and technologies are in constant and reciprocal development. The obvious consequence of this cooperation is diminishing awareness among practicing scholars regarding the latest achievements of science and technologies, especially in interdisciplinary areas. A modern teacher has access to a wide range of information from sources of varying degrees of reliability. In this sea of information, to design, develop and renew a course teachers might find it difficult to find topical materials quickly in relevant advanced

areas of interdisciplinary directions of science and technology. A student might be faced with a similar problem while carrying out a literature study or working on a project.

Approaching scientific education through scientific articles has been conducted at least since the 19th century [1]. Contemporary master's programs of most universities offer a series of courses devoted to the study of scientific materials. For example, master's program in Computational Science of the University of Amsterdam (UA) includes a course in Literature Study¹, and the University of Texas at El Paso offers similar courses in Graduate Research². In 2013, ITMO University³ started a new (for Russian STEM Higher Education) course in Scientific Writing within double-degree master's programs in Computational Science [2], [3]. Many scientific and educational teams joined their efforts to develop and apply original approaches and methods to improve students' skills in literature study and scientific writing and measure the effectiveness of these new tools. In particular, the author of this work [4] offers to change the course or design a new one with the use of the students' reflection upon completion of their work on projects including the study of scientific papers. The paper [5] is devoted to the method of using writing/reading groups to facilitate the efforts of PhD students in acquiring skills in scientific writing. The contribution of [6] is to teach students to write technical reports through peer-writing of non-technical texts. It should be mentioned that many authors confirm that partnerships between teachers of consecutive courses allow the tangible transfer of knowledge. The complex approach to improve teaching methods aimed at developing post-graduate engineering students' skills to prepare scientific publications was offered in [7]. The authors developed a postgraduate course covering a full study of scientific materials and assessment and, for this purpose, they apply various

¹ <http://www.uva.nl/en/education/master-s/master-s-programmes/masters-programmes/masters-programmes/content/folder/computational-science/study-programme/curriculum-schedule/datanose.html>

² <http://ce.utep.edu/mastercourses.htm>

³ Saint-Petersburg National Research University of Informational Technologies, Mechanics and Optics - <http://en.ifmo.ru/en/>

educational methods including a simulated conference sessions.

The mentioned above works show that students are faced with difficulties while working on the tasks in literature study and scientific writing. Analysis of these works and our experience reveal that master's and postgraduate students produce large volumes of materials (texts, software, prototypes) in various areas and quality based on scientific resources. On the other hand, when teachers design a new course in advanced interdisciplinary areas of science and technology, a significant amount of time is spent to find, acquire, actualize and analyze scientific resources to build the required pool of educational materials. In this paper we offer an approach that simplifies and speed up the formation of learning resources for a given course. This approach, based on the above-mentioned works, seeks to answer the following questions:

Q1. How can we prepare up-to-date initial learning materials (ILM) for future courses and involve students in this process through literature study and project work?

Q2. How do we assess the quality of materials prepared by students?

Q3. How do we build a course's content rapidly from ILM derived with the use of mentioned above approach?

Q4. How do we facilitate student's efforts to master future complex interdisciplinary courses?

II. ACADEMIC CONTEXT

In 2012 ITMO University (ITMO) started to apply a double degree master's program (DDMP) in the novel fields of modern science and technologies. At the present time, ITMO has more 30 DDMP, including three programs in computational science [3]. Such a leap in the development of DDMP is directly related to participation of ITMO in the Russian Academic Excellence project called "5-100-2020". The main goal of this program is to maximize the competitive position of a group of leading Russian universities in the global research and education market⁴. In order to meet the requirements of this ambitious project, universities have to provide students not only with courses of high quality but also with skills of literature study, scientific writing and project work. To develop new courses corresponding to the latest advances of related fields in science and technologies [8], we decided to involve not only experts but students who were looking towards developing their project teamwork skills, skills of realization of problem-oriented project, skills to independently solve innovation development tasks and so on. The approach offered in this paper will allow us not only to provide students with above-mentioned skills, but to reduce the time required for gathering ILM for course design and development.

⁴ <http://Stop100.ru/>

III. THE APPROACH DESCRIPTION

In order to accept ILM development of learning resources for the given course (we will call this course a "Next Course" – NC), we engaged students during the "Previous Course" (PrC), which takes place a semester before the NC. This approach involves at least two contact sessions (simulated conferences [7]), where students present results of scientific paper analyses and proposals for IT solutions of problems for the given subjects. To improve the quality of the ILM, we additionally involve the teacher of NC to take part in the contact sessions as an expert.

Fig. 1 shows the sequence of the steps students are engaged in while preparing ILM.

In the first step, the list of papers (2-3 or more pieces per student) is formed and students are asked to fill a so-called "information card". This information card contains the following fields:

- General information of the paper: topic, author(s), organization(s), DOI, journal and abstract;
- Object (process) under consideration;
- Problem statement;
- Brief description of related works (2-3 sentences);
- List of used methods and approaches;
- Description of the offered approach(es) (5-7 sentences);
- List of scientific fields (disciplines) related to the paper;
- Practical (experimental) part of the paper: the real object(s) or process(s), what effect is received, interpretation, discussion and so on (5-7 sentences);
- Conclusion and future works: discussion of solutions to the problem, what are the authors' plans for the future (5-7 sentences);
- Does the article consider methods of system analysis? If "Yes", what is the object of analysis? Could we observe systemic effects?

Having analyzed information seeking patterns [9], this list of fields was formed to facilitate students' efforts of the paper's analysis. In addition, this form allows a teacher (expert) to understand quickly the contents of the paper or determine the *low* quality of student's result. The last field was added in order to provide students with additional opportunity to develop thinking regarding the systems applied. We do not claim that this paper's information card is perfect. Rather, it might (in some cases *should*) be changed depending on the subject area and course level.

The second step is a simulated conference session, where students present the papers they analyzed in a short report with PowerPoint (PP) slides. The teacher of NC is involved in this session and is guided by the following goals:

- selecting first part of the pool of initial learning materials;

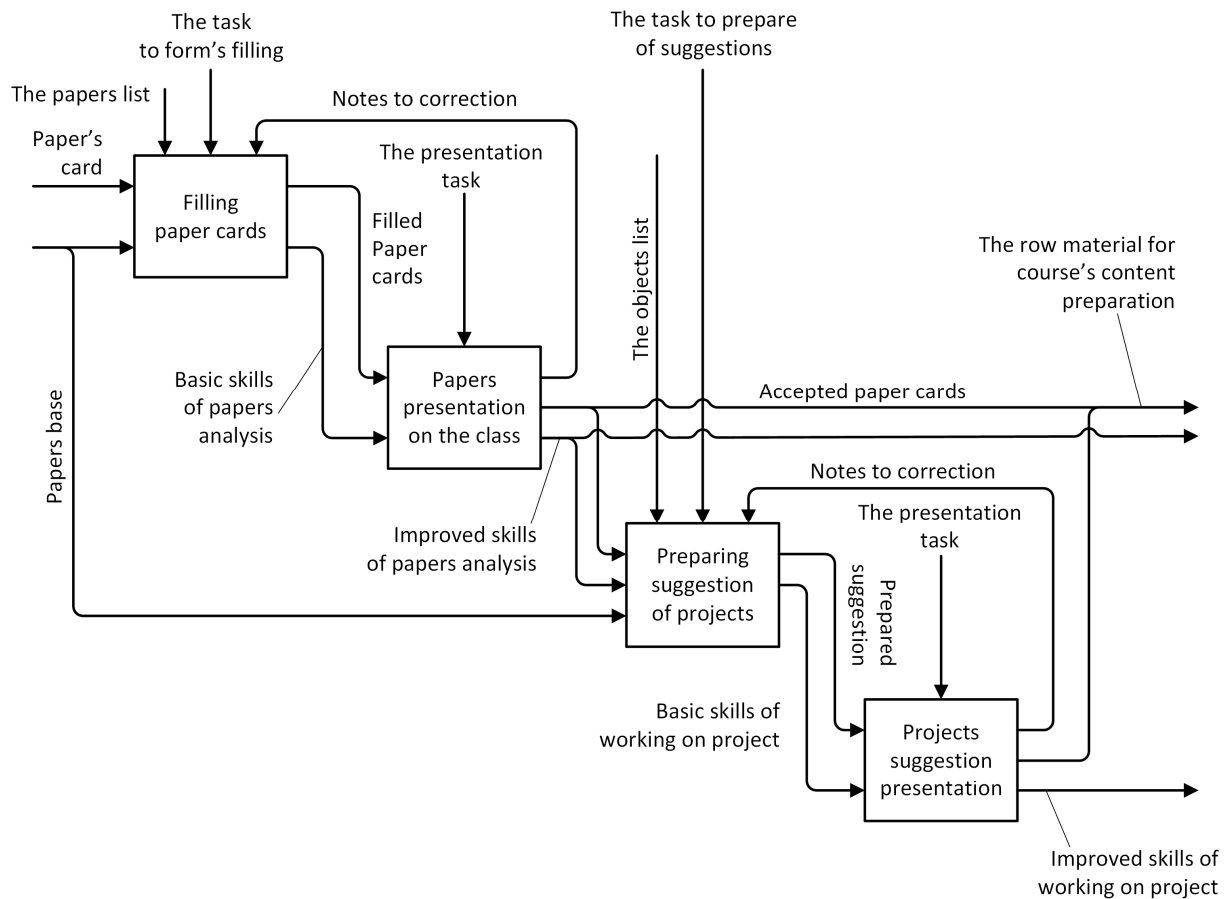


Fig. 1. The scheme of students' involvement into preparation of ILM

- contributing to the assessment of presentations (Q2);
- commenting or introduce corrections if necessary to the students.

If students receive comments from teachers and/or group mates, they should be expecting to analyze them and make any needed corrections. Such students are required to present their updated results again in the next session or, if needed, individually.

When the first and the second steps are completed, students should propose solutions to a chosen problem of the given complex object (step 3). No special requirements are introduced for the text of proposals, except for the following information: problem statement, goals, required data and resources, approaches and methods, application packages (if solution could be implemented in a form of computer program), and description of output results. The text of the proposal should not exceed more than three pages in a Word document. In this way we stimulate students to formulate their joint ideas in a structured manner and in a limited volume.

The fourth step follows second step, but solutions are generated by group work. Students give 15-minute speeches supported by PP slides and followed by Q&A sessions.

Teachers (experts) assess these proposals and make decisions whether to accept proposals or to recommend making modifications. To assess proposals (Q2) teachers use the following criteria (in the scale from 1 to 5 points):

- 1) Completeness of the proposal (what components of the given object are chosen and how they are related each other; what scales were explored);
- 2) Justification of the selected research methods;
- 3) Quality of the selected references, including scientific papers;
- 4) Reasoning for software selection to implement the proposal;
- 5) Interdisciplinary relations (what scientific areas are involved?);
- 6) Suggestions to apply this proposal in education (how the presented suggestion can be used in educational process: at what level, in what area?);
- 7) Quality of presentation, including the speech, slides and answers to questions.

These criteria allow experts not only to render a detailed assessment of the presented group work, but to turn these results into initial learning materials.

These criteria are communicated to the students before they start to prepare for their presentations. In this way, we pursue several goals at once: (i) to clarify the statement of a problem to the students; (ii) to give them exact and clearly evident way of self-assessment; (iii) to prepare the tool for measuring the results of public session by the experts. During the development of the list of criteria we make an attempt to incorporate manifold requirements to high-quality project proposals.

Criteria (1-4) are often used to review scientific papers. For example, criterion 3 corresponds to a “quality of the description of related work”. We intentionally do not determine the quality of a research contribution because at this stage students’ proposals are not fully valid scientific works. They do not implement the prototypes of ICT solutions and do not make experiments with real data. Neither students nor experts should measure the applicability of proposed approaches. However, with the use of criteria 1-4 participants are equipped to develop two important skills: (i) analysis and synthesis of scientific information; (ii) rigorous justification of the proposed solutions (Q4).

The next group of criteria (6-7) focuses on initial versions of learning materials. Interdisciplinary concepts are important because of the essence of computational science. Future professionals in this area should be able to observe complex systems (such as cities) from different perspectives, and to incorporate research methods from several subject fields. Criterion 6 focuses students’ attention to this issue as a way to intensify ‘out-of-the-box’ thinking during the work on proposals. The seventh criteria helps to determine more relevant courses, which can be supplemented with appropriate learning materials. The goal of this last criterion attempts to evaluate speaking and presentation skills.

IV. THE APPROACH IMPLEMENTATION

This unique technique is distinguished by perfecting and shifting the initial learning materials generated at the course in Urban System Analysis of first semester of master program to the course in Methods for Urban Simulation of the second semester of the same program. Moreover, initial learning materials in the format of software solutions are intended to be integrated into CLAVIRE (CLOUD Applications VIRTUAL Environment) platform [10], should these solutions be developed into master graduation projects.

We implemented our scheme to develop initial learning materials (ILM) with the first intake of students to a new master program in Urban Supercomputing. This decision could be viewed as a planned risk, since the average age of teachers at the program is close to 29, and they are inclined to introduce innovations to the course structure. Apparently, it could be explained by the fact that both high performance computing and urban studies are rather novel fields in Russian Higher education, therefore experts in these emerging spheres are willing to move beyond the rigid frames of teachers’ routine.

A. The steps #1 and #2

To launch the first and the second steps, 40 papers devoted to various urban problems were selected. For example, paper [11] analysis the effectiveness of nicotine replacement therapy in New York City with the use of geographic informational systems (GIS).

Eighteen of 20 students successfully mastered this task, e.g. provided good descriptions of papers in a form of information card and managed to deliver their reports during a conference session simulated in class. Therefore we received 18 papers’ description. The remaining two works were not completed since certain students decided to change their majors.

B. The steps #3 and #4

We had chosen a big city as the object for the steps three and four. We asked students to split into small teams of two or three, to choose a large urban area like London and its suburbs they wish to explore (with one exception), determine its problems by studying relevant scientific papers and offer and justify an IT solution. As a result we received nine proposals; six of them were recognized as potential basis for initial learning materials. Large urban areas from around the world were scrutinized, e.g. Guangzhou, Munich, Buenos Aires, Istanbul, Toronto, etc. Special attention was given to the applicability of a solution prototype from one area to the same problem in the other part of the globe. Diversity of cities and its problems as well as unconventional solutions stipulated heated discussions involving students, teacher and experts. Fig. 2 shows the presentation of students’ projects.



Fig. 2. Presentation of the work on the project on identification and extraction of pedestrian trajectories (Step 4).

Below are six proposals of the second part of the experiment that has been proved to be effective as initial learning materials later on in NC:

- 1) Forecast system of trash disposal;
- 2) Database of unstable citizens including personal data ;
- 3) Informational system (IS) for air pollution analysis;
- 4) Model of traffic modeling and air pollution simulation;
- 5) IS for ships traffic in sea port’s area;

- 6) IS for data analysis for police analytics based on graph method.

We are inclined to assume three subject areas:

- 1) Spatial analysis and visualization of industrial city;
- 2) City-logistics model based on SWAT analysis and decision support system with GIS;
- 3) Social network crawling for identification and analysis of people mobility in urban areas;

were left behind due to at least one reason – insufficient background in economics and sociology. This problem may be as an area of the separate research.

V. STUDENT FEEDBACK

Once we have accomplished all four steps, we asked students to comment on their experiences in anonymous survey and some of the feedbacks were:

Student 1. Within the course “Systematic analysis of urbanized areas” an ingenious approach to learning process based on making new ideas and offers using articles on a given topic was used. In a first step we had identified basic goals and motivation in the article. Further, we explored methods and tools, which were applied. Also, one of the main tasks was to make up an information card of the article. This process undoubtedly was helpful as a learning activity and helped me to understand main points of these articles, to perform my individual research project, and to practice my presentation skills.

Student 2. The most interesting part was reading science literature and searching problems in big cities that could be resolved using IT. If we have a problem, and we are sure, that it can be fixed using IT that is not an issue to find an idea of IS. More difficult is to get a picture, how will this IS work. So, I liked this task for two things: you should demonstrate competence in both urban science and IT, and you should do it in group. Unfortunately, there was no *public discussion* about proposed ideas that could be interesting and could give a feedback useful in future.

Student 3. The main advantage of the course in System analysis of urban territories was that it was practice-oriented. We had several tasks of urban problems finding, analyzing and solving. The one, what I appreciate at most was article’s analysis: students were given articles about some urban problem or solution to read it, understand and then present it to group mates. It was valuable experience for me for many reasons: reading scientific work in English, a perfect example of analysis and comparison methods, and understanding modern city transportation system problems, development and policies. Presentations of my group mates, for example, about recreation infrastructure analysis or NY policies on smoking level decrease, showed how many problems exist in cities and could be solved with appropriate application of urban science.

The mentioned above selection of the survey’s results shows that students not only contributed to the preparation of up-to-date ILM (Q1), but formed a good basis to master next complex courses (Q4). This basis includes understanding of

scientific approaches to study and analyze complex systems like urban areas.

VI. PREPARATION OF THE COURSE’S CONTENT BASED ON ILM PARADIGM

Having prepared the learning initial learning materials with the use approach described, we understood that this material could not be used for teaching. Such material needs to be processed. To overcome this problem we might use various approaches to build learning resources with the use of above-mentioned type of materials, for example, Learning Tools Interoperability (LTI) [12] or reusable learning object concept [13]. In the work [14] we proposed a set of methods, cloud tools, based on the CLAVIRE cloud platform [15] and LTI for rapid development of cloud learning resources. In particular, the principles of rapid composition of learning materials for representing the results of scientific research might be applied to build virtual learning labs [16]. Moreover learning models of scientific workflows⁵ in the CLAVIRE cloud platform could be useful [17]. In addition we may complement the learning resources by visualization tools with 3D-Stereo support working on Fusion Engine, as well as design and implement related virtual learning environments [18].

Therefore, we have a set of tools and methods to develop and implement learning resources in course design and to extend existing knowledge base, learning objects including virtual labs with initial learning materials obtained as a result of students’ individual and group work (Q4).

VII. CONCLUSION AND FUTURE PLANS

In this paper, we proposed the approach to form learning initial material for further design and implementation in educational process. The approach of this goal is to involve students into paper’s analysis and to brainstorm solutions to selected problems of the given city. We designed an information card to facilitate analysis of scientific papers and check the quality of the students’ outcome (Q2). Ninety percent of students had mastered this task and proceeded with group tasks searching for computer-aided solutions for diverse urban problems. In the second part of the experiment (steps three and four) students tackled these problems in groups of two or three students. These groups developed prototypes for the problems solutions described in the scientific papers. Two-thirds of teams had presented good results (completed information cards and models of IS for cases from real life). These materials might be used as a starting point to prepare learning resources. Thus, we can form a pool of initial learning materials with the use of students’ resources (Q1). The approach described in this work allows teachers to reduce their efforts in design and development of learning resources and gives student the base for understanding of scientific approaches to study and analyze complex systems (Q4). In addition, we proposed to use the tools and methods for the preparation of the course’s content based on ILM (Q3).

⁵ Scientific workflows is an instruction (sequence of commands) to launch application software in distributed high performance computational environment.

In the future, we are planning to complement the approach with two additional activities: (1) focus on scientific papers' study to boost the command of terminology in the given subject domain of educational program or course and (2) literature review on the given topic (this type of work is often referred to as related works) to stimulate publications in peer review journals and master thesis preparation. This way we could raise English language proficiency level, ability to work in teams and independently and finally focus on in-depth knowledge of the subject matter.

The first activity will be introduced before the first step and will allow students to study papers in the given subject area better and faster. The second activity is planned between the second and third steps to provide students with skills of acquisition, analysis and presentation of information from scientific papers. This experience and skill we hope will allow students to analyze any given case study more effectively and offer adequate and complete decisions to pressing problems of Urban Studies.

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Comparing Microcontroller and Analog Methods for Tracking Control Experiments

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Abstract— this paper describes the development of undergraduate laboratory experiments for solving tracking control problems by using two different approaches. The first approach is based on microcontrollers and the second approach is an analog approach based on operational amplifiers. The main objective is to compare by hands-on experiments the advantages and disadvantages of these two approaches. Preliminary results of the comparison are presented in this paper. These lab experiments are developed to increase the competency skills of the students rather than just an additional topic to be covered in the course. These experiments will provide guidance to the students in making better choices of tracking controllers in their future robotics or other control system design projects.

Keywords—microcontroller applications; tracking control; position control; linear control

I. INTRODUCTION

This paper describes the laboratory experiments developed for solving tracking control problems by using two different approaches- the microcontroller-based approach and the analog approach with operational amplifiers. These experiments will be incorporated into our sophomore level newly revised microcontroller applications course in the future offerings. Tracking control problems are fundamental control problems arising in electrical, mechanical, and other engineering disciplines. Learning the practical skills of solving these control problems will increase the competency level of our students.

A method for solving tracking control problems is by using proportional, proportional-integral or proportional-integral-derivative controllers. It is our objective to develop laboratory experiments that can deliver to the students the skills for building these controllers from scratch using the two different approaches mentioned above. In the first group of experiments the students will build these controllers using the analog approach and test them on a plant- Feedback Inc.'s Mechanical Unit Model 33-100. A picture of the plant is shown in Fig. 1. The students will document the performances of these controllers by measuring the steady state errors, rise time, peak time and percent overshoot. They will record these parameters for various combinations of proportional gains. In the next group of experiments, they will re-build these controllers as C programs running on the Freescale MC9S12C32 microcontrollers. They will also build the signal conditioning

circuits for interfacing the microcontroller to the same plant. Again, they will document the experimental results of this controller. They will then compare the design, performances, cost, development time and other factors of these two different approaches for solving the same problems.

The Feedback Inc.'s Mechanical Unit Model 33-100 is a servo control plant equipped with an input dial that a user can adjust its angular position. It is also equipped with an output shaft with gear mechanism and electronic circuit that with a correctly designed controller can steer the output shaft to track the angular position of the input dial. The controllers to be described in this paper below were tested on this plant.

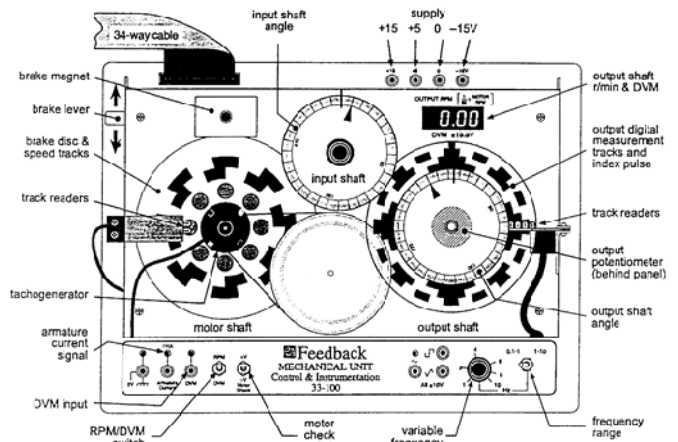


Fig. 1: Feedback Inc.'s Mechanical Unit Model 33-100

Theoretical and experimental solutions for solving tracking control problems have been proposed and can be readily found in the literature [1-5]. Advanced methods for tracking controls, e.g., fuzzy logic and other microcontroller-based methods, are also available in the literature, e.g. in [6-9]. Since we are developing the lab experiments at the sophomore level, advanced methods have not been considered.

Tentatively, we intend to incorporate lab experiments of proportional controller and such controller with velocity feedback into our revised microcontroller applications course using both of the approaches. We have successfully completed the development of tracking control experiments using proportional controllers. We are currently developing new tracking control experiments using proportional controllers with velocity feedback. The tracking control experiments using

proportional controllers (without velocity feedback) are described in the next section.

II. EXPERIMENTS DEVELOPED

A. Analog method for tracking control

A block diagram of the tracking control system with the analog controller is shown in Fig. 2. The block diagram except the controller and the comparator is a representation of the plant shown in Fig. 1.

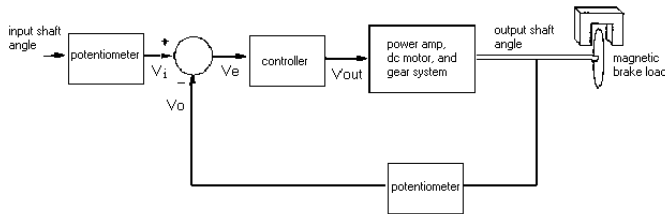


Fig. 2: block diagram of the control system

This tracking control problem is to design a proportional controller using operational amplifiers that will drive the output shaft angle to track the input dial position. Specifically, if the input dial angle is changed, the controller should drive the output shaft to track the changes in the input dial position. The input dial position is read by a potentiometer and is indicated by the signal V_i in Fig. 2. The output shaft position is read by an identical potentiometer which output is indicated by V_o in the same figure. An analog solution of the controller is shown in Fig. 3. The signals V_i , V_o , and V_{out} in Fig. 3 are those indicated in Fig. 2. The operational amplifier circuit in Fig. 3 represents the controller and the comparator combined in Fig. 2. The signal V_{out} is proportional to the error ($V_i - V_o$) and the gain factor is the ratio R_2/R_1 . The selection of R_1 and R_2 are done empirically, not model based because at the sophomore level the students have not taken a model-based control course.

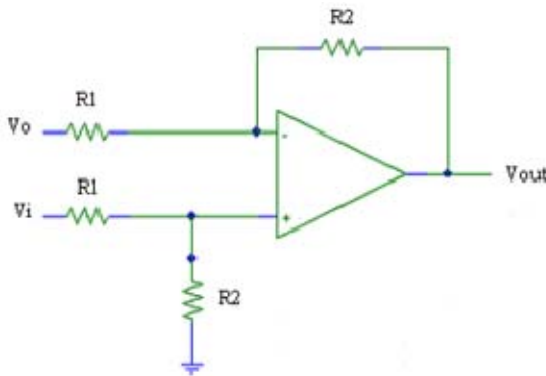


Fig. 3: proportional controller

This analog controller was tested in the plant. Some of the experimental results are shown in Fig. 4. Notice that in Fig. 4 the output shaft signal is tracking the input dial signal but with some undesirable overshoot and ringing. The students will receive guidance on how to resolve this issue by using velocity feedback or derivative control. Such laboratory solutions and the associated lab handouts are being developed.

With this design in Fig. 3 the students can measure the performance parameters for various gain factors. The performance parameters include steady state error, percent overshoot, peak time, etc. These performance parameters can be used as the basis for the comparison of the performance of this controller with the one implemented by using the microcontroller method.

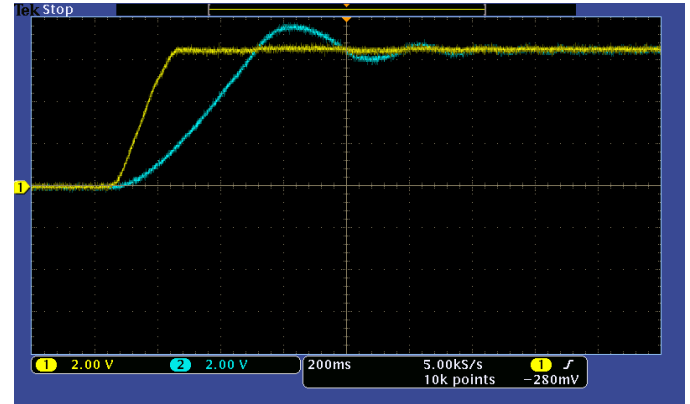


Fig. 4: input dial (yellow) and output shaft (cyan) signals

B. Microcontroller method for tracking control

A block diagram of the microcontroller-based proportional controller is shown in Fig. 5. In that block diagram, the two analog-to-digital (ATD) converters, the comparator and the controller were integrated into the microcontroller. The DC motor of the plant was driven by a pulse-width modulated signal from the microcontroller through an H-bridge housed inside the plant. The pulse-width modulated signal was generated by the microcontroller's on-chip pulse-width modulator (PWM).

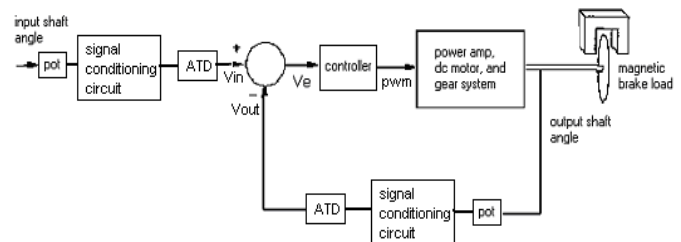


Fig. 5: block diagram of the microcontroller-based proportional controller and the plant

As indicated in Fig. 5, signal conditioning circuits were required. It was because the V_i and V_o voltage signals (as indicated in Fig. 2) were in the range of -10 V to +10 V. They were outside the operating voltage range of the on-chip ATD converter, which is in the range of 0 V to +5 V. The signal conditioning circuit should convert linearly the voltage range of -10 V to +10 V to the voltage range of 0 V to +5 V. A solution of the signal conditioning circuit is shown in Fig. 6. Two of such circuit were built and tested. They were used as the interfacing circuits between the potentiometers and the ATD converters.

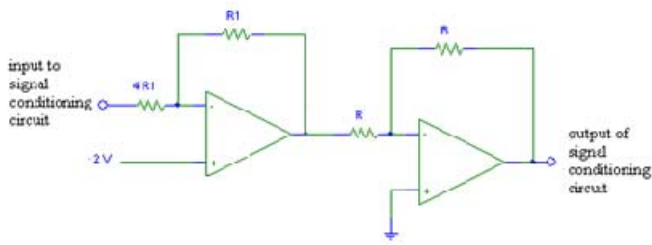


Fig. 6: signal conditioning circuit

The proportional controller was implemented as a C program running on a Freescale MC9S12C32 microcontroller. The tools for developing the proportional controller in C included CodeWarrior Integrated Development Environment, C compiler running on a Windows machine, and P&E USB BDM Multilink Programmer. Tutorial for using these tools have been written. Pseudo codes for the proportional controller were developed and included into the tutorial. An example follows.

1. Sample the input dial position
2. Sample the output shaft position
3. Calculate error
4. Choose proportional gain
5. Calculate the PWM duty cycle as a function of error and the gain value
6. Load the new duty cycle into the PWM
7. Execute a delay function to give time for the PWM to do the control operation.
8. Go back to step 1.

A code snippet of the main function of the C program proportional controller is shown as follows:

```
// infinite loop for reading Vi and Vo
// and set duty cycle accordingly
while(1) {
    ATDCTL5=0x10; // initiate ATD conversion
    delaysms(10);
    Vi=ATDDR0H; // input dial voltage
    Vo=ATDDR1H; //output shaft voltage

    //proportional controller begins
    n=-(Vi-Vo)/255*0.5*gain+0.5; // duty cycle calculation
    n*=100;
    //proportional controller ends

    //limit n to be between 0 to 100
    if (n>100) n=100;
    else if (n<0) n=0;
        else if ((n>45)&(n<=48)) n=45;
        else if ((n>=52)&(n<55)) n=55;

    //load new duty cycle into PWM
    PWMDTY0=n;
    delaysms(50); // give time for the PWM to do control
} // end while loop
```

The proportional controller equation in the code snippet followed the following specification of the DC motor operation in the plant. The motor rotates in the clockwise direction if the duty cycle is less than 50%. A smaller duty cycle will supply more power to turn the motor in the clockwise direction. The motor will rotate in the counterclockwise direction if the duty cycle is greater than 50%. A greater duty cycle will provide more power to turn the motor in the counterclockwise direction. Further details are provided in [10].

The C program was compiled and flashed into the microcontroller. It was interfaced to the plant through the signal conditioning circuits. The PWM output of the microcontroller was connected to the H-bridge that drove the DC motor. Some of the experimental results are shown in Fig. 7. It is noticed that the steady state error is zero. There was overshoot. Guidance will be provided to the students on reducing such effect.

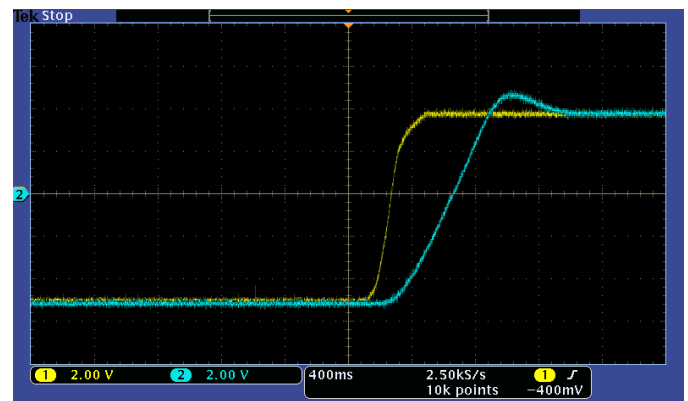


Fig. 7: input dial (yellow) and output shaft (cyan) signals

III. PRELIMINARY RESULTS

The two approaches described in the last section were compared against each other. The analog approach was easier to prototype and was intuitively simpler for the students to understand than the microcontroller approach. However, it is harder to make changes in the analog approach. For example, to change its proportional gain requires replacement of hardware components (replacing the resistors to different values). On the other hand, the microcontroller approach allows a user to make changes easily. For example, the proportional gain could be changed easily in the software. However, the microcontroller approach required precise signal conditioning circuits for converting the voltage ranges of the input dial and output shaft to the voltage range suitable for the microcontroller. We noticed that imprecise signal conditioning circuits could result in constant steady state tracking error.

These labs also brought the following to the students' attention. In the analog approach, a double rail operational amplifiers was necessary for the proportional controller because the input voltages could swing positively and negatively. Next, higher precision resistors, e.g., 1% resistors, instead of the inexpensive 5% ones were necessary in order to ensure the gains of the controller to be more precisely implemented. In the microcontroller approach, it took longer time to build the controller because of more hardware (both

microcontroller and signal conditioning circuits) to be put together and software programs to be developed and debugged. This approach was not as economical as the analog approach. But extra capability can be programmed into the proportional controller and that can outweigh the extra effort and cost.

IV. CONCLUDING REMARKS

We have completed the development of two working stations for the learning of tracking control. One station is for the analog approach and the other is for the microcontroller-based approach. These two stations allow the students to make comparison of the performance of these two approaches. Further exploration on tracking control by the students also becomes feasible by means of these two stations. It was noticed in the experimental results that the output shaft signal was tracking the input dial signal but with some undesirable overshoot and ringing. This issue can be reduced by using velocity feedback or derivative control. Such solutions will be developed and can be built upon these two current stations. We plan to document all of the experiments in a laboratory manual that can be used in an advanced microcontroller course or a control system lab course.

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